UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

FINAL YEAR PROJECT REPORT

IRUNGU K ELIAS

F17/1376/2010

PROJECT NUMBER: PRJ 097

DESIGN OF SPEAKER CABINETS TO GIVE OPTIMUM [BEST] RESPONSE FOR, 100W, 250W WOOFERS.
IRUNGU K ELIAS

REGISTRATION NUMBER: F17/1376/2010

SUPERVISOR: MR. S.L. OGABA

EXAMINER: DR G.S.O ODHIAMBO

SUBMITTED ON 24th of April 2015

This project report was submitted as a partial fulfillment of the requirement for the award of Bachelor of Science degree in Electrical and Information Engineering from University of Nairobi.

DECLARATION AND CERTIFICATION

This is my original work and has not been presented for a degree award in this or any other University.

........................................

IRUNGU K ELIAS

F17/1376/2010
This report has been submitted to the Department of Electrical and Information Engineering, The University of Nairobi with my approval as supervisor:

 MR. S.L. OGABA

Date: ......................

DEDICATION

I wish to dedicate this project to my family and my supervisor for their support during the duration of my project, and the endearing knowledge that they have passed on to me.

You have been a blessing and inspiration to the completion of my studies.
ACKNOWLEDGEMENTS

First and foremost, I would like to thank God for giving me the strength and ability to carry out this project.

I would also like to thank my supervisor, Mr. S.L. Ogaba, for being a source of guidance throughout the duration of the project.

My appreciation goes out to my classmates for their suggestions and opinions on the project.

Lastly, I would like to appreciate my family for their continuous support.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECLARATION AND CERTIFICATION</td>
<td>2</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>4</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>6</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>6</td>
</tr>
<tr>
<td>CHAPTER 1</td>
<td>7</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>8</td>
</tr>
<tr>
<td>CHAPTER 2</td>
<td>9</td>
</tr>
<tr>
<td>2. LITERATURE REVIEW</td>
<td>9</td>
</tr>
<tr>
<td>2.1 Sound wave characteristic properties</td>
<td>9</td>
</tr>
<tr>
<td>2.2 Frequency and Amplitude</td>
<td>10</td>
</tr>
<tr>
<td>2.3 Working Principles of a speaker</td>
<td>11</td>
</tr>
<tr>
<td>2.4 Loudspeakers</td>
<td>11</td>
</tr>
<tr>
<td>2.5 Woofer</td>
<td>12</td>
</tr>
<tr>
<td>2.6 Understanding woofer Data</td>
<td>12</td>
</tr>
<tr>
<td>2.7 Thiele-Parameters</td>
<td>12</td>
</tr>
<tr>
<td>CHAPTER 3</td>
<td>17</td>
</tr>
<tr>
<td>3. DESIGN</td>
<td>17</td>
</tr>
<tr>
<td>3.1 Woofer Enclosure models</td>
<td>17</td>
</tr>
<tr>
<td>3.2 Woofer Enclosure Design Procedure</td>
<td>20</td>
</tr>
<tr>
<td>3.3 Designing The Box</td>
<td>20</td>
</tr>
<tr>
<td>CHAPTER 4</td>
<td>24</td>
</tr>
<tr>
<td>4. Tests on woofers to come up with Frequency Responses</td>
<td>25</td>
</tr>
<tr>
<td>4.1 Open box test</td>
<td>25</td>
</tr>
<tr>
<td>4.2 Frequency test on very large and very small cabinets</td>
<td>27</td>
</tr>
</tbody>
</table>
CHAPTER 5

5. Cabinet design using the bass box pro software ........................................30
5.1 Introduction ........................................................................................................30
5.2 Procedure ...........................................................................................................32
5.3 Data analysis .......................................................................................................33
5.4 Conclusion And Recommendations ..................................................................34

ABSTRACT

Most public service vehicles and even personal cars have music systems installed with woofer but most of them produce very poor sound quality. This is because you may find woofer enclosures poorly designed, hence causing poor frequency response which implies poor sound response.

What makes a good loudspeaker? My definition of good Hi-Fi loudspeaker performance is a speaker system that can accurately reproduce the musical information it is fed. If it is fed a low quality, distorted, compressed recording, it should produce a low fidelity, distorted and compressed sound. If fed a high fidelity signal with wide dynamic range and frequency response, that is the sound that should come out of the speaker system.

Sound is produced from the front and the rear of a speaker’s cone. These sound waves must be separated to achieve usable output. If not separated, the output from the front and rear of the cone would cancel each other out. This is further accentuated with lower frequencies, and the main reason for mounting a speaker on an enclosure. The enclosure also absorbs vibration created by the speaker. If not mounted to an enclosure and simply placed on a solid surface, the vibration created from the speaker’s movement may be louder than the sound it emits. An enclosure that does not resonate with the speaker must be made from a solid and thick material.

Shaping the low-end (bass frequencies below 300Hz) is the reason for choosing a particular enclosure type. A speaker’s cone response dictates the signature shape or sound of the enclosure beyond 200-300Hz. Any speaker will produce sound in any cabinet, but optimizing the relationship between the speaker and the enclosure is the key to good bass.
Designers must prioritize what performance or sonic characteristics they desire from a product and determine what aspects of the speaker and cabinet will make it a reality. Output level (or SPL), power handling, frequency range, and size and weight are all considerations. When one is improved, other factors may suffer. The most difficult part is finding a middle ground. We want to have it all, but unfortunately, it’s not always so simple.

Woofer enclosure (cabinet) design comes in handy to facilitate production of quality bass with a flat frequency response from the woofer drivers. A well designed cabinet is paramount for best entertainment by the users.

CHAPTER 1

1. INTRODUCTION

At ordinary sound pressure levels (SPL), most humans can hear down to about 20 Hz and up to 20 KHz. Woofers are chosen to handle low frequency sounds typically from around 40 hertz up to about a kilohertz or higher. A woofer enclosure is incorporated to facilitate the mounting of woofer drivers and any associated electronic hardware, such as amplifiers and crossover circuits. The primary role of the enclosure being to prevent sound waves generated by the rearward-facing surface of the diaphragm of an open driver interacting with the sound waves generated at the front of the driver.

There are two major types of woofer enclosures:

1. Sealed enclosure
2. Ported enclosure.

Each type of enclosure is chosen depending on the specifications of woofer drivers. Cabinets are a very important part of the woofer systems as they are used to facilitated optimum sound response of the driver at the same time housing the woofer drivers.

In order to understand this, there is thus the need to start from the basics and understand sound as a wave and how its frequency affects its energy which corresponds to its amplitude and how to correlate this concept with the working principle of the woofer.
2 LITERATURE REVIEW

2.1 Sound

Sound is a vibration that propagates as a mechanical wave of pressure and displacement, through some medium (such as air or water). Sometimes sound refers to only those vibrations with frequencies that are within the range of hearing for humans or for a particular animal.

Propagation of sound

Sound propagates through compressible media such as air, water and solids as longitudinal waves and also as a transverse waves in solids. The sound waves are generated by a sound source, such as the vibrating diaphragm of a stereo speaker. The sound source creates vibrations in the surrounding medium. As the source continues to vibrate the medium, the vibrations propagate away from the source at the speed of sound, thus forming the sound wave. At a fixed distance from the source, the pressure, velocity, and displacement of the medium vary in time. At an instant in time, the pressure, velocity, and displacement vary in space. Note that the particles of the medium do not travel with the sound wave.

This is intuitively obvious for a solid, and the same is true for liquids and gases (that is, the vibrations of particles in the gas or liquid transport the vibrations, while the average position of the particles over time does not change). During propagation, waves can be reflected, refracted, or attenuated by the medium.

The behavior of sound propagation is generally affected by three things:

- A relationship between density and pressure. This relationship, affected by temperature, determines the speed of sound within the medium.
- The propagation is also affected by the motion of the medium itself. For example, sound moving through wind. Independent of the motion of sound through the medium, if the medium is moving, the sound is further transported.
• The viscosity of the medium also affects the motion of sound waves. It determines the rate at which sound is attenuated. For many media, such as air or water, attenuation due to viscosity is negligible.

When sound is moving through a medium that does not have constant physical properties, it may be refracted (either dispersed or focused).

The mechanical vibrations that can be interpreted as sound are able to travel through all forms of matter: gases, liquids, solids, and plasmas. The matter that supports the sound is called the medium. Sound cannot travel through a vacuum.

2.1 Sound wave characteristic and properties
Sound waves are often simplified to a description in terms of sinusoidal plane waves, which are characterized by these generic properties:

• Frequency, or its inverse, the period
• Wavelength
• Wave number
• Amplitude
• Sound pressure
• Sound intensity
• Speed of sound
• Direction

2.2 Frequency and Amplitude
An audio frequency (abbreviation: AF) or audible frequency is characterized as a periodic vibration whose frequency is audible to the average human. It is the property of sound that most determines pitch and is measured in hertz (Hz).

The generally accepted standard range of audible frequencies is 20 to 20,000 Hz, although the range of frequencies individuals hear is greatly influenced by environmental factors. Frequencies below 20 Hz are generally felt rather than heard, assuming the amplitude of the vibration is great enough. Frequencies above 20,000 Hz can sometimes be sensed by young
people. High frequencies are the first to be affected by hearing loss due to age and/or prolonged exposure to very loud noises. The amplitude of a sound wave is specified in terms of pressure hence a logarithmic dB amplitude scale used. The quietest sound that humans can hear has amplitude of 20µPa or a sound pressure level of 0dB. Sound pressure
level (SPL) is the local pressure deviation from ambient atmospheric pressure caused by a sound wave measured in Pascal.

2.3 Working principle of a speaker
Technically we can define speaker, as a component which converts the electrical signals into the equivalent air vibrations to make audible sound.

To understand the working of a speaker, we first need to understand the concept of sound. A sound is nothing but vibrations in air particles. When a sound source generates a sound, it generally makes a vibration in its surrounding air particles which finally reaches to our eardrum. Sound is characterized by the parameters like frequency, speed, fluctuation, pressure, etc.

The speaker works on the same concept. It produces vibrations in air particles in order to generate a sound.

2.4 Loudspeakers
A loudspeaker (or "speaker", or in the early days of radio "loud-speaker") is an electro acoustic transducer that produces sound in response to an electrical audio signal input. In other words, speakers convert electrical signals into audible signals.

The term "loudspeaker" may refer to individual transducers (known as "drivers") or to complete speaker systems consisting of an enclosure including one or more drivers. To adequately reproduce a wide range of frequencies, most loudspeaker systems employ more than one driver, particularly for higher sound pressure level or maximum accuracy. Individual drivers are used to reproduce different frequency ranges. The drivers are named subwoofers (for very low frequencies); woofers (low frequencies); mid-range speakers (middle frequencies); tweeters (high frequencies); and sometimes super tweeters, optimized for the highest audible frequencies. The terms for different speaker drivers differ, depending on the application. In two-way systems there is no mid-range driver, so the task of reproducing the mid-range sounds falls upon the woofer and tweeter. When multiple drivers are used in a system, a "filter network", called a crossover, separates the incoming signal into different frequency ranges and routes them to the appropriate driver. A loudspeaker system with \( n \) separate frequency bands is described as "\( n \)-way speakers": a two-way system will have a woofer and a tweeter; a three-way system employs a woofer, a mid-range, and a tweeter. Loudspeakers were described as "dynamic" to distinguish them from the earlier moving iron speaker, or speakers using piezoelectric or electrostatic systems as opposed to a voice coil that moves through a steady magnetic field.

The most common type of driver, commonly called a dynamic loudspeaker, uses a lightweight diaphragm, or cone, connected to a rigid basket, or frame, via a flexible suspension, commonly called a spider, that constrains a voice coil 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 thus, the attached cone) to move back and forth, thereby reproducing sound under the control of the applied electrical signal coming from the amplifier.

![Cross-section of a standard loudspeaker](image)

*Figure 2-1: Cross-section of a standard loudspeaker*

### 2.5 Woofer

A woofer is a driver that reproduces low frequencies. The driver combines with the enclosure design to produce suitable low frequencies. Some loudspeaker systems use a woofer for the lowest frequencies, sometimes well enough that a subwoofer is not needed. Additionally, some loudspeakers use the woofer to handle middle frequencies, eliminating the mid-range driver. This can be accomplished with the selection of a tweeter that can work low enough that, combined with a woofer that responds high enough, the two drivers add coherently in the middle frequencies. It is commonly used to produce low frequency sounds, typically from around 40 hertz up to about a kilohertz or higher. The most common design for a woofer is the electrodynamics’ driver, which typically uses a stiff paper cone, driven by a voice coil which is surrounded by a magnetic field.

![A pair of woofers](image)

*Figure 2-2: A pair of woofers*

### 2.6 Understanding woofer data

The ability to choose the most appropriate enclosure for a particular woofer is directly related to your understanding of the performance data that manufacturers provide with their products.
2.7 Thiele-Small Parameters

In the early seventies, several technical papers were presented to the AES (Audio Engineering Society) that resulted in the development of what we know today as ‘Thiele-Small Parameters’. These papers were authored by A.N. Thiele and Richard H. Small. Thiele was the senior engineer of design and development for the Australian Broadcasting Commission and was responsible at the time for the Federal Engineering Laboratory, as well as for analyzing the design of equipment and systems for sound and vision broadcasting. Small was, at the time, a Commonwealth Post-graduate Research Student in the School of Electrical Engineering at the University of Sydney.

Thiele and Small devoted considerable effort to show how the following parameters define the relationship between a speaker and a particular enclosure. However, they can be invaluable in making choices because they tell you far more about the transducer’s real performance than the basic benchmarks of size, maximum power rating or average sensitivity.

$Fs$

This parameter is the free-air resonant frequency of a woofer. Simply stated, it is the point at which the weight of the moving parts of the speaker becomes balanced with the force of the speaker suspension when in motion. If you’ve ever seen a piece of string start humming uncontrollably in the wind, you have seen the effect of reaching a resonant frequency. It is important to know this information so that you can prevent your enclosure from ‘ringing’. With a loudspeaker, the mass of the moving parts, and the stiffness of the suspension (surround and spider) are the key elements that affect the resonant frequency. As a general rule of thumb, a lower $Fs$ indicates a woofer that would be better for low-frequency reproduction than a woofer with a higher $Fs$. This is not always the case though, because other parameters affect the ultimate performance as well.

$Re$

This is the DC resistance of the driver measured with an ohm meter and it is often referred to as the ‘DCR’. This measurement will almost always be less than the driver’s nominal impedance. Consumers sometimes get concerned the Re is less than the published impedance and fear that amplifiers will be overloaded. Due to the fact that the inductance of a speaker rises with a rise in frequency, it is unlikely that the amplifier will often see the DC resistance as its load.

$Le$

This is the voice coil inductance measured in millihenries (mH). The industry standard is to measure inductance at 1,000 Hz. As frequencies get higher there will be a rise in impedance above $Re$. This is because the voice coil is acting as an inductor. Consequently, the impedance of a speaker is not a fixed resistance, but can be represented as a curve that changes as the input frequency changes. Maximum impedance ($Z_{max}$) occurs at $Fs$. 
**Q Parameters**

Qms, Qes, and Qts are measurements related to the control of a transducer’s suspension when it reaches the resonant frequency (Fs). The suspension must prevent any lateral motion that might allow the voice coil and pole to touch (this would destroy the loudspeaker). The suspension must also act like a shock absorber. Qms is a measurement of the control coming from the speaker’s mechanical suspension system (the surround and spider). View these components like springs. Qes is a measurement of the control coming from the speaker’s electrical suspension system (the voice coil and magnet). Opposing forces from the mechanical and electrical suspensions act to absorb shock. Qts is called the ‘Total Q’ of the driver and is derived from an equation where Qes is multiplied by Qms and the result is divided by the sum of the same.

As a general guideline, Qts of 0.4 or below indicates a transducer well suited to a vented enclosure. Qts between 0.4 and 0.7 indicates suitability for a sealed enclosure. Qts of 0.7 or above indicates suitability for free-air or infinite baffle applications.

**Vas/Cms**

Vas represents the volume of air that when compressed to one cubic meter exerts the same force as the compliance (Cms) of the suspension in a particular speaker. Vas is one of the trickiest parameters to measure because air pressure changes relative to humidity and temperature — a precisely controlled lab environment is essential. Cms is measured in meters per Newton. Cms is the force exerted by the mechanical suspension of the speaker. It is simply a measurement of its stiffness. Considering stiffness (Cms), in conjunction with the Q parameters gives rise to the kind of subjective decisions made by car manufacturers when tuning cars between comfort to carry the president and precision to go racing. Think of the peaks and valleys of audio signals like a road surface then consider that the ideal speaker suspension is like car suspension that can traverse the rockiest terrain with race-car precision and sensitivity at the speed of a fighter plane. It’s quite a challenge because focusing on any one discipline tends to have a detrimental effect on the others.

**Vd**

This parameter is the Peak Diaphragm Displacement Volume — in other words the volume of air the cone will move. It is calculated by multiplying Xmax (Voice Coil Overhang of the driver) by Sd (Surface area of the cone). Vd is noted in cc. The highest Vd figure is desirable for a sub-bass transducer.

**BL**

Expressed in Tesla meters, this is a measurement of the motor strength of a speaker. Think of this as how good a weightlifter the transducer is. A measured mass is applied to the cone forcing it back while the current required for the motor to force the mass back is measured. The formula is mass in grams divided by the current in amperes. A high BL figure indicates a very strong transducer that moves the cone with authority!
**Mms**

This parameter is the combination of the weight of the cone assembly plus the ‘driver radiation mass load’. The weight of the cone assembly is easy: it’s just the sum of the weight of the cone assembly components. The driver radiation mass load is the confusing part. In simple terminology, it is the weight of the air (the amount calculated in Vd) that the cone will have to push.

**EBP**

This measurement is calculated by dividing Fs by Qes. The EBP figure is used in many enclosure design formulas to determine if a speaker is more suitable for a closed or vented design. An EBP close to 100 usually indicates a speaker that is best suited for a vented enclosure. On the contrary, an EBP closer to 50 usually indicates a speaker best suited for a closed box design. This is merely a starting point. Many well-designed systems have violated this rule of thumb! Qts should also be considered.

**Xmax/Xlim**

Short for Maximum Linear Excursion. Speaker output becomes non-linear when the voice coil begins to leave the magnetic gap. Although suspensions can create non-linearity in output, the point at which the number of turns in the gap (see BL) begins to decrease is when distortion starts to increase. has historically been very conservative with this measurement and indicated only the voice coil overhang (Xmax: Voice coil height minus top plate thickness, divided by 2). The Xmax figures on this website are expressed as the greater of the result of the formula above or the excursion point of the woofer where THD reaches 10%. This method results in a more real world expression of the usable excursion limit for the transducer. Xlim is expressed as the lowest of four potential failure condition measurements: spider crashing on top plate; Voice coil bottoming on back plate; Voice coil coming out of gap above core; or the physical limitation of cone. A transducer exceeding the Xlim is certain to fail from one of these conditions. High pass filters, limiters, and enclosure modeling software programs are valuable tools in protecting your woofers from mechanical failure.

**Sd**

This is the actual surface area of the cone, normally given in square cm.

**Usable frequency range**

This is the frequency range for which . feels the transducer will prove useful. Manufacturers use different techniques for determining ‘Usable Frequency Range’. Most methods are recognized as acceptable in the industry, but can arrive at different results. Technically, many loudspeakers are used to produce frequencies in ranges where they would theoretically be of little use. As frequencies increase, the off-axis coverage of a transducer decreases relative to its diameter. At a certain point, the coverage becomes ‘beamy’ or narrow like the beam of a flashlight. If you’ve ever stood in front of a guitar amplifier or speaker cabinet, then moved slightly to one side or the
other and noticed a different sound, you have experienced this phenomenon and are now aware of why it occurs. Clearly, most two-way enclosures ignore the theory and still perform quite well. The same is true for many guitar amplifiers, but it is useful to know at what point you can expect a compromise in coverage.

Power handling

This specification is very important to transducer selection. Obviously, you need to choose a loudspeaker that is capable of handling the input power you are going to provide. By the same token, you can destroy a loudspeaker by using too little power. The ideal situation is to choose a loudspeaker that has the capability of handling more power than you can provide lending some headroom and insurance against thermal failure. To use an automobile as an analogy; you would not buy a car that could only go 55mph if that were the speed you always intended to drive. Generally speaking, the number one contributor to a transducer’s power rating is its ability to release thermal energy. This is affected by several design choices, but most notably voice coil size, magnet size, venting, and the adhesives used in voice coil construction. Larger coil and magnet sizes provide more area for heat to dissipate, while venting allows thermal energy to escape and cooler air to enter the motor structure. Equally important is the ability of the voice coil to handle thermal energy. .is renowned for its use of proprietary adhesives and components that maximize the voice coil’s ability to handle extreme temperatures. Mechanical factors must also be considered when determining power handling. A transducer might be able to handle 1,000W from a thermal perspective, but would fail long before that level was reached from a mechanical issue such as the coil hitting the back plate, the coil coming out of the gap, the cone buckling from too much outward movement, or the spider bottoming on the top plate. The most common cause of such a failure would be asking the speaker to produce more low frequencies than it could mechanically produce at the rated power. Be sure to consider the suggested usable frequency range and the Xlim parameter in conjunction with the power rating to avoid such failures. The . power rating is derived using an EIA 426A noise source and test standard. All tests are conducted for eight hours in a free-air, non-temperature controlled environment. . tests samples from each of three different production runs and each sample must pass a test exceeding the rated power by 50 to 100W. The . music program is double that of our standard Watts rating.

Sensitivity

This data represents one of the most useful specifications published for any transducer. It is a representation of the efficiency and volume you can expect from a device relative to the input power. Loudspeaker manufacturers follow different rules when obtaining this information — there is not an exact standard accepted by the industry. As a result, it is often the case that loudspeaker buyers are unable to compare ‘apples to apples’ when looking at the sensitivities of different manufacturers’ products. Sensitivities are expressed as the average output across the usable frequency when applying 1W/1M into the nominal impedance. ie: 2.83V/8 ohms, 4V/16 ohms.
CHAPTER 3

3. DESIGN

3.1 WOOFER ENCLOSURE MODELS.

Sealed Enclosures

Here’s how a sealed enclosure works. The back of the speaker is completely sealed off from the front. The air inside the enclosure acts as a spring, which helps control the movement of the cone. When the speaker moves out, the pressure inside is decreased. When the speaker moves in, the pressure inside is increased.

A sealed cabinet is considered a punchier, more accurate sound. Sealed cabinets are much easier to design and build than ported enclosures and are typically smaller in size. There is also much more room for error in design and construction because a small change to the internal volume doesn’t affect the lowest audible frequency significantly.

Sealed enclosures have better transient response, which means the system will respond more quickly to a sudden change. This is one reason why they sound punchier and more accurate. When you’re playing a run, it sounds more articulate with better note separation. Sealed enclosures also have good power handling capability and gradual frequency roll-off.

The disadvantages of sealed enclosures are lower efficiency and poor deep or extended bass output. The sealed design will never play as low as the resonant frequency of the speaker. It seems like the easy answer would be to design speakers for sealed enclosures with low resonant frequencies, right? That’s certainly one part of the puzzle, but a lower resonant frequency can negatively impact other design and performance goals. Speakers with lower resonant frequencies are typically low in output and narrow in frequency range. Another disadvantage is higher distortion. Maximum cone movement occurs at the resonant frequency of the enclosure (Fc). Basically, the speaker is working harder where the cabinet is most demanding. Dampening improves below Fc, so control of the cone and mechanical power handling of the speaker are good.
Ported Enclosures

Ported enclosures are also referred to as vented, or bass-reflex enclosures. This design requires a more scientific approach, and there is less room for error in design and construction. Ported cabinets allow for an extended bass response. The result sonically is more “rumble” and deeper bass tone. A port (or vent) is used to tune the enclosure to a specific frequency (Fb). The surface area and length of the port are crucial to the tuning. The Fb of the enclosure does not change with speaker selection, but F3 does. The port uses the speaker’s rear output to enhance the speaker’s front output, which increases bass output (or SPL) above F3 (see Figure 3 below).

![Sealed Enclosure](image)

(Figure 3) Speaker in 0.9 cubic foot sealed enclosure (red) with F3 at 70Hz versus same speaker in 0.9 cubic foot ported (green) enclosure tuned to 45Hz with F3 at 54Hz. Notice gradual roll-off for sealed and steep for ported.

This minimizes the movement of the speaker cone, so mechanical power handling at and above the tuning frequency is very good. The port is actually producing most of the output at the tuning frequency and the speaker’s excursion is minimal. Distortion is lower at this point due to less cone movement.

There are some disadvantages to ported enclosures. Transient response is poor compared to a sealed enclosure. The result is decreased accuracy. Also, there’s less control below the box.
tuning, which allows the cone to move more freely. This can result in damage to the speaker mechanically, a phenomenon known as over-exursion.

A poorly designed ported enclosure can cause all sorts of problems. Tuning the enclosure too high can be a problem. This can create a ringing at $F_b$ and result in a one note wonder with inadequate frequency range (Figure 5 below).

![Normalized Amplitude Response (dB-SPL/Hz)](image)

(Figure 5) Optimal cabinet, $F_b @ 50$Hz, $F_3 @ 52$Hz (green) versus cabinet with high tuning, $F_b @ 80$Hz, $F_3 @ 65$Hz (red), notice peak has narrow range and steep roll-off where you still need sound.

While mechanical power handling is typically a good advantage of a higher tuning, remember that the enclosure is not helping the speaker below $F_b$. If there is a sudden peak at a lower frequency there could be a potential for over-exursion problems. The speaker’s cone will literally jump out of the box. Low tuning can also generate problems. A large enclosure is required for a lower tuning. This can severely lower the speaker’s mechanical power handling. Loose, rumbling bass with no definition or “punch” may be the result sonically. The $F_3$ of a smaller cabinet that is tuned too low will be very high. Sure, transient response and punch will improve, but at this point, it’s more effective to use a sealed enclosure.

A port without adequate surface area can create unwanted noise at higher volume… even when the tuning and size of the enclosure is good for the speaker. If the velocity of the air travelling through the port is too high, a noise often referred to as “chuffing” may occur.

We live in a day where power is relatively cheap and high power handling is a big selling point. Whether it’s the enclosure or the speaker, be aware that there are other specs to consider before you make a design. High power handling and lower output may not be the best bang for your buck. In contrary, a high SPL enclosure or speaker may not require as much amp to reach the desired volume levels. Factors for high a high output cabinet are the speaker’s SPL, power handling, and size, and a cabinet that is well built and free from air leaks.
A parameter called EBP (calculated by dividing FS by Qes) is often used to determine if a speaker is best suited for a sealed or ported enclosure. An EBP close to 100 usually indicates a speaker is best suited for a ported enclosure. An EBP closer to 50 usually indicates a speaker is best suited for a sealed enclosure. A speaker with an EBP 50-100 might work well in both types of enclosures. This is purely a general rule of thumb. Many great designs violate this.

3.2 woofer enclosure design procedure

Time spent

Building our sub box took about an hour and a half. Your project could take more time or less, depending on the complexity of your box’s shape, and the tools you have at your disposal.

Tools and materials

- Jigsaw
- Electric drill with bits for pre-drilling screw holes and driving screws
- 3/4” MDF (medium density fiberboard)
- 2” drywall screws
- Panhead sheet metal screws (1/2" and 3/4”)
- Carpenter's glue
- Silicon caulk
- Non-hardening rope caulk
- Speaker terminal cup

3.3 Designing the box

To determine the correct dimensions for any subwoofer box, you can follow these steps:
Determine the minimum depth of your box. Measure the depth of your subwoofer and add 2 inches. This measurement is the minimum depth of your box (in this project, the depth refers to the front-to-back dimension of the box, with the woofer being mounted to the front).

Determine the minimum height and width of your box. Measure the frame diameter of your woofer, or check the mounting template that may be included with the owner's manual, to determine the minimum height and width for the front of your box. If you plan to mount a grille, be sure to allow for any additional space that may be needed to accommodate it.

Determine the available space (be it a vehicle or a house). Measure the height, width, and depth of the vehicle/house space that you are willing to devote to your subwoofer. If the box must be wedge-shaped to fit, you will need to know the depth at the box's top and bottom.

Sketch out your box. Now's the time to sketch your box on paper using the dimensions you've gathered. Your sketch may look like one of these:

For our example, let's use the following external dimensions:

Rectangular box:
Height: 13"
Width: 14"
Depth: 12"

Wedge box:
Height: 14"
Width: 18"
Depth 1: 5"
Depth 2: 8"

Determine the internal dimensions and volume of your box. The above steps identified the external dimensions of the box. To determine the internal volume, just subtract the thickness of the wood to be used for construction. If you're using 3/4" MDF (recommended), then 2 x 3/4", or 1-1/2", will be subtracted from each dimension.
The internal dimensions for our examples:

Rectangular box:
Height: 11.5"
Width: 12.5"
Depth: 10.5"

Wedge box:
Height: 12.5"
Width: 16.5"
Depth 1: 3.5"
Depth 2: 6.5"

Calculate the internal box volume in cubic inches. Based on the internal dimensions, you can calculate the internal volume of the enclosure using the following formula: Height \times Width \times Depth = \text{Cubic Volume}

Let's plug in some numbers:

Rectangular box:

11.5" \times 12.5" \times 10.5" = 1,509.375 \text{ cubic inches}

Wedge box: Since the wedge box has two depth dimensions, we need to find the average depth before we can determine the volume. To find the average depth, add the two depth measurements together, then divide by two. Remember that Depth 1 = 3.5" and Depth 2 = 6.5. 

3.5" + 6.5" = 10"
10" / 2 = 5"

So, the average depth of the wedge-shaped box is 5". Plug that dimension into the formula:

12.5" \times 16.5" \times 5" = 1,031.25 \text{ cubic inches}
Convert cubic inches to cubic feet. Since most manufacturers will provide the recommended box volume in cubic feet, you'll need to convert the internal volume from cubic inches into cubic feet. This is done by dividing the cubic inches by 1,728.

Rectangular box: \(\frac{1,509.375}{1728} = 0.873\) cubic feet

Wedge box: \(\frac{1,031.25}{1728} = 0.597\) cubic feet

Adjust your box's volume to match the sub's specifications. Now, compare the volume of the box you've sketched to the manufacturer's recommendation. If it's too large or too small, you can make small adjustments to one dimension until your box's internal volume matches the manufacturer's recommendation as closely as possible. Often, manufacturers will recommend a range of enclosure volumes. You can get good results with a box that's anywhere inside the recommended range.

Determine the final exterior box dimensions. Once you've identified the correct internal dimensions, it's time to add back that 1-1/2" we subtracted in step 5, to derive the new external dimensions. Double check to make sure that these dimensions will fit properly in your car, and you're ready to move on to construction.

**Step-by-step instructions.**

Step 1.
We started by measuring and cutting the main pieces of MDF for the front, sides, back and top of the box, using a table saw with a carbide-tipped blade.

We cut seven pieces total — top and bottom, two sides, the back, and two identical pieces for the front (since it was to be a double thickness).

Step 2.
After the pieces are cut to size, use a compass, or the template that may be included in your subwoofer's packaging, to mark the woofer cutout on one of the identical front pieces.

Step 3.
If you choose to use a double-thickness of MDF for the front panel (this method is recommended — it provides an extremely strong, non-resonant mounting surface for the sub), fasten the two identical front pieces together using plenty of carpenter's glue and several sheet metal screws. Also, the double thickness will serve to strengthen the box as a whole.

Step 4.
Using a drillpress, we made a hole near the inside edge of the circle we had traced, large enough for our jigsaw blade to fit in. If you don't have a drillpress, simply use your handheld drill and a large bit.

We jigsawed out the circle, and the woofer cutout was complete.

We also drilled at the back to make a hole for the wires.
Step 5.
Since the back and front pieces were now complete, it was time to fasten everything together. Note: the largest sides of the box should overlap each of the smaller sides to provide the greatest strength. For our box, that meant that the sides were fastened to the front and back first, and the top and bottom were added last.
Because MDF can be prone to splitting, we pre-drilled holes for the screws in each of the pieces to be fastened together.

After pre-drilling the holes, we squeezed plenty of carpenter's glue between the pieces. The glue, not the screws, is what will ultimately seal the box together.

Then, we fastened the pieces together using our cordless drill and 2" drywall screws. Some of the glue will squeeze out during this step — you can wipe it off the outside of the box using a wet rag, but it's OK to leave it on the inside edges (it'll actually help with the seal).

After you put together the front, back, and sides, you may find that the box is a little out of square — we did. When you screw the top or bottom on, it should pull things back into alignment. Ours gave us just a little bit of trouble, though, so we used a furniture clamp to get things straightened out.

After you've glued-and-screwed the sides, front, back, top, and bottom, you're just about done.

The next step is to drop the subwoofer in and make sure it fits. If the box has gotten a bit out of square, you may find that the sub is now a tight fit — if so, use coarse sandpaper or a rasp to enlarge the opening a little.

Step 6.
With the subwoofer in place, we used a pencil to mark the screw hole locations, then removed the subwoofer and pre-drilled holes for the mounting screws.

We then hooked up speaker wires from the terminal cup to the subwoofer and placed the subwoofer back in the box.

CHAPTER 4

4. Test On woofers To come up with frequency Responses.

I acquired 2 woofers with the specifications below:

1. -Power capacity: 50W/100W RMS/peak
   -Sensitivity :86DB(w/m)
   -Impedance 6Ω
   -Re 6.6Ω
   -Le 0.48Mh
   -Frequency response 16HZ-17KHZ
-Fs 65HZ
-Qts 0.365
-Qms 2.25
-Vas 3.15 liters
-Xmax 2.25mm
-Overall frame diameter 6.49”

2. –power capacity 250watts rms
- sensitivity 8dB
- impedance 8Ω
- Re 8.6Ω
- Le 0.5645Mh
- Frequency response 50HZ-60H
- Fs 50HZ
- Qts 0.4529
0-Qms 3.4
- Vas 4.30 litres
- Xmax 3.50 litres
- Overall frame diameter 8.27”

With the above woofers I carried out various tests without and with cabinets to come up with their responses.

4.1 OPEN BOX TEST

Objective: To obtain the frequency response of an unenclosed woofer (without a cabinet).

Apparatus : the two woofers
Laptop which provided me with a microphone and the Diagnostic system for sound fields software (DSSF3), an advanced sound measurement/analysis software.

Procedure
1. I placed the 250 watts woofer (woofer hanging in air which also had an amplifier to amplify the signal) in front of my computer and connected it to the computer.
2. I then opened my software(DSSF3) and using the real time analyzer which has a signal generator, generated a signal to the woofer.
3. I then recorded the frequency response of my woofer, ensuring no external sound interference.
4. I repeated the above steps with the 100 watts woofer and recorded the frequency response data

Results

1. For the 100 watts woofer, the frequency response graph was as shown below:

![Graph 1](image)

2. For the 250 watts woofer the frequency response was as shown below:

![Graph 2](image)
4.2 **CLOSED BOX TEST**

**Objective:** To obtain frequency response of a woofer driver enclosed in a very large cabinet and a very small cabinet.

**Apparatus:**
- Two woofers enclosed in very small cabinets (smaller than the ideal enclosure size for the woofer drivers)
- Laptop which provided me with a microphone and the DSSF3 software (an advanced sound measurement/analysis software).

**Procedure**
1. I put the woofer fixed to its enclosure in open air away from any external noise. And ensured there is no any sound reflecting surface around.
2. I then connected my laptop via an amplifier to the 250 watts woofer.
3. I then opened up my DSSF3 software which I used to generate a signal to my woofer.
4. I ensured the woofer is directly close to the laptops’ microphone.
5. I then recorded the frequency response graph.
6. I repeated the above steps with the 100 watts woofer.
7. I then repeated the above 6 steps with a very large woofer enclosure.

**Results**

*Frequency response graphs for the woofer drivers enclosed in small cabinets:*

**250 watts**
Frequency response graphs for the woofer drivers enclosed in very large cabinets

100 watts

250 watts
Discussion

From the above results, It was observed that the size of the cabinet greatly affects the frequency response of my woofer drivers.
The frequency response curve of a woofer driver without any enclosure was not flat at all, it had bumps at several frequencies, it had roll-offs. In a nutshell the response was not ideal.

The frequency response curve of a woofer driver with a very small enclosure cabinet had the dB of some frequencies to be higher compared to the rest of the frequencies.

The frequency response curve of a woofer driver with a very large enclosure cabinet had an almost flat curve and had no roll-offs.

I also realized that there were some echoes being produced by the very large cabinet.

**Conclusion**

From the above, I came to a conclusion that the efficiency of a woofer system is directly proportional to its cabinet volume, the large cabinet facilitated production of a good bass for the driver, with an almost flat response. This is solely because it (the large cabinet) provided sufficient volume of air behind the driver.

Despite the fact that the large cabinet had good response, a fairly large one (optimum size) is important to avoid the production of the echoes.

I therefore proceeded to come up with cabinets for my woofer drivers which would provide optimum almost perfect sound response.

**CHAPTER 5**

**Cabinet Design Using The Bass Box Pro**

5.1 *Introduction*

BassBox Pro is a state-of-the-art speaker enclosure design program. It is used around the world by professional and amateur speaker system designers to design world class speaker boxes. BassBox Pro is very versatile and can be used to design speakers for a wide variety of applications including home hi-fi, home theater, car, truck, van, pro sound reinforcement, recording studio monitors, stage monitors, PA, musical instruments, etc.
BassBox Pro has many features that make it very easy to learn and use. For example, when the program is first run, a Welcome window (shown below) will appear to help you configure the program and introduce you to its on-screen manual.

The on-screen manual (shown below) is extensive and contains most of the same information as the beautiful 364 page printed manual. Both the on-screen and printed manuals are the best in the industry and include a "Box Designer's Guide", "Sample Designs" and "BassBox Pro Reference".

There are many ways to begin a speaker design with BassBox Pro, including the use of its innovative Design Wizard. In general, speaker design involves the following steps:
1. Enter the driver parameters such as Fs, Vas and Qts. BassBox Pro's driver database contains parameters for thousands of drivers.
2. Calculate the box volume and tuning. This is very easy with the program's helpful "Suggest" button. It will cause BassBox Pro to recommend a box that will produce a smooth bass response.
3. Evaluate the performance with the graphs. This can include the effects of the acoustical environment. For example, BassBox Pro can estimate the in-car response in the graphs to show how the speaker will sound to passengers inside a car.

Each box design can be saved and re-opened or re-used later. As many as ten different designs can be open at the same time. Box designs can also be duplicated so that driver or box information does not need to be re-entered.

5.2 Procedure
After feeding the parameters of the drivers into the Bass box pro software
The software gave me the dimensions of my woofer cabinet for optimum response

Simulated Results
for the 100 watts woofer, the dimensions were:
height=196.5mm
width=75.07mm
length=121.5mm
5.3 Data Analysis

for the 250 watts woofer, the dimensions were:
lengt_h: 119.6mm
width: 73.89mm
depth: 193.4mm

internal volume
Vb: 1.709
Qtc: 1.259
QL: 7
F3: 60.9HZ
**Practical Results**  
**For the 250 watts**

![Graph for 250 watts driver]

---

**For the 100 watts driver**

![Graph for 100 watts driver]

---

**CONCLUSION AND RECOMMENDATION**

The main objective of the project, which was to come up with a cabinet design for my woofer drivers which would have optimum sound response was achieved.
Through trial and error and the use of the bass box pro software, I was able to come up with the best design formula for woofer enclosures. The audio output was of high quality when best size of enclosure was used. After completion of the project I have concluded that this method for design of woofer cabinets is efficient and very accurate as compared to the conventional methods used which involved assumptions and estimation. I have also acquired the necessary skills for implementation of a project like time management. I have also applied theory learned in my course work and also the practical skills acquired in school laboratory in the implementation of the project.

**RECOMMENDATIONS**
My recommendations for future work are:
- □ Further encouragement of study to generate more methods for cabinet design
- □ Further improvement to reduce challenges incurred in designing woofer cabinets which are also more accurate.

**REFERENCES**
5. AVS Forum> audio> speakers.
6. www. prestonelectronics.com
8. Internet- Wikipedia
9. Linkwitz Siegfried, Loudspeakers, 2009

**APPENDICES**
1. Hz= Hertz
2. dB = Decibel
3. SPL= Sound Pressure Level
4. Pa = Pascal
5. KHz =Kilo Hertz
6. μ = micro
7. m = milli
8. H = Henries
9. F = Farads
10. Ω = Ohms
11. π = 3.14
12. R = Resistance
13. L = Inductance
14. C = Capacitance
15. Zo = Impedance
16. f_c = Cross over frequency/ Cut off frequency
17. V = Voltage
18. P = Power
19. f = frequency
20. LPF = Low pass filter
21. HPF = High pass filter
22. BPF = Band pass filter
23. F_L = Lower cut off frequency
24. F_H = Upper cut off frequency
25. W = Watts
26. rms = root mean square