Loudspeaker Cabinet Design

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1 Introduction

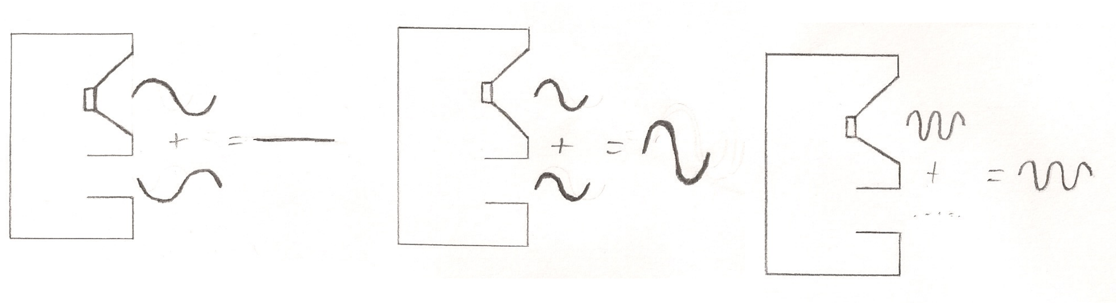
This report focusses on the physical design of a ported loudspeaker cabinet. The woofer and tweeter specifications were given, prompting ideal box and port volume calculations. However a design with given enclousure specifications leaving the ideal driver(s) to be calculated is also a viable approach to loudspeaker design. I have used the Truvox 1225 woofer [1] and the 811582 DT-80H dome tweeter [2].

2 Enclosed Systems

Every driver has a free air resonant frequency (Fs) at which cone excursion is at a maximum. At this point, the back emf of the voice coil is at its largest point[3]. An unbaffled loudspeaker has a poor bass response in comparison to that of an enclosed speaker. The low frequency waves wrap around the cone and destructively interfere with the signal coming from the front, due to phase cancellation. A factor also favouring enclosed designs is the spring like property of the air pressure inside the cabinet. However, this property is more influential on the frequency response in a small closed-box design than a ported cabinet.

2.1 Bass-reflex

A vented (or ported) enclosure, often referred to as a bass-reflex design, offers the option of acoustically equalising a certain frequency band. Acting as a Helmholtz resonator, a ported speaker cabinet has its own resonant frequency. The introduction of a vent to a design has the potential to reduce cone excursion around a tuning frequency Fb. In turn, the port reinforces the desired frequency band using constructive interference. As the acoustic waves produced by the back of the speaker cone rebound off the inner panels of the enclosure, the phase of the waves emitted from the vent have a frequency dependant relationship with those emitted from the front of the cone. The sound waves directly behind the speaker cone (or box waves) are always opposite in phase to those exiting the front of the cone. At frequencies below Fb, the waves in the vent are in phase with the box waves, and thus out of phase with the front waves. As frequencies approach Fb the vent waves shift out of phase with the box waves and subsequently in phase with the waves exiting the front of the cone, performing constructive interference with the signal. As frequencies move upwards from Fb the vent plays a diminished role and the enclosure acts as a sealed container.



(a) at $f << Fb$: phase cancellation

(b) at $f \approx Fb$: phase reinforcement

(c) at $f >> Fb$: acts as sealed container

Tuning a port to match *Fs*, (in the case of the selected woofer 63Hz) results in two satellite impedance peaks slightly above and slightly below *Fs*. The peaks are of a lower magnitude than the original *Fs* peak, which acoustically translates to an improved bass response. However, achieving this even spread is not always possible if the optimum volume for the box is sought after, as it will be in this case. (Plots made using WinISD [5])

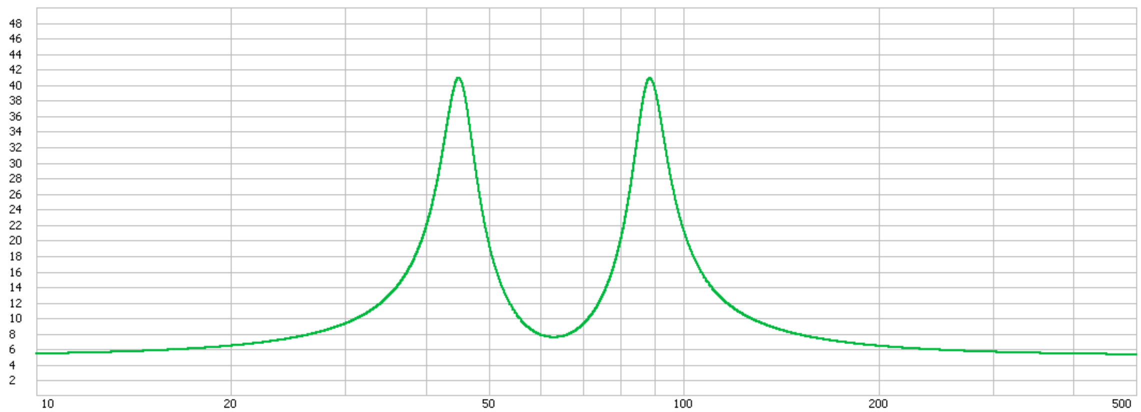


Figure 2: ***Fb=63Hz*** *(x axis frequency in Hz, y axis Impedance in Ohms)*

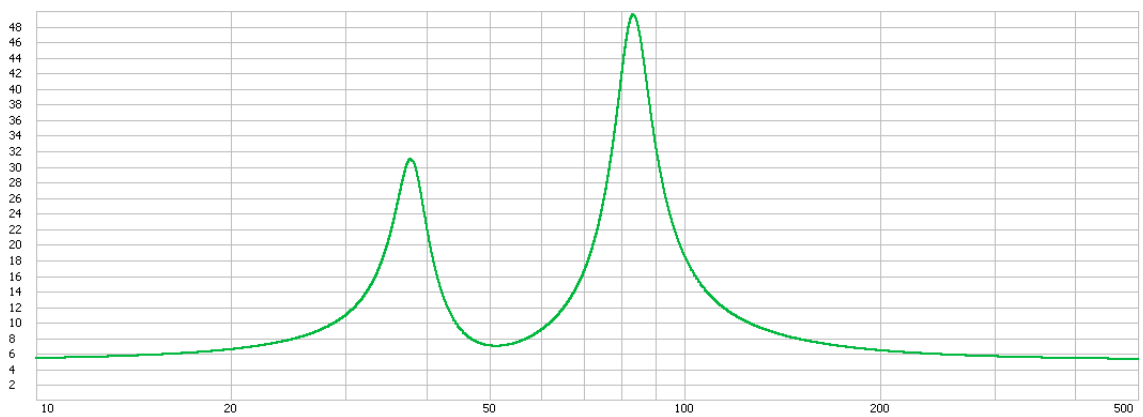


Figure 3: ***Fb=50Hz*** *(x axis frequency in Hz, y axis Impedance in Ohms)*

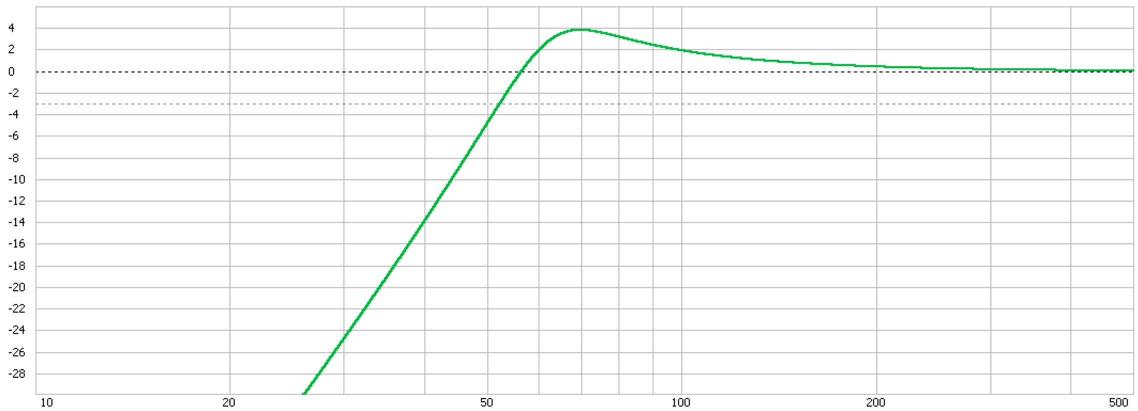


Figure 4: ***Fb=63Hz*** *(x axis frequency in Hz, y axis amplitude in dB)*

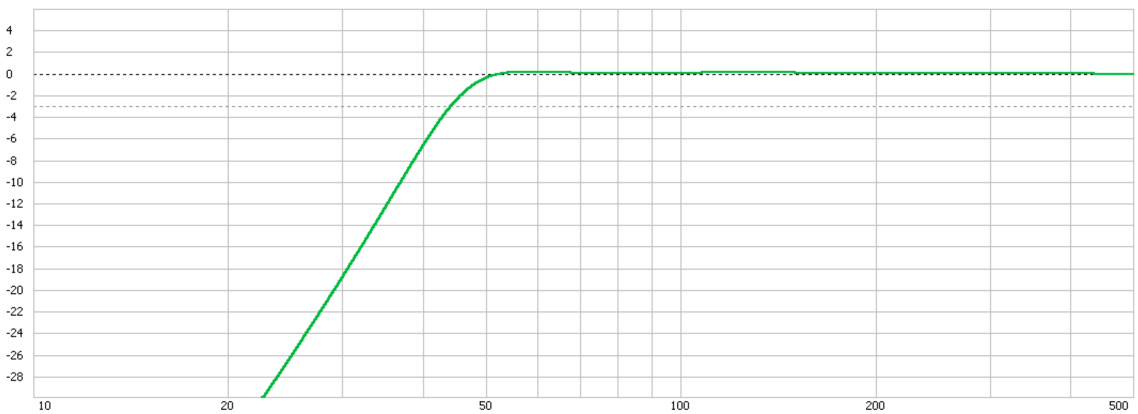


Figure 5: ***Fb=50Hz*** *(x axis frequency in Hz, y axis amplitude in dB)*

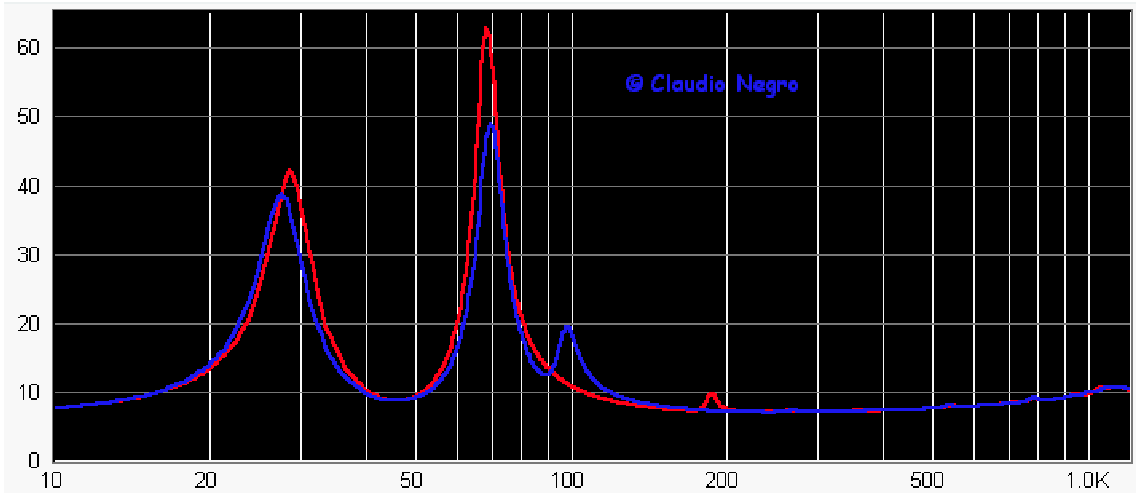


Figure 6: DCR Impedance Response *(x axis frequency in Hz, y axis impedance in Ohms)*

2.2 Double-Chamber Reflex

A double-chamber reflex is tuned to two frequencies, an octave apart. One chamber is double the volume of the other, and each has its own port. The larger box which contains the woofer and the tweeter is linked to the smaller box via a port of the same magnitude as the outward facing ones. An advantage of the dual-chamber design is that cone excursion at the satellite peak above *Fb* is reduced. However one octave above *Fb*, an additional small impedance peak is created. In this design, it is a worthwhile trade because I have elected to tune the box to a frequency below *Fs*. Consequently, the satellite impedance peak which is higher in frequency is of a larger impedance as seen in figure 3. By selecting the tuning frequency to be around the lower limit of the woofer it eradicates potential for destructive interference below *Fb*. Furthermore, tuning the ports to 50Hz gives a much flatter response at the cutoff frequency. However as previously mentioned, an additional impedance peak at ≈ 1.93 *Fb* is created. In my case it would be situated around 96.5Hz. Figure 6 displays how the impedance of a similar design behaves. The red line is a bass-reflex design and the blue line represents a DCR.

3 Enclosure and Port Calculations

In order to calculate the box and port dimensions suited to the driver some Thiele/Small parameters were retrieved from the datasheet:

Parameter	Value	Units
Fs	63	Hz
Vas	55	L
Qts	0.5	
Dia	30.49	cm
$Xmax$	2.5	mm

Vas = equivalent air compliance
Qts = Total Q of the driver at Fs
Dia = Effective diameter of woofer
$Xmax$ = Maximum linear displacement
Sd = Projected area of driver diaphragm (m^2)
Vd = Peak displacement volume (L)
$Dmin$ = Minimum port diameter (cm)
Dv = Internal port diameter (cm)
Np = Number of ports
k = End correction (0.732) [7]

Using the formulae listed in [6] the following calculations were made.

$$Vb = 20Qts^{3.3}Vas = 111.7L$$

$$Sd = \frac{\pi(\frac{Dia}{100})^2}{4} = 0.07296m^2$$

$$Vd = Sd\frac{Xmax}{1000} = 0.00017L$$

$$Dmin = 100\frac{(20.3(\frac{Vd^2}{Fb})^{0.25})}{Np^{0.5}} = 7.08cm$$

$$Lv = (23563.5Dv^2\frac{Np}{Fb^2\,Vb}) - (k\ Dv) = 3.7cm$$

These calculations were cross referenced with the design tables in ([3]*chapter 5*). The number of ports was taken to be 2, as there are 2 ports interacting with the outside air. Furthermore, the end correction coefficient was taken to be 0.732 as both of these ports are flanged at one end [6]. Although the net box volume *Vb* was calculated to be 111.7L, to compensate for losses in practice the volume was increased to 117.5L (not including port, tweeter or estimated crossover volumes) [3]. The total *Vb* was divided into two sections, one of internal dimensions *height=540mm, width=342mm, depth=427mm* and the other of *height=270mm, width=342mm, depth=427mm.* The width was chosen to be smaller than the depth of the speaker for better imaging ([3] *chapter 3*). The golden ratio of 0.618:1:1.618 was considered, but if the width was to be less than the depth, it would have had to be at least 550mm deep which is excessive. Conferring with [8], a vent area:driver area ratio of at least 4:1 is desirable. Therefore the vent diameter was chosen to be 7.62cm and subsequently the length was 3.8cm. The length was slightly rounded up because it is easier to shorten a port than to lengthen it. The tweeter is self contained so requires no additional enclosure.

4 Box Construction

18mm MDF is the material of choice suited for the enclosure. The availability and price of this material prompted the decision. The internal box dimensions have already been calculated which means the MDF thickness is added on to these measurements. To strengthen the structure, glue blocks 25.4m x 25.4mm are inserted into the corners of the larger enclosure from the face to the rear of the cabinet which are secured with nails. The vent linking the enclosures should be properly aligned by simultaneously cutting the holes through the respective panels. After the enclosures are separately constructed the smaller one is glued and screwed into the large enclosure. For the vents, PVC pipes can be used and installed after the box's have been cut to size and firly fixed together. The back panel of the speaker should be removable for maintenance. In order to do this it can be screwed on to the glue blocks.

Figure 7 demonstrates how the design would look. The diagrams on the left show a profile view of the large and small box respectively from top to bottom. The circle on each represents the internal vent which is located 50mm from the back wall and 50mm from the floor of the enclosure. It is aligned so half is in one chamber and half is in the other. The highlighted interior of the top right diagram indicates the internal damping and the blue corners represent the glue blocks. The bottom right diagram represents the internal skeleton of the cabinet, highlighting the port alignments. Due to the 18mm materials used in construction however, the final dimensions would be *h=558mm, w=360mm, d=445mm* for the large enclosure, and *h=288mm, w=360mm, d=445mm* for the small enclosure.

The idea behind the shape of the box was to be able to use different configurations for the same box dimensions. If a box is made with the woofer on the small end of the main enclosure and the tweeter on the end connecting to the smaller enclosure, a rectangular setup could be made using two speakers with respective secondary ports stacked on top of each other between the enclosures with the drivers in them. This design could also be used as some cool desk speakers if a pair of them are designed to mirror of each other.

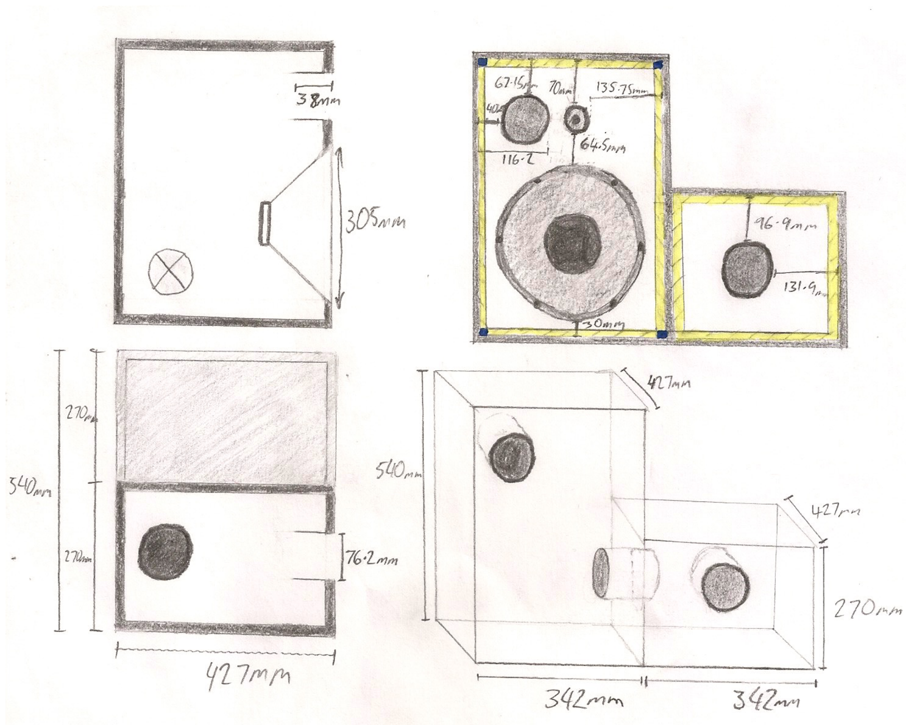


Figure 7: DCR Diagram

4.1 Damping

PVA glue will seal the edges and prevent box losses. To prevent spillage of excess glue, masking tape can be applied to the exterior surface joints [3]. For the removable panel, foam gasket tape [10] should be applied to the edges to act as a further sealant. Optionally, asphalt roofing material can be applied to the internal faces of the wood, excluding the panel the speakers are mounted on. A more common approach to provide damping would be to cover these surfaces with polyester wadding [9]. However both can be done. To further minimise rattling, insulated nuts should enclose every screw [11].

References

[1] https://celestion.com/productpdf.php?id=102.

[2] http://www.d-s-t.com.au/data/Peerless/811582.pdf.

[3] David B Weems *Designing, Building, and Testing Your Own Speaker System with Projects* 1981.

[4] http://www.claudionegro.com/projects/speaker/dcr/dcr.html

[5] http://www.linearteam.org/.

[6] http://www.diysubwoofers.org/prt/ported1.htm.

[7] https://en.wikipedia.org/wiki/Thiele/Small_parameters.

[8] Vance Dickason *Loudspeaker Design Cookbook*, p71, 1987.

[9] https://www.amazon.co.uk/Polyester-Wadding-75gm-100cm-40in/dp/B00AXA4FIA.

[10] https://www.amazon.co.uk/Adam-Hall-Foam-Gasket-Tape/dp/B004LIKWB0.

[11] https://www.amazon.co.uk/Neoprene-Well-Stainless-Steel-Screw/dp/B009ERRCSS.