Maximizing Stereo Output Volume through Subwoofer Enclosure Design

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Objective:

The objective of this experiment is to design and build subwoofer enclosures, then to measure the resonating frequency of the enclosures to see which enclosure maximizes subwoofer volume.

Theory:

The calculation of the resonant frequency of the subwoofer enclosures differs from the sealed box to the ported box. The resonant frequency depends on different variables; the sealed enclosure's tuning is based more upon the subwoofer, whereas the ported enclosures tuning is based upon the port factors.

To calculate the resonant frequency of the sealed enclosure, first calculate the acoustic capacitance of the enclosure using the volume of the box (V_B), the speed of sound through air (c), and the density of air (ρ):

$$C_{CAB} = \frac{V_B}{pc^2} \qquad \text{(Ahonen 15)}$$

Then calculate the acoustic capacitance of the subwoofer using the volume of the subwoofer, the density of air, and the speed of sound through air:

$$C_{CAS} = \frac{V_{AS}}{pc^2} \qquad \text{(Ahonen 9)}$$

Then calculate the total acoustic capacitance using the acoustic capacitance of the subwoofer and the acoustic capacitance of the box:

$$\frac{1}{C_t} = \frac{1}{C_{CAS}} + \frac{1}{C_{CAB}}$$

$$C_t = \frac{C_{CAS}C_{CAB}}{C_{CAS}+C_{CAB}} \qquad \text{(Ahonen 15)}$$

Next measure the inductance of the subwoofer (L_{MAS}) using the resonant frequency of the subwoofer (f_s) and the acoustic capacitance of the subwoofer (C_{CAS}):

$$L_{MAS} = \frac{1}{(2\pi f_s)^2 C_{CAS}} \qquad \text{(Ahonen 9)}$$

Finally use the total acoustic capacitance and inductance of the subwoofer to solve for the resonant frequency of the sealed box:

$$f_{SC} = \frac{1}{2\pi\sqrt{C_t L_{MAS}}} \qquad \text{(Equation 1)} \quad \text{(Ahonen 15)}$$

To solve for the resonant frequency of the ported enclosures, the equation needs to be adjusted to account for the port variables, such as port length (l_t) and cross sectional area (S_V):

$$f_B = \frac{1}{2\pi\sqrt{\frac{\rho l_t}{S_V}*\frac{V_B}{\rho c^2}}} = \frac{1}{2\pi\sqrt{\frac{l_t V_B}{S_V c^2}}} = \frac{c}{2\pi}\sqrt{\frac{S_V}{l_t V_B}} \qquad \text{(Equation 2) \quad (Ahonen 19)}$$

The multiple variables within the equations allow for multiple design configurations to have the same frequency.

Procedure:

Materials:

- ¾" thick MDF board
- Table saw
- Jig saw
- 2" long 5/8" screws
- Drill
- All-purpose caulk
- Wood glue
- 6 bolts and nuts
- Decibel Meter
- Wire cutters
- 14 gauge wire
- Sand paper
- Wrench of the bolts' size
- Pyle Red Label Subwoofer 600W max

Steps:

1. Design three subwoofer enclosures: one cubic foot sealed box, one ported box of equivalent size to the sealed box, and a bigger ported box of about 2.75 cubic feet.
2. Cut the MDF board into the pieces needed for the three enclosures (Appendix Figure 1)
   - For the sealed box, cut two pieces of 13.5" by 13.5" for the top and bottom, two pieces of 13.5" by 12" for the sides, and two pieces of 12" by 12" for the other sides.
   - For the smaller ported box, cut one piece 13.5" by 13.5" for the top, one piece 13.5" by 14.75" for the bottom, two pieces of 14.75" by 12" for the sides, two pieces of 12" by 12" for the other two sides, and one piece 12" by 10" for the port.

- For the bigger ported box, cut one piece of 18" by 19.5"for the top, one piece of 22.25" by 18" for the bottom, two pieces of 22.25" by 16" for the sides, two pieces by 16" by 16.5" for the ends, and one piece of 14" by 16.5" for the port.

3. To assemble the sealed enclosure, place the bottom on the ground and place one of the longer sides on top of it. Apply wood glue between the surfaces and screw the two pieces of wood together. Repeat this procedure with the side pieces until they are all put together.
4. Place the top piece on the box to completely enclose the box.
5. For the ported enclosures repeat step 3, and then place the ported piece within the box the distance from the side of the box as the desired port width (e.g. 2" for a 2" wide port) and screw it into place.
6. Then repeat step 4 and place the top piece over the main volume of the box.
7. Draw a circle of diameter an inch less than the diameter of the subwoofer of which will be placed inside the enclosure.
8. Using a jigsaw cut out the hole that was drawn. Sand the hole if needed to touch up so that the subwoofer will fit snug against the wood.
9. Drill two holes about an inch apart from each other in the side of each box towards the bottom for the bolts to fit into. These bolts will act as the terminals for the box for which power can be delivered to the subwoofer within the box. One bolt will act as the power wire and the other will act as the ground wire.
10. Place nuts on the bolts through the subwoofer hole and use a wrench to ensure the bolts are snug.
11. Connect speaker wire to the bolt on the inside and outside of the enclosure so that the subwoofer can be connected to one side of the bolt and the power supply to the other.
12. Caulk the wood connections within the enclosure to ensure the enclosure is air-tight and no air will leave the box except through the port in the ported enclosures. No air should escape the sealed enclosure.
13. Connect the subwoofer to the leads inside the box and place the subwoofer flush with the box.
14. Play a constant frequency through each subwoofer enclosure and determine which one plays loudest, and compare the determination to the theoretical results.

Data:

The measurements needed for the calculations are:
- The volume of the subwoofer to be used
- The port length of the ported enclosures
- The cross sectional area of the port
- Mass of the subwoofer
- Area of the subwoofer

Table 1: Specifications in English Units

Enclosure	Sub Mass	Sub Frequency	Sub Volume	Box Volume	Port Length	Port Area
Sealed	5.2 lbs	35.9 Hz	.1932 ft³	1 ft³	N/A	N/A
Small Ported	5.2 lbs	35.9 Hz	.1932 ft³	1 ft³	12 in	6 in²
Big Ported	5.2 lbs	35.9 Hz	.1932 ft³	2.75 ft³	16 in	33 in²

(Information found in Appendix Figure 2)

Table 2: Specifications in Metric Units

Enclosure	Sub Mass	Sub Frequency	Sub Volume	Box Volume	Port Length	Port Area
Sealed	2.36 kg	35.9 Hz	0.00546 m³	0.0283 m³	N/A	N/A
Small Ported	2.36 kg	35.9 Hz	0.00546 m³	0.0283 m³	.3048 m	0.00387 m²
Big Ported	2.36 kg	35.9 Hz	0.00546 m³	0.0778 m³	.4064 m	0.02129 m²

Table 3: Decibel reading of each enclosure for 15 seconds of a song

Subwoofer Enclosure	Maximum Reading	Minimum Reading
Sealed	90.0 dB	42.0 dB
Small Ported	72.4 dB	42.0 dB
Big Ported	92.3 dB	42.0 dB

Calculations:

To use any of the equations, first the English measurements must be converted into metric units:

$$1 \text{ ft}^3 = 0.0283 \text{ m}^3$$
$$1 \text{ in}^2 = 0.00064516 \text{ m}^2$$
$$1 \text{ in} = 0.0254 \text{ m}$$
$$1 \text{ lb} = 0.453592 \text{ kg}$$

Variables of Air:

$$\rho = 1.20 \ \frac{kg}{m^3} \qquad c = 343.68 \ \frac{m}{s} \qquad \text{(Ahonen 6)}$$

To calculate the resonant frequency of the sealed box we use Equation 1:

$$f_{SC} = \frac{1}{2\pi\sqrt{C_t L_{MAS}}}$$

First solve for acoustic capacitance of the enclosure:

$$C_{CAB} = \frac{V_B}{pc^2}$$

$$C_{CAB} = \frac{0.0283 \text{ m}^3}{\left(1.20 \frac{kg}{m^3}\right)(343.68 \frac{m}{s})^2}$$

$$C_{CAB} = 1.997 \; x \; 10^{-7}$$

Then solve for acoustic capacitance of the subwoofer:

$$C_{CAS} = \frac{V_{AS}}{pc^2}$$

$$C_{CAS} = \frac{0.00546 \text{ m}^3}{\left(1.20 \frac{kg}{m^3}\right)(343.68 \frac{m}{s})^2}$$

$$C_{CAS} = 3.852 \; x \; 10^{-8}$$

Then solve for total acoustic capacitance:

$$C_t = \frac{C_{CAS}C_{CAB}}{C_{CAS} + C_{CAB}}$$

$$C_t = \frac{(3.852 \; x \; 10^{-8})(1.997 \; x \; 10^{-7})}{(3.852 \; x \; 10^{-8}) + (1.997 \; x \; 10^{-7})}$$

$$C_t = 3.229 \; x \; 10^{-8}$$

Then calculate the inductance of the subwoofer:

$$L_{MAS} = \frac{1}{(2\pi f_s)^2 C_{CAS}}$$

$$L_{MAS} = \frac{1}{(2\pi(35.9Hz)^2(3.852 \; x \; 10^{-8})}$$

$$L_{MAS} = 3205.86$$

Now solve for resonant frequency:

$$f_{SC} = \frac{1}{2\pi\sqrt{C_t L_{MAS}}}$$

$$f_{SC} = \frac{1}{2\pi\sqrt{(3.229 \; x \; 10^{-8})(3205.86)}}$$

$$f_{SC} = 15.64 \; Hz$$

To calculate the resonant frequency of the ported boxes, use the equation:

$$f_B = \frac{c}{2\pi}\sqrt{\frac{S_V}{l_t V_B}}$$

Solve for the resonant frequency of the small ported box:

$S_V = 0.00546$ m³

$l_t = 0.3048$ m

$V_B = 0.00387$ m²

$$f_B = \frac{c}{2\pi}\sqrt{\frac{S_V}{l_t V_B}}$$

$$f_B = \frac{343.68\ \frac{m}{s}}{2\pi}\sqrt{\frac{0.00546\ \mathrm{m}^3}{(0.3048m)(0.00387\ \mathrm{m}^2)}}$$

$$f_B = 117.68\ Hz$$

Solve for the resonant frequency of the big ported box:

$S_V = 0.00546$ m³

$l_t = 0.4064$ m

$V_B = 0.02129$ m²

$$f_B = \frac{c}{2\pi}\sqrt{\frac{S_V}{l_t V_B}}$$

$$f_B = \frac{343.68\ \frac{m}{s}}{2\pi}\sqrt{\frac{0.00546\ \mathrm{m}^3}{(0.4064m)(0.02129\ \mathrm{m}^2)}}$$

$$f_B = 43.45\ Hz$$

Results:

The calculated resonant frequencies for the three enclosures were 15.64 Hz for the fully sealed box, 117.68 Hz for the smaller ported box, and 43.45 Hz for the larger ported box. The resonant frequency of the subwoofer is 35.9 Hz. Any box is better than no box, but the best

boxes are tuned to reinforce the vibrations of the woofer, thus making them louder while using much less power. A tuned box will also have a linear (flat) response to all frequencies (Nevisonics). So the enclosure that most closely matches the resonant frequency of the subwoofer will be loudest, thus the larger ported box should maximize output volume.

Percent deviation between the resonant frequencies of the subwoofer and the subwoofer enclosure:

$$\frac{Frequency\ of\ the\ Enclosure - Frequency\ of\ the\ Subwoofer}{Frequency\ of\ the\ Subwoofer}\ x\ 100\%$$

Deviation in sealed enclosure:

$$\frac{15.64\ Hz - 35.9\ Hz}{35.9\ Hz}x100\% = -56.44\%$$

Deviation in small ported:

$$\frac{117.68\ Hz - 35.9\ Hz}{35.9\ Hz}x100\% = 227.80\%$$

Deviation in big ported:

$$\frac{43.45\ Hz - 35.9\ Hz}{35.9\ Hz}x100\% = 21.44\%$$

Again, the bigger ported enclosure will be loudest, because it has the smallest percent deviation.

This theoretical result agrees with the experimental decibel readings.

Conclusion:

In conclusion, there are infinitely many ways to design an enclosure to be tuned to any given frequency. But for the enclosure to maximize the loudness of the subwoofer, its resonating frequency needs to be as close as possible to the resonating frequency of the subwoofer. For the three box designs presented here, the loudest enclosure for the Pyle subwoofer is the large ported enclosure. This is supported by theoretical and experimental results.

Appendix:

Figure 1:

Attached to Lab Report

Figure 2:

About Pyle Blue (Red) Label Woofer

Congratulations! You have purchased one of our high quality Pyle woofer. Blue (Red) Label Series Woofer are not only in unique design, but also could deliver consistent and high performance.

We do confident that Blue (Red) Label Series Woofer will bring you many hours of enjoyment over the years.

The General Features Pyle Woofers Include:

BLUE LABEL

- Blue CD Wave Electro-plated Polypropylene Cone
- Wide Butyl Rubber Surround With New Pattern
- Blue Steel Basket
- Bumped & Vented Extended Pole Piece
- High Temperature Kapton Polyamide Voice Coils
- 4 Ohm Impedance

RED LABEL

- Red CD Wave Electro-plated Polypropylene Cone
- Wide Butyl Rubber Surround With New Pattern
- Red Steel Basket
- Bumped & Vented Extended Pole Piece
- High Temperature Kapton Polyamide Voice Coils
- 4 Ohm Impedance

BLUE LABEL
PLW10BL   PLW12BL

RED LABEL
PLW10RD   PLW12RD
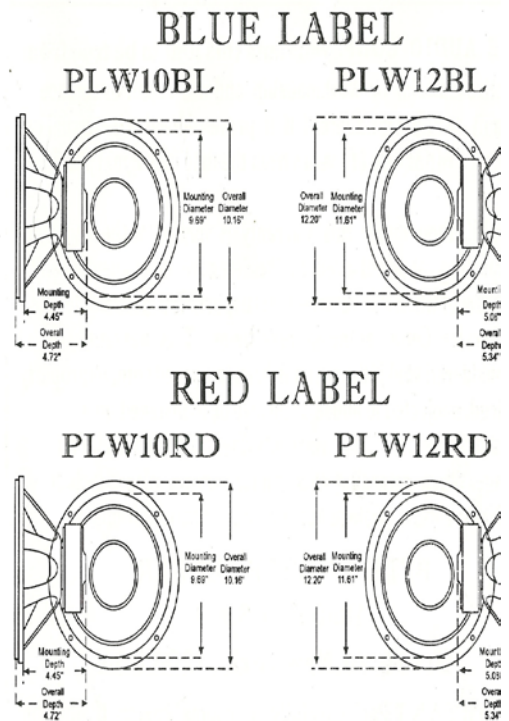
Specification	PLW10BL	PLW12BL	PLW10RD	PLW12...
Steel Frame	Blue	Blue	Red	Red
Cone	Blue Electroplated	Blue Electroplated	Red Electroplated	Red Electropl...
Surround	Wide Rubber	Wide Rubber	Wide Rubber	Wide Rubb...
Power (Watts Peak)	600	800	600	800
Nom. Impedance (Ohm)	4	4	4	4
Voice Coil	1.5" KSV	2" KSV	1.5" KSV	2" KSV
Magnet Structure	70 oz	90 oz	70 oz	90 oz
Fs (Hz)	35.9	26.2	35.9	26.2
Qms	5.72	5.81	5.72	5.81
Qes	0.83	0.90	0.83	0.90
Qts	0.73	0.78	0.73	0.78
SPL (dB)	86.7	85.5	86.7	85.5
Vas (cuft)	1.932	4.146	1.932	4.146

Pyle- Blue (Red) Label - Series continually strives to improve the performance and value of its products- all specifications are subject to change.

Bibliography

Ahonen, Janne. "Electroacoustic Modelling of the Subwoofer Enclosures." *Enclosure Modeling*. June-

  July 2007. Web. April 23 2011.

    <http://koti.mbnet.fi/jahonen/Audio/Papers/enclosuremodelling.pdf>.

"Brand - SKU - Description." *PYLE Audio*. Web. 24 April 2011.

    <http://www.pyleaudio.com/sku/PLW10RD/10-600-Watt-Subwoofer>.

"The Importance of Box Tuning." *NeviSonics Audio Services and Speaker Repair*. Web. 24 Apr. 2011.

    <http://www.woofer.com/boxtune.htm>.