UNIVERSITY OF NAIROBI

FACULTY OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

DESIGN OF AN OPTIMAL SPEAKER CABINET SIZE TO GIVE BEST RESPONSE, FOR A 50 WATT WOOFER

PROJECT INDEX: PRJ 054

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Dedication

I dedicate this project to my family and friends.

Acknowledgements

In the course of research, preparation and completion of this project, I have been helped, advised and encouraged by several people to whom I am greatly indebted.

My special thanks and appreciation to my dedicated project supervisor Mr. L.S Ogaba for his guidance and support in the project implementation.

Great thanks to my friends for their constructive critic and encouragement.

I would also like to thank my family for the much needed moral and financial support.

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Abstract

Music is one of the most important aspects of the social life, of people of all cultures across the globe. Therefore there is a huge interest in developing and designing good music systems. The speaker cabinet which is a very important component of the music system obviously benefits from this interest. Apart from housing the speaker drivers and the crossovers, the cabinet is instrumental in isolating the waves emanating from the rear and those from the front of the speaker so that they don't interact destructively in the listening environment.

Making a good cabinet involves a lot of tradeoffs, for example; if you want increased frequency response, the power output will decrease, and the cabinet will be larger (all other parameters held constant). If you want maximum power output, be prepared to pay more for the drivers and sacrifice some frequency response.

Knowing the best or optimum cabinet size for your chosen driver can mean the difference between very bad low bass sound and very smooth bass output from your speaker. If you have the parameters of your driver it will be easy to make informed decisions and not rely solely on the manufacturers specifications, which more often than not are extremely optimistic.

This project presents a study, design, and analysis of frequency response, power handling and other specifications with a goal of coming up with a simple, efficient, professional and inexpensive speaker cabinet. It will also Endeavour to give good consumer advice.
In the study, different speakers in the market were studied and tested through simulation to determine their characteristics. The woofer used in the project was also analysed to establish the effect of changing the cabinet volume with the same input power.

Finally the frequency response was carried out to establish the difference in the frequency response curves of the speaker inside the optimum volume enclosure and outside the enclosure.

CHAPTER ONE

INTRODUCTION

1.1 introduction

The speaker cabinet does not just house the speaker drivers, crossover networks; it must be carefully engineered and designed. Most people when designing a speaker enclosure have the low-end response in mind. This is because the low frequency signals are tricky to reproduce faithfully due system imperfections.

Before embarking on a cabinet making project there are a few important factors that one should consider; the most important is the driver of choice; i.e. the power rating, the price and the driver parameters are important. The driver's parameters will help you in coming up with the optimum volume for your box. The volume will determine how effective your cabinet damps out unwanted resonances, how well it reproduces the very low frequency signals without devastating distortions, and how smooth the response is.

Generally a small box is to be avoided due to its bad damping characteristics which sometimes even lead to the destruction of the cone. After the optimum volume is established and the correct measurements determined, the ideal material has to be determined. The material should be rigid, light, and readily available. The construction should be meticulous, and exact to ensure that there are no air leaks, which would alter the cabinet's performance adversely.

1.2 Problem statement

Low frequency or bass response is the most important but tricky part of the frequency sound spectrum to control and manage. The low frequency drivers otherwise known as woofers are very susceptible to mechanical damage due to the over-excursion of the cone. To avoid this, it is important to come up with a well tuned enclosure, which will correctly damp the cone to avoid its damage. Apart from protecting the cone the enclosure acts like an amplifier, making the sound output appear louder and smoother.

Main objectives:-

1) To study the existing speaker systems and establish
    - Power of speaker drivers. (RMS and PMPO) ratings.
    - The internal optimum cabinet volume for a 50w woofer.
2) Establish a relationship between the input electrical power and the optimum volume of the cabinet.
3) To carry out comprehensive frequency response of the 50 watts woofer in the cabinets of the following sizes:-

    - A large box($\sqrt{2}$ of the optimum cabinet)
    - An optimum cabinet
    - A restricted cabinet(70.7% of the optimum box)

1.3 Definition of a speaker cabinet: -

This is a purpose engineered enclosure in which speaker drivers and associated electronic hardware, such as crossover circuits and amplifiers are mounted. It provides an appropriate acoustic loading for the driver units so as to obtain a good frequency response. This is achieved when the speaker cabinet or enclosure isolates the waves emanating from the rear and those coming from the front of the driver so they don't destructively interact. The speaker cabinet also increases acoustic resistance so that the driver can work more efficiently at low frequencies. [1]

1.4 classification speaker cabinets:-

There are numerous classifications of speaker cabinets. But the most widely considered, studied, applied and implemented for good low frequency response are; Sealed (closed) and vented enclosures.

a. Closed Cabinets:-

This is a sealed enclosure that uses a calculated volume of air as a "spring" to help dampen and control woofer cone movement.

Advantages:-

- Closed cabinets have a relatively smooth roll-off and flat response,
- The small boxes required ensure higher power handling, excellent damping and a good transient response.

- They are easy to design and build, thus can be forgiving of design and construction errors.

Disadvantages:

- Low bass response not as good as in a vented box.
- Lower efficiency compared to the vented box

b. Vented cabinets:-

Ported enclosures use a tuned port or passive radiating elements to transform and transmit low frequency energy from the rear of the speaker to the listener. Air inside the vent acts like a piston or motor that moves in the phase with the woofer reinforcing frequencies.

Advantages:

- Increased efficiency,
- increased low frequency output,
- Better power handling in vicinity of tuning frequency
- Relatively low distortion.

Disadvantages:

- Larger enclosures thus less tolerant of design/construction errors.
- No woofer control below tuning frequency.

1.5 Previous work

A lot has been done in the design of the speaker cabinet. Most of the major speaker companies like Sony, Pioneer and Eminence have all come up with software to calculate optimum box sizes for their speakers. The problem is that for individuals who want to work with drivers not necessarily from these big companies, it becomes very hard to obtain accurate optimum volume especially if they don’t have the manufacturers’ data sheets. In view of this challenge the project endeavored to come up with an easy, well thought out formula to obtain the same.

1.6 Project Structure

This project is divided into several parts or chapters as follows:-

- **Chapter one**

  It involves the introduction and basic definition of the project title, the problem statement, the project objectives, and the project structure.

- **Chapter two**

  This chapter deals with the literature review, which is the background theory and information behind the project. Components of the speaker system are defined and fully explained to make the designed process clearer.

- **Chapter three**

  This chapter deals with the design of the speaker cabinets. The design equations are derived, and through simulation tools are proved. A woofer is chosen and its optimum volume obtained and confirmed through simulation.

- **Chapter four**

  In this chapter the frequency response of the woofer in different cabinet sizes is determined. This is first done by simulation and later in the lab experimentally. The results both simulated and from the experiment are tabulated and analysed.

- **Chapter five**

  This chapter deals with the cost analysis, and a brief conclusion of the project. It also states what was achieved at the projects conclusion. Future recommendations are also mentioned, to make the making of cabinets easier and more practical.

- **Appendix**

  Tables that were too long, definitions of some terms used, and some important but not very crucial formulae are also found here.

- **References**

  This is a list of resources that helped in coming up with the design of this project.

CHAPTER TWO

1. Literature review

2.1 Speaker system

Speaker or loudspeaker refers to transducers that convert electrical energy into sound. They are otherwise known as drivers, enclosures and crossovers. One or more drivers may be mounted in one enclosure for higher sound level and maximum accuracy.

Most of the work involved in making a good sounding cabinet involves tradeoffs of various parameters within the limits of acceptable cabinet size, low-end frequency response, and maximum acoustic output or perceived loudness and efficiency.

Speaker drivers should exhibit a flat frequency response curve over a wide range of frequencies. To prove that they can reproduce all signals presented to them the same way i.e. the system is distortionless.

It would be very hard for a single driver to achieve this thus the modern high- fidelity (Hi-Fi) or low distortion loudspeaker system is a complex system comprising of:-

a) Speaker drivers- they provide acoustic energy
b) Enclosure- provides a dynamically rigid structural support for the driver units; it also offers good damping thereby reducing vibrations and enhancing the low-end frequency response of the driver.
c) Crossovers- separate the incoming signal into different frequency ranges, and routes them to the appropriate drivers. This ensures that each driver is fully utilized for use in a specific frequency range.

2.2 speaker drivers

There are four major classifications of drivers according to their frequency range specification:-

That is-

a. Sub-Woofers - very low frequencies
b. Woofers - low frequencies
c. Mid-range speakers - middle frequencies
d. Tweeters - high frequencies

Most drivers are made up of different specialized parts which make them more efficient.

That is they use a lightweight *cone*, connected to a rigid *basket*, via a flexible suspension that constrains a coil of fine wire to move axially through a cylindrical magnetic gap. When an electrical signal is applied to the voice coil a magnetic field is created by the electric current in the voice coil, making it a variable electromagnet.

The coil and the driver's magnetic system interact, generating a mechanical force that causes the coil and the attached cone to move back and forth, reproducing sound under the control of the applied electrical signal coming from the amplifier.

The materials used to construct these parts are very important because they contribute greatly to the overall efficiency of the driver.

The diaphragm: - the perfect material would be light, stiff, and with good damping characteristics. Such a material is extremely hard to come by; thus tradeoffs are necessary. Composites are thus popular, for example, a cone might be made of cellulose paper, into which some carbon fiber, Kevlar, glass or bamboo fibers have been added.

The chassis and frame: - Is designed to be rigid, avoiding deformation which would change critical alignments with the magnet gap, and cause the voice coil to rub against the sides of the gap. They are typically cast from aluminum alloy.

The suspension system: - it keeps the coil centered in the gap and provides a restoring force that returns the cone to a neutral position after moving. A typical suspension system consists of:

- Spider - connects the diaphragm or voice coil to the frame and provides the majority of the restoring force, usually made of a corrugated fabric disk, impregnated with a stiffening resin or wood.
- Surround - which helps center the coil/cone assembly and allows free pistonic motion aligned with the magnetic gap. Can be made from rubber or polyester.

The voice coil: - Usually made of copper, though aluminum may be used. The advantage of aluminum is its light weight, which raises the resonant frequency of the voice coil and allows it to respond more easily to higher frequencies. The coil is oriented co-axially inside the gap and moves back and forth within the magnetic structure. The gap establishes a concentrated magnetic field between the two poles of a permanent magnet; the outside of the gap being one pole, and the pole piece being the other. [2]

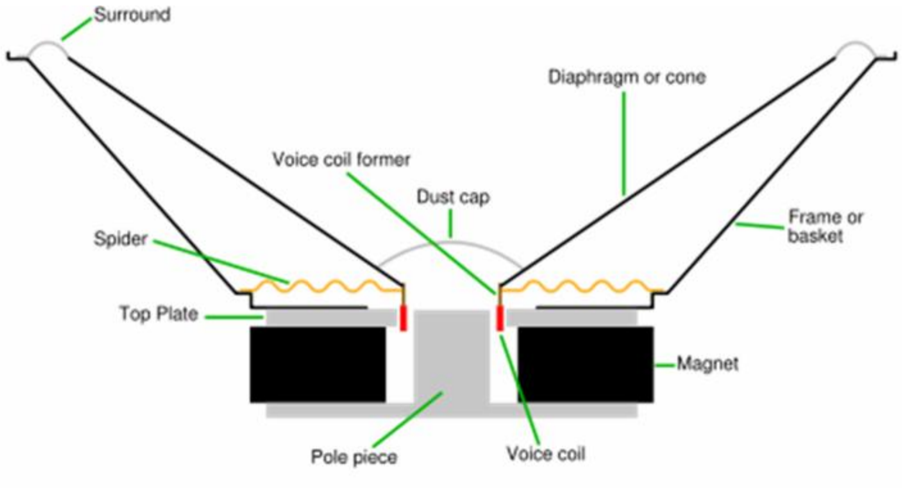

Figure 2-1: cross-section diagram of a driver.

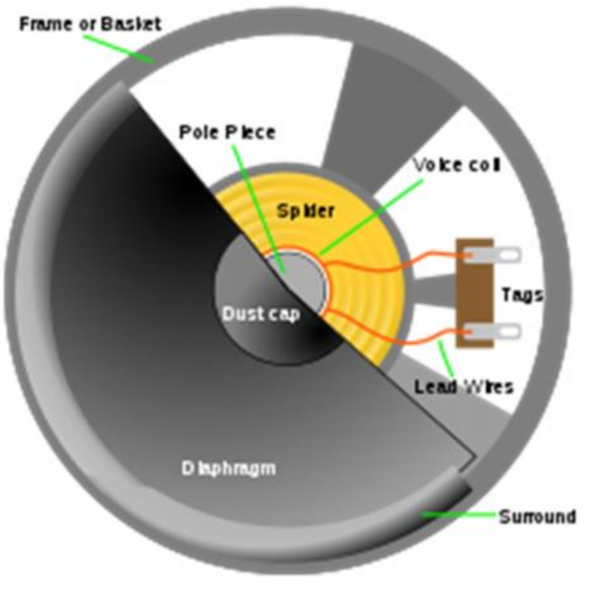

Figure 2-2: diagram of a woofer. [2]

2.3 Enclosures

Definition: - a loudspeaker enclosure is a purpose engineered cabinet in which speaker drivers and associated electronic hardware, such as crossover circuits and amplifiers are mounted.

Types of enclosures:-

1. Sealed
2. Vented
3. Dipole
4. Horn

2.3.1 Sealed or closed enclosures

This is an airtight enclosure whose purpose is to enhance speaker performance. It separates the front and rear firing waves, which if not isolated could cancel out and adversely affect the bass response of a speaker. The sealed enclosure is preferred in many installations because of its superb damping, very good power handling capabilities and relative ease in construction. Types of sealed enclosures include:-[1]

a) Infinite baffle: - where you mount a driver in a very large sealed enclosure, providing minimal 'air spring' restoring force to the cone. Its main advantage is that it minimizes the change in drivers resonance frequency caused by the enclosure.

b) Acoustic suspension: - (small sealed box) these have light power handling, excellent damping and transient response. They are also easy to design and build

2.3.2 Vented (ported or bass- reflex)

They use cabinet openings or passive radiating elements, to transform and channel low frequency energy from the speaker rear and the front into the listening environment (making them more efficient than their sealed counterparts). Other advantages of the vented design include better reproduction of low bass, a reasonably flat response curve, low distortion, and enclosure size reduction

Others in this class are:-

a) Passive radiators: - They use a second "passive" driver, to produce similar low-frequency extension, efficiency increase and enclosure size reduction, similar to ported enclosures. The passive driver is not wired to an amplifier; instead, it moves in response to changing enclosure pressures.

Advantages

- Very low tuning frequencies can be realized in small boxes.
- No port noise

Disadvantages

- Passive radiator may run out of excursion at low frequencies
- As passive radiator has finite compliance, it creates notch in frequency response at passive radiator's resonance frequency. That notch may impair transient response.
- Passive radiator unit is not normally suitable for horizontal mounting.
- Passive radiator requires precision construction thus increasing costs.

b) Compound or band-pass**: -** A 4^{th} order electrical bandpass filter can be simulated by a vented box in which the contribution from the rear face of the driver cone is trapped in a sealed box, and the radiation from the front surface of the cone is into a ported chamber. In its simplest form a compound enclosure has two chambers. The dividing wall between the chambers holds the driver; typically only one chamber is ported. Other variations include; a 6th order or an 8th order electrical bandpasss which are more complicated in construction.

Advantages:-

- Allows the user to select very specific woofer for specific needs.

Disadvantages:-

- It is very difficult to construct.

c) A periodic enclosure: - It can be thought of as either a leaky sealed box or a ported box with large amounts of port damping. By setting up a port, and then blocking it precisely, with sufficiently tightly packed fiber filling, it's possible to adjust the damping in the port as desired. The result is control of the resonance behavior of the system which improves low-frequency reproduction. Although adding damping material reduces the efficiency of the system, the same result can be achieved through selection of a driver with a lower Q factor, or even via electronic equalization.

2.3.3 Dipole enclosures:-

This is when a driver is located on a flat baffle panel. The baffle dimensions are typically chosen to obtain a low frequency response. Its main shortcoming is that it causes reduction in sound pressure or sound loudness in some areas. [1]

2.3.4 Horn enclosures

The horn is used to couple the speaker driver and the air. It transfers more electrical energy from the driver cone to the air. It also helps control dispersion at higher frequencies. But due to their physical complexity they are expensive. [1]

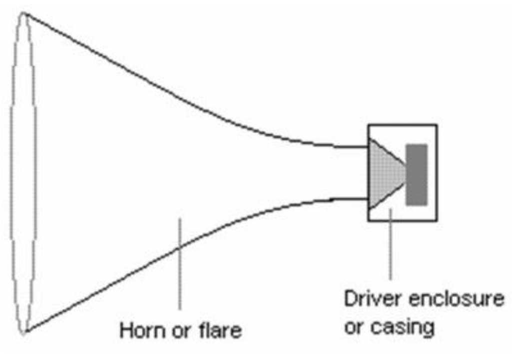

Figure 2-3. diagram of a horn speaker

CHAPTER THREE

3 DESIGN OF THE SPEAKER CABINET

3.1 Design considerations

1) Frequency response: - these are the highest and the lowest frequencies that a speaker can faithfully reproduce (bandwidth). A frequency response curve is a graph showing the acoustic energy produced by a speaker over its entire bandwidth. A frequency response curve should be as linear as possible, because if it exhibits large peaks and dips then certain frequencies presented to the system will be louder than others even when presented with the same amplitude. A broad and linear frequency response curve is the most important indicator of a well designed speaker.[2]

2) Power handling: - Measured in watts, it is a measure of how much power a speaker can take without getting damaged. On the other hand if the power into the speaker is too low the cone is impaired. Generally the distortion rises dramatically between 50% and 75% of its maximum rated power handling capacity.

3) Efficiency: - Rated in decibels, efficiency is considered to be the true measure of a speaker's loudness. It is the amount of energy required to hear a sound of 0.00002Newtons/sq.meters or one decibel. Efficiency can also be estimated from the magnet size, the strength of the magnet, and how much of this strength is focused on the magnetic coil gap.

4) Distortion: - distortion is a measurement of inaccuracy in a speaker system. Usually given in percentage it indicates how much of a signal heard is a result of system imperfections.

   Several factors cause distortions and most can be eliminated through careful speaker system design. The woofer is made using an electromagnetic or electrostatic linear motor assembly connected to a cone. The motor should be carefully designed to ensure that it moves in a controlled fashion, and with the signal presented to it.

The cone is usually attached to the motor and may not be rigid enough making it vibrate at harmonic frequencies when presented with certain signals. Further to mount the cone you require a suspension, which may prevent the cones free movement causing the cone to twist or move more in one direction. Considering that all of the above can go wrong in the motor assembly, it’s important to choose only high quality motors. [5]

5) Dynamic range: - This is an indication of the highest and lowest acoustic amplitude that a speaker can reproduce. It is a combination of efficiency and power handling.

6) Impedance:-this is a measure of the difficulty electrical energy has when passing through a conductor. The impedance of the loudspeaker should be properly matched to the impedance of the amplifier. A driver with higher impedance will make it hard for the amplifier to transfer energy into them, and a driver with lower impedance will draw too much power from the amplifier without properly transferring the electrical signal; which creates harmonic distortions in the amplifier that can be damaging. When using multiple drivers, they should also have similar impedances.

7) Reflections: - The response of a drive in a loudspeaker system is modified by reflections from the cabinet panels, cabinet edge molding, and mounting hardware, from the listening environment and from other parts of the system. The effect of these reflections on the quality of the sound emanating from the system has been long recognized. Studies carried out to determine the effect of these reflections on the loudspeaker system, have concluded that cabinet edge molding and speaker mounting surfaces are considered specific reflecting surfaces.

3.1.1 Cabinet construction:-

a) Materials: - The enclosure has to be strong enough to be able to cope with the high pressure changes that the speaker cone creates, and the sides of the box should not move or vibrate as this contributes to the resonant sound or rattles. Thus a dense material is important so as to create a strong, rigid enclosure which ensures that the designed cabinets damp out or virtually eliminate all cabinet resonances. To achieve reasonable resonance-damping, a sturdily-built cabinet with internal bracing is critical, damping materials are also glued to the insides of the cabinet walls. Generally a knuckle rap on the cabinet should produce a ‘thud’ this means that the cabinet has good resonance damping characteristics. Different manufacturers use different materials, some use hardwood, metal and others using resin and concrete. For this project I used chip wood which has good damping characteristics.

b) Stuffing: - Enclosures should have a percentage (around 50%) of their internal volume stuffed with acoustic stuffing material. Stuffing increases the apparent volume of the cabinet, and helps compensate for volume lost by driver baskets, handles, crossover components, etc. It also helps break up standing waves inside the cabinet and damp out vibrations. Ensure that the material is firmly glued otherwise it will cause unnecessary distortions.

c) Walls and joints: - walls should not be the same size to avoid standing waves. The joints should be tightly glued together strong; the strongest joint are dovetail joints although they are a bit hard to construct for a carpentry beginner. Just ensure that there are no air leaks as this will compromise the output of your driver.

d) Shape and type of cabinet: - the main concern when considering a shape for your cabinet is the standing waves. Cubes are the most susceptible to these waves and so should be avoided. Cylinders and spheres are excellent, although for aesthetics the shape is subjective. For a rectangular enclosure you may consider using the ratio; - (height 1.40: width 1.00: length 0.7) this will get rid of the standing waves.

e) Speaker drivers’ alignment: - in case you are using more than one driver, it is important to come up with an ideal alignment to keep them in phase. That is the tweeter, midrange, and woofer should be in a straight vertical line. With the woofer closest to the bottom, and the tweeter at the top closest to the listening level, and the midrange in-between. The drivers should also be close together to reduce phase shifting.

3.2 Thiele small parameters

These are usually small signal parameters of a driver. These parameters were introduced in the 1970's by scientists A.N Thiele and Richard H. small. Basically these are mechanical parameters of a driver measured at small signal levels, used in equivalent electrical model circuits.

They include:

Fs

Also called F_0, resonance frequency measured in (Hz). The frequency at which the combination of the energy stored in the moving mass and suspension compliance is maximum, and results in maximum cone velocity.

Qes

A unit less measurement, describing the electrical damping of the loudspeaker . It decreases the total current through the coil near the resonance frequency, thus reducing cone movement and increasing impedance. It depends on the amplifier's output impedance.

Q_{ms}

A unit less measurement, characterizing the mechanical damping of the driver, that is, the losses in the suspension (surround and spider) at resonance frequency (Fs). High Q_{ms} indicates lower mechanical losses and a lower Qms indicates higher mechanical losses.

Qts

- A unit less measurement, characterizing the combined electric and mechanical damping of the Vas- driver i.e. total Q of driver at Fs.

Vas

Is a measure of the 'stiffness' of the suspension with the driver mounted in free air. It represents the volume of air that has the same stiffness as the driver's suspension when acted on by a piston of the same area (S_D) as the cone. Larger values mean lower stiffness.

S_D

The effective projected area of the cone or diaphragm. Measured in square metres (m^2). Generally accepted as the cone body diameter plus one third to one half the width of the surround.

X_{max}

Maximum linear peak (sometimes peak-to-peak) excursion of the cone (in mm). Note that, because of mechanical issues, the motion of a driver cone becomes non-linear with large excursions.

P_e

Measured in watts. Frequently two power ratings are given: - "RMS" rating and a peak reading, usually peak is given as about twice the RMS rating. There are two aspects of power handling, thermal and mechanical. Actual mechanical power handling depends greatly on the enclosure in which the driver is installed.

V_D

Measured in litres (L). The volume displaced by the cone, equal to the cone area (S_d) multiplied by X_{max}. Small cone diameter, high X_{max} drivers are likely to be inefficient, since much of the voice coil winding will be outside the magnetic gap at any one time and will therefore contribute little or nothing to cone motion. Likewise, large cone diameter, small X_{max} drivers are likely to be more efficient as they will not need, and so may not have, long voice coils.

η_0:–

Reference Efficiency, Specified in percent (%).

Sensitivity

The sound pressure, in dB, produced by a speaker in response to a specified stimulus. Usually this is specified at an input of 1 watt or 2.83 volts (2.83 volts = 1 watt into an 8 ohm load) at a distance of one meter.

These parameters are used in deriving useful equations. These equations are pertinent in establishing the relationship between speaker driver's power rating and the volume of their optimum or ideal enclosures.

The Thiele-Small approach is to first analyse the electro-mechanical behavior of a speaker voice coil, magnet, and cone, interacting with the cone suspension and the air in and outside the enclosure. The resulting equations are applied in calculating losses occurring in the system, pressure in and outside the enclosure and cabinet volume. They are also important in establishing the relationship between voice coil motion and the voltage induced by the driver magnet and the associated forces in the system.

3.3 DESIGN EQUATIONS

We derive the following equations from the work of Neville Thiele and A.N Small.
These equations are used to obtain the optimum cabinet size of a particular driver.

$$\alpha = \left[\frac{Qtc}{Qts}\right]^2 - 1$$

α → constant

Free air reference efficiency of the system

$$\eta_0 = \frac{2.7 \times 10^{-8} f_s^3 Vas}{Q_{es}}$$

In terms of efficiency the system resonance frequency can be expressed as:-

$$F_s = \left[\frac{\eta_0 Q_{es}}{2.7\times10^{-8} V_{as}}\right]^{1/3}$$

$$V_{as} = \frac{\eta_0 Q_{es}}{2.70\times10^{-8} f_s^3}$$

Net cabinet internal volume (Vb)

$$Vb = \frac{V_{as}}{\alpha}$$

Where Vas is the air volume with the same acoustic compliance as the speaker suspension

The electrical quality factor of the speaker driver: Q_{es}

$$Q_{es} = \frac{2.7\times10^{-8} f_s^3 V_{as}}{\eta_0}$$

Maximum air volume displaced by the cone excursion (as it moves in and out):- V_d

$$V_{d} = S_d \times x_{max}$$

Where S_D: - cone effective area

X_{max}: - cone peak linear displacement

$$X_{max} = \frac{V_d}{S_d}$$

Acoustic power input

$$P_{er} = \frac{P_{ar}}{\eta_0}$$

$$\eta_0 = \frac{P_{ar}}{P_{er}}$$

Acoustical power output: - P_{ar}

$$P_{ar} = \frac{P_{er}}{\eta_0}$$

η_0 is the free air reference efficiency.

3.3.1 Relationship between cabinet volume and the drivers' power rating

Developing the relationship between cabinet volume and the driver's power rating:-

We know that:-

$$P_{ar} = \frac{P_{ar}}{\eta_0}$$

And the cabinet volume is:-

$$V_b = \frac{V_{as}}{\alpha}$$

Efficiency:-

$$\eta_0 = \frac{2.7 \times 10^{-8} f_s^3 V_{as}}{Q_{es}}$$

Substituting efficiency we have:-

$$P_{ar} = \frac{P_{er}}{2.7{\times}10^{-8} f_s^3 V_{as}}$$

Also $V_{as} = V_b \times \alpha$

Therefore:-

$$P_{er} = \frac{P_{ar} \times Q_{es}}{2.7{\times}10^{-8} \times f_s^3 \times V_b \times \alpha}$$

Thus:-

$$V_b = \frac{P_{ar} Q_{es}}{2.7{\times}10^{-8} f_s^3 \alpha P_{er}}$$

To simplify the equation we can put a constant K as:

$$K = \frac{P_{ar} Q_{es}}{2.7{\times}10^{-8} f_s^3 \alpha}$$

$$V_b = \frac{K}{P_{er}}$$

These equations give a clear, direct relationship between the cabinet volume and the power rating of your particular driver.

3.3.2 Application of the formula:-

Consider a Precision TD205R-8 with the following parameters:-

P_{er} =100 watts, Qtc= 0.71, Q_{es}= 0.46, V_{as}= 42.0 litres, Q_{ts}= 0.38, F_s= 37.0 Hz

$$\alpha = \left[\frac{\text{Qtc}}{\text{Qts}}\right]^2 - 1$$

$$\alpha = \left[\frac{0.71}{0.38}\right]^2 - 1$$

$$\underline{\alpha = 2.491}$$

$$\eta_0 = \frac{2.7 \times 10^{-8} f_s^3 Vas}{Q_{es}}$$

$$\eta_0 = \frac{2.7\times10^{-8} 37.0^3 42.0}{0.46}$$

$$\eta_0 = 0.125$$

$$K = \frac{P_{ar} Q_{es}}{2.7\times10^{-8} f_s^3 \alpha}$$

$P_{ar} = P_{er} \times \eta_0$ = 12.5

K = 1687.82

$$V_b = \frac{1687.82}{100}$$

V_b = 16.87 litres

These formulae were applied as shown above to create table 1:-

Table 3-1: comparison of the simulated cabinet volumes and the calculated volumes.

Woofer model	Power rating (rms)	Simulated volume WinISD	Calculated volume
Seas 11 -FGX	40 watts	0.8 litres	0.8 litres
Ultimate Pm 6520	60 watts	5.3 litres	5.27 litres
Credence 6C12PP1	50 watts	10.4 litres	10.17 litres
Precision TD 205R8	100 watts	17.16 litres	16.8 litres
Pioneer TS- W160 [design woofer]	50 watts	21.9 litres	21.24 litres

From the table it is clear that the derived formula is fairly accurate. And thus was also used to calculate the optimum cabinet volume for the driver used for design that is Pioneer TS-W160, whose parameters are: - Q_{tc} =0.71, Q_{ts} =0.6, Q_{es}= 0.38, f_s = 73.20litres, per = 50watts, V_{as}= 8.5litres.

From the given parameters the volume was calculated and found to be: - 21.24 litres

CHAPTER FOUR

ANALYSIS AND DESIGN

4 THE EFFECTS OF CHANGING THE CABINET VOLUME WITH CONSTANT INPUT POWER:-

4.1 SIMULATED RESULTS

4.1.1 WinISD test of a Pioneer TS-W160 in different cabinet volumes

Volume	Q_{tc}	Lower cutoff frequency (hertz)
3.2	1.15	105.4
5.48	0.96	93.24
10.95	0.80	87.99
15.49($21.9 \div \sqrt{2}$)	0.75	86.68
21.9 (optimum)	0.71	86.20
30.97($\sqrt{2} \times 21.9$)	0.68	86.40
61.94	0.64	87.11

Table 4-1: Effects of changing the cabinet volume for a 50 watts Pioneer TS-W160 woo

4.1.2 WinISD test for ultimate PM6520 in different cabinet volumes.

VOLUME	Q_{tc}	Lower cutoff frequency (hertz)
1.0	1.44	166.98
2.05	1.04	132.16
3.74	0.81	118.89
5.3 (optimum volume)	0.71	116.77
7.49	0.63	118.6
10.59	0.57	121.82
14.98	0.52	126.23
21.18	0.48	130.47

Table 4-2: effects of changing the cabinet volume of a 60 watts Ultimate 6520 woofer

From tables 2 and 3 we can see that:-

1. An increase in the cabinet volume led to a decrease of the Q_{tc}.
2. An increase in the cabinet volume up to the optimum volume led to the decrease in the cutoff frequency.
3. A further increase in the cabinet volume past the optimum volume led to an increase of the cutoff frequency.

Analysis: - Q_{tc} is basically the combination of the Q_{ms} mechanical damping factor (losses in the suspension) and Q_{es}; electrical damping factor (reduces current across the coil thus reduces the cone excursion). This means that a decreasing Q_{tc} is a clear indication of increased damping of the cone which essentially gets rid of vibrations and other distortions. The enclosure basically dampens the cone to give a smooth distortionless low frequency response.

4.2 Graphical representations of the simulated results

4.2.1 The graph of restricted cabinet volume for the Pioneer TS-W160

The graph of (restricted) small cabinet volume (less than optimum) for the same woofer.

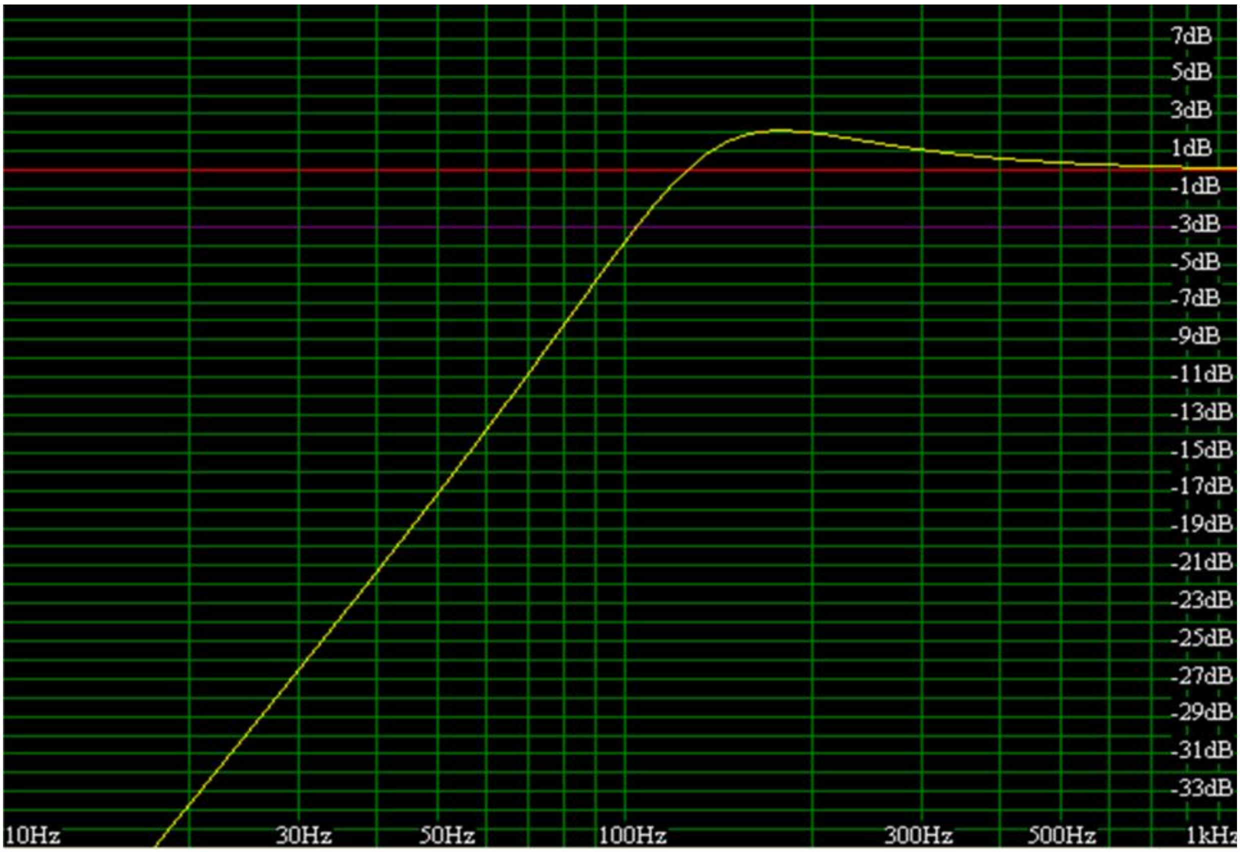

Figure:4.1 the graph of restricted cabinet volume for the Pioneer TS-W160

The lower cutoff frequency is 105.4Hz; this means that much of the power in the lower frequencies is lost and since the woofer is ideally supposed to work in the low frequency part of the spectrum; which is unacceptable. This is observed due to the fact that if a driver is placed in a small box, the cone of the driver moving forward has to overcome a huge amount of suction caused by the lack of air in the box, which will cause the driver to take way more power to excurse the cone, this suction effect alters the movement of the cone causing distortion, it can also be powerful enough to destroy the cone. When the cone goes into its negative cycle, it tries to compress that small amount of air into the box, which provides a lot of resistance.

4.2.2 The graph of optimum cabinet size (21.9litres) for a given power input into the driver.

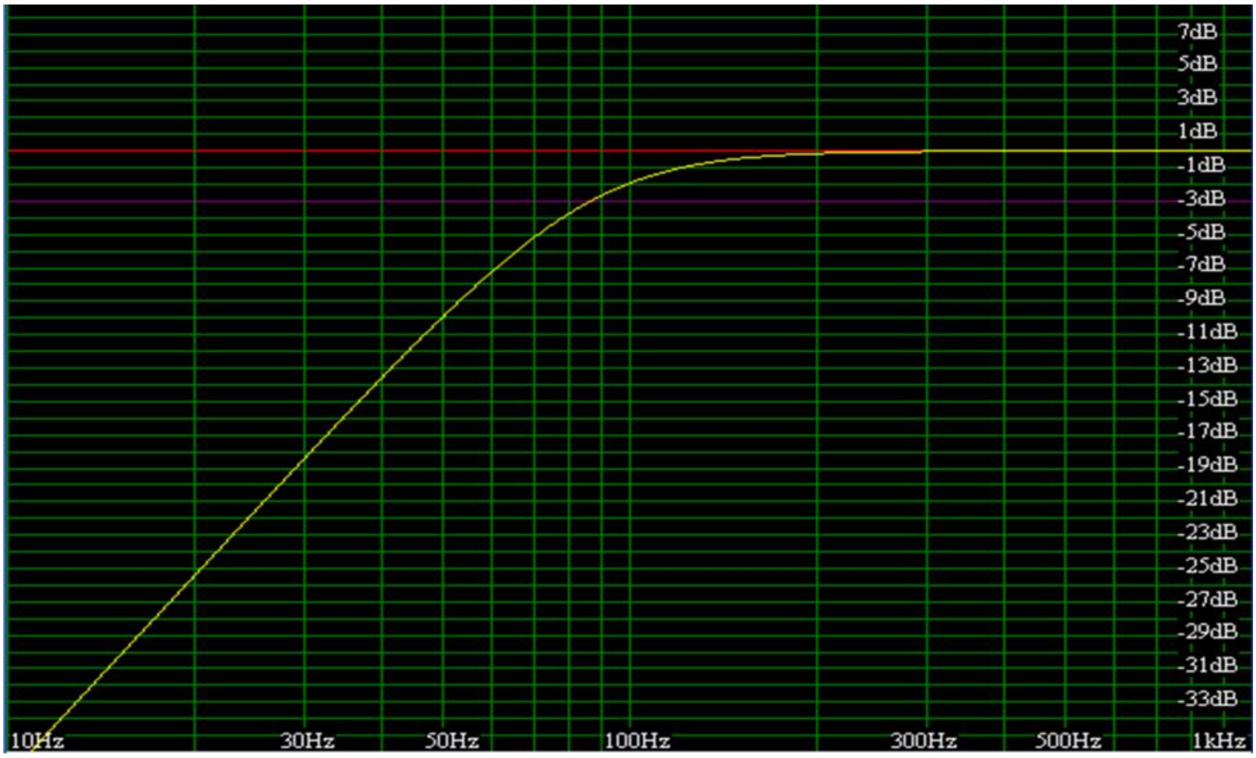

Figure 4-2: the graph of optimum cabinet volume for the Pioneer TS-W160

This graph shows an excellent lower cut-off frequency (least frequency allowable) of 86.20 Hz. This means that this woofer in this particular cabinet size has a much wider bandwidth as compared maybe to the small size cabinet. It also exhibits a flat frequency response which is another mark of a good cabinet.

4.2.3 The graph of large (relaxed) cabinet volume for the Pioneer TS-W160

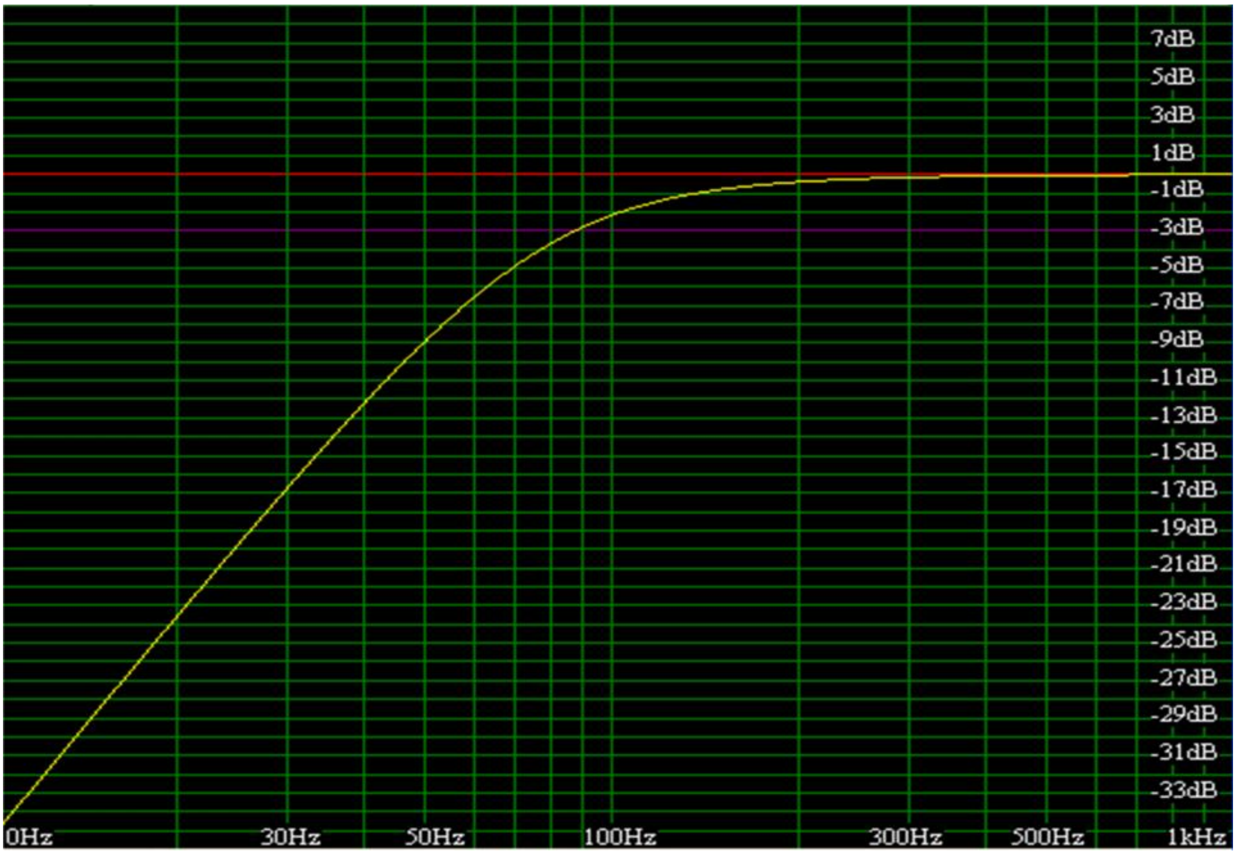

Figure 4-3: *the graph of large (relaxed) cabinet volume for the Pioneer TS-W160*

The graph indicates that the woofer in this cabinet will have a slightly higher cutoff frequency as compared to the optimum volume. This means that it still doesn't utilize some lower frequencies as desired. The gain plot is flat as required, indicating reduced distortion.

4.3 FREQUENCY RESPONSE ANALYSIS OF A 50 WATTS WOOFER:

4.3.1 Experimental setup

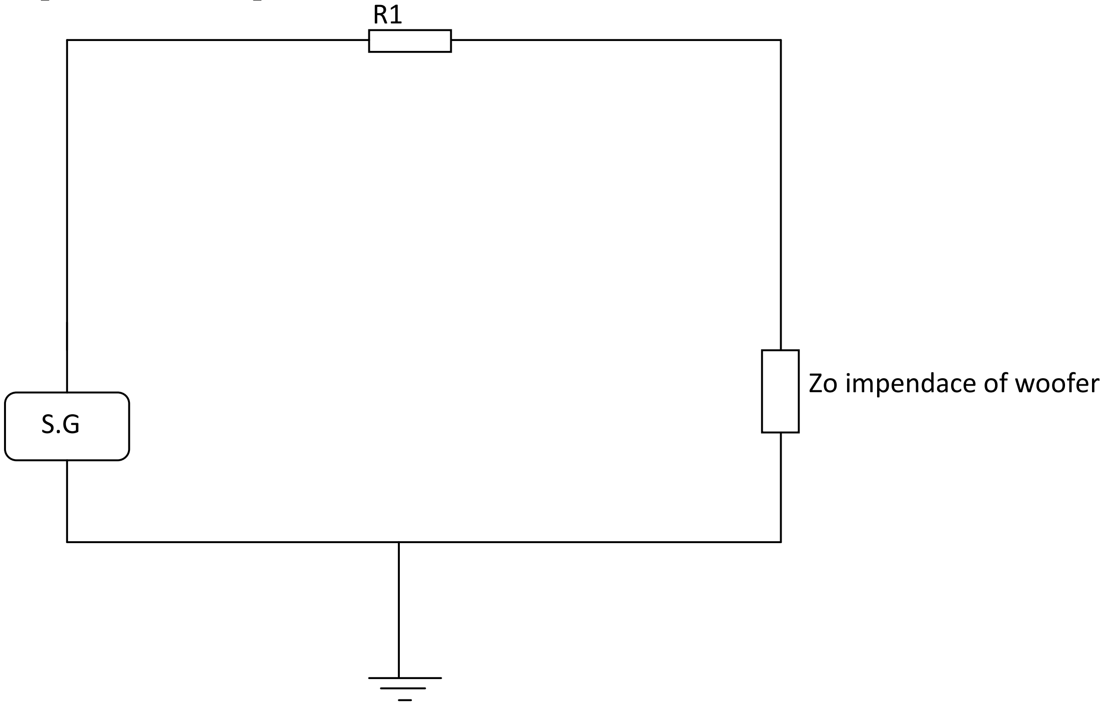

Figure 4-4: the experiment setup

Procedure in the lab.

Equipments

1) R1- 4.1 Ohms.
2) 50 watts woofer with Z_0 – 3.8 Ohms
3) 1 Signal generator.
4) An oscilloscope.

EXPERIMENT:-

- To carry out the frequency response of the woofer (pioneer TS-W160), the experiment was setup as shown above.
- Use the digital meter to take the readings of Z_0 and R1.

- Use the signal generator (considered as the audio signal) to vary the frequency over a range of 50Hz – 100KHzs.
- Obtain the results.

- Plot the gain plot, i.e. $\log_{10}$ frequency vs. gain.

Theory:

The above experiment was done with the woofer outside the cabinet and again using the same setup with the woofer inside the cabinet. This is to establish the importance of the cabinet to the performance of a woofer by observing how the gain plot varies, inside and outside the cabinet.

4.3.2 Results of woofer in free-air

Frequency response analysis of a 50 watts woofer (pioneer TS-W160) , Outside the cabinet.

Table of results:-

frequency (Hz)	Log_{10}frequency	V_{in} X 10^{-3}	V_{out} X 10^{-3}	Gain (Av)	$20log_{10}Av$	Normalized (Av)
50	1.699	100	48	0.48	-6.375	6.299
200	2.301	100	40	0.4	-7.959	7.863
1000	3.000	100	46	0.46	-6.745	6.664
4000	3.602	100	56	0.56	-5.036	4.976
8000	3.903	100	64	0.64	-3.876	3.830
12000	4.079	100	80	0.8	-1.938	1.915
16000	4.204	100	74	0.74	-2.615	2.584
20000	4.301	100	77.8	0.778	-2.180	2.154
50000	4.699	100	85	0.85	-1.412	1.395
100000	5.000	100	87.5	0.875	-1.160	1.146

Table4-3:-Results *of the frequency response analysis of a 50 watts woofer (pioneer TS-W160) .Outside the cabinet.*

Discussion and analysis:-

The graph of gain against $\log_{10}$ frequency with the woofer outside the cabinet:-

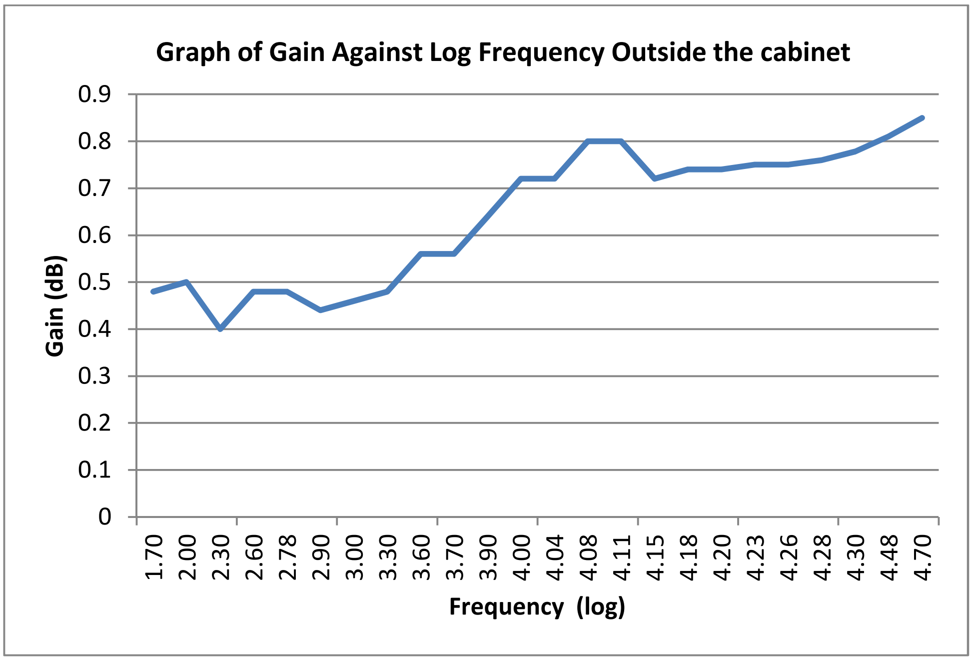

Figure 4-5:

From the graph:-

The graph shows a much distorted, and inconclusive gain plot. It is very hard to obtain a desirable frequency response curve when the enclosure is outside the box; this is because of destructive interference between the rear and the front emanating waves.

4.3.3 Result For woofer inside cabinet

The experiment results when the woofer (a 50 watts Pioneer TS- W160) is placed inside the cabinet;-

Table of results:-

frequency (Hz)	Log_{10}frequency	V_{in} X 10^{-3}	V_{out} X 10^{-3}	Gain (Av)	$20log_{10}Av$	Normalized (Av)
50	1.699	100	50	0.5	-6.021	0.833
600	2.778	100	50	0.5	-6.021	0.833
5000	3.699	100	60	0.6	-4.437	1.000
12000	4.079	100	44	0.44	-7.131	0.733
15000	4.176	100	40	0.4	-7.959	0.667
20000	4.301	100	40	0.4	-7.959	0.667
100000	5.000	100	40	0.4	-7.959	0.667

Table 4-3:- the experiment results of the woofer Pioneer TS-W160 inside the cabinet the lab

Discussion and analysis:-

The graph of gain against $\log_{10}$ frequency of the woofer inside the box.

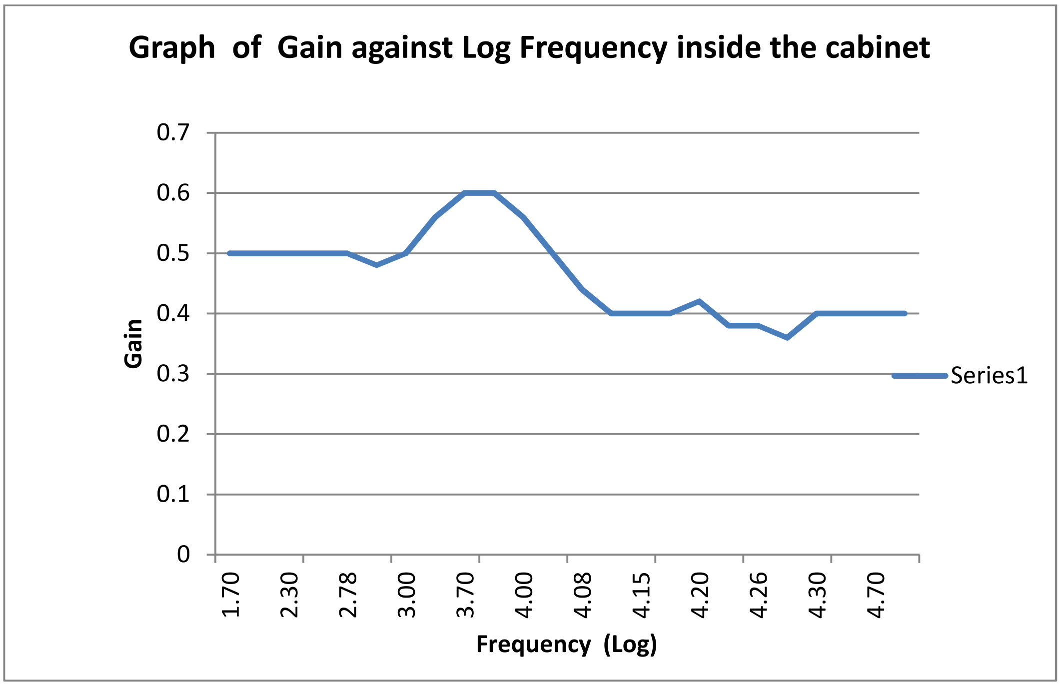

Figure 4-6:

Graph analysis:-

From the graph and taking errors into consideration it is clear that the frequency response curve is linear. The box acts like an amplifier'. This is because it is well tuned to the drivers' resonance frequency, thus making the woofer louder while using less power i.e. it is well damped.

CHAPTER FIVE

5 Conclusions and future work:-

5.1 Conclusions:-

This project has essentially covered everything about speaker cabinet design and analysis. Looking at the results from the lab and the simulated results it is clear that the there is a very direct relationship between the power rating of a driver and the volume of its cabinet; overlooking this relationship will cost the user a good smooth bass output and in some cases may even destroy the woofers cone which will lead to added expenses. The project objectives were met.

5.2 Future work:-

In the course of this project a very important equation has been developed; and has been used to calculate the cabinet volume for a given woofer as long as the its Thiele Ssmall parameters are known. This is done manually and it is time consuming and tiring.

In future it would be better if there is universal software that would calculate accurate cabinet volumes and would be able to deal with all the drivers regardless of their manufacturers, power ratings or the availability of its datasheet.

APPENDIX

Appendix A

The sketch of the designed cabinet:-

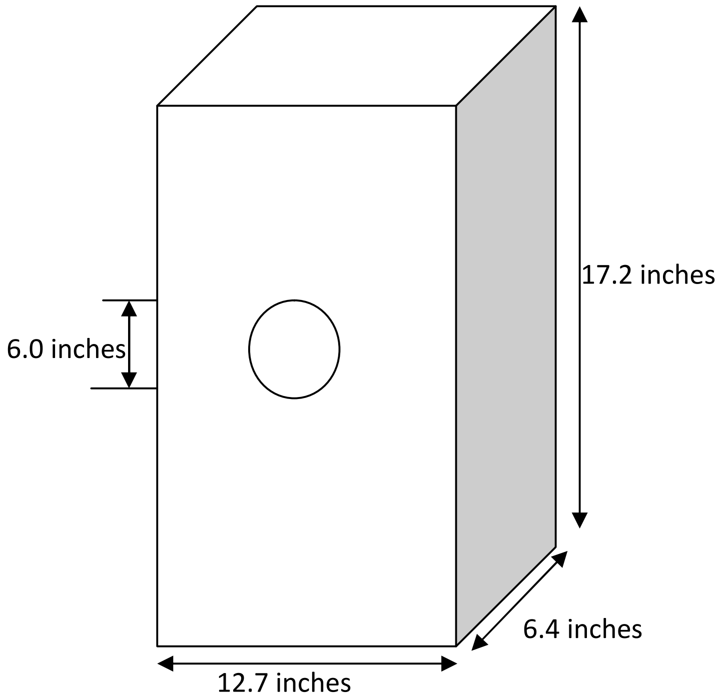

Figure6-1

Explanation of some terms used:-

1) Cabinet means box or enclosure
2) Speaker drive:- means woofer, subwoofer, midrange or tweeter unless specified

Some additional Thiele parameters definitions:-

R_{ms}

R_{ms} is a measurement of the losses, or damping, in a driver's suspension and moving system. It is the main factor in determining Q_{ms}. R_{ms} is influenced by suspension topology, materials, and the voice coil former material.

C_{ms}

Measured in metres per Newton (m/N). Describes the compliance (i.e., the inverse of stiffness) of the suspension. Cms is proportional to Vas and thus has the same tolerance ranges.

R_e

Measured i*n Ohms* (Ω), this is the DC resistance (DCR) of the voice coil, usually measured with the cone blocked, or prevented from moving or vibrating because otherwise the pickup of ambient sounds can cause the measurement to be unreliable.

L_e

Measured in milliHenries(mH), this is the inductance of the voice coil. The coil is a lossy inductor, so the apparent inductance changes with frequency. Large L_e values limit the high frequency output of the driver and cause response changes near cutoff frequency.

Bl

The product of the magnetic field strength in the voice coil gap and the length of wire in the magnetic field, in tesla-metres (T.m)

Formulas used to derive the volume calculation:-

Efficiency bandwidth product

$$EBP= \frac{F_s}{Q_{es}}$$

System resonance frequency (closed cabinet)

$$F_c= \left[\frac{Qtc \times f_s}{Q_{ts}}\right]$$

-3dB, half power frequency: the cutoff frequency of the speaker

$$F_3= \left|\frac{\left(\frac{1}{Q_{tc}}-2\right)+\left(\sqrt[2]{\frac{1}{Q_{tc-2}}}\right)+4}{2}\right|^{1/2} \times f_c$$

System resonance frequency (f_c)

$$F_c = \frac{f_3}{\left[\frac{\left(\frac{1}{Q_{tc}}-2\right)+\left(\sqrt[2]{\frac{1}{Q_{tc-2}}}\right)+4}{2}\right]^{1/2}}$$

Efficiency in terms of SPL:-

$$\eta_0 = Anti\_log_{10}\left(\frac{\text{SPL} - 112}{10}\right)$$

S_D can also be expressed as:-

$$S_{D} = \frac{\pi D^2}{4}$$

Where D is the cone diameter:-

$$D = \sqrt{\frac{4S^d}{\pi}}$$

Acoustical power output: - P_{ar}

$$P_{ar} = \frac{K_1}{A_{max}}$$

Maximum power input P_{max}:

$$P_{max} = \text{anti-log}\left[\frac{SPL-112}{10}\right]$$

Where SPL (sound pressure level)

$$SPL_{peak} = 112 + 10\log_{10} P_{max}$$

Appendix B

Extended tables of results:-

Extension of table 4-3 is shown in Table6-1.

frequency (Hz)	Log_{10}frequency	$V_{in} \times 10^{-3}$	$V_{out} \times 10^{-3}$	Gain (Av)	$20log_{10}Av$	Normalized (Av)
50	1.698970004	100	48	0.48	-6.37517525	6.298673149
100	2	100	50	0.5	-6.02059991	5.948352714
200	2.301029996	100	40	0.4	-7.95880017	7.863294571
400	2.602059991	100	48	0.48	-6.37517525	6.298673149
600	2.77815125	100	48	0.48	-6.37517525	6.298673149
800	2.903089987	100	44	0.44	-7.13094647	7.045375113
1000	3	100	46	0.46	-6.74484337	6.663905246
2000	3.301029996	100	48	0.48	-6.37517525	6.298673149
4000	3.602059991	100	56	0.56	-5.03623946	4.975804586
5000	3.698970004	100	56	0.56	-5.03623946	4.975804586
8000	3.903089987	100	64	0.64	-3.87640052	3.829883714
10000	4	100	72	0.72	-2.85335007	2.819109871
11000	4.041392685	100	72	0.72	-2.85335007	2.819109871
12000	4.079181246	100	80	0.8	-1.93820026	1.914941857
13000	4.113943352	100	80	0.8	-1.93820026	1.914941857
14000	4.146128036	100	72	0.72	-2.85335007	2.819109871
15000	4.176091259	100	74	0.74	-2.61536561	2.583981218
16000	4.204119983	100	74	0.74	-2.61536561	2.583981218
17000	4.230448921	100	75	0.75	-2.49877473	2.468789435
18000	4.255272505	100	75	0.75	-2.49877473	2.468789435
19000	4.278753601	100	76	0.76	-2.38372815	2.355123417
20000	4.301029996	100	77.8	0.778	-2.18040806	2.154243163
30000	4.477121255	100	81	0.81	-1.83029962	1.808336027
50000	4.698970004	100	85	0.85	-1.41162149	1.394682028
100000	5	100	87.5	0.875	-1.15983894	1.145920872

Table6-1

Table 6-2 shows the extension of data in table 4-4

frequency (Hz)	Log_{10}frequency	V_{in} X 10^{-3}	V_{out} X 10^{-3}	Gain (Av)	$20log_{10}Av$	Normalized (Av)
50	1.699	100	50	0.5	-6.021	0.833
100	2.000	100	50	0.5	-6.021	0.833
200	2.301	100	50	0.5	-6.021	0.833
400	2.602	100	50	0.5	-6.021	0.833
600	2.778	100	50	0.5	-6.021	0.833
800	2.903	100	48	0.48	-6.375	0.800
1000	3.000	100	50	0.5	-6.021	0.833
4000	3.602	100	56	0.56	-5.036	0.933
5000	3.699	100	60	0.6	-4.437	1.000
8000	3.903	100	60	0.6	-4.437	1.000
10000	4.000	100	56	0.56	-5.036	0.933
11000	4.041	100	50	0.5	-6.021	0.833
12000	4.079	100	44	0.44	-7.131	0.733
13000	4.114	100	40	0.4	-7.959	0.667
14000	4.146	100	40	0.4	-7.959	0.667
15000	4.176	100	40	0.4	-7.959	0.667
16000	4.204	100	42	0.42	-7.535	0.700
17000	4.230	100	38	0.38	-8.404	0.633
18000	4.255	100	38	0.38	-8.404	0.633
19000	4.279	100	36	0.36	-8.874	0.600
20000	4.301	100	40	0.4	-7.959	0.667
30000	4.477	100	40	0.4	-7.959	0.667
50000	4.699	100	40	0.4	-7.959	0.667
100000	5.000	100	40	0.4	-7.959	0.667

Table6-2

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