Acoustics 4 Loudspeaker Design Assignment 2018

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1 Introduction

This report will explain the design process for my speaker cabinet design. I was tasked the physical cabinet design, and thus there will be no consideration in this document of the electronics which would be involved in the operation of the speaker. The report by student number 2127147 covers the design of the electronics for this cabinet. The Thiele-Small parameters of my chosen tweeter and woofer drivers can be seen in the datasheets in the bibliography.[1, 2]

2 Priniple of Ported Cabinets

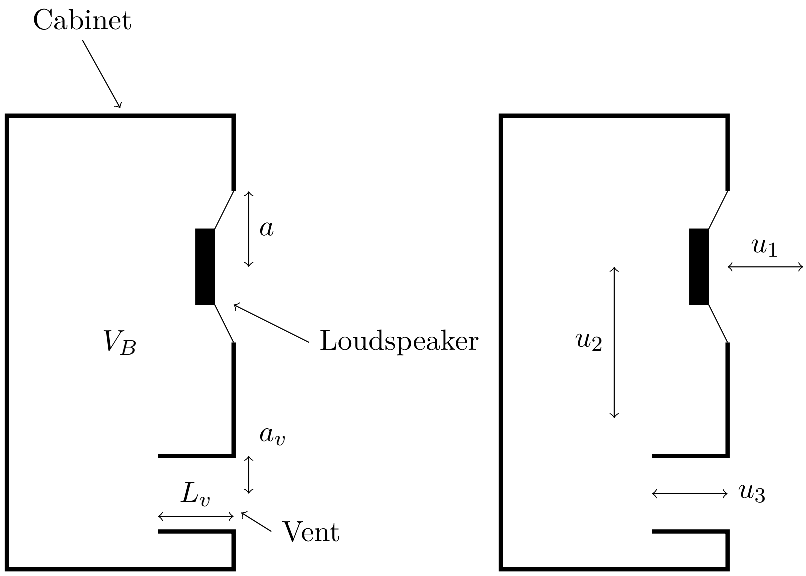

Figure 1: A diagram of a speaker mounted in an Bass Reflex cabinet, and a diagram showing the important velocities in the system.

My speaker design is a ported bass reflex cabinet. This differs from an enclosed cabinet in that it has a port connecting the volume of the cabinet to the outside of the cabinet. The main principle is that the cabinet uses constructive interference of the sound emitted from the back of the speaker to improve low frequency response of the speaker. The vent acts as a Helmholtz resonator with the volume of the cabinet with resonant frequency f_b.

2.1 Frequency Response of a ported cabinet

In order to understand the purpose of this, we should consider Figure 1. This figure shows a diagram of a ported cabinet, and the right hand side has three different velocities to consider.

$\mathbf{u_1}$ is the velocity of the air immediately on the surface of the speaker.

$\mathbf{u_2}$ is the velocity of the air inside the volume of the enclosure

$\mathbf{u_3}$ is the velocity of the air within the vent.

u_1 and u_2 are always exactly 180° out of phase, because they are being driven by opposite sides of the same loudspeaker. The relationship between u_2 and u_3 is frequency dependent. We will consider the interaction at three different cases:

2.1.1 When $f << f_b$

If we think of u_2 and u_3 as two pendulums pushing slowly against one another, at low frequencies u_2 is moving so slowly against u_3 that it is gently pushing it forward, and then as it moves back u_3 swings back before it is pushed again. u_2 and u_3 are therefore in phase. u_1 and u_3 are therefore out of phase and will destructively interfere.

2.1.2 When $f \approx f_b$

As u_2 moves with the same frequency as the resonant frequency of the vent, the velocities u_2 and u_3 become equal in magnitude but 180° out of phase. This is like two pendulums having the same frequency and striking each other with the same magnitude in opposite directions. This means that u_1 and u_3 are therefore in phase, contrustively interfering and increasing the radiated power around the resonant frequency.

2.1.3 When $f >> f_b$

If again return to the pendulum analogy, as the frequency becomes very high, u_2 is so fast that u_3 cannot respond. u_3 is being pushed so fast by u_2 that it stays extended and doesn't vibrate. So at high frequencies $u_3 = 0$, and the cabinet is similar in response to a completely enclosed cabinet.'

2.2 Resonance equations

As mentioned before, the vent acts as a Helmholtz resonator, the dimensions of which determine f_{vent}. The equation for a Helmoltz resonance is:

$$\omega_0 = c\left(\frac{Y}{L'V}\right)^{1/2} \tag{1}$$

This can be related to our ported cabinet as:

$$f_b = \frac{c}{2\pi}\left(\frac{\pi a_v^2}{V_b L_v'}\right)^{1/2} \tag{2}$$

This will be rearranged later as we will be designing for a specific resonant frequency.

3 Allignment of the Bass Reflex Cabinet

3.1 An explanation of Allignments

Because of the nature of a vented system, it is very complicated to consider an electrical equivalent circuit, there are defined calculations which give specific frequency responses based on the paramaters of the speaker. For a given Q_{ts} an allignment gives values for H, which is the ration of f_s of the speaker to f_b of the box, α, which is the ration of V_{as} for the driver to the volume of the enclosure V_B, and the ratio $\frac{f_{3\text{dB}}}{f_s}$ which determines the steepness of the roll off of the response.

There are two different kinds of allignment, flat and non-flat. Flat allignments are generally only possible for $Q_{ts} < 0.4$. There also exist what are called *discrete* flat allignments, which only exist for specific individual values of Q_{ts}. For Q_{ts} values greater than that, choice becomes a design choice about whether it is preferable to have a peak at the resonant frequency or a ripple in the pass-band.

3.2 Woofer Driver Choice

The choice of woofer driver at this point is very important at this point, as it totally defines the allignments which are possible, and the required dimensions of the enclosure. I started my design initially with the TRUVOX 1125 woofer driver supplied with the assignment instructions, but I found several limitations with that driver. The first of these was due to the Q_{ts} value of the driver, which is 0.5. This is too big to give a flat allignment, so it would be a fundamentally unsatisfactory design. The other limitation was the frequency range of the driver, which was 50–4000Hz.

The driver I chose to replace it in the design was the Dayton Audio DC300-8 woofer driver. This driver has a Q_{ts} value of 0.33 and a frequency range of 25–2500Hz. This means the driver is able to be used in flat allignments and also adds an extra octave of usable frequency below that of the TRUVOX 1225. From my initial calculations of both, the DC300-8 could give a much better frequency response in roughly the same volume or less than when using the 1225. The price of the DC300-8 is £46.63 for one driver,[3] which is a relatively small price to pay for such a significant increase in desired response.

3.3 Allignment calculations

In order to choose an allignment, I completed the calculations to determine the parameters for the enclosure for the woofer. It is possible to make the calculations for the allignments directly from the Thiele-Small parameters,[4, p. 5–11] but it is an extremely involved process. I used design tables which had already been calculated for values of Q_L[1] and Q_{ts} of the driver[5, p. 64–69] since it sped up the process. The table gives values for H, α, and $\frac{f_{3\mathrm{dB}}}{f_s}$[2]. H and α are related to the parameters of the enclosure as follows:

$$H = \frac{f_b}{f_s} \qquad \alpha = \frac{V_{as}}{V_b} \tag{3}$$

where f_s is the resonant frequency of the driver in free air, and V_{as} is the equivalent air compliance. These are both taken from the Thiele/Small parameters of the driver.

The results of these calculations is seen in Table 1, where I have only considered the non-discrete allignments since it is too complicated to design for one specific value of Q_{ts}. There isn't a huge amount of variance in these

Allignment	f_b,Hz	$f_{3\mathrm{dB}}$,Hz	V_b,L
SBB_4	22.90	34.72	87.08
QB_3	27.54	31.68	84.05
SC_4	25.34	33.05	82.51

Table 1: The calculations for the non-discrete flat allignments

allignments, so it is a fairly heuristic choice for which allignment is best suited to the design. I chose the Third-Order Quasi-Butterworth (QB_3) allignment because it has the lowest $f_{3\mathrm{dB}}$.

[1] These have been made using the assumption that the box losses $Q_L = 7$, since it is impossible to predict the actual box losses. I will outline the process of dealing with the real box losses in section 10.3.

[2] $f_{3\mathrm{dB}}$ is the frequency at which the speaker is outputting at half the power of the pass-band of the response. It is a good measure of the lowest usable frequency of the speaker.

4 Vent Calculations

Now that I had values for V_b and f_b, I could then make the calculations for the port size to the cabinet which meets these requirements. Remembering that:[3]

$$L_v' + 1.45a_v \tag{4}$$

We can rearrange equation 2 to be in terms of the length of the vent.

$$L_v = \left(\frac{c}{2f_b}\right)^2 \frac{a_v^2}{\pi V_b} - 1.45a_v \tag{5}$$

PVC piping is a standard material used for the construction of the port, which comes in standard diameters, which is why I put the equation in terms of L_v. I decided to use it for making my design as it is easily available and easy to cut to length to tune the box. There is a balance to be made when deciding the size of the port, as if it is too small there is increased turbulence on the port. However, the increased length of the port which comes with the increased diameter introduces resonances which can introduce noise.[5, p. 71] Some of these issues can be lessened through the flaring of the ports, which increases the effective length of the port, however I decided not to pursue this in my own design to retain the simplicity of being able to just use PVC pipe. Using Small's equation for the minimum diameter of the port[5, p. 69] I arrived at a minimum port diameter of 3 inches, and thus chose a_v to be 80mm, and thus L_v to be 178.4mm. The total volume of the port is therefore 0.015L, which important to consider as it does not count towards V_b, but since it is so small it will not contribute much to the total volume.

5 Tweeter

For the tweeter driver, I am using the 811582 DT-80H driver suggested in the assignment instructions. The parameters of this driver were good enough that it is fine to use in the design. Since the tweeter is independently sealed, it does not need its own enclosure and can be mounted in the same chamber as the woofer driver. In order to simplify phase considerations it is mounted so that it is vertically alligned with the woofer. The volume of the tweeter, when calculated from the dimensions given on the datasheet[2] is 0.00126L, which is so small it will not contribute significantly to the tuning of the box and can safely be ignored.

[3] I'm assuming here that there is no flange on the end of the pipe inside the enclosure

6 Materials and Damping

6.1 Material Choice

Any fixed body will have its own natural resonances at which it will vibrate. The sound energy emitted from the back of the speaker will resonate with the cabinet walls. Ideally, the only sound emitted will be directly from the speaker drivers and the port, and any additional sound from the resonating cabinet walls is obviously completely unwanted. The cabinet should then therefore be constructed of high density materials with high internal damping. From my research, medium-density fibreboard (MDF) is a very common choice for cabinet construction.[6] Because of the size of my enclosure I decided to use MDF of thickness 22mm. Another way of approaching choice of construction materaials is to use thinner matrerials and then use extensive damping materials to reduce the resonances. I chose the approach of using heavier materials since there are less factors to consider in the design.

6.2 Damping Materials

Although the choice of construction material prevents the leakage of sound through the material, it does not prevent the resonance of standing waves within the cabinet, from the radiation of the back of the speaker cone. There are many differering opinions on how to install damping materials to minimise these resonances. I decided to follow an example vented loudspeaker project I found online[7] with approximately similar dimensions where 1 inch thick fibreglass was stapled to the inside walls. Since this is similar I decided to mimic this for my design. Since will reduce the volume of the box V_b, I will increase the dimensions of the box by an inch when it comes to calculating the specific dimensions. The damping will be installed on every surface on the inside of the cabinet, with gaps left for the drivers to be installed on the front, and the crossover circuit to be installed on the base. The size of the hole cut for the crossover circuit is 160mm by 180mm.

6.3 Driver Mounting

In addition to the damping materials installed in the cabinet, further vibration in the enclosure will be reduced through the use of Well-Nut screws to mount the drivers.[8] Well-Nut screws operate by placing a rubber hole through a pre-drilled hole, and then screwing down what is to be mounted into the rubber hole. This acts to dampen vibration between the driver and the cabinet, further reducing unwanted vibrations throughout the cabinet.

7 Construction Considerations

7.1 Bracing

The only bracing I added to the design is corner braces. These increase the stiffness of the enclosure, and are made of lumber of with cross-section 1 inch by 1 inch. This is so that they will be included in the additional volume with the fibreglass insulation. Lumber is a standard material used in bracing [5, p. 114-115]

7.2 Cabinet Assembly

All the MDF panels will assembled with wood glue, apart from the back panel. The back panel will be attached to the rest of the cabinet by screwing into the bracing so it can be removed and the internals of the speaker can be accessed for repairs and maintenance. In order to allow for this panel, the back bracing will be installed inset to the cabinet by 26mm, which is the thickness of the MDF panel with an additional 2 mm to fit foam weather stripping. The foam weather stripping is to ensure the fit of the back panel is airtight when screwed in, and is applied to the back bracing. I used this because I saw it was used in several example designs online where the back panel is screwed on.[7, 9]

8 Dimensions

My speaker design is rectangular in shape, which I have chosen purely on the basis that it would be the simplest to construct, and also design. The final important calculation which is still required is the volume of the woofer driver to be included in the total enclosure volume. From the dimensions given in the data sheet[1] I estimated the volume to be 3.24L.

8.1 The Golden Ratio

Although steps have already been taken to reduce the effect of standing wave resonances within the cabinet, by designing the enclosure to have dimensions related to each other with the golden ration ϕ, they will not share any standing wave resonances.[5, p. 112-113] The side lengths will therefore be related as such:

$$x = \sqrt[3]{V_{total}} \qquad y = \frac{x}{\phi} \qquad z = \phi \cdot x \tag{6}$$

where $Vtotal = V_b + V_{drivers} + V_{vent}$. From the previously calculated volumes, $V_{total} = 87.31$L. Converting this into mm, we can then calculate the final dimensions when adding 98.8mm to the width, 76.8mm to the depth, and

98.8mm to the heightto account for the damping and the thickness of the MDF. The final dimensions are therefore:

$$width = 538.4\text{mm} \qquad depth = 347.0\text{mm} \qquad height = 812.6\text{mm} \tag{7}$$

9 Final Schematic

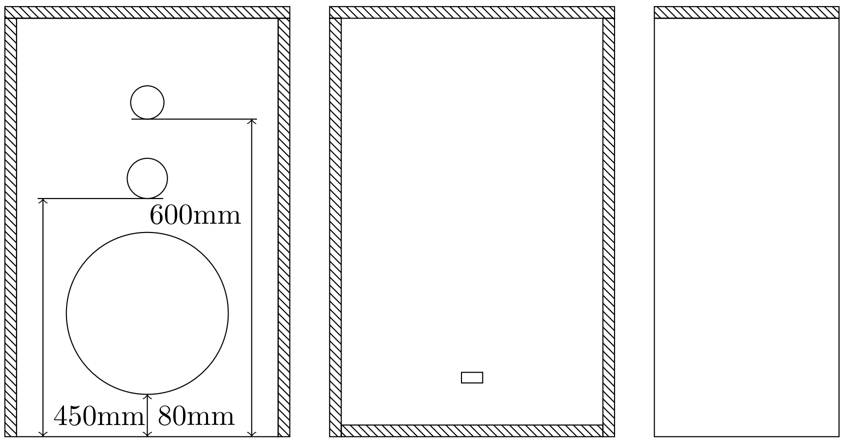

Figure 2: Front, Back and Side views of the exterior of the cabinet

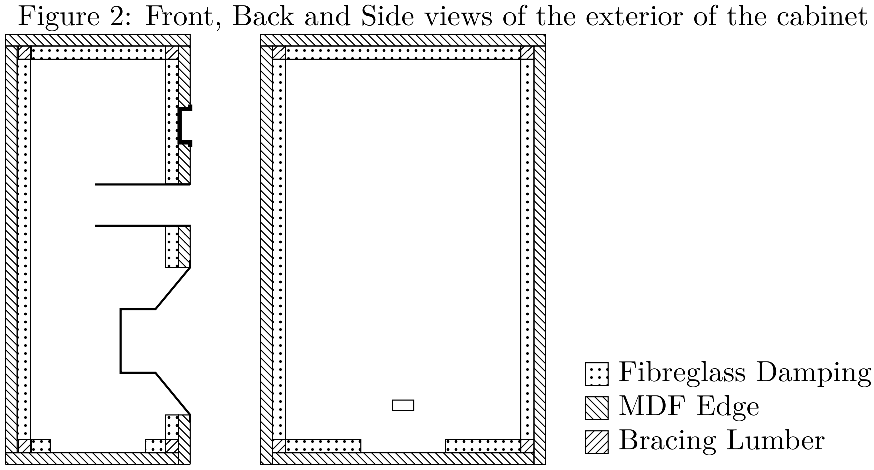

Figure 3: Cross-Sectional views of the interior

Figures 2 and 3 show the layout of the outside panels and also the cross-sectional dimensions of the speaker cabinet. These diagrams are to scale. The exact dimensions of the MDF panels are as follows, with the thickness of all of them equal to 22mm:

- The front panel is 494.4mm by 790.6mm, with holes cut in for the drivers and the vent.

- The side panels are 347mm by 790.6mm
- The bottom panel is 325mm by 494.4 mm
- The top panel is 538.4mm by 347mm
- The back panel, with a hole for the connectors to the electronics cut into it, is 494.4mm by 768.6mm

10 Design Testing

At this point, the design is complete, however since this design was made based on research and use of calculations, it is very possible that it will perform differently than expected once actually realised. This section will outline some of the testing which can be carried out after constructing the design.

10.1 Break-In

Prior to testing the performance of the speaker cabinet, the drivers to be tested must be brokien in. This doesn't significantly change any of the actual Thiele-Small parameters, but it is important to know that the driver is working correctly before making any measurements with it mounted in the enclosure.[5, p. 195-196]

10.2 Driver Measurements

Although data supplied from the manufacturers of the drivers, it is important that meausurements can be taken for f_s, V_{as} and Q_{ts} from the specific driver. I will not outline the methodology for these measurements here, but suffice to say they can be taken and accurate calculations for the allignment can be made using these. These are likely to be very similar to those calculated using the datasheet, but it is still a way that the design can be improved.

10.3 Measurement of Box Losses

As mentioned in section 3.3, the box losses Q_L have been assumed as 7 when calculating the allignment, which is a standard value. The actual value of Q_L can not measured until the box has actually been constructed and assembled. I will not outline the methodology for calculating Q_L here, but I will go over what should be done once it has been obtained.

If Q_L is measured to be higher than expected, the volume can be reduced by adding filler to the volume. If it is measured to be lower, then the enclousure will have to be reconstructed with a larger volume.[5, p. 67–69] If Q_L is hugely different than expected, many of the calculations will have to made again and all the dimensions will have to be recalculated for the enclosure and the port.

11 Improvements

There are several aspects of this design's performance which can not be predicted until construction, which may improve the performance.

11.1 Flared Ports

It is possible that the ports that I have designed are insufficient in sze and may contribute large ammounts of noise through the movement of air. One way to reduce this is to use flared ports. These generally increase the linearity of the performance and reduce port noise[4, p.71–72], but are awkward to calculate. Using straight ports seems to be acceptable in the case of this design, but it is something that can be changed if the port noise is unacceptable.

11.2 Speaker Grills

Speaker grill cloth offers a way to protect the speaker drivers, as in my current design they are exposed to the user. However, the effect of covering the speaker with any material is very unpredictable, and as such I have not considered it for my design. Although I have not added it, adding a speaker grill cover would undoubtedly improve the speaker as it would make it much less succeptible to damage. Although the effect on the performance is not easy to predict, it is also entirely possible it will have a negligible effect on the audible performance anyway.

11.3 Finishing

As a final consideration, the cabinet can be painted or stained. Obviously this will not have not an effect on the actual performance of the design, but will improve the aesthetics of the cabinet greatly, as bare MDF is very plain.

12 Conclusion

Overall, I believe that through this design I have made nearly every possible consideration that one could make in a design without actually constructing it, and as such is a good starting point for a real constructable design with high performance.

References

[1] Dayton Audio DC300-8 datasheet. `http://loudspeakerfreaks.com/datasheets/dayton/DC300-8.pdf`.

[2] 811582 DT-80H datasheet. `http://www.d-s-t.com.au/data/Peerless/811582.pdf`.

[3] Dayton Audio DC300-8 store page. `http://loudspeakerfreaks.com/Product.asp?mfr=Dayton%20audio&part=DC300-8&Product_ID=7105`.

[4] Niels Elkjær Iversen. Introduction to loudspeaker modelling & design.

[5] Vance Dickason. *Loudspeaker Design Cookbook*. 7th edition, 2006.

[6] Cabinet materials. `https://www.loudspeakerbuilding.com/Practical-guide/Cabinet-materials/10101,en`.

[7] W. Marshall Leach. Georgia Tech Audio Laboratory Loudspeaker System. `http://leachlegacy.ece.gatech.edu/labsp/`.

[8] Well-Nut Description. `https://www.rivetwise.co.uk/rivets/rivet-nuts.asp?product=well-nut-44`.

[9] W. Marshall Leach. A Compact 2-Way Loudspeaker System. `http://leachlegacy.ece.gatech.edu/labsp2/`.