Development of extended low frequency enclosure

Introduction

The rationale for this work is to present a theoretical and practical analysis of an extended low frequency enclosure capable of 20-65Hz, obtained through a method of careful cabinet design built around a suitable transducer and to support the findings with a build supporting sufficient evidence through implementation of testing.

Low frequency tones…

Enclosure types

Reinforced low frequencies cannot depend entirely on the driver itself for extended low end and requires a form of baffle or enclosure to completely isolate the front and rear drives. D. Weems (page 11) states also that a speaker can deliver 100 times greater sound intensity at low frequencies in a suitable box than in free air. Nearly all drivers are sat in an enclosure or at least some kind of baffle in order to increase and extend the low frequency output from the speaker system (J. Murphy pg 17). It is shown in figure 1 the importance of separation, illustrating how pressure waves from the front of the cone equal that of the pressure radiating from the rear and therefore are of opposite polarity and cancel each other out. Sound is directional at mid and higher frequencies and so these can be audible at a greater level, though wavelengths as long compared to the diameter of the speaker curve back and around the cone so that the out-of-phase waves mix (J. murphy pg17). When a baffle or box is utilized, the driver becomes much more efficient, using the much more contained air in front and behind the driver like a spring. Another purpose to house a speaker in an enclosure is its help

to dampen the driver further from excessive vibrating at its frequency of resonance (fs) and furthermore to increase definition on the musical notes by reducing its ' hangover'. If accurately designed, this should be kept to a minimum and is the relationship or air pressure against the cone between a speaker and its enclosure that helps balance the mechanical properties of air volume within and help generate a smooth flat frequency response. This is known as acoustic or resistive loading. S. Stark (pg141) explains in the lower two-thirds or so of a drivers intended frequency range, the speaker cone requires an extra amount of acoustical impedance (or load) to keep its motion under control. Again if both appliances are well designed, especially the driver construction, this acoustical impedance is balanced out on the diaphragm movement.

Loudspeaker drivers…These are known as Thiele-Small parameters and are essentially a set of electromechanical parameters that determine the performance of a low frequency driver. Each driver is sent out with these specifications from the manufacture and help define a relationship between a speaker and an intended enclosure for use. They are very accurate and crucial in establishing constitution in the enclosure design in respect to sound quality and response output. One way to look at these in more depth is to see a direct correlation with the voice coil, magnet, and cone interacting with the cone suspension and the air in and outside the enclosure as an electrical circuit made up of resistors, capacitors and inductors. This can be seen as a relatively simple analysis circuit where changing the parameter increments of the individual components can alter the needed frequency. By then changing these parameters back into physical attributes such as

enclosure size for a sealed box, a design can be implemented (A. Ludwig 1997). This practice sets a scientific foundation in the practice of loudspeaker design as much a science as an art. It can often be seen in some cases, speaker designing a trial and error process, though with simple calculation correction methods based on these parameter formulas. For example, from predicted theory or software modelling, once a loudspeaker build has been complete, an initial test for electrical impedance across the driver terminals will demonstrate the first step in comparing the finished result with the simulations. If these are in contrast with the predictions, the enclosure can be ' tuned' founded on these measurements. Often impedance spikes are sensitive to design faults and can cause extended amplification or location shifts at unintended frequencies. Ludwig (1997) however, suggests how these responses can be due to mutual coupling though in some cases such as a bass-reflex or ported designs actually a necessary result benefitting the design by allowing air to enter the duct and work in alliance with the speaker cone.

There are three parameter categories as constituted by Neville Thiele and Richard small. These are acoustical, mechanical and electrical and can be determined by either an ' A', ' M' or ' E' in their symbol script. Acoustic parameters are established by the effective piston area of the cone where the mechanical attributes are obtained by multiplying by the square of this area in the case of mass and resistive loss, or dividing by the square of the area in the case of compliance. Ludwig (1997). The electrical components involve two energy diffusions: the voice coil DC resistance and the amplifiers output resistance.

To build a loudspeaker these parameters must be fully understood so justified usage can be applied in the different stages of design.

' Q' has no dimensions though is a measure of damping on a speaker. It is simply the ratio between energy storing and energy dissipative mechanisms at resonance and in electrical terms, it is the ratio of the reactance to the resistance at its resonant frequency. D. Pierce (1995). The greater the damping of a speaker i. e. higher the Q, the lower its output is at resonant frequency indicating a small mechanical energy transfer in the driver. In other words, the amount of resistance available to dissipate the energy is small compared to the amount of energy stored. Therefore, for larger applications such as long horn or ported enclosures, generally a lower Q is required to produce the synonymous low frequency responses. This is induced by damping the resonant motion quickly as the resonant energy is dissipated quickly and removed from the resonant system. D. Pierce (1995). The mechanical and electrical mechanisms are classed as Qms and Qes with a combined unification closely described as Qts, also determined by the enclosure volume (Vas) and total Q of the driver.

EQUATIONS

Essentially the compliance is the measure of stiffness of a driver's suspension measured in litres or cubic ft. Written as Vas, It denotes the same volume of air for the cone as it does for the speaker suspension. Larger drivers predominantly have a larger Vas due to the resistance of air it has to push in comparison to a smaller driver. The compliance must be established in order to ascertain whether an enclosure size is too small or large for the driver. A larger value equates to a stiffer surround and therefore being more

suited in large enclosures. This said however, often results in a lower Qts and would correspond better as a mid-bass region either in a three or four way system.

To follow on from these few basic parameters, a look into some basic speaker enclosures allows a practical look into the enclosure variables and how each box evolves to ascertain the diagnostics of my final build.

EQUATION

Compliance ratio = 3 α = Vas / Vab = Cms/cmb

compliance of driver is expressed as an equivalent volume of air or Vas (Murphy pg24)

Speaker designs can be put into two main classifications: direct radiators and acoustic horns with many variations and combinations to gain different frequency responses from the size, shape and air tightness of the box. Within these classifications bring four sub category types, each with their own advantages and disadvantages so suit different applications.

Asealed boxor ' air suspension' enclosure uses quite a compact design, mainly found in home hi-fi where excessive SPL is not such an essential necessity. It utilizes the force of air at the rear driver more so than its own suspension, though a ' floppy' driver is often used along with the spring to help dampen the driver cone movement. The rear of a speaker in any enclosure plays a fundamental part in shaping the sound waves. It is therefore clear to see why these types of enclosures are not commonly seen in the larger scale venues or for live music due to its inefficient design of

soley manipulating the rear waves of the diaphragm as a linear air spring in a sealed enclosure. The compliance ratio decides whether the box is sealed (infinite baffle) or air suspension. An infinite baffle box usually has a low ratio of about one or two as the box replies predominantly on the cone suspension as a its control with a large box volume behind. This in turn acts similarly to a baffle of infinite proportion where the air gives little resistance to the movement of the cone. On the other hand, an air suspension can have a relatively high compliance ratio of four or five due to the air being reasonably stiff which in turn allows a looser driver where most the control is regulated. This enclosure has one self contained variable known as Vb and as mentioned by Ludwig, by altering the volume size in co-ordinance with driver parameters can help tune the box to its optimum response. As well as a drivers resonance frequency, the enclosure simultaneously also produces a system resonance known as fsc and a second order high pass filter defined as Qtc and corresponds to the sealed box Q. These parameters will perpetually be greater than the drivers uniformed fs and Qts.

To gain the enclosures resonance, both the volume of the enclosure and driver parameters have to be applied. Therefore:

F(sc) = F (fs, Qts, Vas, Vb)

Portedbox has two variables – V(B) the box volume and F(B) the tuning frequency

A ported enclosure essentially allow for extended low end with a given driver and is even possible to reduce the size of box gaining extra low end frequency without increasing the internal stiffness of the air. The air inside

the box continues its proficiency as a spring yet the port serves as an additional piston where the vibrating air supplements the resonant frequency for two other contemporary resonances; one in phase slightly higher than the Fs and one lower than the Fs working out of phase. As with a sealed enclosure a balance has to be struck as this lower Fs and out of phase response can run the risk of over excursion as the roll off frequency quickly becomes a much steeper gradient. Stark (2004) explains how when a speaker is given a significant amount of power below the resonant frequency, the speaker ' unloads' and becomes drastically more inclined to push beyond its normal excursion limits. At its best sound bad, but at worst can risk driver failure.

Helmholtz resonator stark 178

Port tuning frequency = Fb

Further advances on ported designs such as installing additional baffles inside the enclosure result in an even lower resonant frequency of the air mass in the enclosure, fabricating a smaller enclosure at the front with a larger air space at the rear of the driver. These are known as ' bandpass' enclosures and by adjust the volumes of air in the two compartments help to equalize the enclosure with the duct or port used to tune the fs. This again comes as a compromise where a considerable amount of power is needed to produce the equivalent output levels.

Transient response differences page 29 murphy

What the different frequencies do

More about the port

Variations, band pass 4th 5th 6th order

Hornloaded speakers serves a much more beneficial approach of further increasing efficiency over direct radiators and serve two paramount parameters: A higher composure of directivity control (especially in the higher frequencies) and loading of the driver. By increasing the loaded of the driver over that of the free air, increases efficiency and hence the output and by further concentrating the sound into a fixed solid angle increases the output further (B. Kolbrek horn theory). This method of amplification is not a recent discovery and has dated back thousands of years where ram horns have been used consisting of a small throat and large mouth where perceivable amplification is recognized. Thomas Edison then evolved this principle in 1877 where the first tin horn phonograph was invented, coupling the minute vibrations of the diaphragm to the air of the listening area (J. Dinsdale horn loudspeaker design). To expand this principle further, a loudspeaker propagates pressure producing an internal source impedance and external load impedance and essentially acts as an acoustical transformer, matching the high impedance at the driver to the low impedance of the room air by its smooth rate of increased cross sectional area from the driver cone to the horn mouth. In a direct radiating enclosure, because a mismatch between source and the load, most the energy is converted into heat in the voice coil and the mechanical resistances where the size of source is small compared to the wavelengths it's trying to produce and therefore merely push the medium away and making it quite an inefficient design (B. Kolberk). Kolberk goes on to say that high frequency

output consist of plane waves (Wave in which the wavefront is a plane surface; a wave whose equiphase surfaces form a family of parallel planes (J. D. Jackson, 1998)) that do not spread out. The system will therefore be at its optimum efficiency as the load from the driver is at its highest. If the lower frequencies could be radiated also in pane waves

Quarter wave horns

Tapped

The build

Initially, a tapped horn build was not first choice. A model of a twin loaded 18″ 4th order bandpass sub was modelled using the software winISD. This program allows modelling of vented, bandpass and passive radiator enclosures with additional tools such as filter calculators and signal generators with help if designing multi-way systems. Various drivers were configured such as B&C 6PE13, Beyma G550, PD 1850 and an RCF LF18X400 though a 800W Ciare 18. 00sw would have been the driver of choice with a low fs of 22Hz at.

This illustrates the maximum SPL response from the predicted cabinet. This was as close to flat as possible with a low f3 (cut of frequency -3db) and tuned to 29Hz. However, size would have been a serious issue with a cabinet size of 600 litres.

This was the first initiation into speaker design with little appreciation to what is really intended from a low frequency enclosure. The purpose of this build is to establish an efficient, effective and accurate acoustical

reproducing circuit. The circuit system should be able to emphasize the necessary frequency tones and accordingly dampen unwanted characteristics. Furthermore, through the desired frequency bandwidth, an ideal flat response contour should be achieved where the structure should collaborate, emphasizing the bass tones in the music content. From looking at sealed enclosures, an analytical careful design should be constructed where the use of both sides of the speaker should be implemented to its maximum performance. Therefore, by constructing a circuit where the change in phase from the front and rear of the driver actually couple and in turn reinforce the sound level output.

For these reverse polarity sound waves to couple and increase efficiency, a folded horn arrangement seems a coherent route to pre-empt and can be either exponential, hyperbolic, tractix, parabolic or conical each giving their own individual response in terms of efficiency and distortion.

In essence of a loudspeaker box, distinctively the drivers competence plays a considerable role in quality and magnitude of the sound as much as the structure of the box. A paramount feature of a good enclosure besides its principle design is its backbone of rigidity and strength. A feature of good quality cabinets demand a sturdy design with minimal or no waver from the surrounding walls or internal baffles caused by the high pressure sound waves. Correspondingly, joins and fixings should also be air tight and free from unwanted vibrations. Stark (pg 144) explains how this possible flexing of the walls can create unnecessary resonances and consequently reduces efficiency and maximum output. Furthermore, it also degrades the principle of the infinite baffle and can also diminish transient response. In other words,

the enclosure is likely to continue vibrate after the driver has stropped moving.

From analysing the different enclosures in research, a further look into quarter wave horns was undertaken. It was found that transmission lines absorbed much of the intensity on output though a slightly adapted rear loaded horn with a ' tap' and could accomply a larger driver could be much more suitable resulting in a smaller driver and box with extended efficiency at low end.

A new driver had to be found with a much more in depth look into the thiele-small parameters and which characteristics would work in such a horn. Again various speakers were modelled but the Eminence Lab-12 predicted the best results due to…

WinISD is not capable of calculating tapped horn responses so a look into the horn modelling software; Horn Response (Hornresp) designed by D. J. McBean was carried out. Here the parameters of the driver can be inserted along with the length and area of each horn section, the rear chamber parameters including acoustical lining specifications and a series of predicted test tools such as schematic diagram of the horn, acoustical impedance, SPL response, electrical impedance, diaphragm displacement, phase response and group delay.

On first look at this program the input parameters for each section looked somewhat perplexing and took a lot of time calculating what each section could achieve with different horn designs. On initial play, parameters from other designs were inserted where alterations could be adjusted to see the

possible outcome. Advancing from this further, looking at a pattern in previous models and trying to design a horn suitable for the needs of my own chosen driver. It wasn't until extensive reading in speaker design, that the different thiele-small parameters really came into play where a clear relationship between the driver parameters and enclosure parameter knowledge that a formulated pattern could be understood and used on further developments.

Although the variables can be adjusted on the different sections, a starting point had to be established. Firstly a driver had to been chosen. It was quickly found however that not any driver would suit a tapped horn. For example, as ownership of a several 12″ Ciare drivers a logical and initial route to take to help save money was to use these drivers.

Dick pierce: Closed boxes store energy that interacts with the loudspeaker driver in complex ways, especially in vented enclosures. Boxes themselves also have resonances. Normally a high-Q closed box is combined with low-Q loudspeaker driver to give a desirable total system Q. But when we mount a loudspeaker driver on an open baffle this situation is reversed. An open baffle stores no energy and has a low-Q of 0. 2 and Carver chose to use a high-Q woofer with a total Q of 3+ to arrive at a desirable total system Q.

Sound is the element which occurs when an object is set to vibrate. Reproduced sound can be seen as an art to reinforce these inputs accompanied using sciences of physics, mechanical and electrical engineering.

Loudspeakers have evolved considerably since E. W. Siemens built the first moving-coil transducer in 1875.

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