DECLARATION

I declare that this Bsc work is my original work and also affirm that its contents have not been presented in this University or any other university.

Signed.......................................................... Date..........................................................

Ernest Kiprono Moso
F17/1793/2006

This project report has been submitted to the department of Electrical and information engineering. University of Nairobi with my approval and supervisor;

Signed.......................................................... Date..........................................................

Mr.S.L Ogaba
ABSTRACT

The typical loudspeaker product is designed to make money and not necessarily to provide accurate sound reproduction. Since customers prefer small, unobtrusive speakers and judge sound quality by the amount of bass that they hear and by high frequencies they had not noticed before. There are a staggering number of essentially identical designs on the market that meet these requirements at different price.

In addition current loudspeaker system technology needs a large amount of investment in drivers and enclosures. So the price usually become expensive and a large number of customers could not afford to buy the prestige and high quality loudspeaker system. Furthermore in addition to achieve great and accurate sound reproduction, most manufacturers begin to use high cost material such as Aluminum, Titanium & Diamond for the drivers.

For 3-way a loudspeaker which is designed perfectly, it is enough to cover the range of frequency from 20 Hertz until 20 Hertz. 3-way loudspeaker allows drivers to operate in more narrow, optimized ranges, eliminating the distortion that result from excessive driver excursion. Many advantages can be achieved especially decreasing the cost for research and production to build full range loudspeaker sound reproduction.

In this project the 3-way loudspeaker system was designed and developed successfully.
Acknowledgement

To my father, mother and siblings for their support and assistance towards the completion of this degree course.
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### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q)</td>
<td>Quality factor</td>
</tr>
<tr>
<td>(Q_{ms})</td>
<td>Driver mechanical quality factor</td>
</tr>
<tr>
<td>(Q_{tc})</td>
<td>Driver quality factor in a box</td>
</tr>
<tr>
<td>(Q_{ts})</td>
<td>Driver total quality factor</td>
</tr>
<tr>
<td>VAS</td>
<td>Equivalent air compliance</td>
</tr>
<tr>
<td>ZDP</td>
<td>Zero delay plane</td>
</tr>
</tbody>
</table>
Chapter 1

INTRODUCTION

1.1 Background.
The human audio frequency range has been determined to be 20 Hz – 20 kHz. The loudspeaker device has been developed and acts as a transducer that converts electrical energy to acoustic waves hence sound.

The ideal situation would be that one driver can reproduce the entire spectrum, but a lot of distortion occurs and sound quality is low. For more accurate sound reproduction, three-way loudspeaker system has been developed to cover the entire range more accurately with each driver operation in more optimized ranges hence reducing distortions resulting from excessive driver excursion.

The loudspeaker model used in this design is the moving coil loud speaker. The driver consists of solenoid situated in a radial magnetic field. When a current is passed through the coil the magnetic field generated, reacts with steady field of permanent magnet, mechanical force developed moves coil axially producing acoustic sound waves.

Due to the limitation that a single driver cannot produce the entire audio frequency spectrum efficiently, filter networks (crossovers) have been developed to differentiate signals sent to drivers. In turn the drivers produce acoustics sounds at different frequencies hence improving sound fidelity.

There are two types of crossover networks:

1. Passive
2. Active

Passive crossover networks comprise inductors and capacitors and are located between the amplifier and drivers.
Active crossover networks are electronic filters and contain active components such as transistors and integrated circuits. They have an advantage over passive filters since they experience fewer losses and perform better at lower frequencies.

1.2 Project objectives

The project objective is to design and implement three way speaker systems with two cabinets per channel employing passive filter networks. All considerations to achieve optimum speaker performance are to be considered.

This includes:

a) Crossover network design
b) Box size and shape design
c) Frequency coverage in the audio range (20Hz -20kHz)
Chapter 2

REVIEW

2.1 Speaker driver types

2.1.1 Woofer

A woofer is a loudspeaker capable of reproducing the bass frequencies. The frequency range varies widely according to design. Whilst some woofers can cover the audio band from the bass to 3 kHz, others only work up to 1 kHz or less.

2.1.2 Midrange

A mid-range loudspeaker is designed to cover the middle of the audio spectrum, typically from about 200 Hz to about 4-5 kHz. The distinction between woofers and mid-ranges is blurred however since many woofers can operate up to 3 kHz. These are used when the bass driver is incapable of covering the mid audio range efficiently. Mid-ranges typically appear where large diameter woofers are used for the bass end of the audio spectrum.

2.1.3 Tweeter

A tweeter is a loudspeaker capable of reproducing the higher end of the audio Spectrum efficiently, usually from about 5 kHz to 20 kHz. [Ref]

2.1.4 Passive filters

Loudspeaker passive crossover networks are made up of L and C filters, these are networks that can be termed frequency dependent attenuation circuits, and this property is defined by reactance formulae.
\[ = \frac{1}{2} \]
\[ = 2 \sqrt{L} \]

- Capacitor reactance is inversely proportional to frequency
- Inductive reactance is directly proportional to frequency[1]

2.2 Passive filter types

Filters are generally described by three properties

- Roll off
  Depending on circuit topology roll off can be 6db, 12db, 18db, 24db of attenuation per octave
- Filter resonance
  Circuits containing reactance is said to be in resonance if voltage across the circuit is in phase with the current, the circuit thus behaves as a pure resistance and power factor is unity. Components reactance are equal, given by formulae

\[ = \frac{1}{2 \sqrt{L}} \]

- Q(quality factor)
  Defined as the ratio of inductive reactance to total resistance in the circuit

\[ = \frac{1}{1} \]

For circuits formed by R and L circuits only, resistance is due to inductor alone since capacitor losses are negligible; Q of the circuit is controlled by the inductor alone.
2.3 Passive filters formats

The parallel filter is the ideal configuration in crossover design since it has the advantage of allowing each driver in a multi way system to be treated independently. Crossover networks apply three basic formats.

a) Low pass filters.
   Roll off the upper frequency response and are generally used with woofers.

b) High pass filters
   Roll off lower frequency response of a speaker, and are mostly used with tweeters.

c) Band pass filters.
   Roll off both lower and upper frequency ranges, and are typically used with midrange drivers. [1]

2.4 filter types

2.4.1 First order filters

First order filters have a 20dB/decade (or 6 dB/octave) roll off. All first order filters have a Butterworth filter characteristics, they are considered ideal for crossover because they have near perfect transient. They also use least number of components, often just an inductor or capacitor. However, they are also disadvantageous because they allow more unwanted frequencies to get through compared to higher order filters. In practice speaker systems with first order acoustic slopes are difficult to design because of overlapping bandwidths and shallow slopes leading to more interference between drivers.
2.4.2 Second order filters

Second order filters have a 40dB/decade (or 12dB/octave) rolloff. This order is commonly used in passive crossover as it offers balance between complexity, response and high frequency driver protection. Second order filters have a phase difference of 180° between low and high pass. To correct this, high pass is normally connected in reverse polarity.

2.4.3 Third order filters

Third order filters have a 60dB/decade (or 18 db/octave) roll off. These crossovers usually have Butterworth filter characteristics; phase response is good, the level sum being flat and in phase quadrature, similar to a first crossover. Third order crossovers are often built from first or second order filter circuits [6]

2.5 Filter response

L and c circuit response are not easily predicted because inductor and capacitor form series resonant circuits which can produce a peak in output voltage at the cut off frequency \( f_c \)

![Sample network containing a capacitor and inductor](image)

Fig 2.1 sample network containing a capacitor and inductor [2]

The damping effect can be quantified by calculating Q (quality factor) value.

\[
\frac{R_L}{R_S} = \frac{Q}{\pi} \quad \text{Total} \quad = \frac{Q}{\pi}
\]

\[
= \__\quad \text{Total} \quad = \__
\]

= __
Greater values of Q gives more peaked response at $f_c$. [2]

Fig 2.2 resonant low pass filter with low Q [3]

There is slight rise in magnitude at cut off.

Fig 2.3 resonant low pass filter with high Q [3]

There is a considerable rise in magnitude at cutoff frequency.

2.5.1 Butterworth response

Butterworth filters response is "maximally flat" frequency response. This means that the response in the pass band is as flat as it can possibly be, until the cutoff (-3dB) frequency is reached. Response beyond cut off is said to be monotonic, i.e. attenuation constantly increases.
### 2.5.2 Bessel filters

A Bessel filter has a slower and "sloppier" response, that starts to droop well before the cutoff frequency, but has the minimum phase shift (and best transient response), and one that is comparatively gentle.

### 2.5.3 Chebyshev filter

The Chebyshev filters is characterized by peaks and/or dips in its response, and usually have a (slight) rise in amplitude just before the cutoff frequency, the magnitude of which is determined by the Q. The higher the Q, the greater the peak in the response. Depending on the order of the Chebyshev filter, it may have dips as well as peaks.

<table>
<thead>
<tr>
<th>Filter</th>
<th>Main characteristic</th>
<th>Other characteristics</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butterworth</td>
<td>Maximally flat amplitude</td>
<td></td>
<td>0.707</td>
</tr>
<tr>
<td>Bessel</td>
<td>Maximally flat phase</td>
<td>Fastest settling time</td>
<td>0.5 to 0.7</td>
</tr>
<tr>
<td>Chebyshev</td>
<td>Fastest roll off</td>
<td>Slight peaks / dips</td>
<td>0.8 to 1.2</td>
</tr>
</tbody>
</table>

Table 2.1 showing main characteristic and Q (quality factor) of different filter types.

Table above shows the three primary filter alignments that can be used, and they differ only in the damping factor Q or "quality factor" which is a term that is applied to many passive components in many applications, and is effectively the inverse of damping. Thus, Q=1/d or d=1/Q. The number in electronics is \( \sqrt{2} \) and its inverse, 0.707 can be seen in the table as the figure that provides "maximally flat" frequency response. This means that the response in the pass band is as flat as it can possibly be, until the cutoff (-3dB) frequency is reached. This forms the Butterworth filter that has been the mainstay of nearly all crossover systems in common use.
Loudspeaker speaker literature

3.1 Enclosures

Loudspeaker enclosures can be made with different shapes which exhibit different characteristics, results of variation in the SPL from various cabinet shapes that might be practically used are as follows

<table>
<thead>
<tr>
<th>SHAPE</th>
<th>VARIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphere</td>
<td>± 0.5</td>
</tr>
<tr>
<td>cube</td>
<td>± 5</td>
</tr>
<tr>
<td>Beveled cube</td>
<td>± 1.5</td>
</tr>
<tr>
<td>rectangle</td>
<td>± 3</td>
</tr>
<tr>
<td>Beveled rectangle</td>
<td>± 1.5</td>
</tr>
<tr>
<td>cylinder</td>
<td>± 2</td>
</tr>
</tbody>
</table>

Table 3.1 table of shapes and variations

The sphere gives least “ripple” in response but is most difficult to construct.

Speakers can be designed with closed or vented enclosures. The closed box is the simplest and best of all designs because of highly controllable response and transient characteristics and also relative ease of achieving box parameters.

Enclosures usually stuffed with absorbent or damping material e.g. fiberglass, long fiber wool to avoid reflections and resonance before the drivers are set.

In designing of multi way speakers, the alignment of drivers is considered due to the fact that the drivers have radiating centers at different distances from vertical axis. The way in which two independent signal sources combine depends on phase relationship between the sources. When two drivers fed by same signal source are phase correlated the two combine as a simple scalar quantity and sum to a level 6db greater than output of a single driver. [1]
For speakers with non-coincident drivers separated both vertically and horizontally, solution is to minimize driver separation, and make certain that no low pass/high pass combination is separated by distance greater than one wavelength of crossover frequency.

Fig 3.1 to illustrate different mounting configurations [1]

From above, driver configurations yield varying driver radiating centers or zero delay point (ZDP). In c and d ZDP has been tilted by sloping the front baffle in order to be coincident with listening axis. Another ways used to return the zero delay point back to zero degrees is electronic time delay
3.1.1 Zero delay plane

In order for the same phase and magnitude consequences for the networks to occur acoustically, which is the goal, certain assumptions are made. The most important assumption is that the radiation by the two drivers must be coincident. This means that they must radiate from the exact same point in space and time. This doesn’t, however, describe the way the majority of loudspeakers work.

The only loudspeaker drivers with high-pass and low pass drivers which radiates from the same point are the coaxial types. These usually have a dome tweeter mounted on top of the woofer pole piece so that the radiating positions are nearly identical.

When none coincident drivers are used for different frequency ranges, the radiating origins are separated in both the horizontal and vertical planes. Vertical separation of drivers can also cause radiation patterns tilt depending upon the cross over network type being employed. The first and third order Butterworth all i-impass networks have a frequency dependent tilt in the vertical polar response. This occurs because of the $90^\circ$ phase difference on the high and low pass sections. All in i-phase networks, which include all even $i$ order networks, do not have the same frequency dependent tilt and exhibit a symmetrical vertical polar response
3.2 Crossover networks

When two or more drive-units are used to cover the audio range, it is usually very important that they only receive signals over their respective, intended frequency ranges. Signals at other frequencies must be omitted; as it will usually degrade a drive-unit’s sonic by exciting resonances. At moderate to high drive levels, physical damage is also likely. The frequency division is done by employing filters that ensure drivers receive their intended frequencies, this is done by crossovers.

Passive crossovers are made up of inductors and capacitors designed to divide the signal into necessary frequencies, often placed between the power amplifier and the loudspeaker drivers. Passive crossover circuits need no external power beyond the audio signal itself, but do cause overall signal loss.

There are two main types of crossover, two way crossovers and three way crossover systems, two way crossovers normally comprise of a woofer and tweeter covering lower and higher
frequencies. The three way crossover comprise of filter network that separates frequency spectrum to low frequencies for the woofer, mid frequencies for the midrange and high frequencies for the tweeter.

The 3-way loudspeaker system is advantageous compared to the two way system

- Three way loudspeakers can control both mid and high frequencies with minimal distortion
- Possible to achieve ultra high sensitivity with low distortion and more manageable. can control all range of frequency with greater ease
- 2-way loudspeaker has smaller format high frequency and produce much less distortion, but lack the necessary pattern control at certain frequencies.
- Since 3-way design does not ask a single driver to control directivity from large range of frequency, pattern control can be optimized without introducing distortion. [2]
Chapter 4

Driver’s parameter measurement and component’s value identification

4.1 Loudspeaker testing.

This procedure is necessary to provide needed parameters to complete calculations and identification of desired qualities of the speaker. The most important measurement is to measure the driver’s characteristics especially for the woofer because the size and dimension of the enclosure are fully dependent on the woofer’s characteristics and parameter.

**Equipments**

a) Signal generator

b) AC voltmeter

c) Frequency counter

d) R1 10Ω resistor

e) R2 10 Ohm (10%) Resistor

f) Woofer.

g) Oscilloscope
4.1.1 Measuring resonance.
Measurement are made at the lowest nominal voltage level, less than 1 Volt. To achieve free air state the driver is suspended in the air. The connections are as shown.

Fig 4.1 connection to measure the driver’s resonant frequency characteristics

Procedure

a) Set the oscillator voltage below 1V.

b) The generator frequency is then varied between 10 Hz to 20 kHz while taking values of voltage.

c) Frequency at voltage peak is the driver’s resonant frequency.

d) Procedure above is repeated for the midrange driver.

4.1.2 Driver’s impedance characteristic’s measurement

a) Start with calibrating with 10% 10 Ω resistant. Set s1 to 10 Ω resistor. Setting the generator up to 100 Hz and adjust the amplitude output of the signal generator to read 1V on the voltmeter. This means the 1V reading represents the load of the 10 Ohm 10% precision resistor. All the readings by the voltmeter will represent the load of the driver. This represents equivalent impedance, 1v=10Ω, 0.5v=5Ω
b) Measurement using figure (4.1.2) are made by varying oscillator frequency between 10 Hz and 20 Hz and recording voltage values at frequency intervals. Calibrated circuit enables reading at ohms equivalent.

c) The results are recorded and plotted on a semi

d) Procedure is repeated for midrange 2 driver.

![Impedance characteristic measurement connection](image)

**Figure 4.2 impedance characteristic measurement connection. [4]**

From the figure 4.2, all the measurement equipment are connected and all the reading from the measurement result will appears on the AC Voltmeter screen. The driver is placed on a support to mimic free air state
Figure 4.3 showing the equipment used to carry out impedance characteristics of woofer and midrange.
Chapter 5

Procedure

5.1 Crossover design

The quality of the components used in the filter system has a direct impact on the fidelity of sound which can be achieved.

The further apart cross points are the better the combined response of the drivers. Crossover point closer than 3 octaves suffer from undesirable interference patterns.

The formulae for calculating the component values are:

1\textsuperscript{st} order filters

\[ L = \frac{1}{2} \]

Where

L = inductor value.

C=capacitance value.

= Nominal speaker impedance.

= crossover frequency.

2\textsuperscript{ND} order filters

\[ L = \sqrt{\quad} \]

\[ C = \sqrt{\quad} \]

Figure 5.1 showing crossover points chosen.
The design involves two cabinets one holding a midrange driver and a woofer and the second cabinet holds the second midrange driver and the tweeter. In the crossover design, two types of filters are utilized:

- 1st and 2nd order low pass filters
- Band pass filters

The choice of filter types is made considering the slope, selecting the best slope is important both to ensure drivers are all operated within their optimum frequency and power handling range. 6dB/Octave has most predictable response and is affected less by impedance variations, however, loudspeaker drivers will be producing sound frequencies outside their limit. 12dB/Octave filters are better at keeping unwanted frequencies out of individual speakers but are more complex and affected by impedance variations to much greater degree. Tolerance of components used will be greatly affected.

The desired power response of the crossover network is as shown, special consideration is taken as to the rolloff of each network. Rolloff rate is carefully chosen to minimize frequency overlap at the crossover point.

**Cabinet 1**

![Cabinet 1 Diagram](image)

Figure 5.2 showing the desired frequency response of cabinet 1
Woofer cut off frequency is chosen to be 1khz. Since the woofer and midrange drivers are both mounted on the same cabinet there is interference. To minimize this, crossover roll off can be manipulated. In this case the filters chosen are the second order filters which roll off at 12dB/Octave at the interaction point of 1khz. At the 5 kHz end of the band pass filter there is no frequency overlap between drivers hence roll off chosen is 6dB/Octave and filter type to achieve this is the 1st order type.

**Cabinet 2**

![Diagram showing frequency response](image)

**Figure 5.3 showing the desired frequency response of cabinet 2**

Enclosure two consists of the midrange two and tweeter. To obtain the desired frequency response illustrated above, the band pass filter is made up of first order and second order filters. The high pass roll off is 6dB/Octave and the low pass is 12dB/Octave. At the interaction point between the mid range and tweeter, roll off chosen is 12dB/Octave so as to minimize frequency overlap.
Cabinet 1 crossover design and component values

1000Hertz/5000Hertz

8Ω woofer/8Ω midrange

Parts list

Capacitors

= 15µ

= 15µ

Inductors

= 1.8

= 1.8

= 0.25

Figure 5.4 shows crossover design result; there are five components in the crossover design including two different values of capacitors and three inductors. These components are connected to form first and second order filters that give the desired roll off.
Cabinet 2 crossover design and component values

1000Hertz/5000Hertz

8Ω midrange/8Ω tweeter

design consisting of three capacitors and two inductors.

Figures 5.5 showing cabinet two crossover

<table>
<thead>
<tr>
<th>Parts list</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitors</td>
</tr>
<tr>
<td>= 20μ</td>
</tr>
<tr>
<td>= 2.7μ</td>
</tr>
<tr>
<td>Inductors</td>
</tr>
<tr>
<td>= 360</td>
</tr>
<tr>
<td>= 360</td>
</tr>
</tbody>
</table>
5.2 Procedure to obtain frequency response of designed network.

The objective of this experiment was to investigate frequency response of the speaker drivers of the crossover network designed by observing the voltage drop with the frequency varying from 20 Hz to 20 kHz.

5.3 Equipment.

Simulation of the network was done using NI Multisim 10, National Instruments software. The components used are:

- Bode plotter
- Resistors to simulate the 8Ω speaker drivers
- The derived network components
- Signal generator

5.4 Experiment procedure

The signal generator was set to output 1V peak to peak signal varying from 20 Hz to 20 kHz. Apparatus was connected as show.

Ac analysis simulation was then carried out.
Figure 5.6 connection for observing frequency response of cabinet 1 using NI ELVIS schematic of multisim software
Figure 5.7 connection for observing frequency response of cabinet 2 using NI ELVIS schematic of multisim software

By following exactly from the crossover design values calculated and therefore transfer characteristics studied the crossover design were completed, the drivers then need to be tested again by connecting to this crossover to measure the efficiency and suitability of designed crossover.
5.5 Loudspeaker enclosure design and construction

Based on the result and analysis from the measurement taken, data collected and manufactures specifications are used to design and construct the loudspeaker’s enclosure. Formulae for calculating the volume of the speaker are;

\[
\frac{A}{\Delta} = \ldots
\]

\[
\frac{A}{\Delta} = \ldots - 1
\]

Free air resonance value is read from graph plotted;

\[
= 38 \text{ Woofer value.}
\]

\[
= 85 \text{ Midrange two value.}
\]

This values above together with diameter of woofer after being specified, were used to get required parameters for box size calculation

8â€’woofer parameters

\[
= 48
\]

\[
= 38\overline{6}
\]

\[
= 0.3
\]

\[
= 0.52
\]

\[
= \frac{\ldots}{\ldots} - 1=2.024
\]
= 24litres

6Ω midrange parameters

= 28

= 85°

= 0.34

= 0.9

= 1 = 1.64

= = 17litres

5.5.1 Cabinet 1

The desired volume is 26litres equivalent to 1710 ; the box design chosen has the front baffle inclined so that the speakers radiate from same axis reducing phase difference of radiated acoustic waveforms. Dimensions of the box are as shown carefully designed to achieve desired volume and shape
Figure 5.8 Design plan for the driver’s location on the enclosure
Chapter 6

Results

6.1 Table of results

During the woofer and midrange testing and parameter measurement, there are several results that could support on how to decide design the loudspeaker's system enclosure. These results are important in determining the suitable size of box to be designed.

Table 6.1 Measurement result for woofer’s impedance characteristic.

<table>
<thead>
<tr>
<th>FREQUENCY</th>
<th>IMPEDANCE(Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
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<td>800</td>
<td>19</td>
</tr>
<tr>
<td>1000</td>
<td>20</td>
</tr>
</tbody>
</table>
Table 6.2 Measurement result for midrange 2 impedance characteristic.

<table>
<thead>
<tr>
<th>FREQUENCY</th>
<th>IMPEDANCE</th>
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</thead>
<tbody>
<tr>
<td>20</td>
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<td>30</td>
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6.2 Graphs

Figure 6.1 graph of impedance versus frequency for the woofer.

Figure 6.2 graph of impedance versus frequency for midrange 2.
Cabinet response

![AC Analysis graph of woofer frequency response](image)

**Figure 6.3** graph of woofer frequency response

![AC Analysis graph of Midrange 1 frequency response](image)

**Figure 6.4** graph of Midrange 1 frequency response
Cabinet 2 response

Figure 6.5 graph of Tweeter frequency response.

Figure 6.6 graph of Midrange 2 frequency response
6.3 Considerations

During crossover design, the parts and component mostly do not match to calculated value. Some of the capacitor especially for midrange has big different value to the circuit. Inductor type suited for crossover networks is the air core type, however, since it is not favorable to use core material in cross over network without introducing loses and distortions, coils used for crossover are nearly always air core inductors.

When dealing with large value inductors, compromise has to be made due to the cumbersome nature of air core inductors. This means that many more turns than might otherwise be needed must be used resulting in very large, heavy and expensive coils or the alternative smaller and lighter ferrite core with significant resistance.

Because of loses inductors, should be wound with thick wire that is reasonable possible. To prevent mechanical noise (rattle), the wound inductors are taped or soaked in vanish so as to hold the windings together.

Because inductor coils use magnetic coupling they are sensitive to stray magnetic fields this include cross coupling from inductors or even speaker .Another problem is resistance, inductors introduce relative resistance which greatly affect the damping factor of the circuit the resistance cause power loss and heat which is deteriorating to cross over functionality. Adding core to reduce losses also introduces distortion.
6.4 Conclusion

This report has covered topics of crossover design, box size and shape design so as to implement a three way speaker system with two cabinets per channel. The size of the enclosure and shape contribute a large effect to the quality and good sound reproduction to the loudspeaker system besides the quality of the driver and crossover relaiabilty. Active filters will almost certainly give a better result than the most carefully designed passive system, and may even work out cheaper some passive crossover networks can become very complex difficult to design due to use of components like air core inductor which is large in size.
References


Appendix
Calculation of crossover component values

**Capacitors**

\[
\frac{\sqrt{\cdot \cdot}}{\cdot} = \cdot \cdot \cdot \times = 14.06 \mu F
\]

\[
\cdot \cdot \cdot \times = 14.06 \mu F
\]

\[
\cdot \cdot \cdot \times = 2.8 \mu F
\]

\[
\cdot \cdot \cdot \times = 19.89 \mu F
\]

\[
\cdot \cdot \cdot \times = 2.8 \mu F
\]

**Inductors**

\[
\frac{\sqrt{\cdot \cdot \cdot}}{\cdot \cdot \cdot} = \cdot \cdot \cdot \times \cdot \cdot \cdot \times = 1.8 mH
\]

\[
\cdot \cdot \cdot \times = 0.25 mH
\]
= \_{\text{\text{\_}}} \times \_{\text{\text{\_}}} = 1.8\text{mH}

= \_{\text{\text{\_}}} \times \_{\text{\text{\_}}} = 360\mu\text{H}

= \_{\text{\text{\_}}} \times \_{\text{\text{\_}}} = 360\mu\text{H}