Speaker Design Proposal
Ben Boeshans
FA 4740
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**Introduction**

"From my vantage point, loudspeakers are the single most important musical instrument developed in the 20th Century, perhaps ever. They have certainly transformed the way music is made, as well as the way it is listened to. Equally important loudspeakers have transformed the way music sounds, for better and for worse."[1] David Moulton accurately sums up the important role that loudspeakers play, not only in the music industry, but also in our everyday lives. There were several factors that I considered when designing my ideal pair of loudspeakers. A set of functional goals guided the driver selection, enclosure design, and crossover configuration that combined to form the instrument that is this loudspeaker.

**Functional Goals**

The primary design goal is to construct an all-purpose music speaker for everyday listening. I listen to music on a regular basis and want to design a speaker with good low-end extension, and good clarity that can be listened to for long periods of time without fatigue. The speaker will be used either in a living room or bedroom setting and will play a fairly wide variety of music. Because of its setting the size of the speaker is a concern. Large floor standing units would require too much space, but small bookshelf speakers are unlikely to produce the desired low-frequency response. Therefore, the speakers should be the size of large portable studio monitors. That size strikes the balance between size and low-end frequency response. Additionally that size will also allow the speakers to have the portability that the college lifestyle demands.

I want to design a two-way speaker with a full range that has crisp highs and solid, defined lows. Technically, the crisp highs require a good transient response time and the solid,

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[1] Moulton, David. Total Recording. Nick Batzdorf. KIQ Productions Inc., 2000. p. 207

defined lows require a low $f_3$. I hope to obtain the transient response through selection of a quality tweeter and selection of a low crossover point. My goal is an $f_3$ of 50 Hz. That will allow the speakers to be used in either a 2.0 or a 2.1 channel system. The speakers should have enough low-end response as to not require the use of a subwoofer, but when used in conjunction with one, the overall sound is enhanced.

The speakers must also be designed to operate at desired listening levels. It is rare that I listen to loud music for extended periods of time. My normal listening level measures approximately 65 dB SPL at 4 feet. I increased the level and at 72 dB it was almost unbearable and was certainly louder than I ever listen to music. My current room is quite small, which accounts for the relatively low SPL levels before the music gets too loud. The likelihood that the speakers will move into larger rooms is quite high. Taking that into account, I want to design for higher levels. The speakers will be designed to be K-14, which is described as "for the vast majority of moderately-compressed high-fidelity productions intended for home listening (e.g. some home theatre, pop, folk, and rock music).[2] K-14 specifies an 83 dB capability with a 14 dB crest factor, bringing the total required SPL to 97 dB SPL at 1m.

Since I am designing a speaker whose primary use is listening to music, I need to carefully consider off-axis response. When I am in my room I am almost constantly listening to music. What that translates into is that I'm listening while sitting and moving around. Therefore, it is a necessary design a criterion to have a speaker with near flat response on- and off-axis. I want to design and build a speaker that sounds good all over the room rather than just in one part of it.

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[2] Katz, Bob. "Level Practices (Part 2)." http://www.digido.com/media/articles-and-demos/13-bob-katz/21-level-practices-part-2-includes-the-k-system.html (accessed 19 Feb 2009).

**Drivers**

I did quite a bit of reading on response charts for different types of drivers. One of the more insightful things I read was in Phillip Newell's book. He talks about frequency response plots saying, "Subjectively, it has long been considered that the magnitude of the pressure amplitude response (the frequency response in everyday language) is the most significant measure of a loudspeaker's performance, and yet no loudspeakers are truly flat. Smooth deviations from flatness are generally acceptable, and are easily grown accustomed to by listeners who are familiar with the loudspeakers."[3] Keeping this information in mind, I tried to find a driver that didn't have any sudden changes in its response, but rather one whose response was smooth.

I wanted to select a tweeter that was accurate, yet not overly harsh. Upon researching hard verses soft tweeter materials I found, "Often, the debate has degenerated into a question of taste - soft dome advocates say that metal domes sound too bright, while metal dome advocates say that soft domes sound muffled or "mushy".[4] Combined with my opinions after personally comparing some soft domes to metal ones, I decided to peruse the soft domes.

Several factors were considered in selection of the tweeter. As part of the music speaker design goal, I wanted to select a tweeter that could have a relatively low crossover point. The lower crossover point allows a greater part of the program material to be sent to the tweeter, which, due to its size, has a better transient response than a woofer. My end goal was to have a

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[3] Newell, Philip, and Keith Holland. *Loudspeakers for Music Recording and Reproduction*. (1 ed. Burlington, MA: Focal Press, 2007.) p. 276

[4] Stout, Bob. "Appendix B - Materials Technology." 25 Mar 07.http:/Idsg.snippets.org/appdx-b.php (accessed 01 Feb 09). p. 2

crossover point between 1-1.5 kHz. This therefore became a discriminating factor in the tweeter selection.

There were several tweeters available that had really flat looking response when measured on-axis. Most of the tweeters had decently flat response 30 degrees off-axis. The major discriminating factor became the response 60 degrees off-axis.

After taking price into account, the driver that met my goals turned out to be the Vifa DX25TG05-04. Madisound's website provides the following highlights for this driver[5]:

*Vifa 1" Fabric high dispersion dome tweeter*
*Low compression chamber design*
*Lightweight voice coil*
*High power handling*
*High Sensitivity*

The frequency response curve of the driver taken from the speaker's data sheet is shown in Figure 1[6]

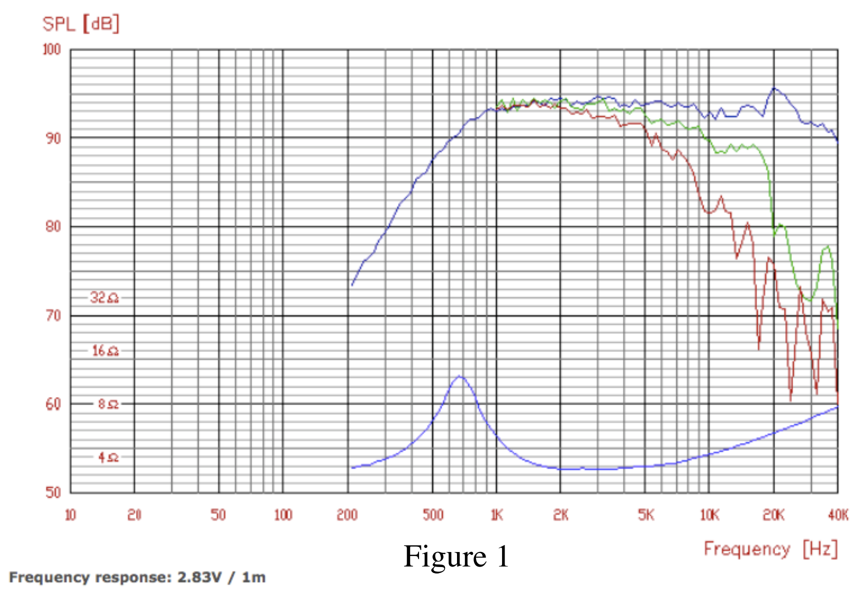


Figure 1

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[5] Madisound, "Vifa DX25TG05-04 ohm 1" Fabric high dispersion Dome Tweeter." http://www.madisound.com/catalog/product_info.php?cPath=45_229_324&products_id=1115 (accessed 25 Jan 2009).

[6] Vifa, "Vifa DX25TG05-04 ohm 1" Fabric high dispersion Dome Tweeter." http://www.madisound.com/catalog/PDF/vifa/dx25tg05-04e.pdf (accessed 25 Jan 2009).

As can be seen from the response curve, the driver has very similar on-axis and off-axis response between 1kHz and 5 kHz. Between 5 kHz and 20 kHz the 60 degree off-axis response starts to fall off quite rapidly and has several problems, but the 30 degrees off-axis response, though lower in level, remains fairly flat. Above 20 kHz the off-axis response falls apart, but it is above the hearing spectrum and so it is of little concern. Because the overall response curve is stable until around 1 kHz it allows me to chose an initial crossover point of 1.2 kHz. Below 1 kHz the driver has a natural roll-off that I can capitalize upon in designing my crossover.

After I found a tweeter that could reasonably be crossed at 1.2 kHz, I began looking for a woofer. I considered several different types and styles of woofers. My search was primarily focused on drivers that were six to eight inches in diameter. The first discriminating factor was price. To stay within budget, the price of the drivers could not exceed $100/driver. That cut out a great number of drivers. From there, I used the recommended driver implementation as the next screening factor, eliminating those intended for band-pass or reflex enclosures for example.

From the driver options that remained, I entered their specifications into WinSpeakerz so I could see how they would perform in the two cabinet types I was considering. Because of my desire for a fast transient response, I began by modeling all of the drivers in a 40 L, 2$^{nd}$ order closed-box system. The graphs were very insightful. Of the woofers I modeled, I found they generally had very poor low-end frequency response in a sealed box. All in all, most of the drivers ended up with their $f_3$ around 100Hz. There were two drivers that had good low-end response in the sealed box. For comparison, I modeled them in a 4$^{th}$ order vented box. The difference in low-end response was enough to convince me to build the 4$^{th}$ order box. There were a few drivers whose response stuck out above the rest and that were seriously considered.

The first driver considered was the Vifa XT18WH09-08. The driver's highlights, taken from the Madisound website[7] are:

*Vifa 7" Wood fiber cone mid-woofer*
*Phase integrated dust cap*
*Low resonance multi-roll surround*
*Airflow optimized low distortion chassis and magnet system*
*Flange 180mm*

The driver's specification sheet lists the $f_s$ as 38 Hz and its sensitivity as 87 dB. Figure 2 shows the response of the driver as provided by the driver's data sheet.[8] Figure 3 shows the WinSpeakerz calculations for a 4th order vented system of 1.5 cubic feet.

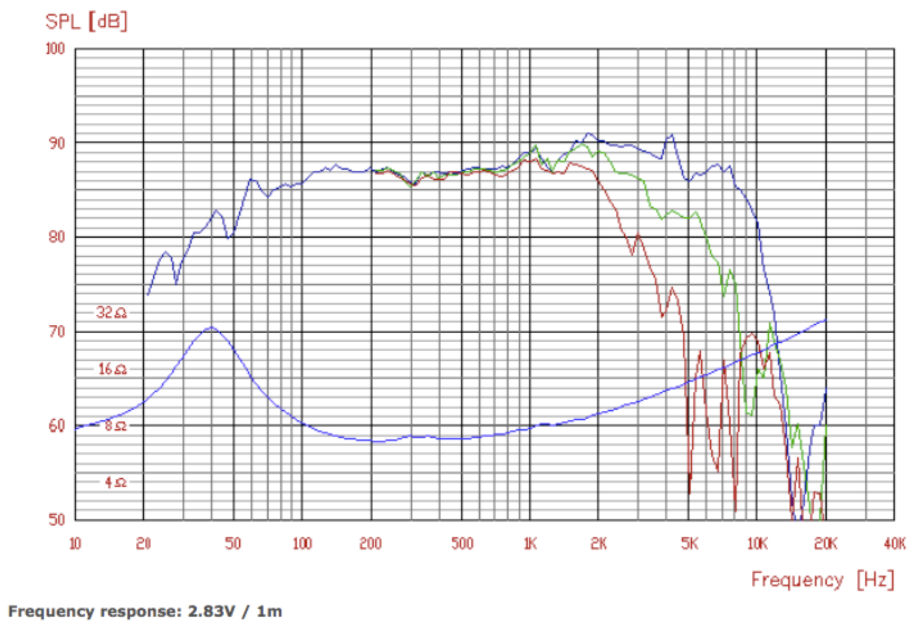


Figure 2

[7] Madisound, " Vifa XT18WH09 7" Wood fiber Cone mid-Woofer." http://www.madisound.com/catalog/product_info.php?products_id=1176 (accessed 25 Jan 2009).

[8] Vifa, "Vifa XT18WH09 Data Sheet." http://www.madisound.com/catalog/product_info.php?products_id=1176 (accessed 25 Jan 2009).

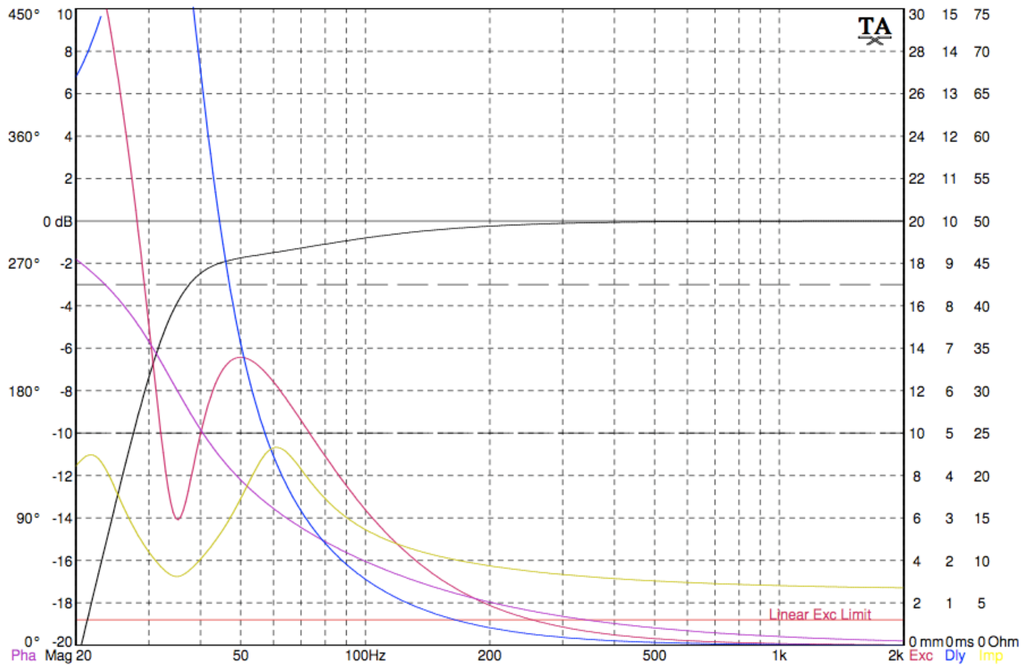


Figure 3

As can be seen from the frequency response graph, the driver performs very well up to around 1 kHz. At that point, there is a peak, after which the driver starts to experience problems. The driver could be a good match for a crossover around 1.2 kHz. I could put in a filter that would soften out the peak and then begin the roll-off. The problem with using the driver in this application is twofold, and can be seen on the Winspeakerz plot. Although the plot shows $f_3$ of the driver as approximately 38 Hz, the roll off slowly begins around 300 Hz and at 50 Hz is down 2 dB. The second, and more worrisome problem is the driver's excursion. The specification sheet does not lists max linear excursion and from the Winspeakerz plot it appears that excursion may be an issue.

The second driver I considered was the Fountek FW168. The driver's highlights, from the Madisound website, are shown below[9]:

*Aluminum Cone*
*Aluminum Phase Plug*
*Die Cast Chassis*
*36mm Voice Coil Diameter*

The driver's specification sheet lists the $f_s$ as 45 Hz and its sensitivity as 87.3 dB. Figure 4 shows the response of the driver as provided by the driver's data sheet.[10] Figure 5 shows the WinSpeakerz calculations for a 4th order vented system of 1.5 cubic feet.

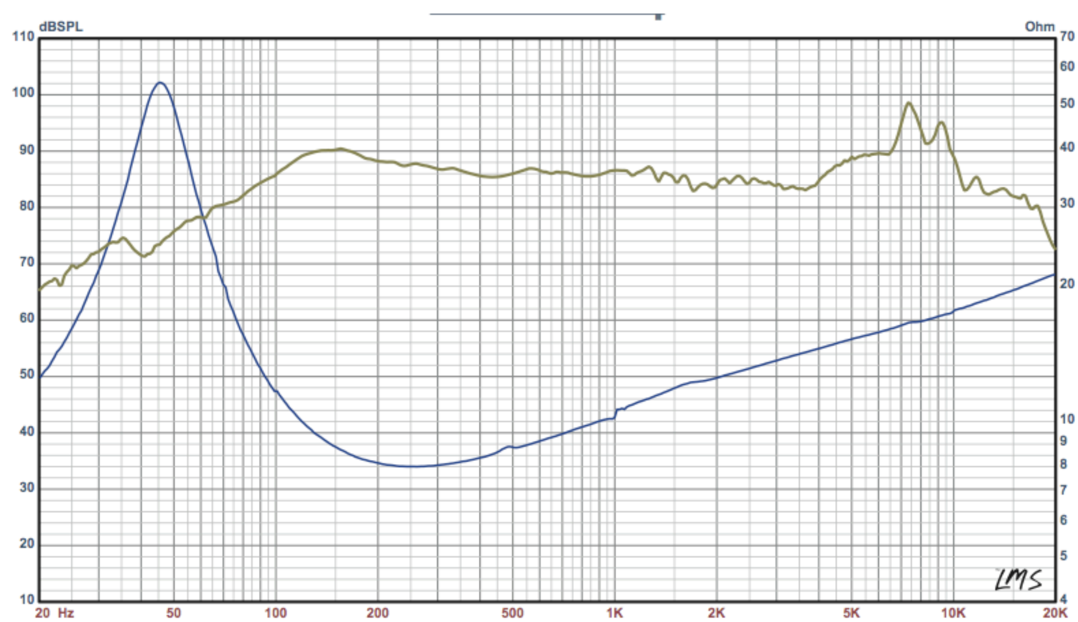


Figure 4

[9] Madisound, " Fountek FW168 6.5" Aluminum Cone Woofer" http"://www.madisound.com/catalog/product_info.php?products_id=8492 (accessed 25 Jan 2009).
[10] Fountek, "Fountek FW168." http://www.madisound.com/catalog/PDF/fw168.pdf (accessed 25 Jan 2009).

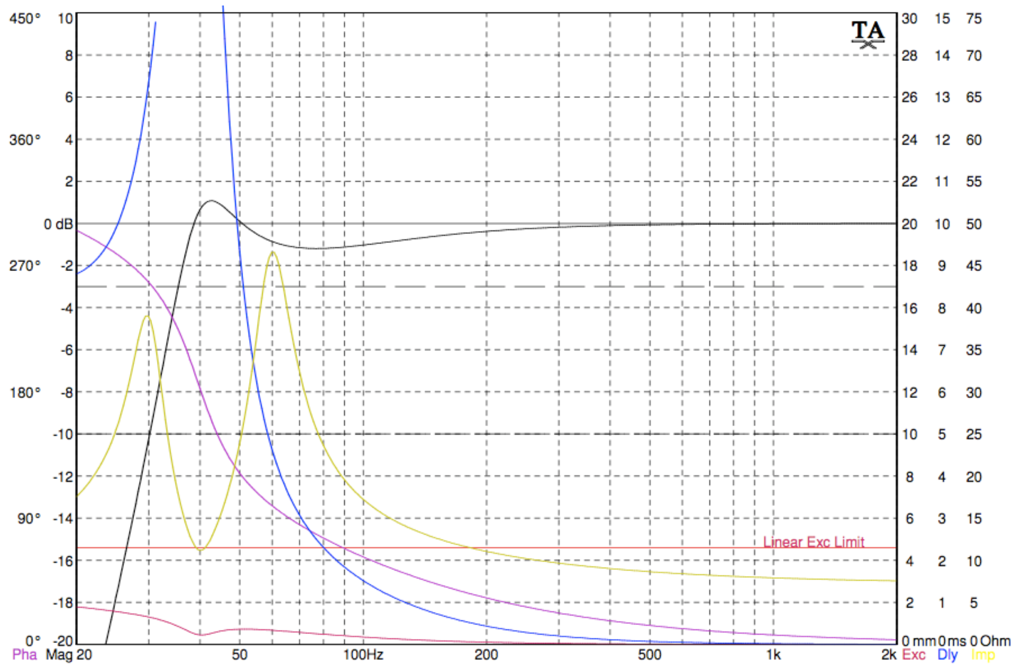


Figure 5

This driver has a much less smooth frequency response plot compared to the other two drivers. The apparent discontinuities in response are as extreme as 5 dB beginning at 4 kHz and peaking at 7.5 kHz. While the driver could work, better options are available. Another problem with using the driver in this application can be seen on the Winspeakerz plot. The frequency response starts to dip around 400 Hz, reaches a low around 70 Hz and then peaks at 43 Hz before rapidly falling off. As a result woofer performance from 70 to 100 Hz suffers in an area when the woofer is needed most.

The third woofer that I considered was the Peerless 830868. The drivers highlights, again taken from the Madisound website, are shown below[11]:

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[11] Madisound, "Peerless PPB 831868 - 8" Poly Cone Woofer." http://www.madisound.com/catalog/product_info.php?products_id=1610 (accessed 25 Jan 2009).

*Peerless 8"*
*Polypropylene cone*
*Rubber surround*
*Cast Frame - truncated*
*Ventilated raised spider*
*Shorting rings*

The driver's specification sheet states that the $f_s$ is 32.5 Hz and its sensitivity as 90.1 dB. Figure 6 shows the response of the driver as provided by the driver's data sheet.[12] Figure 7 shows the WinSpeakerz calculations for a 4th order vented system of 1.5 cubic feet.

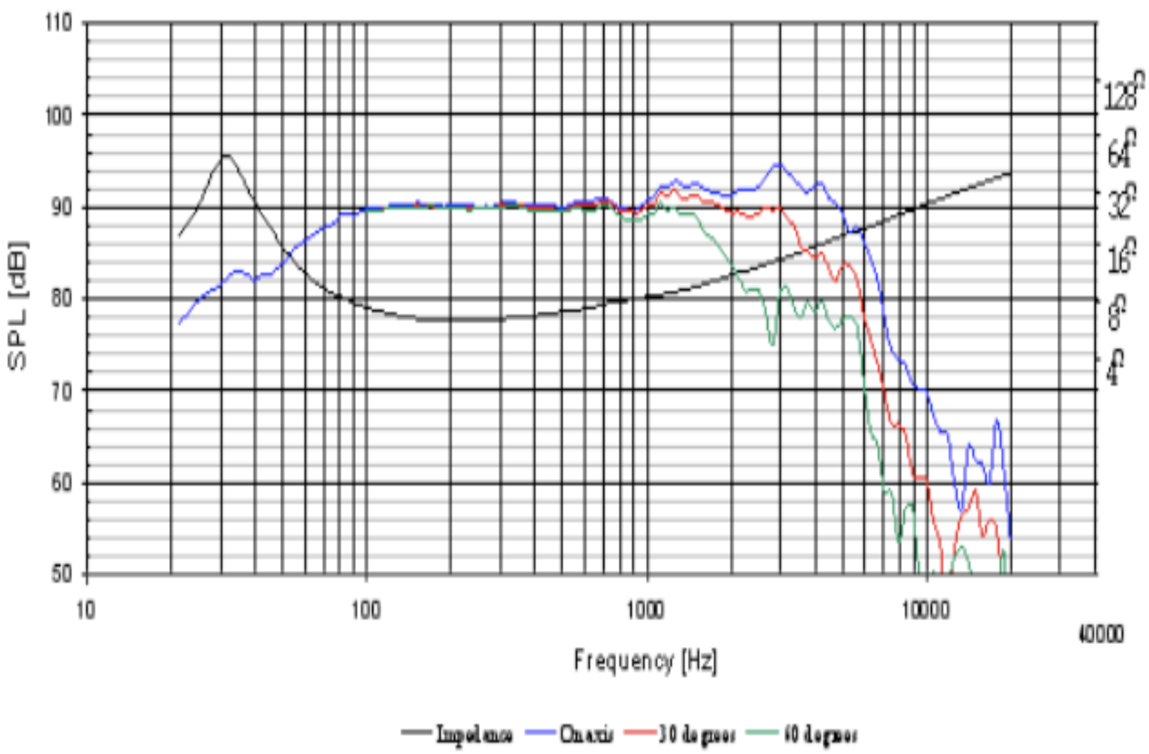


Figure 6

[12] Peerless 830868, "Peerless PPB 831868 - 8" Poly Cone Woofer.http://www.madisound.com/catalog/PDF/peerless/830868.pdf (accessed 25 Jan 2009).

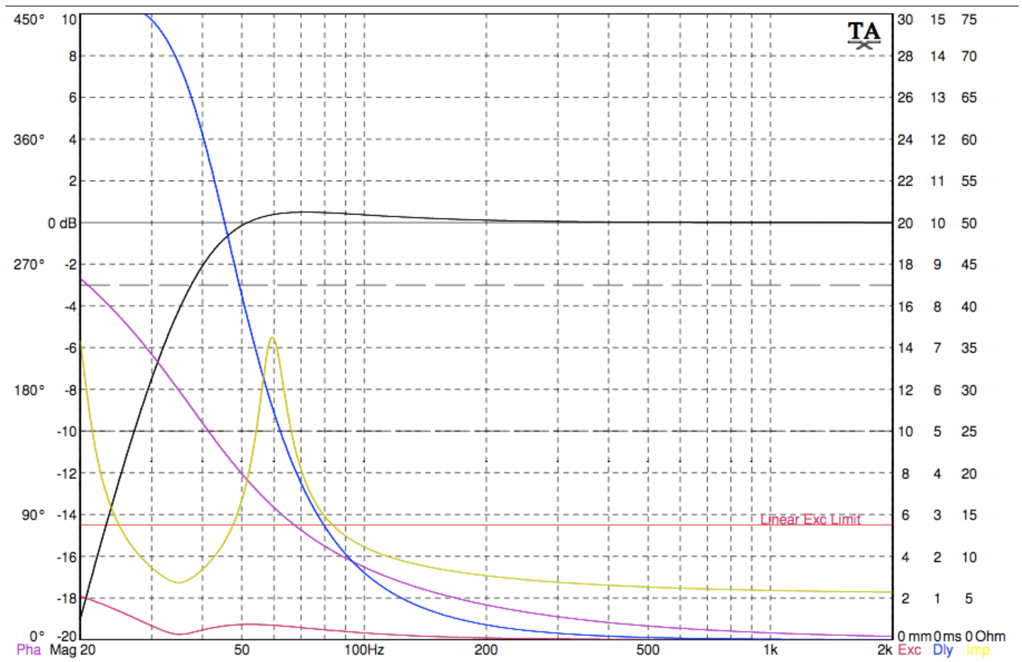


Figure 7

As can be seen from the frequency response graph, the driver doesn't have any sharp discontinuities until 3 kHz. At that point, the off-axis response starts to differ from the on-axis response. Also, around 1.3 kHz there is a shelf in the response. Since the driver appears to be very stable up until 3 kHz, it is an excellent match for the tweeter that I selected. Three kilohertz is well above the crossover frequency and is 1.5 octaves above the crossover point. Looking at the response plot generated with WinSpeakerz, the speaker has an $f_3$ of approximately 38 Hz in a $4^{th}$ order vented box. This definitely meets the low frequency response goal. Also, the slight rise in frequency response is preferred over the dips of the other drivers. Because of its performance, this driver was chosen.

The tweeter is specified with 93.5 dB SPL, 1W/1m sensitivity. No specified maximum power rating was given, but other drives with similar response curves and sensitivities generally have a maximum rating of 100W with a second order crossover at 2 kHz. My design will utilize a 1.2 kHz first order crossover, discussed in detail below. As a result, I estimate the maximum power handling of the driver to be 25W. The calculated maximum output of the tweeter is approximately 104 dB SPL at 2m. The woofer is specified as having a 90.1 dB SPL, 1W/1m. Once again, using the inverse square law, the woofer is calculated to have an output of 101 dB at 25W/2m. Therefore the tweeter requires a 3 dB pad. The speaker should therefore have a maximum output of 101 dB 25W/2m. This satisfies the K-14 standard.

**Enclosure**

The need for and logic behind a cabinet originates with the concept of the baffle. John Murphy explains the need for baffles, "The reason for the lack of bass when the driver is operated in free air is the fact that the sound radiated from the opposite sides of the driver cone is of opposite polarity… When the listener hears a combination of the sound from both the front and rear of the driver the low-frequency cancellation will be audible as a high pass filter effect where mids and highs play at full level but the low frequency range of the driver is greatly reduced."[13] In other words, the increase in air pressure created by the motion of the speaker outward is negated it combines with the area of low pressure from the rear of the speaker. The pressure differences effectively cancel themselves out. To help reduce this problem the driver is mounted in a baffle, such as a board. The board creates a barrier that helps to decrease the ability of the air to equalize the pressure differences; the air must travel around the barrier.

There are two types of baffles: infinite and finite. In the theoretical world, "if the board were to extend in all directions to infinity, it would be a true infinite baffle. It would cause no change in the air loading on each side of the diaphragm, it would exhibit no resonances, it could

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[13] Murphy, John L. *Introduction to Loudspeaker Design*. (2 ed. Andersonville, TN: True Audio, 1998.) p. 17

cause no diffractions, and, with a good quality driver would sound excellent."[14] If a speaker were mounted on a board that stretched to infinity, the air would have no way of getting to the other side and negating the pressure differences. The problem with this theory is that an infinite baffle is only theoretical and cannot be practically implemented. There is however an alternate way to obtain the benefits of an infinite baffle – a sealed box.

A sealed box is built on the premise that if there is no way for the sound from the rear of the cone to get to the front of the cone, aka it's sealed in a box, then the pressure differences can not negate each other. The sealed box succeeds in that manner; however, it is not without drawbacks. "The constraint of the air within a sealed box causes it to act like a spring, which reacts against the movement of the diaphragm in either direction. This effectively stiffens the suspension of the drive unit, and raises its resonant frequency… As the system resonance defines the frequency at which the low frequency roll-off will begin, then for any given driver the low frequency-response will become progressively more curtailed as the box size reduces."[15] What this means is that due to the pressure of the air inside the box, the speaker's cone cannot counteract the pressure enough in order to accurately produce lower frequency waveforms. While this drawback exists, sealed box speakers certainly have their place.

In an effort to extend the bass response of sealed box cabinets, ports or vents are often added to the sealed cabinet transforming it from a sealed box into a reflex or ported enclosure. "All things being equal, with the vented box you can get either more bass extension, more efficiency, or you can use a smaller box compared to a closed box. The vented box has a definite performance advantage in many regards."[16] In a vented box system the port acts in a way very

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[14] Newell, Philip, and Keith Holland. *Loudspeakers for Music Recording and Reproduction*. p. 65
[15] Newell, Philip, and Keith Holland. *Loudspeakers for Music Recording and Reproduction*. p. 67
[16] Murphy, John L. *Introduction to Loudspeaker Design*. p. 27

similar to an organ pipe. Dependant on the diameter and length of the port, it resonates at a particular frequency. Assuming the resonant frequency of the port is slightly below where the low frequency roll off of the speaker begins, the combination of the speaker and the resonance of the port combine to create a curve with extended bass response. The port itself creates drawbacks however. "Below the port resonance, air simply pumps in and out of the port under the influence of the driver. At these frequencies, the cabinet is just a box with a big air leak, and it can provide no loading on the driver diaphragm, which then behaves as if it were an open baffle with no air loading protections, so over-excursions are easy to encounter in reflex enclosures unless the low frequency drive signal is filtered or has no natural content, below the resonant frequency of the box."[17] It therefore becomes very important to filter the input signal as to avoid damage to the physical speaker. Due to the extended bass response, a vented box enclosure is often preferred over the sealed box. In order to achieve the desired $f_3$ goal, the ported box was selected.

My speaker design will utilize a ported-box of approximately 1.5 cubic feet. From the modeling with WinSpeakerz, the $f_3$ of the box should be 38 Hz when used in a $4^{th}$ order vented enclosure with a vent area of 3.14 square inches and a length of 3.163 inches. Using that port will tune the enclosure to 35 Hz and provide the optimal conditions for low-end response. Once again, this satisfies my design criterion of 50 Hz.

The shape of the cabinet is very important. The first thing to consider is the shape and its role in contributing to diffraction loss. The issue arises because of how sound radiates. When the sound waves encounter a bump in the baffle, such as the baffle's edge, they are refracted, which likewise affects how the speaker sounds. "the sudden increase in expansion rate of the

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[17] Newell, Philip, and Keith Holland. *Loudspeakers for Music Recording and Reproduction*. p. 73

wave creates a lower sound pressure in front of the wall, near the edge, than would exist if the edge were not there. This drop in pressure then propagates away from the edge into the region in front of the plane of the source…the one that propagates to the front is in phase opposition.” [18] In other words, every time a wave reaches an edge in the radiating plane, some of the sound is diffracted. That diffracted sound can then radiate into the listening field in opposite phase from the desired sound, thus causing destructive interference with the desired sound. Since the diffraction occurs at edges in the radiating plane, as is seen at the edges of the cabinets, the overall shape of the enclosure has a big impact on how the speaker will sound. In 1951 Harry F. Olson published his findings about the effects of diffraction loss. As can be seen in Figure 8, a perfect sphere with no edges will not suffer the effects of diffraction loss. Figure 9 shows the diffraction loss of a cube, and Figure 10 shows the loss of a rectangular enclosure. [19]

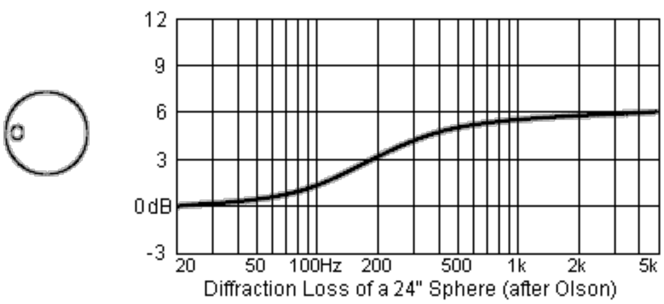


Figure 8

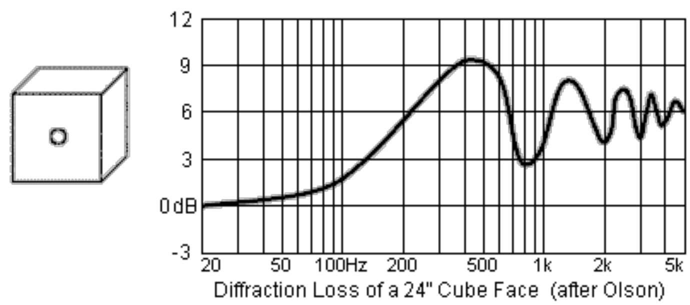


Figure 9

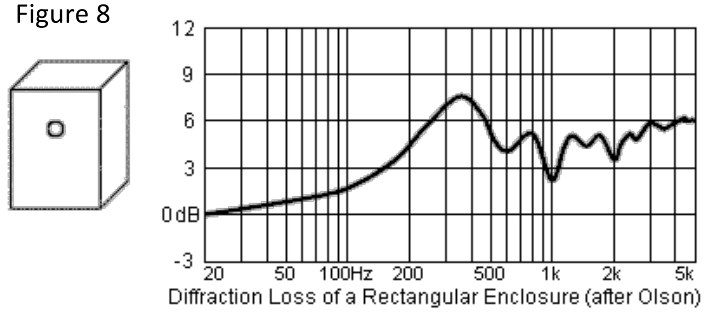


Figure 10

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[18] Newell, Philip, and Keith Holland. *Loudspeakers for Music Recording and Reproduction*. p. 88-89

[19] Murphy, John L. "Loudspeaker Diffraction Loss and Compensation." http://www.trueaudio.com/st_diff1.htm (accessed 11 Feb 2009). p. 2-3

From looking at the response plots of various shapes of enclosures the affect of diffraction loss can be seen. The sphere clearly has the optimum conditions, as there are no corners that can diffract the sound. The cubic enclosure suffers from problems because the driver is equidistant from all of the edges causing the same frequency to be refracted at every edge. By varying the distance of the driver to one of the edges the affect is reduced. For visual reasons, rectangular speakers are often the enclosure shape of choice, but for a rectangular speaker to work well, several factors must be considered. "The rectangular loudspeaker enclosure is, however often judged less than optimal as a radiating surface because of edge diffraction issues and also less than optimal regarding internal standing wave modes."[20] While these drawbacks do in fact exist, steps can be taken to minimize their effect. A great deal of the problem with refracted waves exists because when a driver is mounted in the center of a box the refracted waves all occur at the same frequency, thus creating a boost at that frequency in the overall response curve. The solution to that issue becomes quite simple, "Make sure that the distance from left to right is different from the distance top to bottom and those should be different from the distance front to back. In other words, the internal height, width and depth should each be different numbers."[21] Doing so causes it to be different frequencies that are refracted, thus reducing the overall noticed effect of the refractions.

Once the shape of the enclosure has been chosen another aspect that must be taken into account is the dimensions of the box. My design specifies an interior volume of 1.5 cubic feet. Using the golden ratio and a table of internal dimensions given a specified volume, I determined

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[20] Dickason, Vance. The Loudspeaker Design Cookbook. 7 ed. Peterborough, NH: Audio Amateur Press, 2006. p. 105

[21] Murphy, John L. *Introduction to Loudspeaker Design*. p. 87

my enclosure must have interior dimensions of 22.23” x 8.49” x 13.74”.[22] The woofer will be mounted ½” off center and the bottom of the tweeter will be 6.23” from the bottom of the cabinet. The tweeter will be 2” off the centerline of the speaker and the top of the tweeter will be 5” from the top of the cabinet. The port will be located below the woofer in the lower corner of the baffle. The faces of the speakers will be mirrored.

The box itself will be constructed with an inner layer of ¾” MDF and an outer layer of ¾” birch plywood. The front baffle will be made of a solid birch, also layered with MDF. North Creek Music Systems recommends using the combination because “The MDF and plywood panels are rigidly coupled, and the resulting panel is substantially stiffened. The Baltic Birch plywood also offers additional stiffness because of its grain and highly layered construction. Stiffness is proportional to the square of panel thickness, therefore the composite panel is at least four times as stiff as a single MDF layer.”[23] The rigidity is very important because it helps prevent panel resonances, which in turn color the sound.

Another way to reduce resonances is to brace the enclosure. “The addition of the bracing structure moves the first panel resonance up in frequency. Those standing waves that find stability are generally at a frequency well above the unbraced panel’s fundamental resonance. The nature of vibration within panels tends to “bleed” energy from one side to the other, therefore a standing wave in one side will migrate to the other, where it is unstable.”[24] The more that can be done to reduce unwanted vibrations the better. “Bracing material must possess qualities very different from side wall material... the job of a brace is to remain dimensionally stable under the forces of tension and compression… The correct material to use for internal

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[22] Murphy, John L. *Introduction to Loudspeaker Design*. p. 88-89
[23] North Creek Music Systems, The North Creek Music Systems Cabinet Handbook. 2 ed. Old Forge, NY: North Creek Music Systems, 1992. p.5
[24] North Creek Music Systems, The North Creek Music Systems Cabinet Handbook. p. 9

bracing is multidirectional plywood. Plywood is very strong in any direction under tension because wood does not stretch along the grain."[25] My speaker will have a horizontal brace. It will have several holes cut into it as to minimize the affect on the interior volume of the cabinet.

The way a cabinet is constructed is very important. The way the front of the speaker is designed is also very important and affects how the speaker will sound. I want the speakers to sound good whether I'm sitting on my bed or working at my desk. To help with this, I want to have a fairly narrow baffle. This will allow sound waves with a higher frequency to bend around the baffle creating a more omni-directional speaker. But it is not just placement of the drivers on the baffle that is important - the size of the baffle also affects the sound. "As the area of a loudspeaker baffle increases, it will offer more and more reinforcement to the very lowest frequencies right up to the point where the baffle becomes infinitely large."[26] In this situation it is more important to me to have a good sounding speaker in several places than a perfectly flat one in one place. The narrow baffle will help me achieve my functional goal of good on- and off-axis response.

**Crossover**

Another major factor in how a speaker sounds is the crossover. An individual driver cannot accurately reproduce a full range signal. As David Moulton explains, "The size of the driver diaphragm is extremely important. Unfortunately, the bandwidth of any given driver is limited to about three octaves, and the actual frequency range is determined primarily by the size of the diaphragm. At long wavelengths (low frequencies), a small driver cannot displace

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[25] North Creek Music Systems, The North Creek Music Systems Cabinet Handbook. p. 10
[26] Dickason, Vance. The Loudspeaker Design Cookbook. 7 ed. Peterborough, NH: Audio Amateur Press, 2006. p. 135

sufficient air volume to generate meaningful sound pressure levels, while a larger driver cannot move quickly or uniformly enough to linearly generate short wavelengths (high frequencies). Therefore, drivers are usually assembled into systems of drivers, each covering a different portion of the audio spectrum."[27] It becomes essential therefore to split the full spectrum of audio into parts, with each speaker getting the part of the spectrum that it can accurately reproduce.

In simple terms, a crossover is a network of resistors, capacitors and/or inductors that only pass part of the full spectrum audio signal and that filter the rest. The parts combine to form a series of high and low-pass filters that shape the sound to fit the needs and capabilities of the drivers in the system. Each inductor or capacitor the signal passes through ads 6dB to the roll off curve, and ads what is called an order. It sounds like a simple enough process, however, complications arise when the full range signal is split, and when it is sent to multiple drivers.

A major factor to consider when designing a crossover is the crossover point itself. "One of the critical issues here has to do with coverage of the "voice range," from 1,500 to 4,000 Hz. This is a critical frequency range for loudspeaker performance and it is difficult to get a "crossover point" to sound good in this range while reproducing voice."[28] The crossover point needs to be transparent, and when that point is located in the vocal range, it becomes very hard to mask the shift between tweeter and woofer. In an effort to achieve the fast transient response functional goal, I have selected a crossover point of 1.2 kHz with a 12dB/octave roll off.

To achieve my crossover point goal I started by evaluating the tweeter's frequency response. It has a natural 6 dB roll off that begins around 1 kHz. Due to the natural roll off, the

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[27] Moulton, David. Total Recording. Nick Batzdorf. p. 208
[28] Moulton, David. Total Recording. Nick Batzdorf. p. 209

6dB/octave roll off of a simple first order crossover would achieve the goal of 12dB/octave. Actual implementation of the crossover can easily be achieved through insertion of a capacitor in series with the driver. Its value was calculated using the formula[29]:

$$C = 1 / (2\pi f R)$$

To achieve a 12 dB roll off for the woofer, I chose a Linkwitz-Riley 2nd order filter. It places a capacitor in parallel with the driver and an inductor in series with that combination. The values for the components are calculated[30]:

$$C = .0796 / R_H f \qquad L = .3183 / f$$

Due to the differences in the sensitivities of the drivers, a 4 dB pad was designed for the tweeter using the chart in Eargle's *Loudspeaker Handbook*.[31] The values were determined to be

$$R_1 = 1.5\Omega \qquad R_2 = 6.8\Omega$$

To help compensate for the inductive reactance of the woofer's voice coil, a Zobel network was designed using the following formulas[32]:

$$C = L_e / R_C 2 \qquad Rc = 1.25\ R_E$$

Finally, a baffle step correction filter will go at the input of the crossover. "The essence of [Diffraction Loss] is this: at high frequencies the speaker is radiating into "half space" i.e. it is only radiating into the forward hemisphere. No significant energy is radiated to the rear of the speaker. At low frequencies the speaker is radiating into both the forward hemisphere and the

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[29] Colloms,Martin. High Performance Loudspeakers. West Sussex, England: Wiley, 1997. p. 242
[30] Dickason, Vance. The Loudspeaker Design Cookbook. p. 165
[31] Eargle,John. Loudspeaker Handbook. 2 ed. Norwell, MA: Kluwer Academic Publishers, 2003. p. 112
[32] Eargle,John. Loudspeaker Handbook. p. 175

rear hemisphere.  That is, at low frequencies the speaker radiates into "full space" or "free space".  Because the "energy density" at low frequencies is reduced there is a loss of bass."[33] Thankfully, the loss can be accounted for with simple equations[34]:

$$f_3 = 4560 / W_B$$

$$L_{BSC} = 8 / 2\pi f_3$$

$$R_{Parallel} = 8(10^{4/20} - 1)$$

The elements of the crossover combine to form the crossover in figure 12.

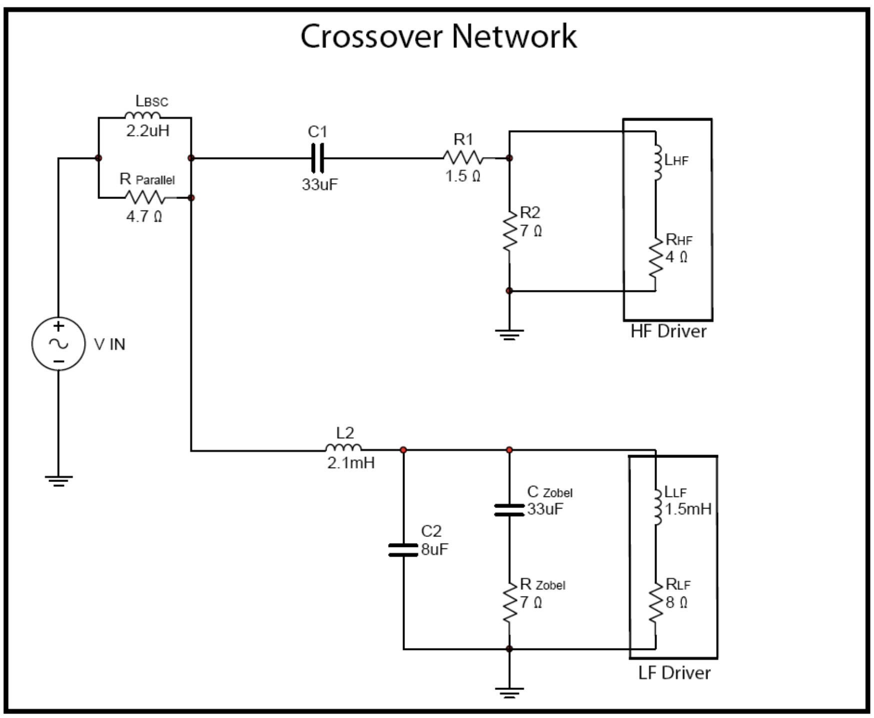

Figure 12

[33] Murphy, John L. *Introduction to Loudspeaker Design*. p. 68
[34] King, Martin J.. "Simple Sizing of the Components in a Baffle Step Correction Circuit." 24 Feb 2004. p. 4

The crossover will in fact obtain a crossover point of 1.2 kHz. The low crossover point should meet the design criterion of a fast transient response time.

**Conclusion**

The speakers that I have designed should work well as all-purpose, easy listening music speakers. They will be a size that is portable yet able to support low-frequency response. The drives I have selected as well as the crossover configuration will provide the crisp highs and solid, defined lows, reaching down to approximately 38 Hz. The speaker also exceeds the K-14 standard with and output of approximately 101 dB. After this design process it is clear that not only are loudspeakers an important musical instrument, they are also very complicated instruments.

**Appendix**

Required Parts List
Vifa DX25TG05-04 Specification Sheet
Vifa XT18WH09-08 Specification Sheet
Vifa XT18WH09-08 WinSpeakerz Analysis
Fountek FW168 Specification Sheet
Fountek FW168 WinSpeakerz Analysis
Peerless HD 830868 Specification Sheet
Peerless HD 830868 WinSpeakerz Analysis

**Required Parts List**

Peerless HD 830868 (2)

Vifa DX25TG05-04 (2)

Terminal R Cups (2)

10 ft. Supra CLASSIC-4.0 /bulk cable per foot (11 AWG)

Inductors (mH):
- 2.2
- 2.1

Resistors (Ω)
- 4.7
- 1.5
- 7 (2)

Capacitors ($\mu$F)
- 33 (2)
- 8