Comparison of the Bass Performance of Passive Open Baffle, U Frame, and H Frame Speakers

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Introduction :

My first article on OB design, Designing a Passive Two Way Open Baffle Speaker System, provided some general guidelines for selection of a bass driver and what could be expected in the way of bass performance. The conclusion was that for a passive OB system a high Qts driver that is significantly more efficient then the midrange or full range driver was required to produce a flat SPL frequency response. It was also demonstrated that the natural response hump occurring in open baffle designs could be combined with a low pass crossover to produce an extended bass SPL frequency response. These were the key points for designing the bass section of a passive OB speaker system.

After this initial article was completed, I started thinking about other types of dipole speakers like the popular U and H frame designs. In the past, I had never really spent much time trying to optimize U or H frame designs even though I had generated MathCad worksheets to handle these configurations. Seigfried Linkwitz's Orion[1] and John Kreskovsky's NAO[2] use H and U frames respectively in their commercial OB speaker systems. Both designs use active equalization and active crossovers to produce extended low bass response from drivers typically found in standard box speakers. I did not find a passive U or H frame dipole speaker on the Internet so I began wondering what would be required to design such a system.

Finally the light bulb went on when I realized that the U and H frame geometries do not augment the bass like a typical box speaker, they behave as a dipole in a similar manner as the OB but in a more compact package. This realization and my experience with passive OB designs made me wonder how the U and H frame dipoles would perform if I used my favorite OB driver, the Eminence Alpha 15A. This article documents my findings.

Skipping Right to the Results :

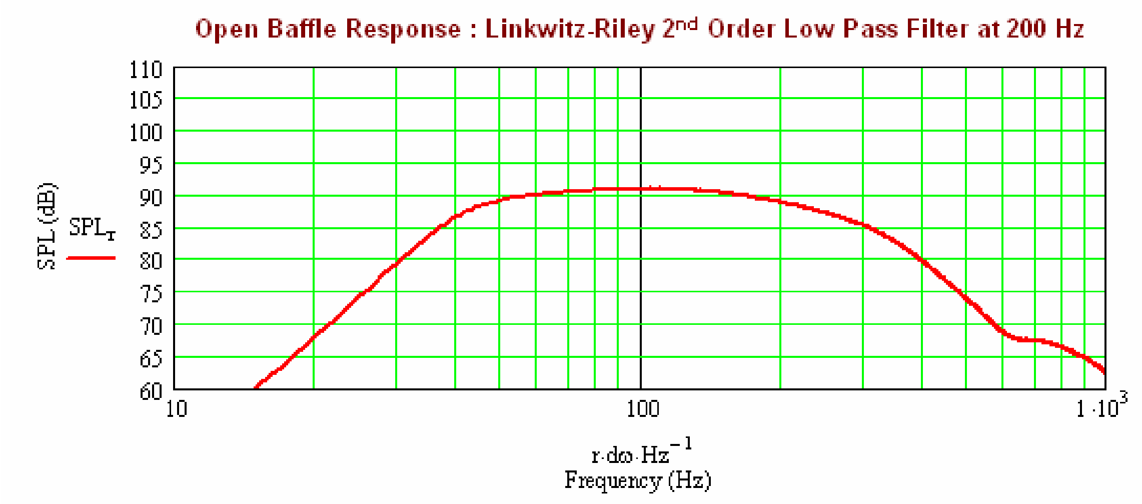
Before getting into all of the design trade-offs, let's look at the results I was able to achieve. Figure 1 shows the SPL response for the OB, U frame, and H frame using an Eminence Alpha 15A driver. The SPL responses were calculated at a 1 m distance and 32 inches above the floor (the same location as the previous article). The goal in each design was to produce a smooth bass SPL response and cross over to a suitable midrange or full range driver at approximately 200 Hz. Looking at the three response curves, you can see that going from OB to U frame and then to H frame results in increased bass extension but at the expense of reduced SPL. Table 1 shows the results I used to characterize the bass performance of these three design options.

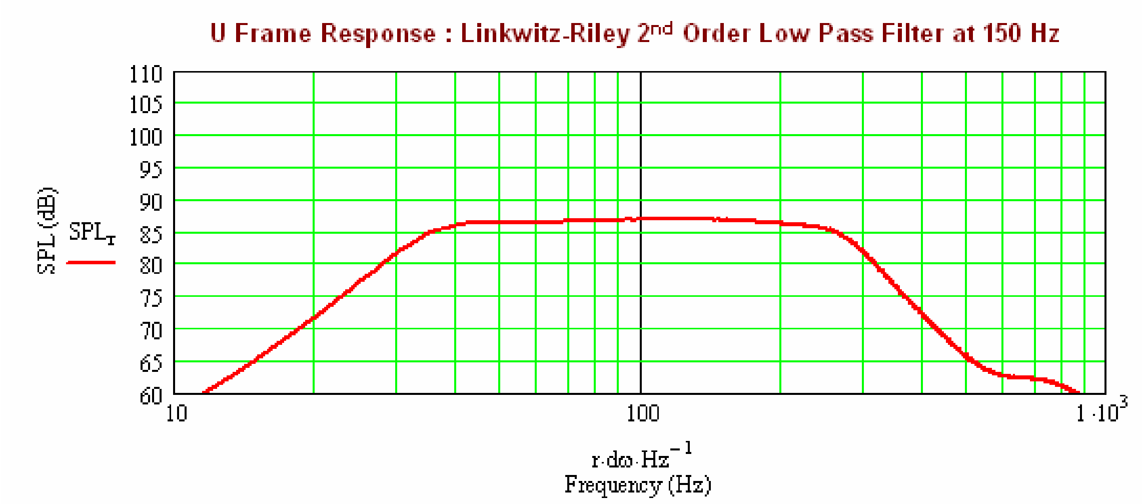
Table 1 : SPL and -3 dB Frequency

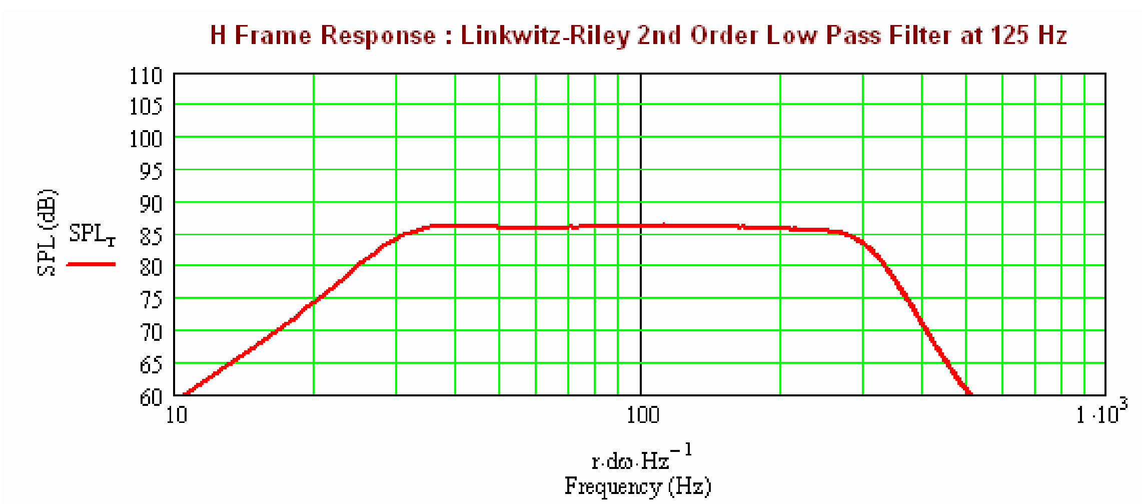
Design	SPL	f_3
OB	90.0	41
U Frame	86.5	32
H Frame	86.0	28
Units	dB	Hz

Note, 90 dB was chosen for the OB since it is the SPL value just above the onset of the OB induced bass roll-off.

Figure 1 : Calculated SPL Response for OB, U Frame, and H Frame Designs







So now the obvious discussion concerns what trade-offs were made to produce these SPL response plots. The following section will examine each end of the SPL response curves highlighting the geometric dimensions used to produce the bass roll-off and then the impact on the SPL frequency response of the specified crossover frequencies.

Geometry Definitions :

As described in the previous article, the OB is 20” wide, 38” tall, and stands directly on the floor. The Eminence Alpha 15A driver is centered 10” above the bottom edge of the baffle. The full range driver axis was 32” above the bottom edge of the baffle.

The U and H frame designs used a common cross-sectional area and cavity depth. The internal cross-sectional area is 16” wide and 16” tall. The depth of the cavity was defined as 7.5”. The depth was selected to push the first quarter wavelength resonance above the desired crossover frequency of approximately 200 Hz.

$$L_{effective} = 7.5" + 0.6 \times r_{effective}$$

$$L_{effective} = 7.5" + 0.6 \times 9.0"$$

$$L_{effective} = 12.9" = 0.328 \text{ m}$$

$$f_{1/4} = c / (4 \times L_{effective})$$

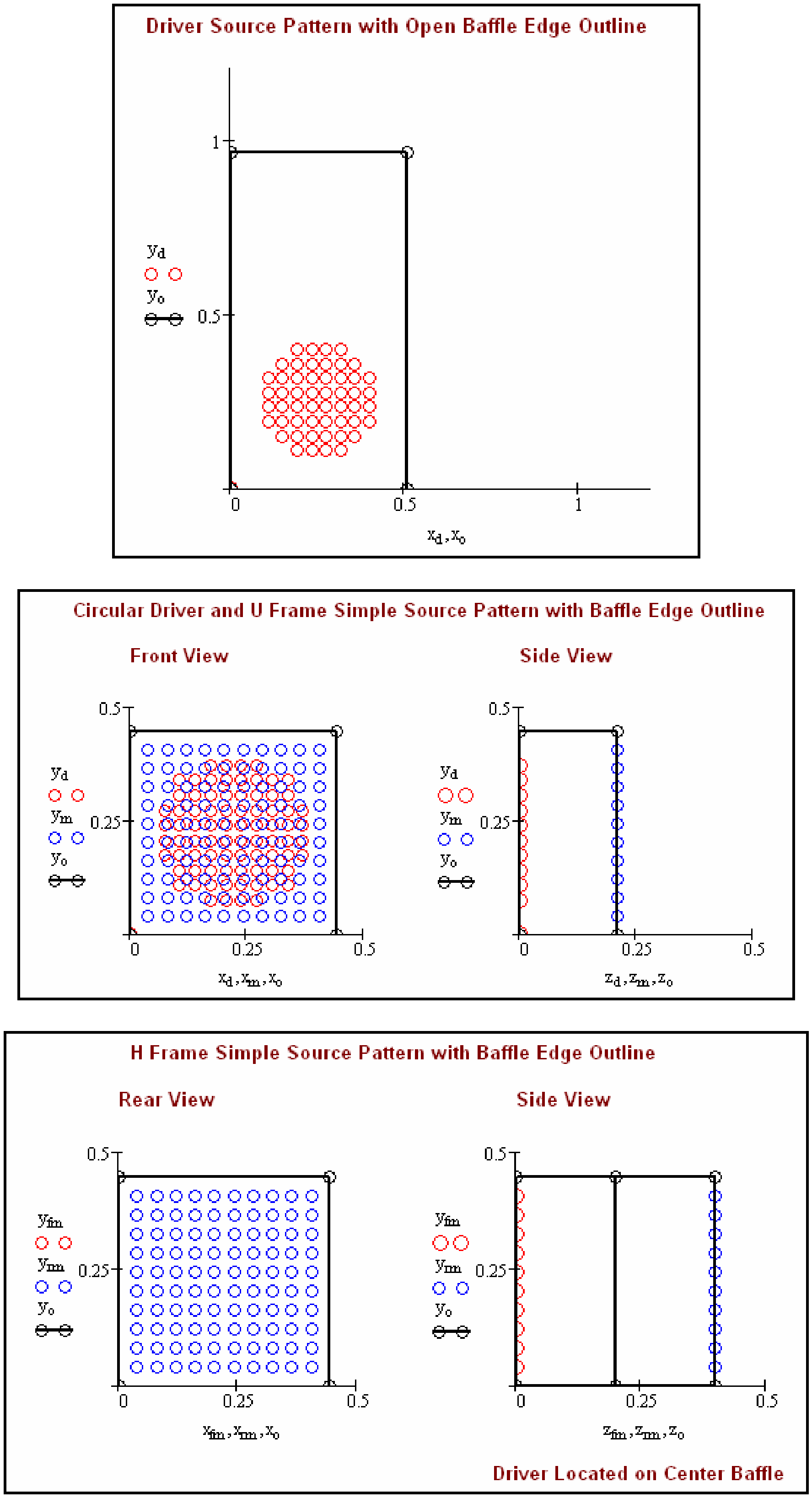
$$f_{1/4} = 344 \text{ m/sec} / (4 \times 0.328 \text{ m})$$

$$f_{1/4} = 262 \text{ Hz}$$

Adding additional length to either the U or H frame drops the quarter wavelength resonant frequency resulting in a peaking SPL response around the crossover frequency. Efficiency of the bass output would not be increased with this additional length. The efficiency of a U or H frame could be increased by using a larger cross-sectional area. The depth of U frame or either side of H frame enclosures should be set to place the quarter wavelength resonance above the selected low pass crossover frequency.

At the risk of repeating myself, the SPL responses for all three designs in this study are calculated at a 1 m distance from the front baffle and 32” above the floor. Again, the intent is to calculate the bass contribution to the system SPL response on the axis of a full range or midrange driver positioned approximately at ear level for a seated listener.

Figure 2 : Geometries of the OB, U Frame, and H Frame Designs



Impedance :

The electrical impedance of the OB, the U frame, and the H frame are shown in Figure 3. Plotted in each curve is the infinite baffle impedance as a reference. Moving from top to bottom in Figure 3, the OB driver resonance is equal to the infinite baffle value of 41 Hz while the U and H frame resonances drop to 35 Hz and 31 Hz respectively. If we attribute these drops in resonant frequency solely to a portion of the air in each cavity adding parasitic moving mass to the driver cone, the mass of added air can be calculated to be approximately 22 gm. This represents about 60% of the air in each 7.5" deep cavity.

Assuming added mass is the only property contributed by the enclosure near the system resonant frequency, the impact on the Eminence Alpha 15A Thiele / Small parameters can also be estimated. These calculations are shown in Figure 4. The conclusions drawn from Figure 4 are that the added mass drops the system resonant frequency and the SPL/W/m while increasing the effective Q_{td}. This is consistent with the results shown in Figure 1 for the three different dipole configurations and is consistent with experiences adding weights to woofer cones for traditional speaker designs.

Crossover Design :

The SPL response of the OB, the U frame, and the H frame are shown in Figure 5 without the crossover filter applied. It is clear that a rising response starts to appear above 100 Hz in each case. The height of the peak determines the frequency of the applied 2^{nd} order Linkwitz-Riley crossover filter. The small hump present in the OB SPL response allows a 200 Hz crossover frequency. For the U and H frames the quarter wavelength resonant peaks become more severe and require the crossover to be set lower in frequency at 150 Hz and 125 Hz respectively. In each case, the height of the peaks helps to extend the SPL response above the crossover frequency to achieve the goal of a 200 Hz acoustic SPL roll-off. Comparing Figures 1 and 5 shows the impact of the crossover on each of the responses.

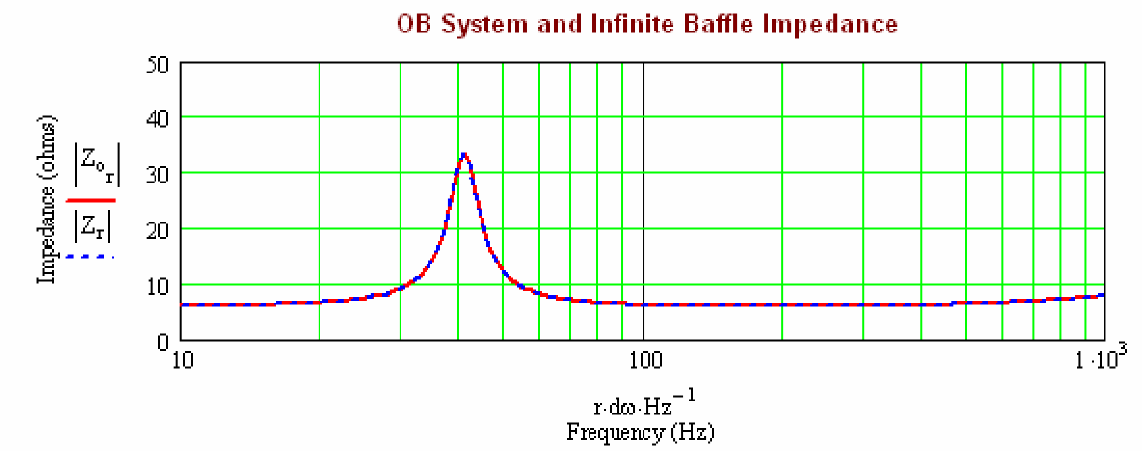
Impulse Response :

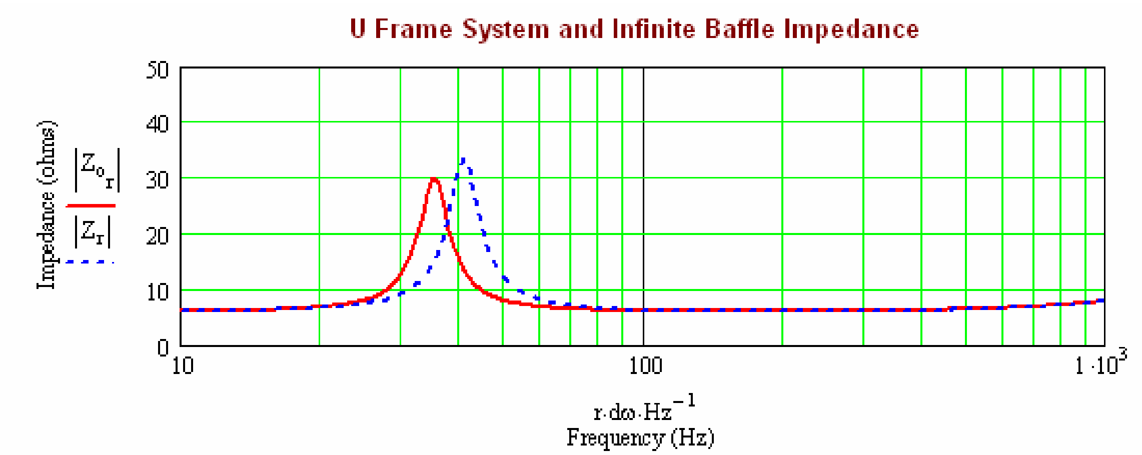
Figure 6 shows the impulse response for the OB, the U frame, and the H frame. For all practical purposes these responses are very similar and I would expect similar bass transient performance from each configuration. Comparing the OB impulse response with the U and H frame impulse responses one could conclude that the U and H frame are slightly better damped since they settle back to zero in a little less time. The slight ripple in the U and H frame responses, which can be seen around 0.01 sec, is due to the quarter wavelength resonance that is located at approximately 260 Hz. Having lived with the Eminence Alpha 15A in an OB for the past few years, the similarity in the time traces indicates that the bass output from these U and H frame geometries should be very good. Getting even lower bass extension, from a relatively small enclosures, makes the U and H frames a very attractive design concept.

Figure 3 : Impedance of the OB, U Frame, and H Frame Designs

Solid Red Curve is the System Impedance

Dashed Blue Curve is the Infinite Baffle Impedance





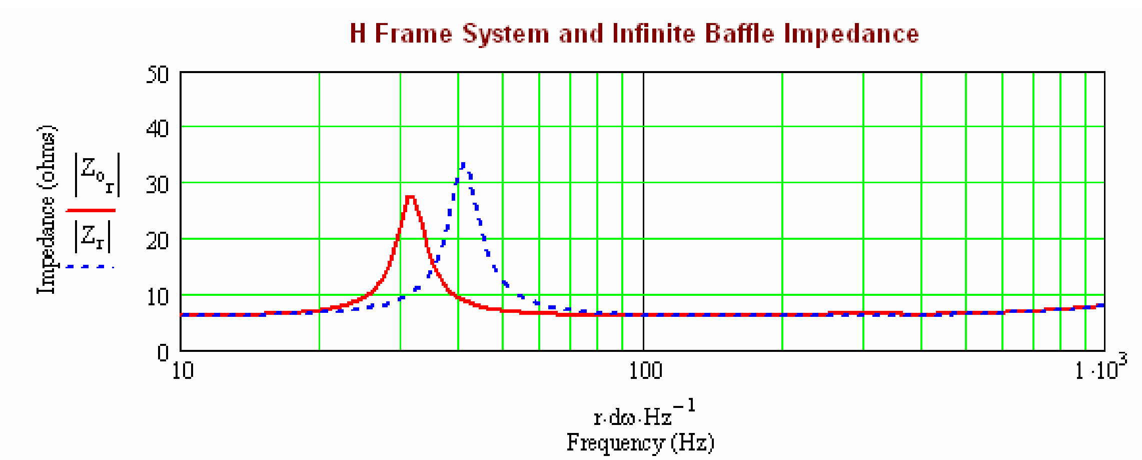


Figure 4 : Adjusted Thiele / Small Properties

Data for the Eminence Alpha 15A in an Open Baffle

$f_d := 41 \cdot Hz$ $\quad Q_{md} := 7.23$

$R_e := 5.88 \cdot ohm$ $\quad Q_{ed} := 1.53$

$S_d := 856.3 \cdot cm^2$ $\quad Bl := 7.7 \cdot \frac{newton}{amp}$

Calculated Parameters

$Q_{td} := \left(\frac{1}{Q_{ed}} + \frac{1}{Q_{md}}\right)^{-1}$ $\quad Q_{td} = 1.263$

$M_{md} := \frac{Bl^2 \cdot Q_{ed}}{f_d \cdot R_e}$ $\quad M_{md} = 59.887\, gm$

$C_{md} := \left(M_{md} \cdot f_d^2\right)^{-1}$ $\quad C_{md} = 2.516 \times 10^{-4} \frac{s^2}{kg}$

$R_{md} := Bl^2 \cdot \left(\frac{Q_{ed}}{R_e \cdot Q_{md}}\right)$ $\quad R_{md} = 2.134 \frac{newton \cdot sec}{m}$

$V_{ad} := C_{md} \cdot \left(\rho \cdot c^2 \cdot S_d^2\right)$ $\quad V_{ad} = 264.177\, liter$

$\eta_o := V_{ad} \cdot \left(2 \cdot \pi \cdot c^3 \cdot Q_{ed} \cdot f_d^{-3}\right)^{-1}$ $\quad \eta_o = 1.154\,\%$

$SPL := 112 + 10 \cdot \log(\eta_o)$ $\quad SPL = 92.6$ dB

Effective Q_{td} and SPL/W/m Estimates for the U and H Frame

$M_{air} = 22.271\, gm$

U Frame

$f_d := 35 \cdot Hz$

$Q_{ed} := (M_{md} + M_{air}) \cdot f_d \cdot R_e \cdot Bl^{-2}$ $\quad Q_{ed} = 1.792$

$Q_{md} := (M_{md} + M_{air}) \cdot f_d \cdot R_{md}^{-1}$ $\quad Q_{md} = 8.467$

$\left(\frac{1}{Q_{ed}} + \frac{1}{Q_{md}}\right)^{-1} = 1.479$ <--- U Frame Q_{td}

$\eta_o := V_{ad} \cdot \left(2 \cdot \pi \cdot c^3 \cdot Q_{ed} \cdot f_d^{-3}\right)^{-1}$ $\quad \eta_o = 0.613\,\%$

$SPL := 112 + 10 \cdot \log(\eta_o)$ $\quad SPL = 89.9$ dB

H Frame

$f_d := 31 \cdot Hz$

$Q_{ed} := (M_{md} + 2 \cdot M_{air}) \cdot f_d \cdot R_e \cdot Bl^{-2}$ $\quad Q_{ed} = 2.017$

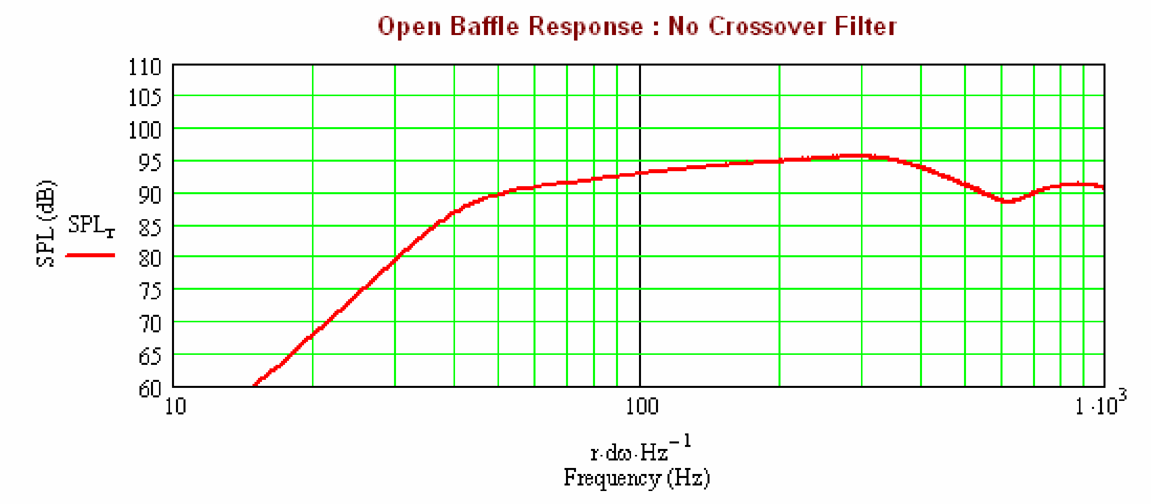
$Q_{md} := (M_{md} + 2 \cdot M_{air}) \cdot f_d \cdot R_{md}^{-1}$ $\quad Q_{md} = 9.532$

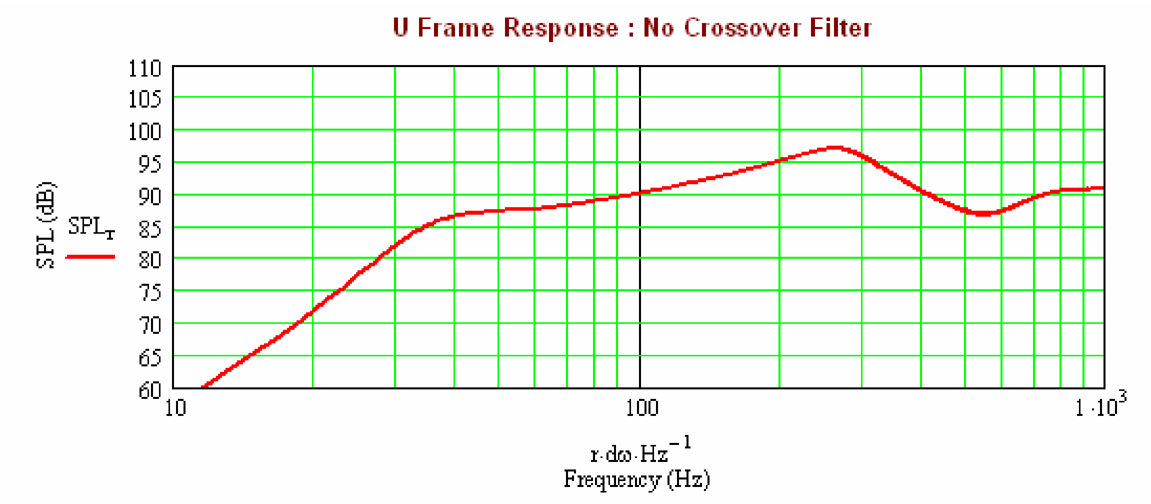
$\left(\frac{1}{Q_{ed}} + \frac{1}{Q_{md}}\right)^{-1} = 1.665$ <--- H Frame Q_{td}

$\eta_o := V_{ad} \cdot \left(2 \cdot \pi \cdot c^3 \cdot Q_{ed} \cdot f_d^{-3}\right)^{-1}$ $\quad \eta_o = 0.378\,\%$

$SPL := 112 + 10 \cdot \log(\eta_o)$ $\quad SPL = 87.8$ dB

Figure 5 : Calculated Unfiltered SPL Response for OB, U Frame, and H Frame Designs





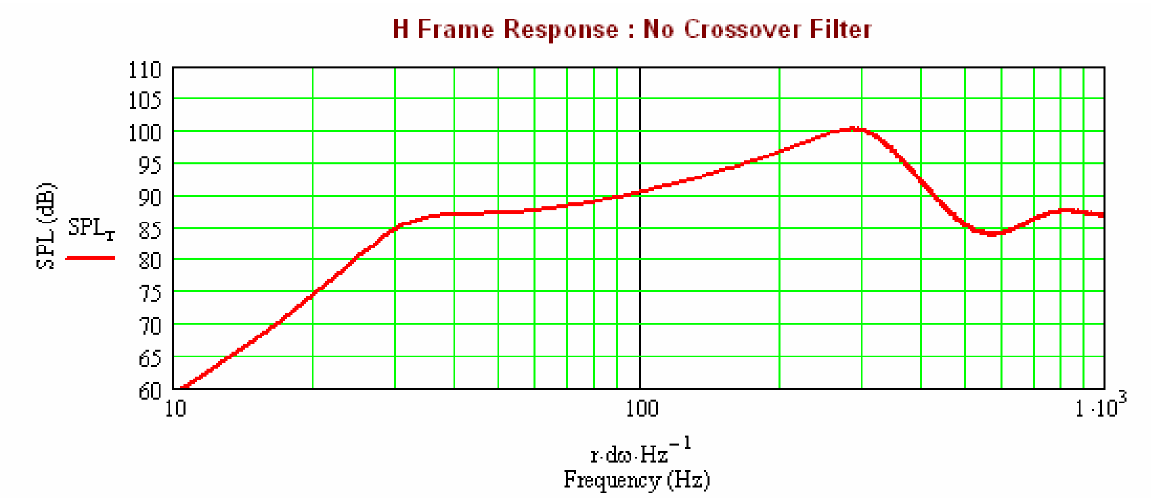
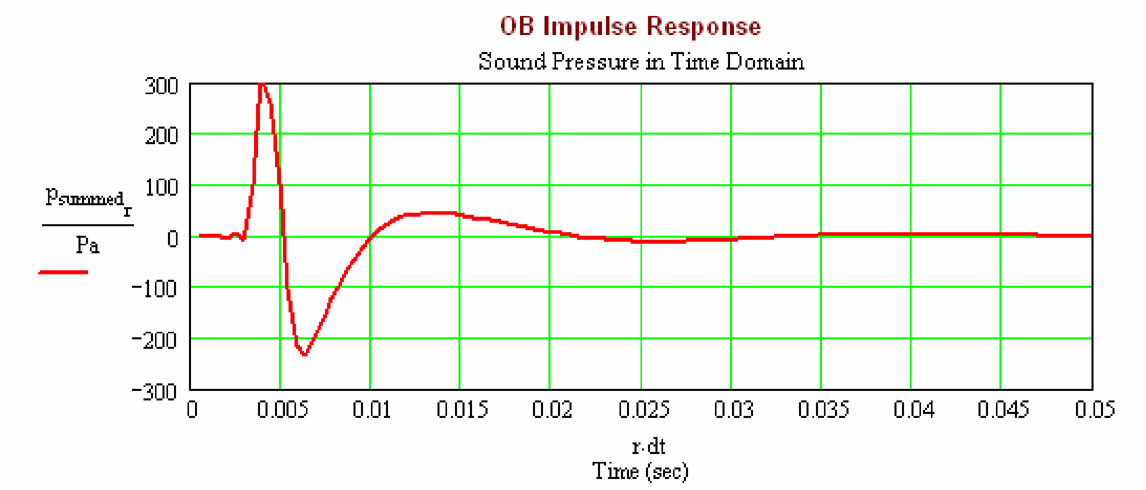
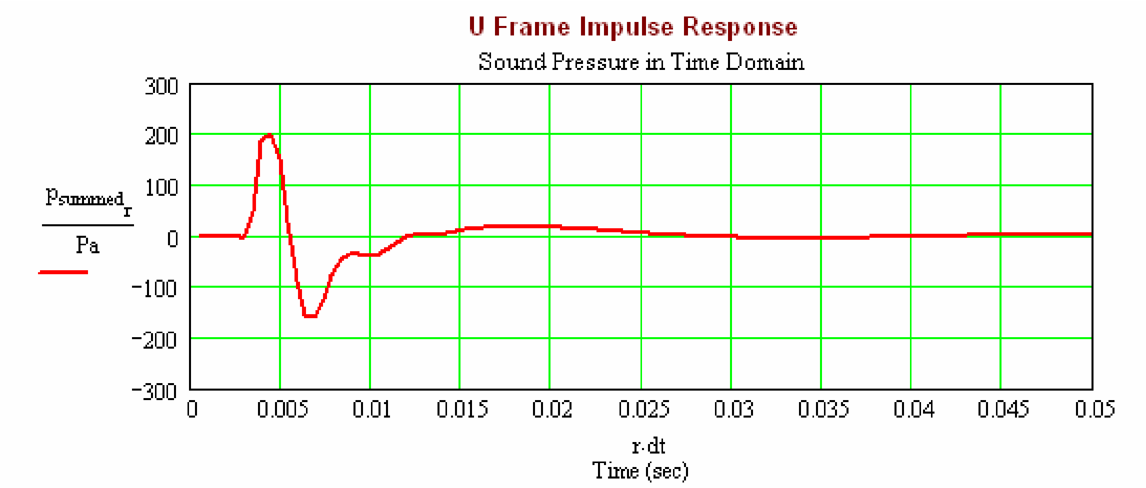
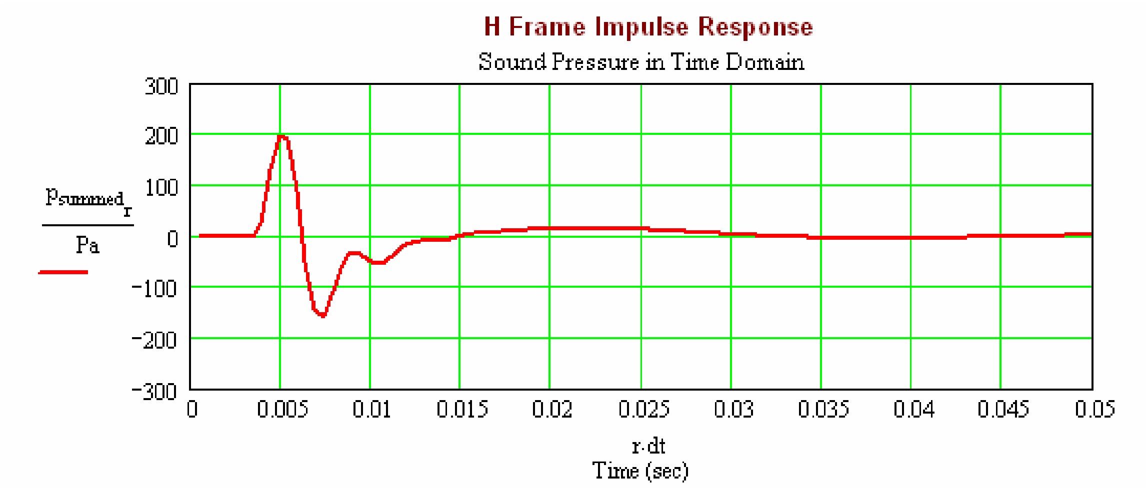


Figure 6 : Calculated Impulse Response for OB, U Frame, and H Frame Designs







Conclusions :

For a passive dipole speaker system, the U and H frame geometries represent an interesting set of trade-offs against an OB configuration. However, in each case the recommendation is still to use a high Q_{td} woofer driver. Many of the lessons learned in the previous study of a passive two way OB speaker system also apply to passive U and H frame designs. The trade-off between OB and U or H frames is increased bass extension with a loss of SPL. This needs to be carefully balanced against the important requirement to mate with a suitable midrange or full range driver.

The maximum length of the U and H frame geometry should be sized so that the first quarter wavelength resonance occurs above the low pass crossover frequency.

$$L_{maximum} < c / (4 \times f_{crossover})$$

If the length is set correctly, there is no need for fiber stuffing in the cavities used to form the U or H frame. Adding length will not increase low frequency efficiency, it will only produce peaks in the SPL response. Efficiency of a U or H frame can be adjusted up or down by increasing or decreasing the cross-sectional area of the cavities.

A few concepts not explored in this study are the impact of an unsymmetric H frame and tapered or expanding U or H frame geometries. Each of these options could be used to control or fine tune the bass system's SPL frequency response. There is still a lot of interesting possibilities for U or H frame design which can be reviewed using the appropriate MathCad worksheet. The three cases shown in this document are the default configurations in the latest MathCad worksheets. If I decide to incorporate one of these dipole geometries in a future speaker system design, which is highly likely, I will be trading off many of these variables looking to maximize bass extension and SPL.

References :

1) Linkwitz Lab (http://www.linkwitzlab.com/index.html)

2) Music and Design (http://www.musicanddesign.com/)