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Department of Electronic Engineering

FINAL YEAR PROJECT REPORT

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Single Ended Audio Power Amplifier Design

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Project Title : Single Ended Audio Power Amplifier Design

Student Name : LI KWOK CHUEN Student ID:

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Acknowledgment

I would like to express my most profound gratitude to my supervisor, Dr. WU, Angus K M, for his considerate encouragement and sincere support throughout this project.

Abstract

The aim of this project was to design and develop a vacuum tube single ended audio power amplifier. This amplifier is mainly for the CD, VCD and DVD players which are the most common audio players today.

In this project, we study the vacuum tube and audio amplifier circuits. Moreover study the flow of the whole system from the music player to the loudspeakers. Each functions of the components in the amplifier.

Then, the whole single ended audio power amplifier is built by using vacuum tubes. After finish the whole have some different test and measurement to define the performance of the amplifier.

Finally, the most important thing was use the amplifier listen music and feels the different of the transistor amplifier.

Objective

1. To study the theory of vacuum tube and the amplifier circuit.

2. To study the different of the single ended and push pull output stage.

3. To design and develop the single ended audio power amplifier

4. To test and measure the performance of the amplifier

Introduction

In these recent years, the vacuum tube audio power amplifiers become more and more popular. Vacuum tube amplifier was a very large demanded consumer electronic market.

The vacuum tube is an early device and the tube compare with the transistor that the tube has many disadvantages. So the transistor is replacement the vacuum tube in many applications. That what reason to lead many people like to use the vacuum tube to make an audio amplifier.

The main reason is that most of the people feel the sound of vacuum tube audio amplifier better than the transistor amplifier. Because of the even order harmonic will make the sound pleasant. The tube can make the amplifier have richer even order harmonic.

The forced of this project is how to design a vacuum tube amplifier. And the cost of this amplifier is low.

Chapter 1 Background Studies [1][2][3][6][9]

Section 1.1

History of Vacuum Tubes

In 1883, Thomas Edison discovered that a current streamed between the filament of a lamp and a plate in the vacuum (see the figure 1.1). The effect was called that *Edison Effect*, but this unexplained effect was no important application at the time.

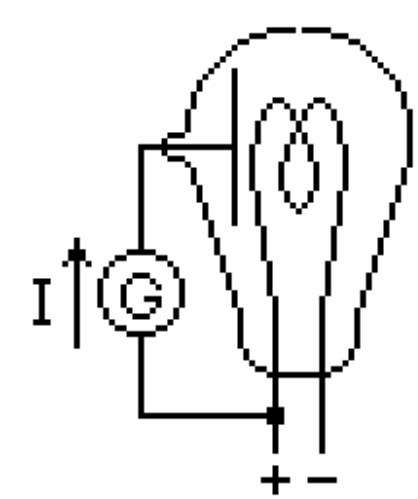

Figure 1.1

In 1899, J. J. Thomson proved that the current flowed was because of the stream of negatively-charged particles, electrons, that could be leaded by electric and magnetic fields.

In 1907, Lee de Forest patented the triode that he called the audion. The triode was a third electrode, the grid was used to control the electron flowed. It was made a more sensitive detector, however amplifying characteristic was not used at the first time. To recommend of the high vacuum, and furthermore the improvement of the materials

and processes, especially the metal–to–glass seals which the vacuum tube become a very useful amplifying device. The vacuum tube made great developments in radio, telephony and sound reproduction.

In 1919, Schottky used a screen grid between the plate and grid that the vacuum tubes become more useful at higher frequency.

In 1935, the introduction of metal tube which the glass tube did not disappeared and furthermore was constantly improved. The final type of the vacuum tube was the "miniature" or all-glass that types of tube become the predominant tube after about 1945.

Figure 1.2

Figure 1.3

In 1948, the transistors were invented that it used in the amplifying applications widespread. Moreover the transistors take over the position of the vacuum tubes.

Section 1.2

Vacuum Tube Vs Transistor

Disadvantage of vacuum tube:

- Lager size
- Easy to over heat
- Expensive
- Lower reliability
- High power dissipation

Why were vacuum tubes still used?

First, we will need to know the affect of even & odd harmonics in audio.

- Even order harmonics sound as musical chords which can makes the sound "richer". Human listen the even order harmonics will feel pleasant.
- Odd order harmonics sound makes the sound less pleasant.

The vacuum tube can make the audio amplifier more harmonics. Because of the reason most people will feel the vacuum tube audio amplifier have better sound than the transistor amplifier. Other reason to use the vacuum tube which was the characteristic of tube was more linear than the transistors.

Section 1.3

Theory of Vacuum Tubes

Section 1.3.1 Principles

A vacuum tube was an electronic device that it uses to increase or amplify an electrical signal. This function makes it the basic part required to build an analog electronic circuit. A tube allows you to manipulate electrical signals by controlling or modulating electricity. The electricity goes in one end and then comes out the other in an altered state. It was the elements inside the tube that affect the electricity and cause it to behave in a different manner.

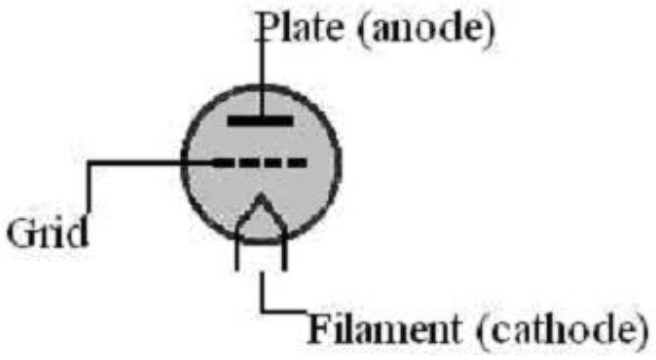

Figure 1.4

The concepts of the vacuum tube were based on the early device Audion. We provide a heater voltage to the filament (cathode) that the heated cathode will emits the electrons. The electron will through a grid to the plate. The position of grid was between

the plate and the cathode that was use to control the current flow through the vacuum. The electrons then absorbed by the plate. A typical plate voltage was about positive several hundred voltages, and a grid voltage was normally about negative several voltages. The small AC signal voltage become larger AC signal voltage after the tube amplifies.

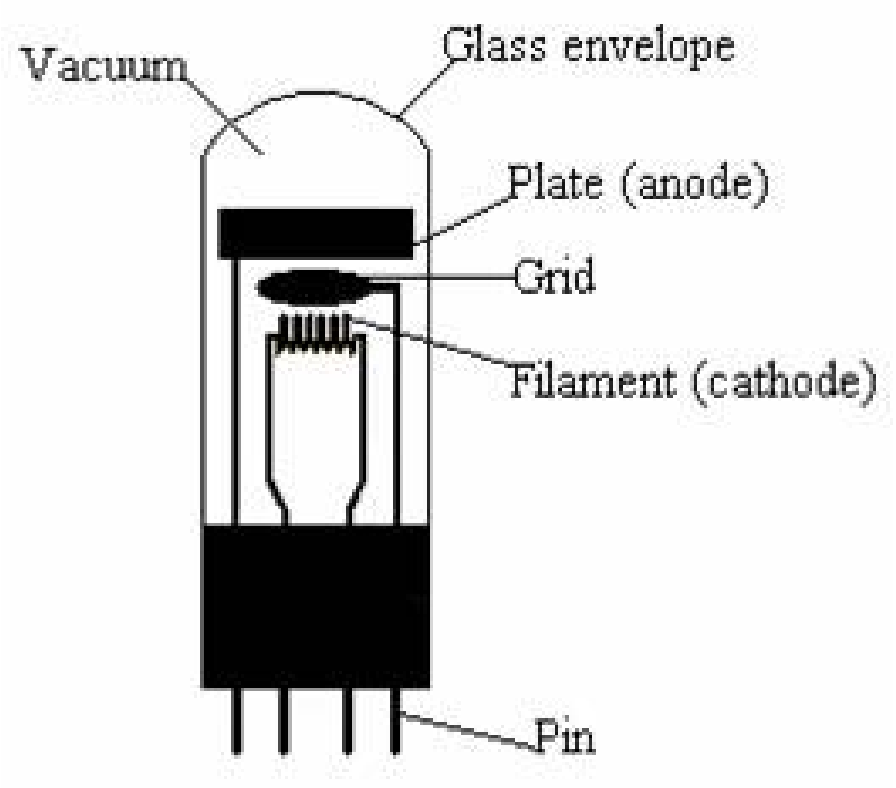

Figure 1.5

Section 1.3.2 Vacuum

A special environment must exist that isolates the tube elements from the outside world. If there was air inside the tube, its molecules would interfere with the flow of the

electrons through the tube. Also, the air would react chemically with the internal parts and ruin them. So a vacuum tube must be a very pristine environment.

Tube was a glass bulb which before the glass envelop was sealed which the air and gases were absorbed by a powerful vacuum pump. The standard of a good tube was vacuum can not more than a millionth of the air pressure. The good vacuum environment can lead the tube work better and increase the life time.

Section 1.3.3 Heater and Filament

Heat was the source of energy used to stimulate the electrons to leave the cathode, in a process called thermionic emission. The element provides heat energy called a heater if it was separate from the cathode. It was called a filament if it was used for both heating and emitting. Because of the heater or the filament need a time to warm up sufficiently to emit the electrons, the electric circuits using tubes start slowly.

Section 1.3.4 Cathode

Two type of cathode:

1) The thoriated filament:

This filament makes of tungsten which was similar the filament of the light bulb. The difference of the two filaments which was adds a less quantity of thorium to the tungsten filaments. The filament will emit electrons because of the thorium pass toward the surface of filament when it was heated to white hot (~ 2400 °C). The filament with thorium compare with the plain tungsten filament that the electrons was easy to make by the filament with thorium. Most of the thoriated filaments usually use in the radio transmitters power tubes.

2) The oxide-coated cathode or filament:

The mixture of barium, strontium oxides and other substances will coat to this filament which cathode was heated orange-hot (~ 1000 °C). The oxides compare with the thoriated filament that was better to make electron. However, it was easy to damage by high voltages. It was seldom used in the power tubes. Normally, it was always used in smaller glass tubes.

Section 1.3.5 Plate (anode)

The output signal will appear to the plate (anode) which was an electrode. The plate was easy to get hot because it was absorb the electron from the cathode. It was easy to observe in power tubes. Because of the reason it will specially designed to cool itself, it will radiate the heat through the glass envelope or metal envelope. Most of the tubes use graphite to make a plate because it can accept high temperatures. The secondary electrons was emitted by the graphite plate was very few.

Section 1.3.6 Grid

In early years, the grids of glass tubes almost were make of plated wire that grids were wound around two soft-metal posts.

In the power tubes the grids need to accept a lot of heat energy. Thus it was always made of tungsten.

Inside the amplifying tube, the most important thing was called secondary emission. The secondary emission was caused by electrons striking a smooth metal surface. The secondary electrons come out of the grid that it will lose control of the electron stream. This effect will cause the current run away and the tube destroys. Because of the reason, the grid usually coated with a metal. The metal gold can reduce the secondary emission. To prevent secondary emission can use surface finishing.

The grid was use to control the current through. From the figure 1.6, we can see how changing the voltage on the grid of a triode which can controls the current through the tube.

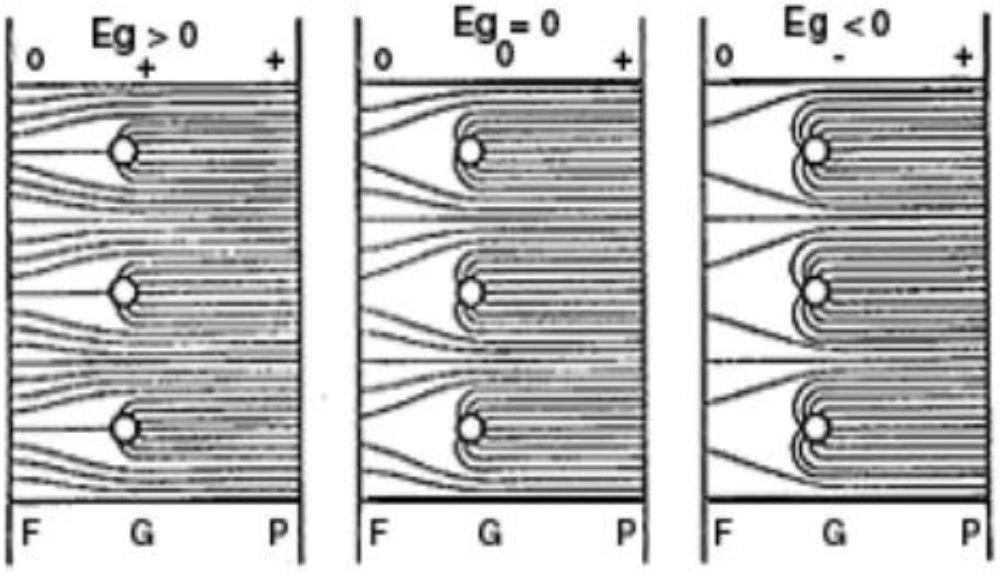

Figure 1.6

Section 1.3.7 Tube Life

Speaking of tube life, the amount of plate current that flows through a tube was related to how long the tube lasts. The lower of the plate current that make the longer life time of the tube. That Designs class A or other high-current consume tubes in a hurry. By designing circuits that operate at lower current levels, you can greatly extend tube life. Class A was not a panacea for bad design; it was possible to design excellent-sounding circuits that consume much less current, put out less heat, and last much longer.

And the other factor that the tube life depends on the life time of the cathode emission. The life of the cathode depends on the temperature of cathode, the degree of the vacuum and the materials in the cathode.

- Tube life depends on the temperature that it depends on the operating voltage of the heater or filament. The heater or filament operates too hot or cool that it will make a shortened life. Some researchers proved that the life time of an oxide-cathode tube can be increased when its heater operating at 20% below the rated voltage.

- The thoriated filaments provide longer life times than the oxide cathodes. Purity of the materials was a large issue in making a long life oxide cathode. Some impurities, such as silicates in the nickel tube that impurities will cause the cathode to lose emission prematurely.

- Oxide cathodes always use to make a small signal tubes. Good quality tubes of this type when it operated well within their ratings and at the correct heater voltages. It can last 100,000 hours or more.

Section 1.3.8 Why vacuum tube working in negative voltage?

Through this example we can easy to observe why vacuum tube working in negative voltage.

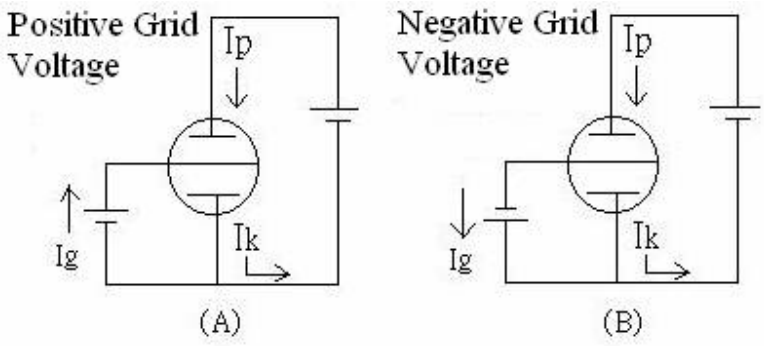

Figure 1.7(A) & (B)

First we provide the grid voltage from -5V to 5V that we can see the performance of the tube in the positive and negative grid voltage.

Grid Voltage (V)	+5	+4	+3	+2	+1	0
Plate Current (mA)	24	24	22	18	12	10

Grid Voltage (V)	−5	−4	−3	−2	−1	0
Plate Current (mA)	0	2	4	6	8	10

Table 1.1

From the table 1.1, we can see that the plate current increase when the grid voltage.

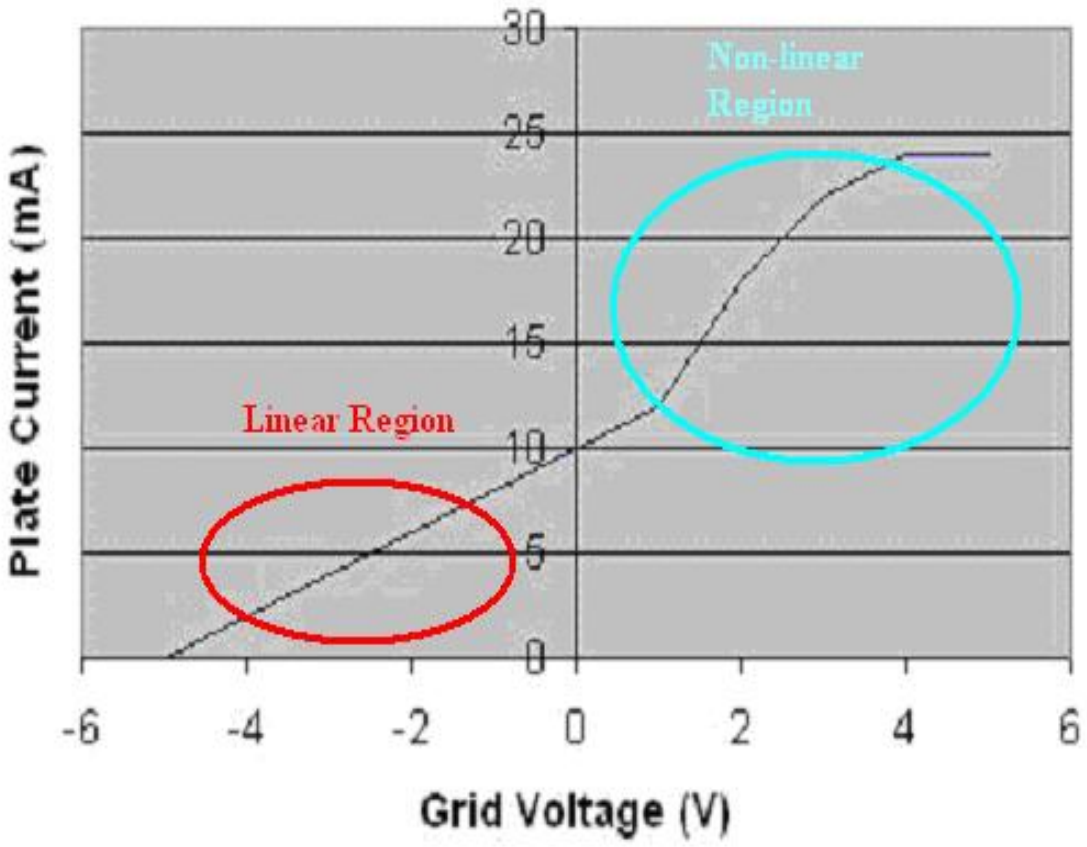

Figure 1.8

From the figure 1.7, we can see that the negative grid voltage region was linear however the positive grid voltage region was nonlinear. Because of this reason the vacuum tubes need to operate in the negative grid voltage.

Section 1.3.9 How to amplify the signal?

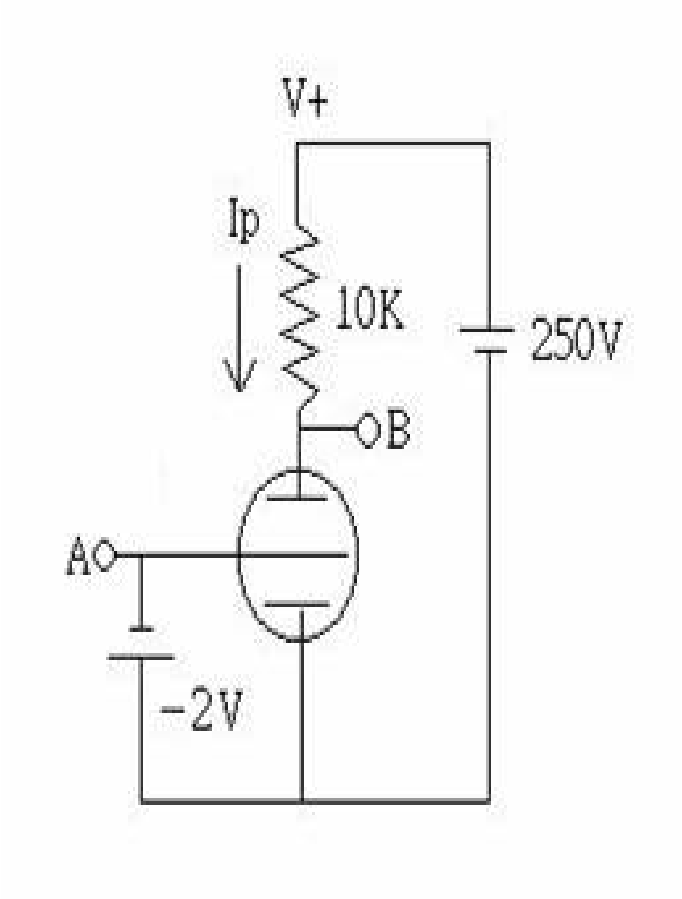

Figure 1.9

The circuit was provide -2V grid voltage. From the table 1.1, the plate current was 6mA when the grid voltage was -2V.

- The point B voltage:

  250V－ (10k*6mA) = 250-60=190V

  The grid voltage was decrease to -3V which the plate current become 4mA.

- The point B voltage:

  250V－ (10k*4mA) = 250-40=210V

The 1V of the grid voltage change which the voltage of point B change to 20V. The signal was amplify 20 times.

Chapter 2 Structure [9][10]

Section 2.1

The flow to the loudspeaker

The flow that was show the CD converted to a music output.

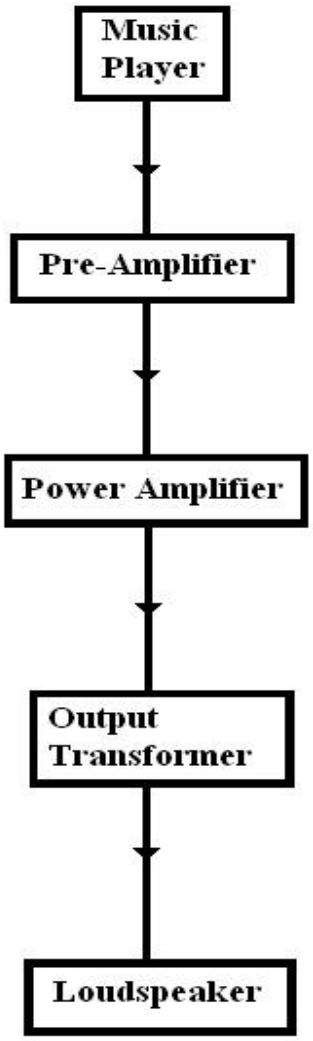

Figure 2.1

Section 2.2

Music Player

Nowadays, the main music players were CD, VCD and DVD. These kinds of the music players have providing a high signal levels output. Sine the maximum possible output was about 2V. However, if we make an amplifier for phonograph that the gain of the audio power amplifier must larger due to the very small phonograph signal about 30 to 50mV.

Figure 2.2

Two type of the music player:

- High signal output – CD, VCD, DVD
- Low signal output – phonograph, tape

High signal output music player

Compact Discs (CD) player was an electronic device that can play audio CD. This kind of the music players were usually installed in home audio systems, car audio systems and personal computers (PC). Recently, most of the players support different formats in addition to CDs; such as DVDs, CD-ROMs with audio files and video compact discs (VCD).

Figure 2.3

The CD player was including three major parts. These were drive motor, lens system and tracking mechanism. The function of the drive motor rotates the CD about 200 to 500 per minute. Then the lens system was moved to the spiral tracks by the tracking mechanism. And the lens system will use the laser beam to reads the information. The laser system was focusing a beam on the CD to read the information that the information will reflect to the sensor. And the sensor can detect the changes of the beam which change will convert to data. The data will pass through a digital to analog converter (DAC) to become sound output.

Section 2.3

Pre-amplifier

Pre-amplifier was the first part of the amplification which amplifier use to prepare an electronic signal to further amplifier. Normally, the function of the pre-amplifier use to amplify a very low level input signal to a suitable level for further amplifier. In general, the pre-amplifier in a home audio system which use to switch the different music sources and provide a volume control. The voltage gain provides of the preamplifier was about 10 which was no current gain. Typically, the second amplifier was a power amplifier in an audio system.

Figure 2.4

From the figure 2.4, show the volume control in the front.

Characteristic of the pre-amplifier:

- amplify about 10
- have volume control
- can select the input source
- first stages of the audio amplifier
- combine into a housing or separate housing
- mounted in some equipment, such as turntables, electric basses and microphones.

Figure 2.5

The figure 2.5, show the socket of the different music input.

Section 2.4

Power Amplifier

Amplifier was a device which uses a small signal to control a larger signal. It was usually use in audio applications. Power amplifier relate to the amount of power delivered to the load. Normally, power amplifier was design the last amplifier in a transmission chain. Moreover, the amplifier stage requires most attention to power efficiency.

The pre-amplifier and power amplifier were similar however they provide different gain. The power amplifier provides high current not the voltage gain that the high current use to drive the loudspeaker

Amplifier output stages

Two type of the output stages that these were the single ended and push pull. The difference of these two output stages were the connection of tubes to output transformer and use different types of the output transformer.

Section 2.4.1 Push-Pull Stage

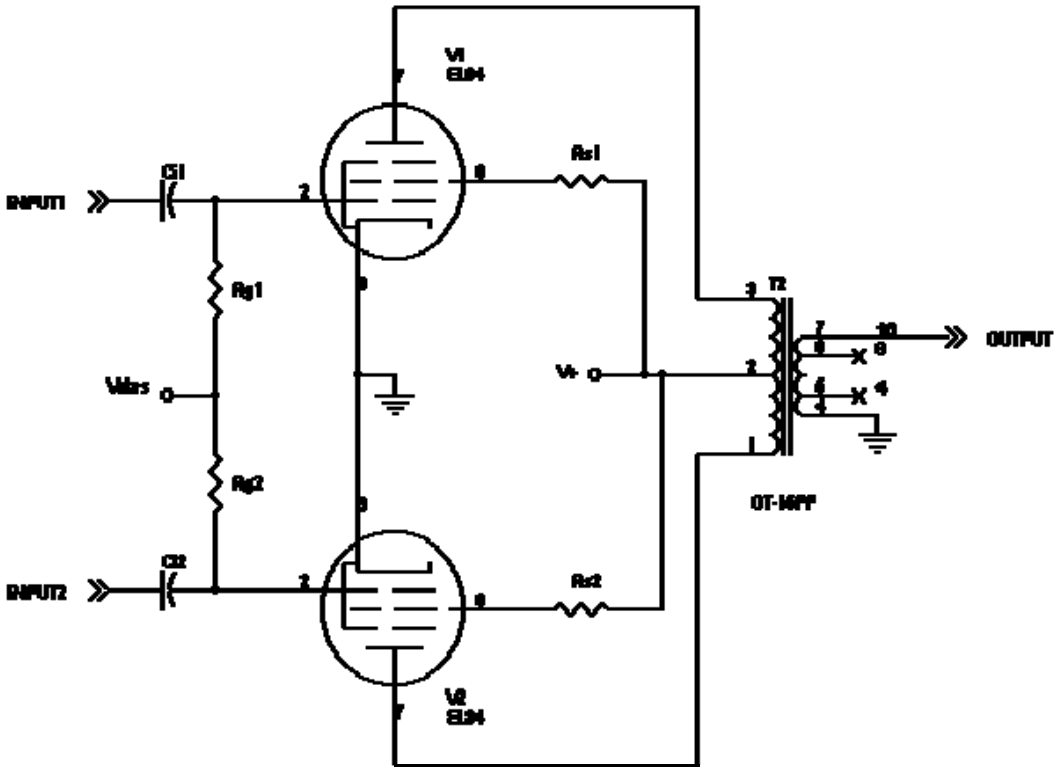

Figure 2.6

The power supply was connected to the center-tap of the output transformer in the push-pull stage. Moreover the upper and lower side of the center-tap primary was connected to the tubes. The alternate cycles of the input waveform were conducted by the tubes. Most of the design push-pull were biased to class AB which connect have better efficiency and the output with less crossover distortion.

The push-pull stage can connected more tubes in parallel with each side that the resulting in the amplifier with four, six or even eight output tubes for higher power amplifiers. This parallel operation was called parallel push pull. However, the push-pull stage operates at least two tubes.

The advantage of the push-pull stage that the tubes were matched and the output stage was balanced that the push-pull circuit was less or no unbalanced DC current in the output transformer. Even order harmonics and distortion products generated in the output stage were canceled out. Power supply hum was canceled out, allowing the designer to get by with less filtering of the power supply. However, this stage usually has more odd order harmonic distortion.

The disadvantage in class AB operation was the DC supply current changes between off and full signal that require heavier filter to prevent supply "sag".

Section 2.4.2 Single Ended Stage

Class A was always in the single ended amplifier output stage. The output transformers have two connections that were not having the center tap in the transformer primary. The two connections of the output transformer connect to the power supply and the plate of the power tubes.

Also, the tubes can connect in paralleled for high power operation which was similar to the parallel push-pull operation. And this connection was called parallel single ended.

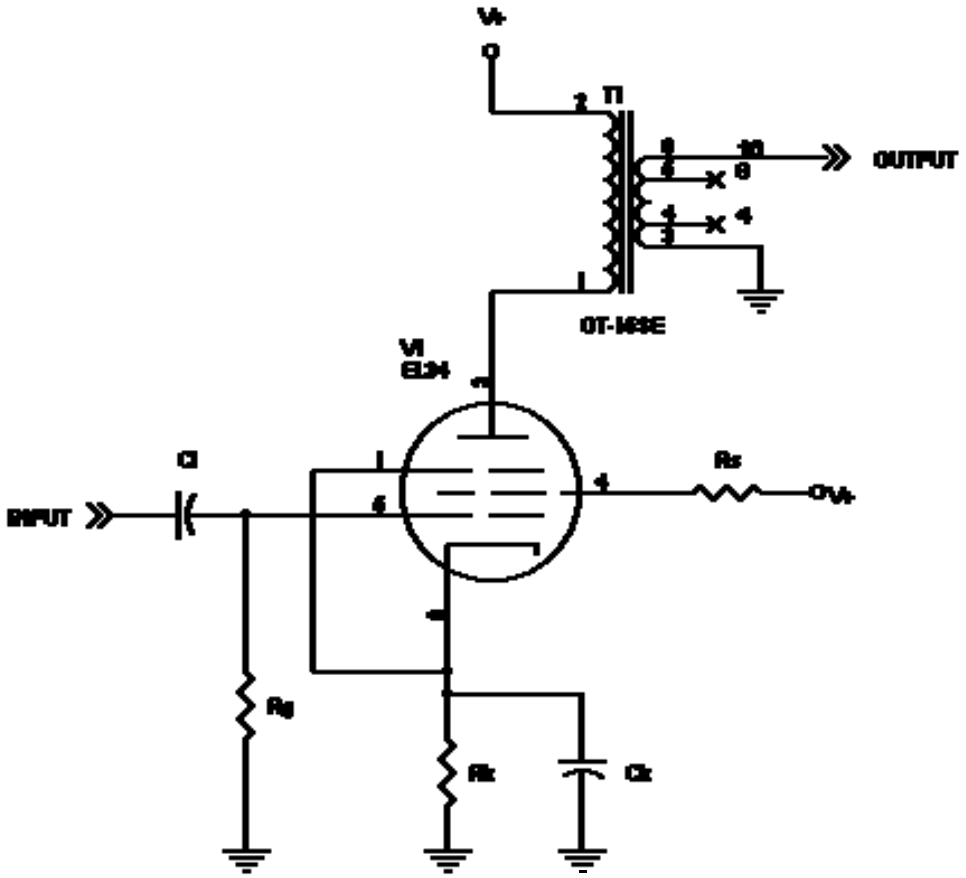

Figure 2.7

The single-ended stage was the type of output stage which was used in the venerable Fender champ guitar amplifier and countless millions of early radios and TV. This output stage was good sounding and putting out low power level compare with the push-pull stages. However, the single ended stage was very inefficient. This type of stage also has another problem that was the continuous DC current must handle by the transformer. The results of this reason make the output transformer larger and higher cost.

The disadvantages of the single-ended output stage were including:

- Need a heavier filtering to make the hum become acceptable because low rejections of power supply hum.
- No rejection of even order harmonics (advantage to guitar players).
- The asymmetrical limiting on overloads which further emphasizes even order harmonics. These disadvantages give the single-ended output stage a unique tone, compared to the push-pull output stage. The better or not was depending on the taste.

Section 2.5

Output Transformer

The sound quality was limited by the audio transformers. The wide frequency response and low distortion were related to the output transformers design.

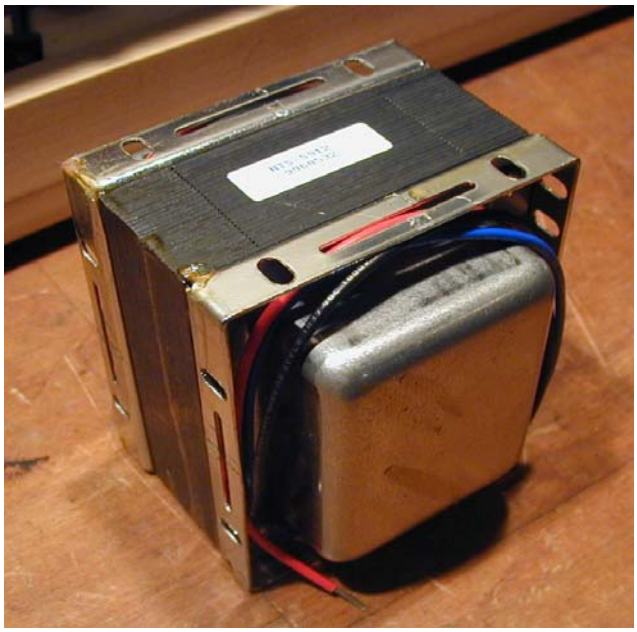

Figure 2.8

In audio power amplifier that the audio output transformer was a main component. The vacuum tube output connects to the high impedance output transformers primary and the low impedance of secondary connects to the loudspeaker. It was because the vacuum tube operates a high voltage at low current and the loudspeakers operate a low voltage at high current. The output transformer was not applying in the transistor amplifier.

The large iron core of the output transformer can make better low frequency response. However the large iron core size was increase the high power handling. The designed of windings to make without any leakage inductance and stray capacitance which can lead better high frequency response. Because of the design and the large iron core that make the output transformer was an expensive component.

Section 2.6

Loudspeaker

The electrical signal to sound was converted by the speaker system. The range of its cost was from about $100 to several thousands dollars.

Figure 2.9

- Loudspeaker can divide to four different type:

    1. **Full range type**
    2. **Woofer type**
    3. **Mid-range type**
    4. **Tweeter type**

- Loudspeaker was need to handle a continuous power and peak power.
- Typically the input impedance of the speaker systems were 4 Ω, 8 Ω and 16 Ω.
- The complete speaker systems can include 2 or more number of the drivers.
- The frequency response of the loudspeaker must lager than 20Hz to 20kHz.

Chapter 3 Methodology[1][2]

Section 3.1

Design Procedure

Have several steps to design an audio power amplifier.

1) -- Design number of stage of the amplifier

2) -- Choose Vacuum Tube

3) -- Design Driver Stage Circuit

4) -- Design Output Stage Circuit

5) -- Transformer

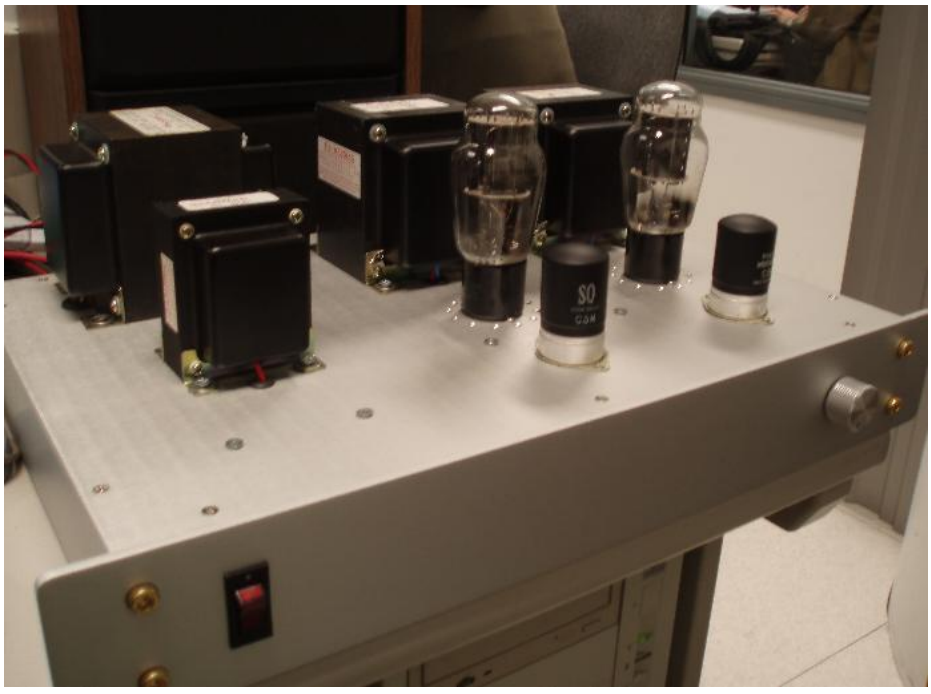

Figure 3.1

Section 3.2

Design number of stage of the amplifier

Normally, the numbers of stage of the amplifier were either two or three stages. There were depending on the signal output of the music player.

The high signal output music player can provide about 0.7V to 2V such as CD, VCD and DVD players. The low signal output music player only provide about several mV to 30 mV, such as phonograph.

When the audio power amplifier was force on the high signal output music player that only need two stages to amplify the signal. However, the amplifier for the low signal music player that amplifier need one more stage to amplify the signal.

Section 3.3

Choose the Vacuum Tube

Normally, the vacuum tube can divide to two types:

- Driver stage tube
- Power stage tube

Figure 3.2

From the figure 3.2, shows the difference of the driver stage tube and the power stage tube.

Section 3.3.1 Power Stage Tube

The characteristic of the power stage tube:

- Larger size
- Higher power dissipate
- Very hot

When talk about the power stage tube most of vacuum tube player will know the popular tubes 300B and 2A3. There two models were famous for provide a good sound. However, the costs of these two tubes were very expensive that cost was about 1000 dollars per each. Moreover it was not the best brand of the tubes. Because of the budget of the project that kind of tubes can not consider in the project.

Figure 3.3

Finally, find a power stage tube 6B4G that characteristic was similar to the 2A3. Moreover the cost of 6B4G was cheaper about 200 dollars when it was made by Russia. The differences of these two tubes were the heater voltage. Other differences were the pin out of the tube.

Power tube 6B4G:

- Heater voltage of 6B4G--6.3V
- Eight pins

Power tube 2A3:

- Heater voltage of 2A3--2.3V
- Four pins

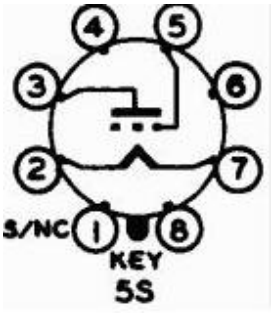

Figure 3.4

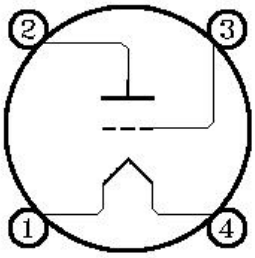

Figure 3.5

Section 3.3.2 Driver Stage Tube

The characteristic of the power stage tube:

- Smaller size
- Lower power dissipate
- Not very hot

Normally, the cost of the driver stage tube was cheaper which the cost usually below 100 dollar. So the driver stage tube forces on the linear characteristic.

Finally, the driver stage tube uses the model C3M. It was not a popular driver tube and less people will use it to make an audio amplifier. However the tube have very good characteristic.

Figure 3.6

The characteristic of the C3M:

- Characteristic very linear
- Low noise
- Higher lifetime

The C3M tube has three grids pin, so it can connect in triode mode and pentode mode. The advantage of the triode mode connects less components however it only can provide low gain. And the pentode mode can provide high gain but more components in the circuit.

Disadvantage of the C3M was the heater voltage of the tube was 20V. Normally, the heater voltage of tube was about 6V and 12V. The 20V heater voltage was very special. That reason the power supply must make one more group for this heater voltage.

Section 3.4

Design Driver Stage

When start to design a driver stage the most important thing was the amplifier for what type of the music player. Because the audio power amplifier was mainly for the CD players that players can provide a high signal output (max about 2V). Because of the high signal output of the CD players that I believe the gain of driver stage was about 15. The driver stage can connect in triode model.

The figure 3.7, show the characteristic of C3M tube in triode connection.

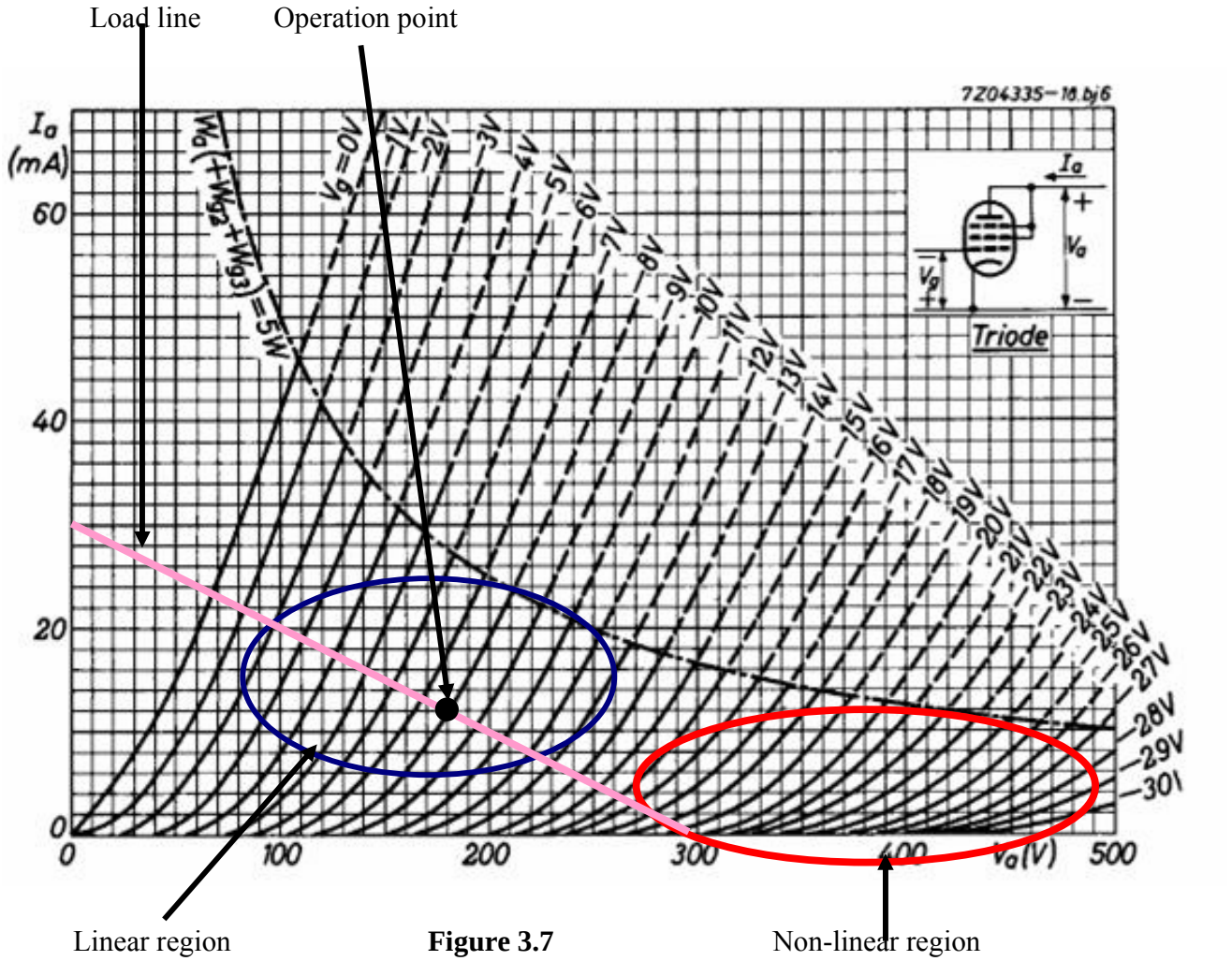

Figure 3.7

From the figure 3.7, can obverse the linear region and non-linear region. When design the driver stage need to avoid the tube operate on the non-linear region. Then set the load line and the operation point on the linear region. Finally, use the difference equations to calculate the values of each component.

From the load line, we can see no current through the anode the voltage of anode was 300V. And no voltage across the anode the anode was 30mA. That we can set the value of anode resistor was 10kΩ (300V / 30mA = 10kΩ).

Then the voltage of the operation point was 180V and the current was 12mA when no input signals. The grid voltage was -8V when no input signals. The cathode resistor was -8V/12mA = 666.67Ω that we use the 680Ω resistor.

From the load line and the operation point that can observes the 1V change of the grid voltage will change about 15V of the anode voltage. That mean the gain of the circuit was about 15.

The figure 3.8 shows the circuit of the driver stage that connects in triode mode.

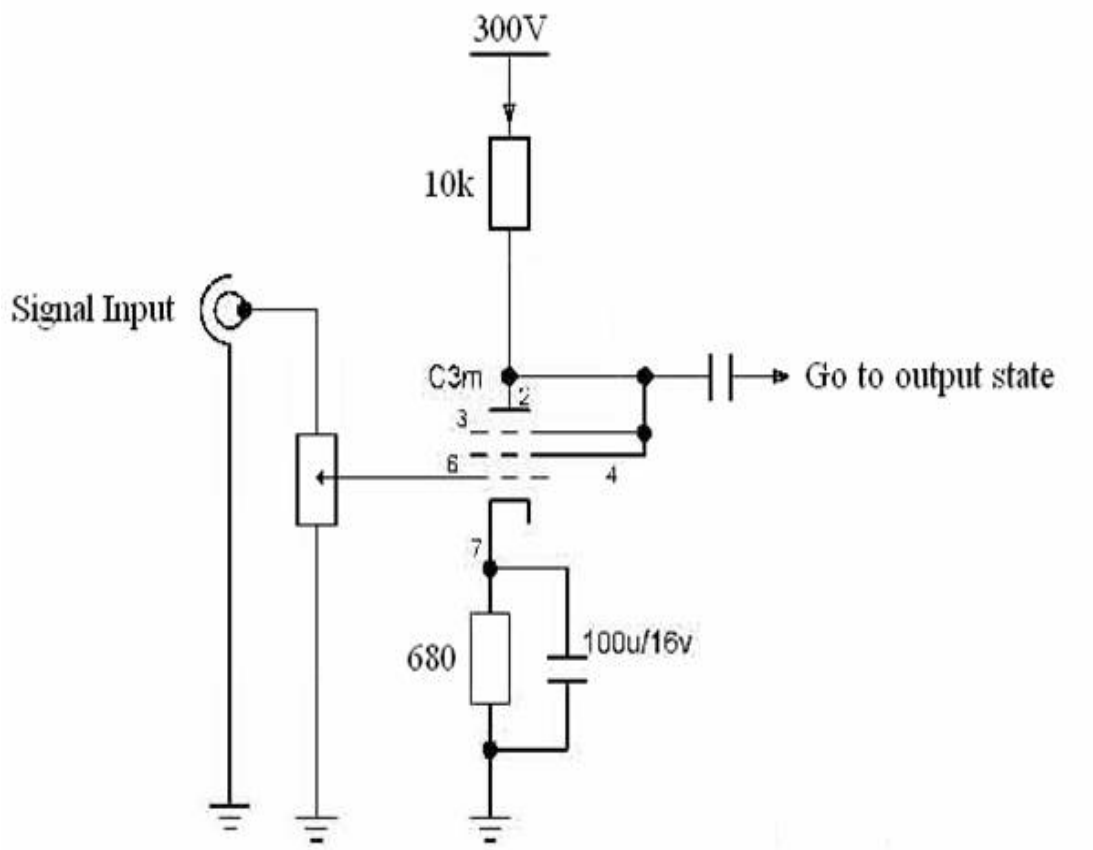

Figure 3.8

However, after finish all parts of the amplifier then connect the loudspeaker and CD player to test the sound of the amplifier. The volume of the triode connection was not enough lager when the volume tunes to max. It was because the output of the music player was not enough. When I design the driver stage which was force on the max output of the music player was about 2V. But the average output of the CD player was about 0.8V. So we need to use the pentode mode to provide high gain.

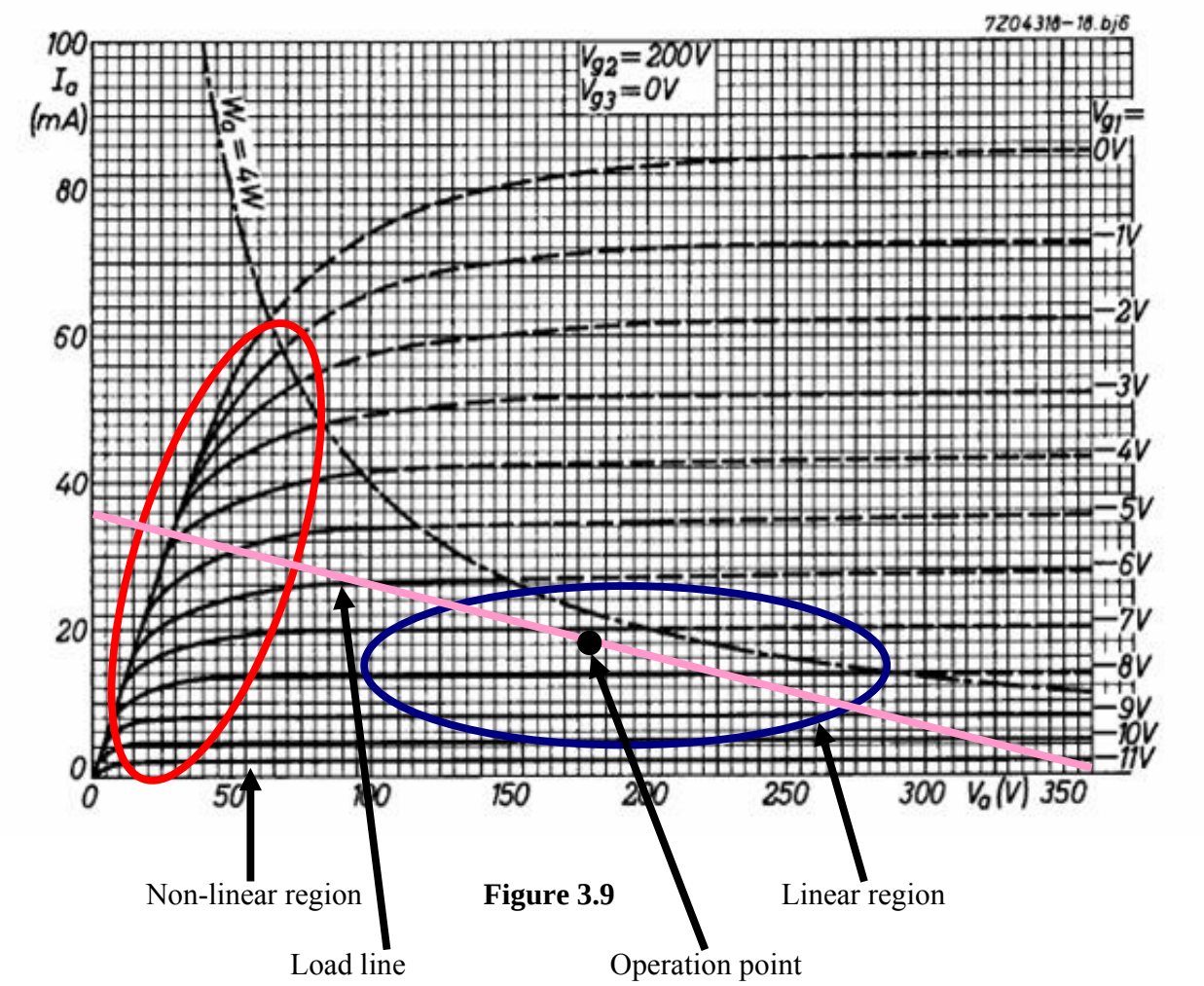

Figure 3.9

The figure 3.9 shows the characteristic of C3M tube in the pentode connection. The characteristic of pentode connection was different the triode mode. However the design procedure was similar to the triode connection.

- Find the linear and non-linear region.
- Make the load line and the operation point on the linear region.
- Use some equation to calculate the value of each component.

After calculate the whole circuit shows below figure 3.10. And the gain of the circuit was about 58.

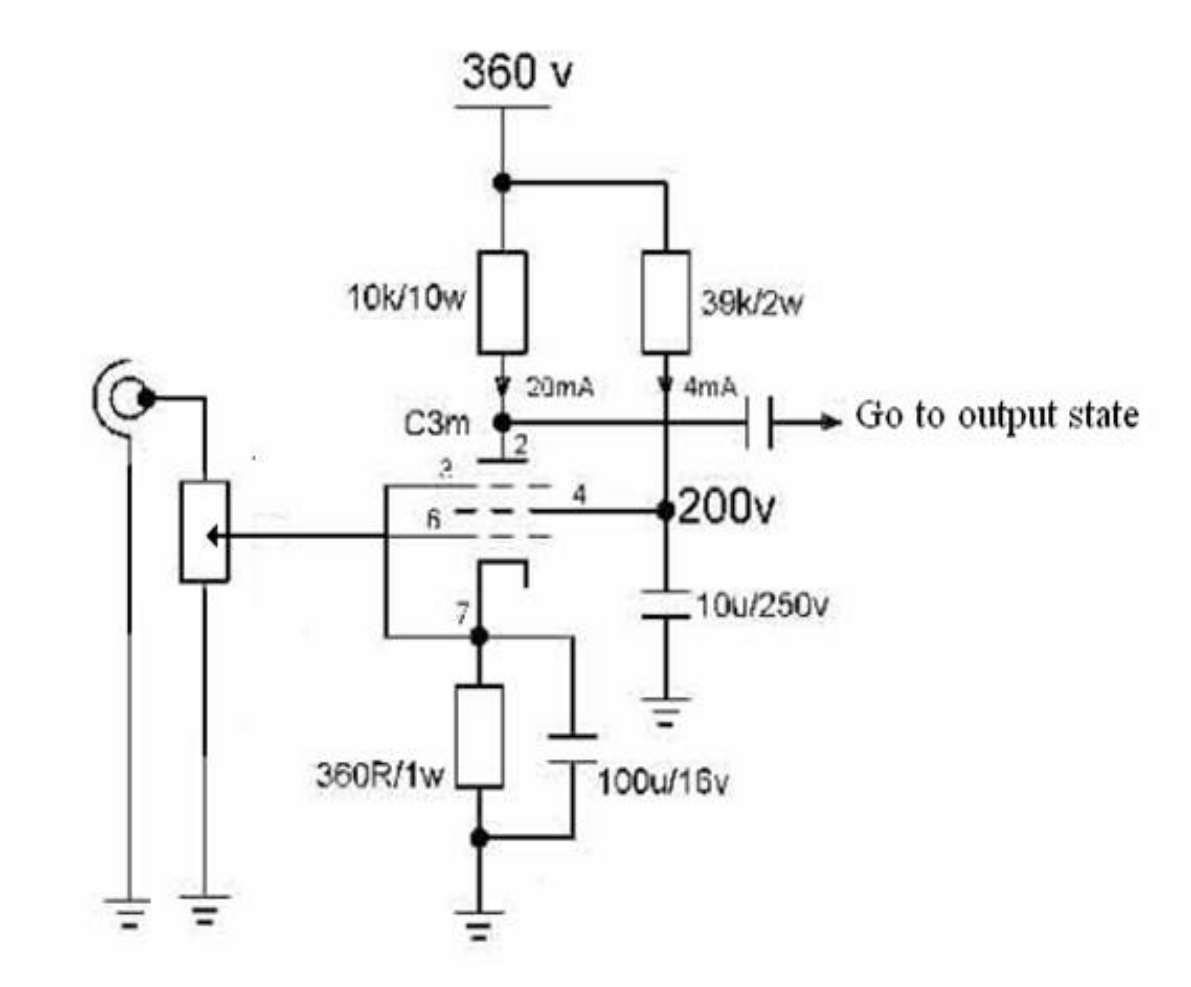

Figure 3.10

Section 3.5

Design Power Stage

The characteristic of the 6B4G was similar to the C3M was triode connection. Moreover the design procedures also like the C3M triode mode. The main difference was the power tube was connecting to the output transformer not a resistor.

P = (Vmax-Vmin)(Imax-Imin)/8

= ((370-105)(120-10)/8000 = 3.64W

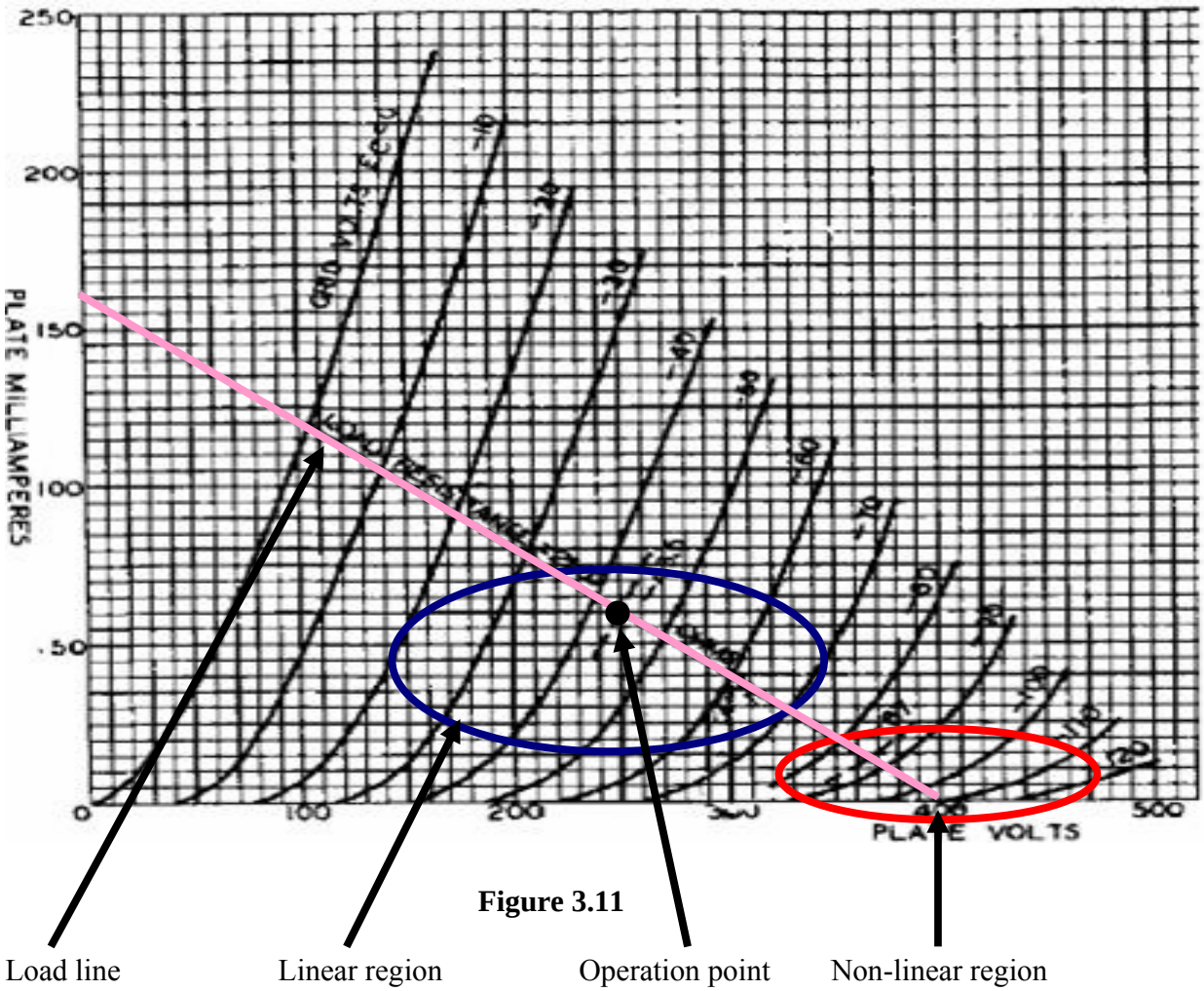

Figure 3.11

The below figure was the final of the power stage circuit.

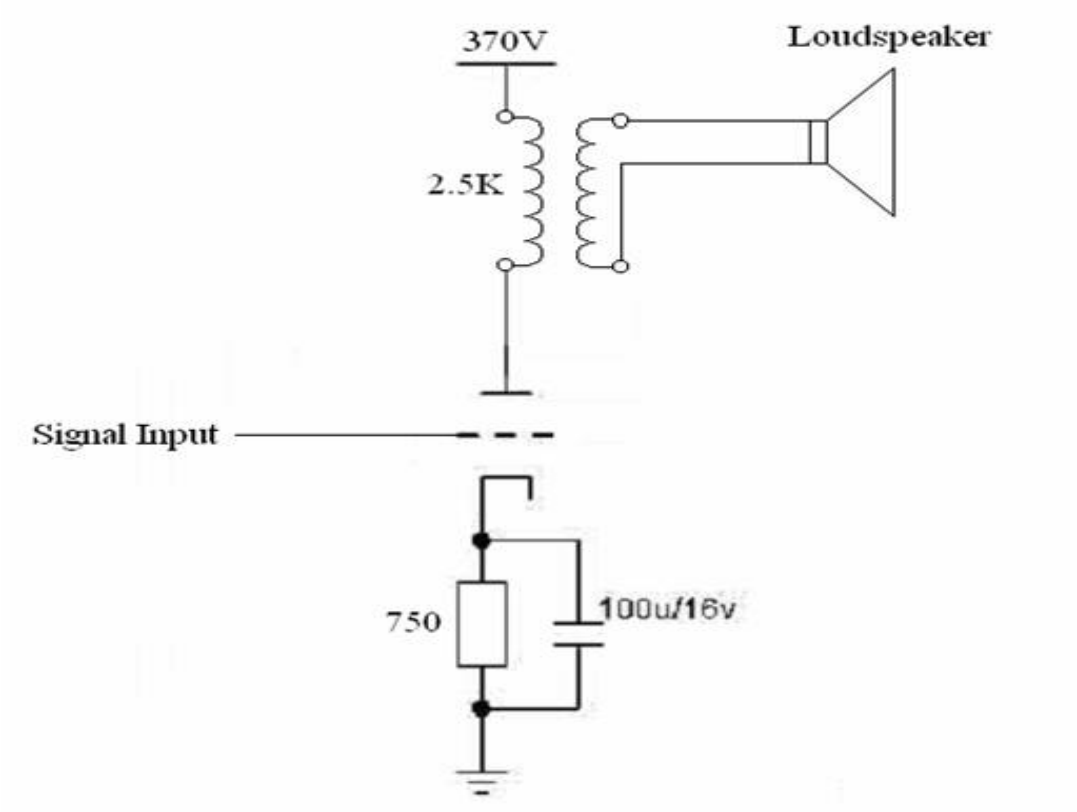

Figure 3.12

Section 3.6

Transformers

Section 3.6.1 Output transformers

The output transformers were basic on the design to make. Because the resistance of the output stage was 2.5kΩ that the primary wing of the output transformer was 2.5kΩ. And the secondary wings of the output transformer were 0Ω, 4Ω, 8Ω and 16Ω that was match the standard of the loudspeakers.

The figure 3.13 shows the structures of the output transformers.

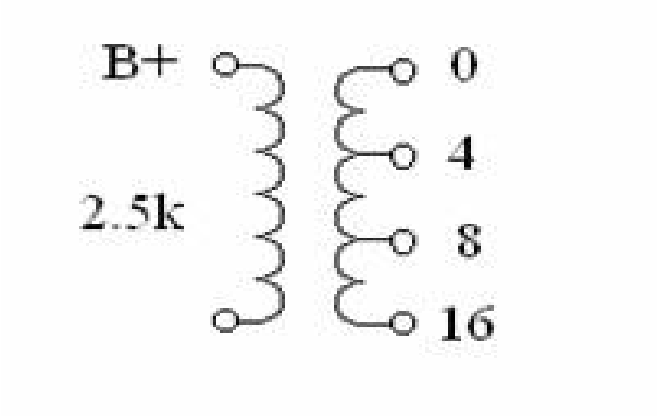

Figure 3.13

Section 3.6.2 Supply transformer

The most important things were design the supply transformer:

- Need how many groups of voltage
- Need how many currents of each group.

A group of the supply can provide more than one group of voltage. E.g. the below figure, can observes that the 6.3V supply group is provide 6.3V and 5V.

The figure 3.14 shows the structure of the supply transformer in this project. The 6.3V and 20V were the heater voltage for the 6B4G and C3M respectively. The 300V was main supply for the whole circuit.

After design the output and supply transformer that can go to find a factor to make it.

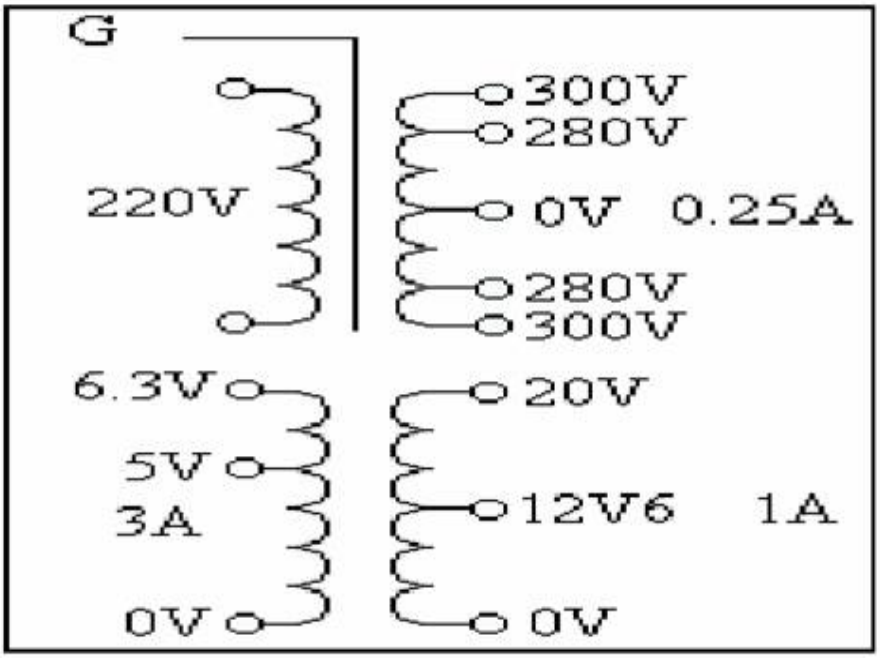

Figure 3.14

The figure was the whole circuit in the case.

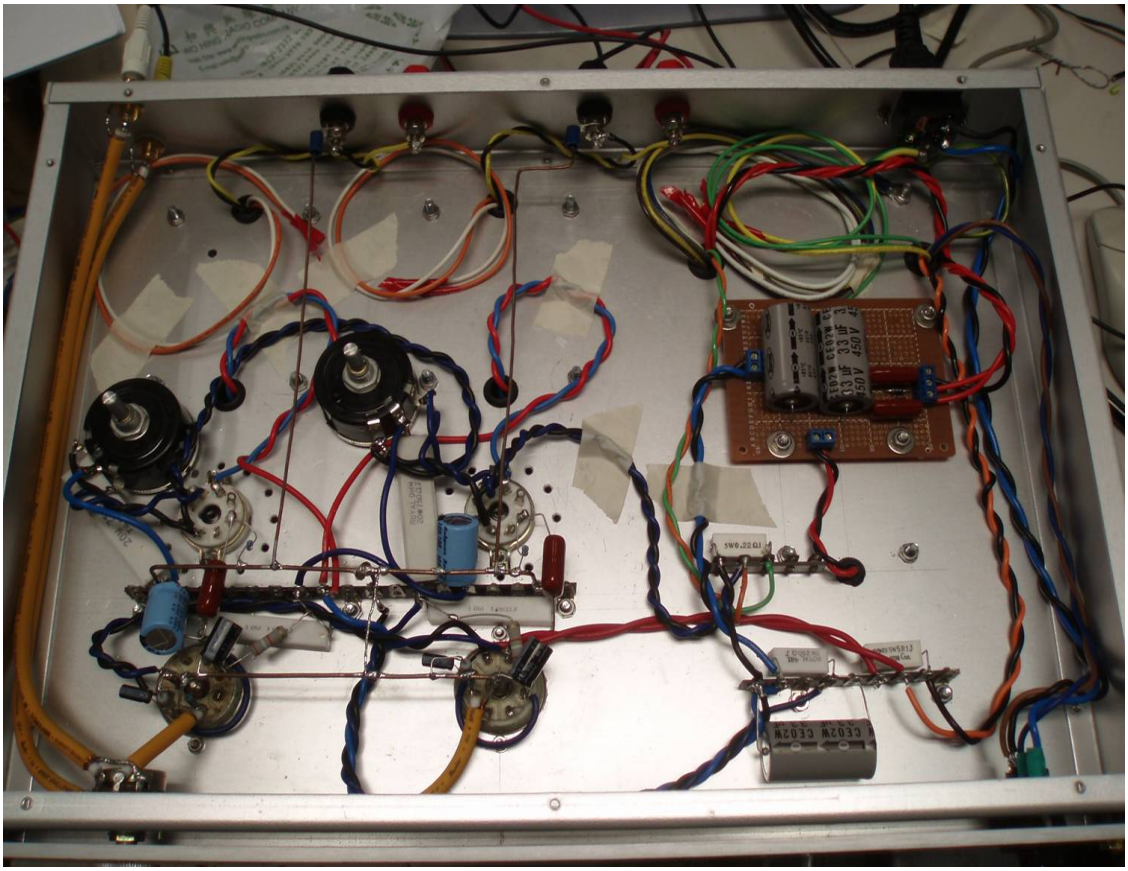

Figure 3.15

Chapter 4 Testing and Measurement

Section 4.1

Basic Testing

After finish the whole circuit that needs to test the circuit. First, need to measure the voltage of each point. Then use the measure values compare with the calculate values (If two type of the date were similar that can do the next part). Next insert the tube and connect the 8Ω load to observe the waveform when input a sine wave (1 kHz and 500mV).

The figure 4.1 shows the output waveform of the right channel driver stage. It showed the voltage equal 27.4V when input 500mV. The gain of the right channel driver stage is 54.8 (27.4V/500mV).

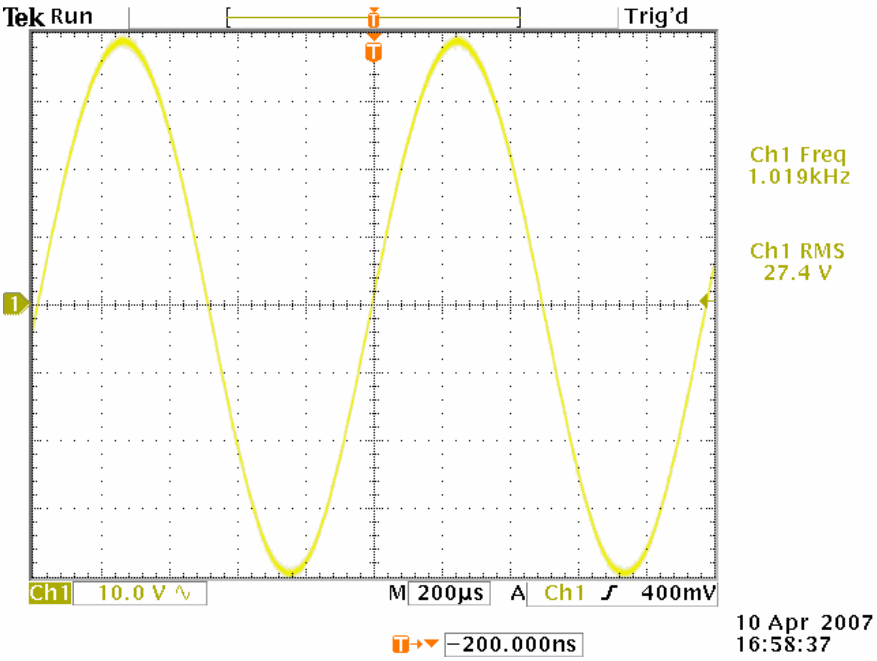

Figure 4.1

The figure 4.2 shows the output waveform of the left channel driver stage. It showed the voltage equal 27.9V when input 500mV. The gain of the left channel driver stage is 55.8 (27.9V/500mV).

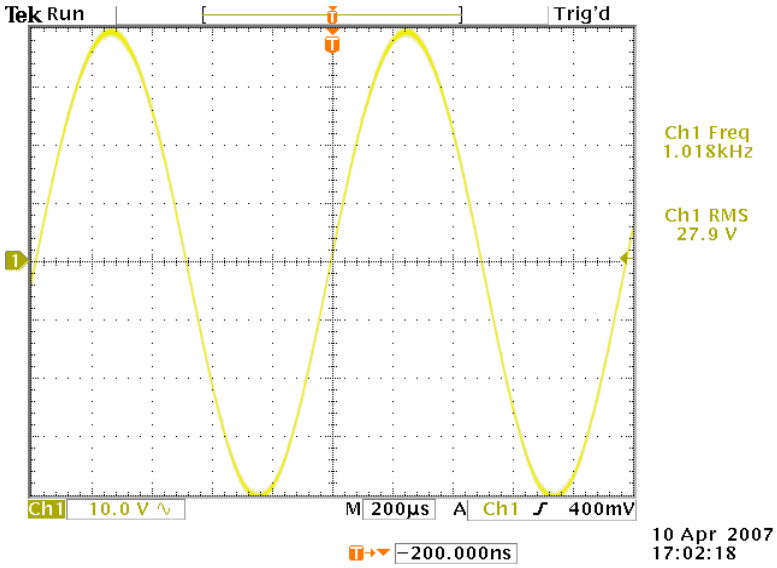

Figure 4.2

The figure 4.3 shows the output waveform of the left channel power stage. It showed the voltage was reduced because the power stage was provided current gain.

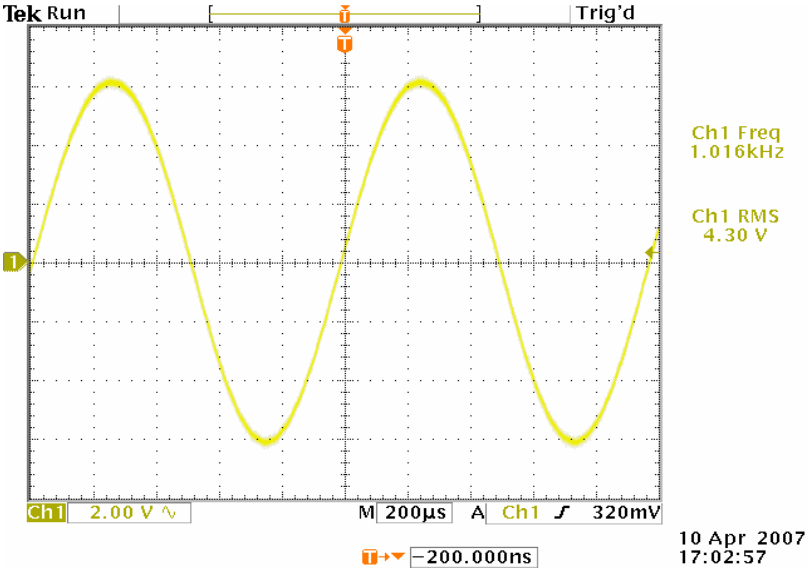

Figure 4.3

The figure 4.3 shows the output waveform of the right channel power stage. The output waveform was very smooth.

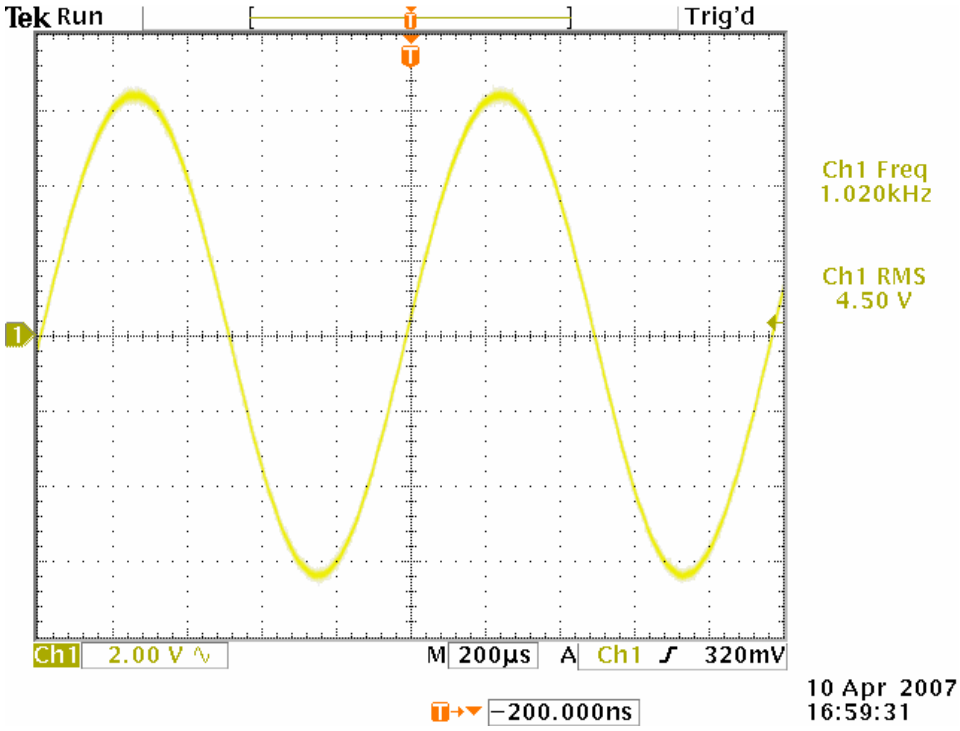

Figure 4.4

Section 4.2

Measure the Distortion

The methods to measure the distortion use the signal generator. It generates a 1 kHz signal to the amplifier. Then connect the CRO to the output that increase the voltage of the input from 0V to a voltage that the waveform starts to distortion.

From figure 4.5, shows the output waveform starts to distortion when the output reaches to 5.57V (Right channel).

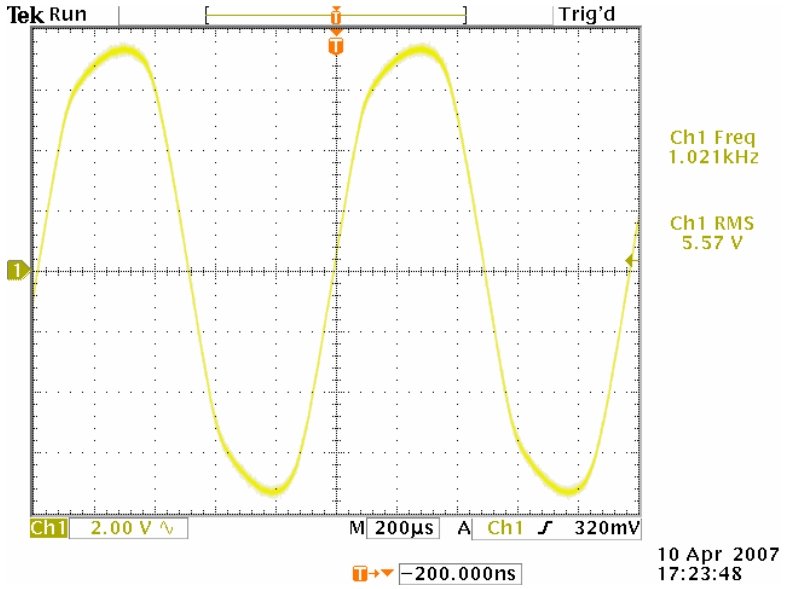

Figure 4.5

From figure 4.6, shows the output waveform starts to distortion when the output reaches to 5.57V (Left channel).

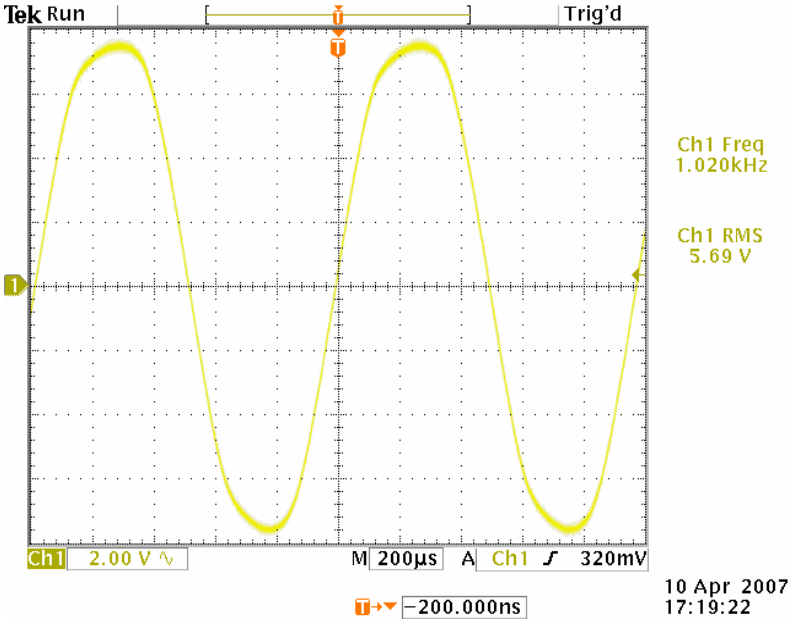

Figure 4.6

Section 4.3

Measure the Frequency Responds

When measure the frequency responds that use the generator to generate a 500mV signal. Then change the frequency from 5Hz to 40kHz. This test wanted to know the amplifier can or not handle the frequency between 20Hz to 20kHz (human can hear).

Frequency(Hz)	Voltage(V)		Frequency(Hz)	Voltage(V)
5	0.475		8500	3.84
10	1.21		9000	3.81
20	2.8		9500	3.79
30	3.44		10000	3.74
40	3.7		11000	3.7
50	3.71		12000	3.67
60	3.75		13000	3.62
70	3.78		14000	3.57
80	3.8		15000	3.55
90	3.8		16000	3.44
100	3.8		17000	3.3
200	3.82		18000	3.28
300	3.86		19000	3.11
400	3.87		20000	2.89
500	3.95		21000	2.74
600	4		22000	2.52
700	4		23000	2.42
800	4.03		24000	2.3
900	4.1		25000	2.17
1000	4.07		26000	2.04
1500	4.06		27000	1.89
2000	4.05		28000	1.74
2500	4.04		29000	1.67
3000	4.02		30000	1.45
3500	4.02		31000	1.23
4000	4.01		32000	1.17
4500	3.98		33000	1.08
5000	3.97		34000	0.95
5500	3.95		35000	0.84
6000	3.94		36000	0.77
6500	3.92		37000	0.61
7000	3.9		38000	0.51
7500	3.88		39000	0.45
8000	3.86		40000	0.32

Table 4.1

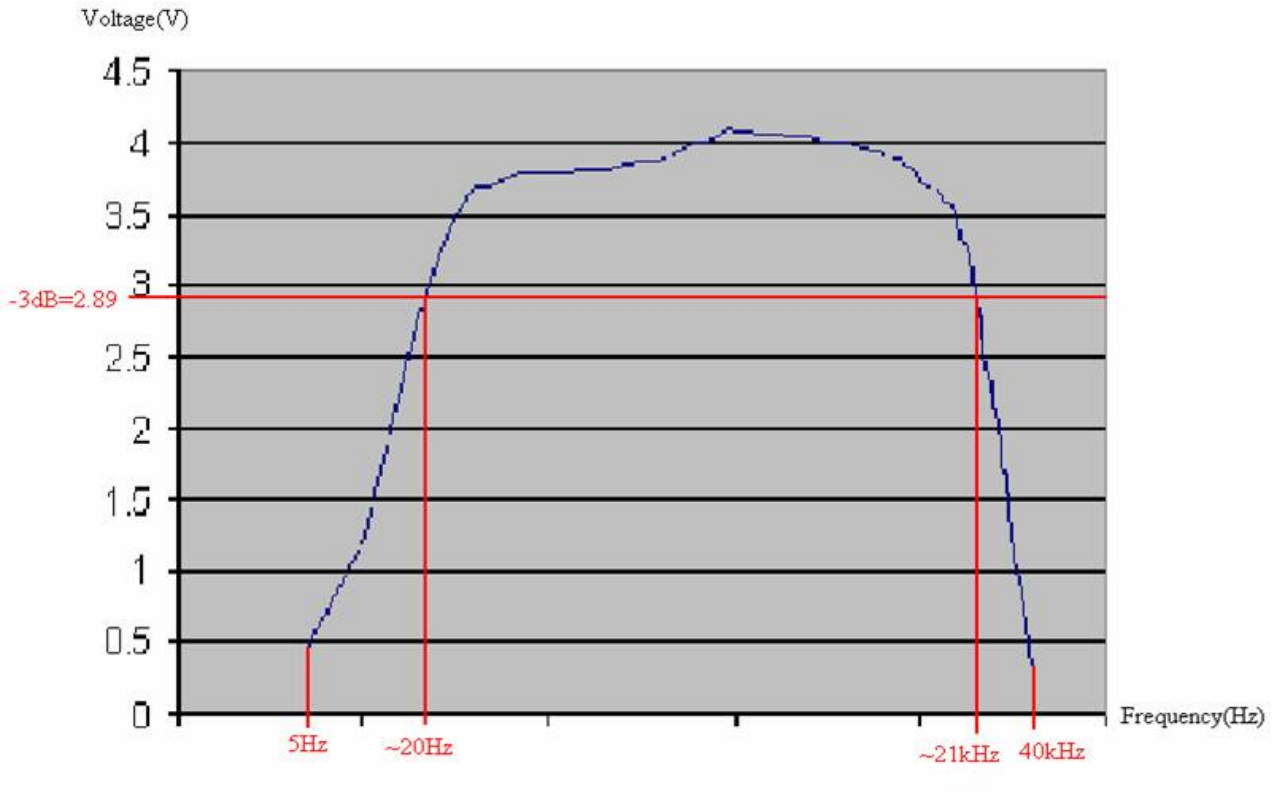

Figure 4.7

The above table and figure was showed the frequency responds in right channel. That showed the right channel of the amplifier can handle the human hear range.

The below table and figure was showed the frequency responds in left channel. That showed the left channel of the amplifier can handle the human hear range.

Frequency(Hz)	Voltage(V)		Frequency(Hz)	Voltage(V)
5	0.564		8500	3.95
10	1.34		9000	3.85
20	2.89		9500	3.83
30	3.58		10000	3.72
40	3.8		11000	3.7
50	4.02		12000	3.68
60	4.03		13000	3.62
70	4.05		14000	3.58
80	4.06		15000	3.53
90	4.09		16000	3.49
100	4.1		17000	3.44
200	4.11		18000	3.35
300	4.11		19000	3.15
400	4.12		20000	3.03
500	4.14		21000	2.98
600	4.14		22000	2.83
700	4.15		23000	2.58
800	4.2		24000	2.49
900	4.23		25000	2.34
1000	4.1		26000	2.2
1500	4.14		27000	2.04
2000	4.13		28000	1.87
2500	4.11		29000	1.73
3000	4.1		30000	1.63
3500	4.09		31000	1.45
4000	4.08		32000	1.37
4500	4.06		33000	1.22
5000	4.05		34000	1.11
5500	4.04		35000	0.9
6000	4.03		36000	0.836
6500	4.01		37000	0.657
7000	4		38000	0.59
7500	3.98		39000	0.52
8000	3.97		40000	0.458

Table 4.2

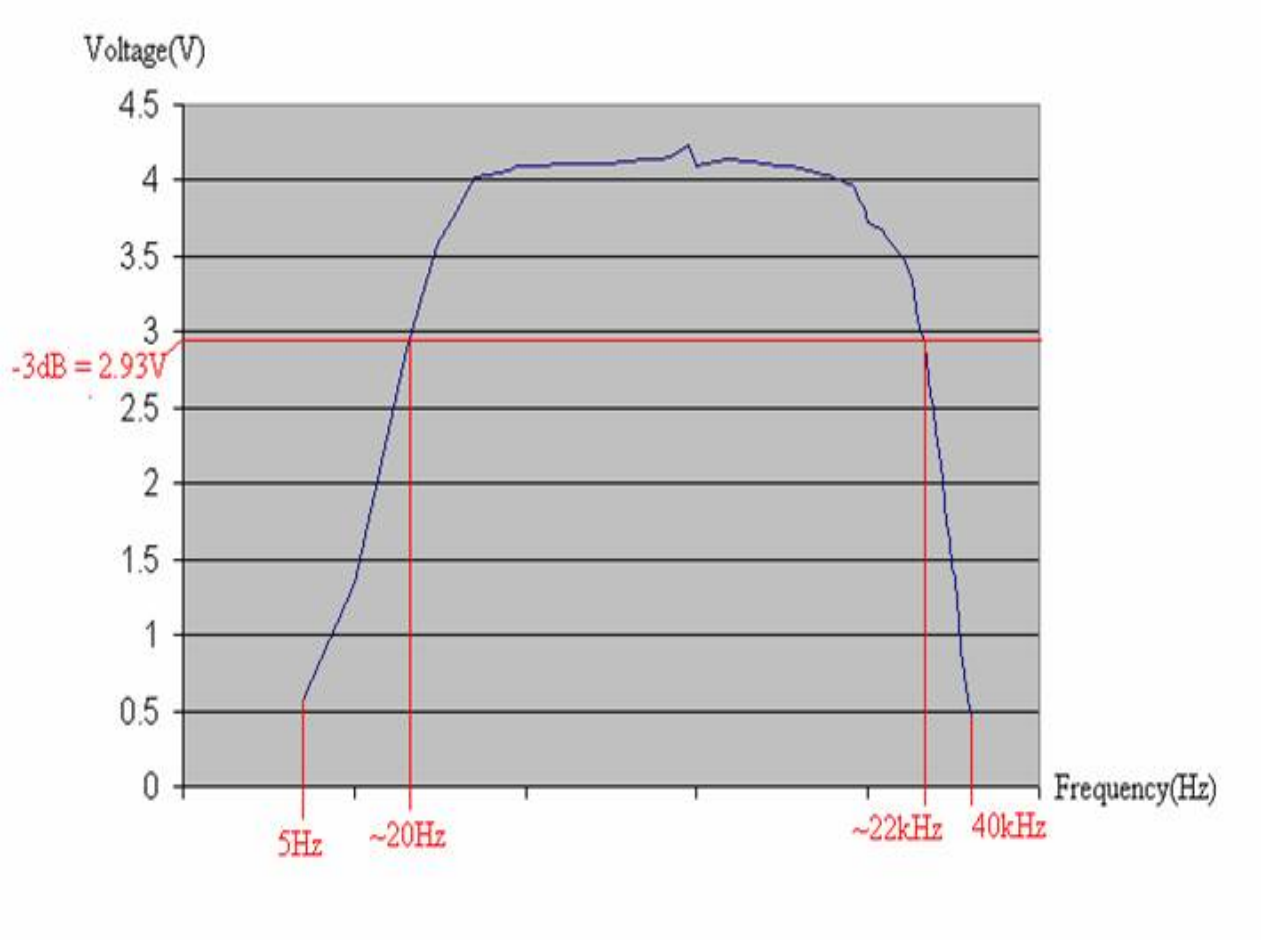
Voltage(V)
4.5
4
3.5
3
-3dB = 2.93V
2.5
2
1.5
1
0.5
0
Frequency(Hz)
5Hz
~20Hz
~22kHz
40kHz

Figure 4.8

The final testing connected the amplifier to the loudspeakers and the CD player. Then play a CD and listen the song. And careful to listen the sounds have any problem or not. The connection liked the below figure.

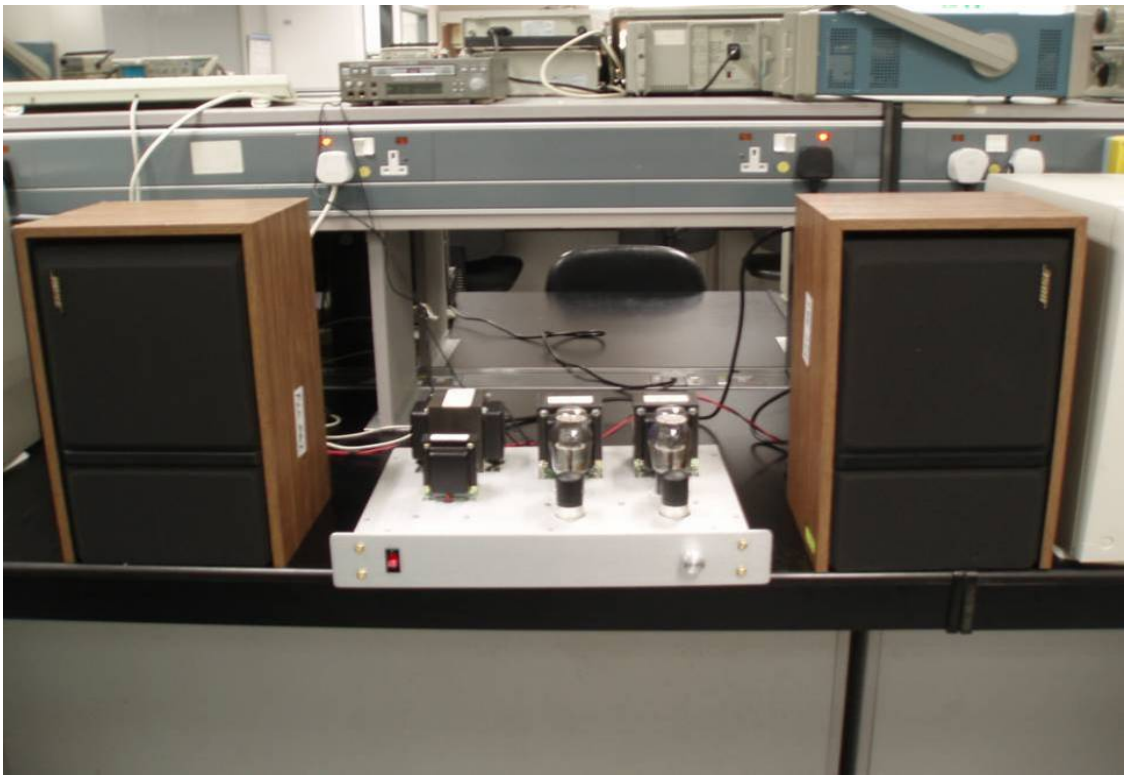

Figure 4.9

Chapter 5 Discussion

From the part of the testing and measurement I can observes that the output of the left channel is larger than the right channel. This is easy to observe when we force on the output waveform of the driver stage and power stage. The gain of the left driver stage is 55.8 but the gain of the right driver stage is 54.8. Also the output stage of the left channel is lager than right 0.2V. This effect will make the volume of one side is larger than other side.

The reason is the left and right channel components are not the same. Moreover each component has about 5% error, so the two channels have different value is very common.

Because of the difference is not very larger that will not have larger effect. When we want to reduce the problem the more accurate component needed. And the vacuum tubes can use match pair that the tube characteristics are same.

Chapter 6 Conclusion

Through this project I study the theory of the vacuum tube, amplifier circuit and advantage of the vacuum tube. Then start to design and build a single ended audio power amplifier. The testing and measurement also include in this project.

The testing and measurement parts are observes a little problem that is the output of left channel larger than the right channel. To solve this problem is need to use the more accurate components

Finally, I succeed to build the whole single ended audio power amplifier. This is mainly for the high output signals music player, such as CD, DVD, VCD players. And the amplifier can provide a good sound.

Reference

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2. Morgan Jones (1999). Valve Amplifiers
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4. http://www.vt4c.com/bb/
5. http://www.dwfearn.com/whytubes.htm
6. http://www.jacmusic.com/html/articles/ericbarbour/howavacuumtubeworks.html#basics
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9. http://en.wikipedia.org/wiki/Main_Page
10. http://www.aikenamps.com/SingleEnded.htm
11. http://www.av-forums.net/plus/index.php

Appendix

1. Data sheets of the C3M tube
2. Data sheets of the 6B4G tube