Vacuum Tube Amplifier

ECE 445 Design Document

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Group 1

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1. Introduction

1.1 Objective

Steve Guttenberg once stated: Most people listen to music in their cars, portable players, or $10 computer speakers. Audiophiles are the 1 percent still listening at home over a hi-fi [1]. Because of the expensive professional Hi-Fi audio system and the convenience of the smartphone, people hardly ever sit down in home, and quietly listen to the heavenly melody the nature brings to us.

The goal of this project is to build an affordable vacuum tube amplifier to lower the barrier for the people who would love to enter the “audiophile” aspect of life. Instead of normal solid state amplifier, we will build a vacuum tube based amplifier. The reason to use vacuum tubes is that although the transistor has a very low distortion level, it produces more odd harmonic distortions than the even ones, while the vacuum tubes produce more even harmonic distortion than the odd one, which human ear perceives as consonances other than dissonances [2].

1.2 Background

Music has been all around our life since we were born. We cannot imagine our life without music.

However, people usually do not care about the sound quality. Most of people, will only care about loudness. Statistics shown that most of people own Beats headphones or Apple Ear-pods [3], but the fidelity of those “elegant looking” headphones or earphones are not worth their price, since the frequency response of Ear-pods only range from 100 Hz to 10 kHz, which is way below human hearing range [4]. Also, the “Monster Beats by Dr. Dre Solo”, which has an exponential decay of its frequency response curve, will result in a huge imbalance between the bass and treble [5]. Through above discussion, we found that most commercial headphones and earphones that targeting most of the consumer will not give us a pleasant listening experience.

Thus we turned to the lean market that target to specific group of people called “audiophile”. We found most of the product have a specification that meet our standard, but the prices are way higher than people’s normal budget for audio systems. For example, MC275 2-Channel Vacuum Tube Amplifier from McIntosh will cost around 5,800 USD [6].

The above two reasons make people under average income decide not to buy expensive audio system, rather using Ear-pods instead. So we decide to design a entry level of vacuum tube amplifier that targets average income people, and let them can enjoy high quality music.

1.3 High-level requirements

- Vacuum Tube Amplifier must produce at least 70 dB of loudness level through speakers.
- The total cost of the device should not exceed $200.
- Vacuum Tube Amplifier must consume no more than 80 Watts of power.

2. Design

2.1 Block Diagram & Physical Design

In order to work, vacuum Tube Amplifier needs four operating components: Transformer, Rectifier, Voltage Amplification Stage and Power Amplification stage Shown in Fig. 01. The Source consists of two parts: Sound input and power of 110 V AC at 60 Hz. Voltage and power Transformers are used to step up and step down voltage. And Output Transformer has high input impedance and low output impedance to provide impedance matching to the speaker. Rectifier converted the different voltages to steady DC value. The Voltage and Power Amplification Circuits serves as amplification of input signals, where in tubes are biased to optimal operating point to ensure the maximum gain. The optimal gain can be found in the datasheet.

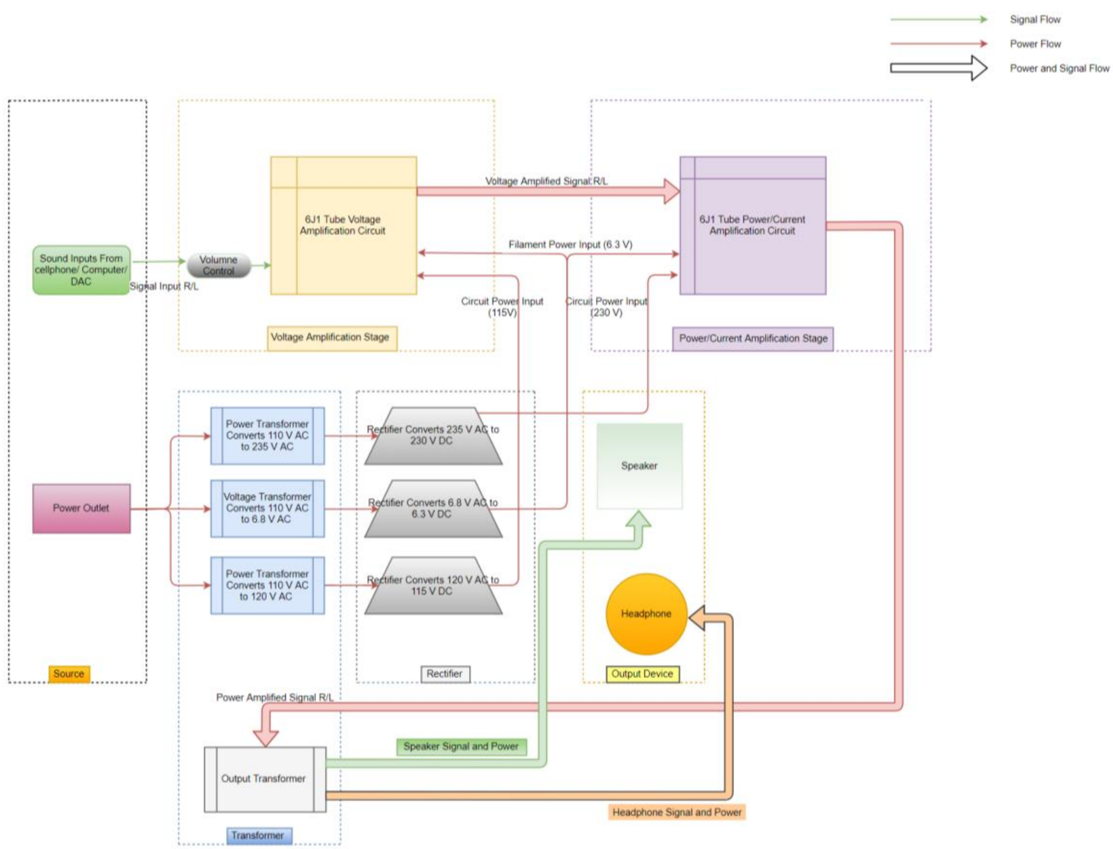

Fig. 01. Block Diagram

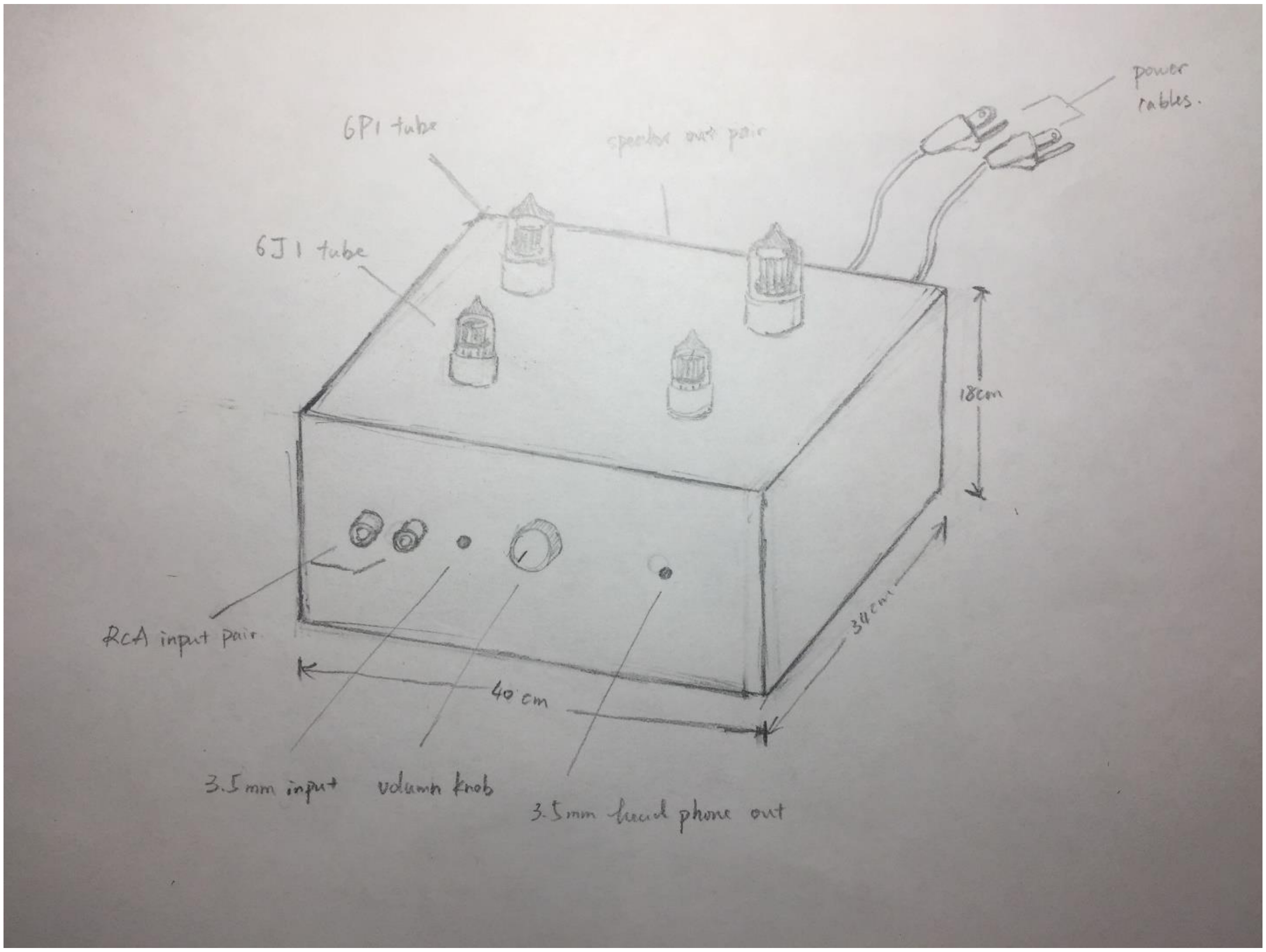

Fig. 02. Physical Diagram

2.2 Functional Overview

2.2.1 Analog Signal Inputs

We will use 3.5mm jack and as well as RCA pair as our audio inputs. This kinds of inputs are most common inputs for amplifiers, therefore we can offer maximized compatibility while lowering the total cost.

Requirements	Verification
1. The input side and connection side should be perfectly connected, the connection resistance should be less than 0.4 Ω.	1. A. Connect two terminals of multimeter to the input side and the connection side of the inputs jack respectively B. Measure the reading from multimeter to make sure it's below 0.4 Ω.
2. The switch should switch from one signal source to another signal sources well.	2. A. Connect two terminals of multimeter to the input side of 3.5 mm and the connection side of RCA jack respectively B. Measure the reading from multimeter to make sure it's open circuit.

2.2.2 Volume Control

We will use a fixed resistor in series with a variable resistor to make our volume control. Using the configuration as Fig. 03. We will get most of the voltage, ranging from 0 to 0.91 Vsig.

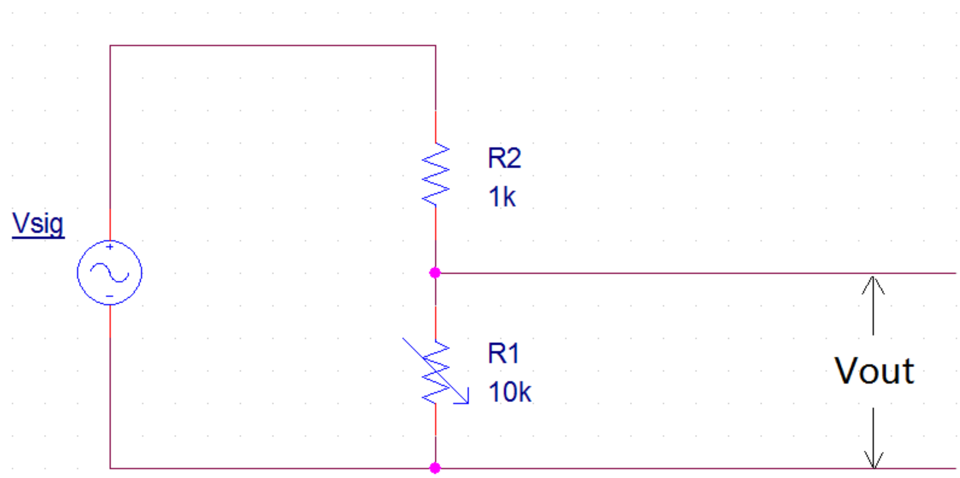

Fig. 03. Circuit Diagram Shows Volume Control Module

Requirements	Verification
1. The output voltage should be greater than 0.9 of the input voltage	1. A. Connect two terminals of function generator with peak to peak voltage equals 2 V. Connect 2 terminals of oscilloscope to the ends of the variable resistor. B. Measure the reading from oscilloscope to make sure it's greater than 1.80 V.

2.2.3 Rectifier circuit

We will have 3 rectification circuits. They will all have the same function that convert AC supply to DC supply. The only difference is that they will be fed with different voltages. For simplicity and cost effective, we will only use passive elements to design and build our rectifier circuit. Fig. 04 shows the circuit schematics.

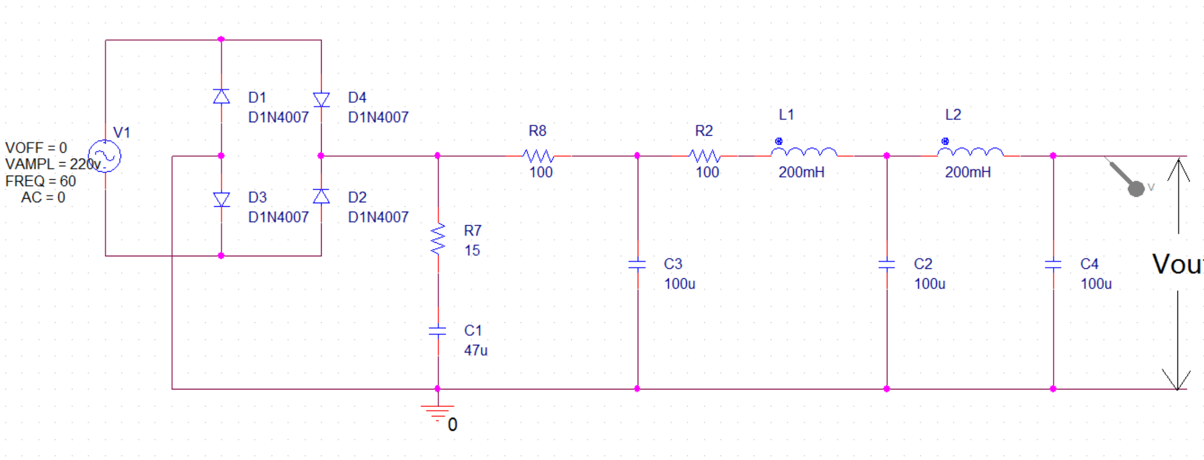

Fig. 04. Circuit Diagram of Rectifier

Requirements	Verification
1. The output voltages for 3 rectifiers should be at least 6.3 V, 120 V, and 230 V respectively.	1. A. Connect the input terminal to wall outlets. B. Connect the output terminal to multimeter. Then turn on the switch. C. Measure the reading from multimeter to make sure it's larger our planned value.
2. The ripple voltage at output stage should be less than 0.5% of the output DC voltage.	2. A. Connect the input terminal to wall outlets. Connect 2 terminals of oscilloscope to the output terminal of the 6.3 V rectifier. Then turn on the switch. B. Using oscilloscope to measure the ripple voltage, and make sure it's less than 0.5% Vout. C. Using simulation to determine the ripple voltage of 120 V and 230 V rectifiers.

2.2.4 Voltage Amplification Stage

We will use common cathode connection. We will also connect the pentode using triode connection.

From the datasheet (see Fig. 04 below), we found that the typical plate voltage (Vp) is 120 V, we want to operate in a linear region, thus we choose our plate current (Ip) is approx. 9 mA . Thus, we need to bias the grid to be -2.0 V. In other word, the cathode has a 2.0 V higher potential. Grounding the grid using a resistor of approx. 1 MΩ (The grid can be considered as open circuit, thus a large resistor can do the ground). To make the cathode 2.0 V higher than ground, we use another resistor Rk. The schematic is as Fig. 05. The value of the capacitor that in parallel with the cathode resistor is going to be tweaked to adjust the frequency response.

To determine Rk's value, we use Ohm's Law:

$$R_k = \frac{\mathrm{V}_k - 0}{I_p} = \frac{2.0}{0.0009} = 2222\Omega \qquad \text{eq. 1}$$

Once the operating point is confirmed, we can draw the small signal model, as Fig. 06. We need another parameter which is Rp to determine the voltage gain of this stage

$$g_m = \frac{\partial I_p}{\partial V_g} = -4.7 \times 10^{-4}\Omega^{-1} \qquad \text{eq. 2}$$

$$V_{out} = -g_m \times V_{gk} \times (r_p || R_p) \qquad \text{eq. 3}$$

And

$$r_p = \frac{\partial V_p}{\partial I_p} = \frac{120}{0.009} = 13333\Omega \qquad \text{eq. 4}$$

Thus,

$$\mu = g_m \times r_p || R_p = 13.33 || 45 \times 4.7 = 48 \qquad \text{eq. 5}$$

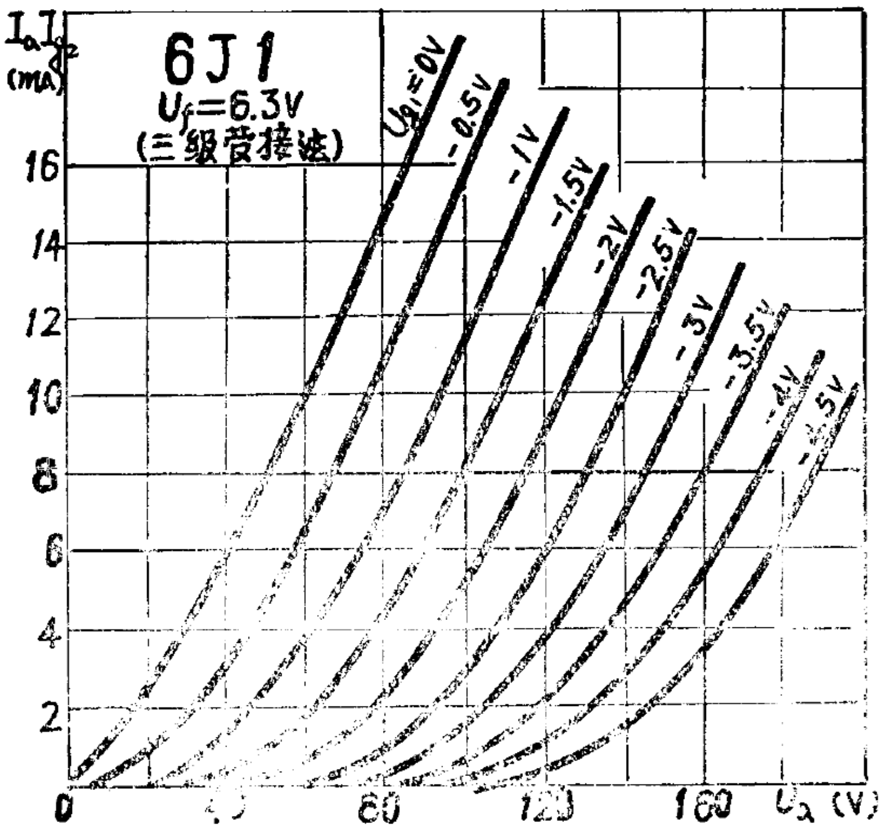

Fig. 05. I-V Curve of 6J1 Tube (From Datasheet).

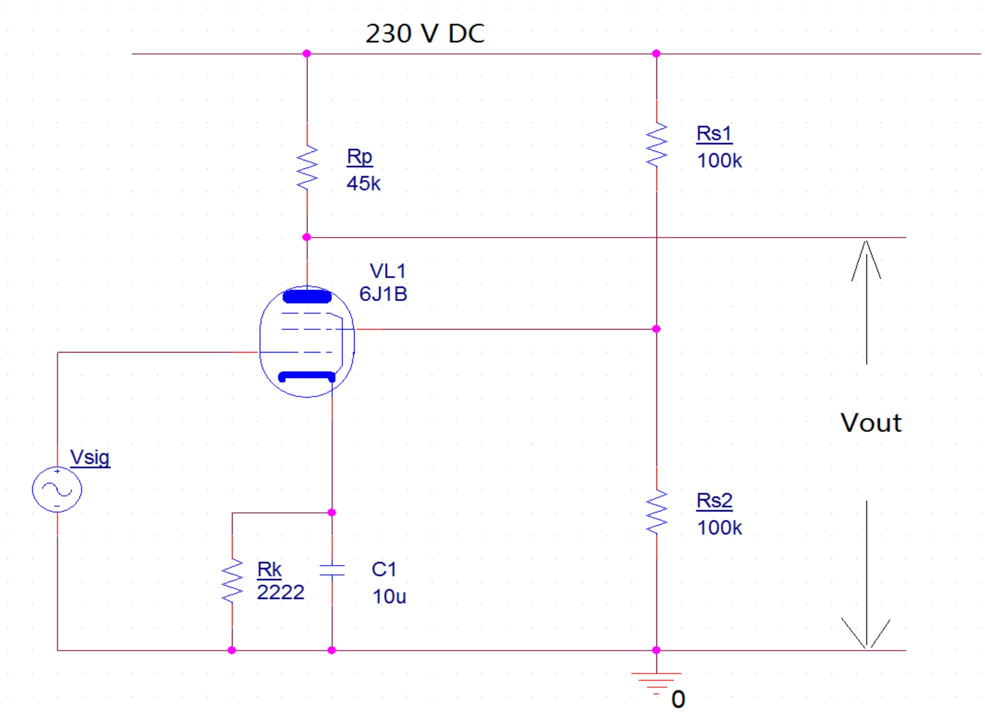

Fig. 06. Actual Circuit Diagram Consisting 6J1 Tube.

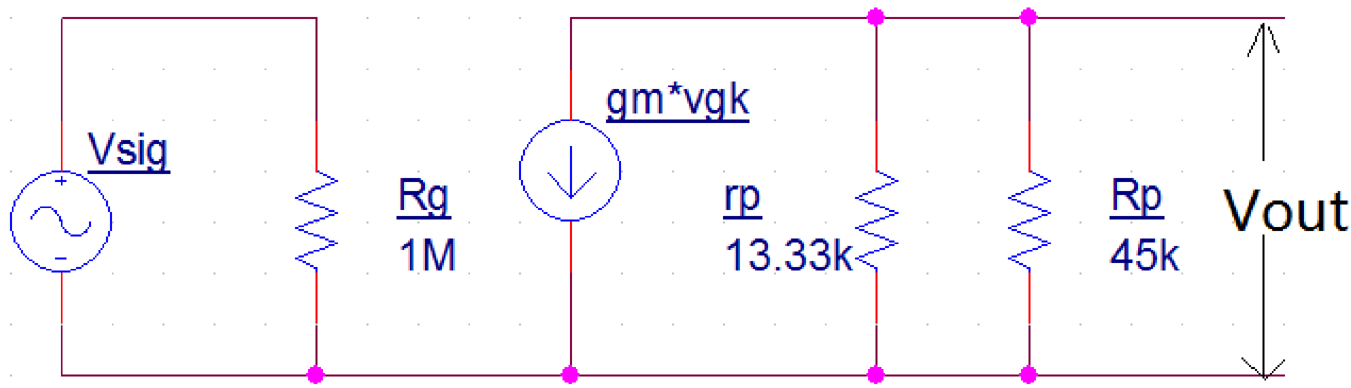

Fig. 07 Small Signal Model

Requirements	Verification
1. The voltage gain should be greater than 16.	1. A. Connect two terminals of function generator with peak to peak voltage equals 0.1 V to the input of the tube circuit. Connect 2 terminals of oscilloscope to the plate and ground. B. Measure the reading from oscilloscope to make sure the output waveform has a peak to peak voltage greater than 1.6 V.
2. The frequency response should be 30-19 kHz minimum	2. A. Connect two terminals of function generator with peak to peak voltage equals 1 V to the input of the tube circuit. Connect 2 terminals of oscilloscope to the plate and ground. B. Sweep the frequency of function generator from 20 to 20 kHz, manually record the output waveform amplitude. C. Plot the data, make sure the 30-19 kHz band is at most 3 dB attenuated.

3. The total harmonic distortion (THD) should be less than 1% @ 1 kHz.	3. A. Connect two terminals of function generator with peak to peak voltage equals 1 V to the input of the tube circuit. Connect 2 terminals of oscilloscope to the plate and ground. B. Set the frequency of function generator to 1 kHz, Using the tools on oscilloscope to find the THD.

2.2.5 Power Amplification Stage

In power amplification stage, we will also use common cathode connection, but the screen will be connect to 230 V DC power supply. In this stage, we choose our operating point to be such that plate voltage is 200 V and plate current is 115 mA. So we will bias our 6P1 tube's grid to 0 V, in other words, no bias. From the datasheet (Fig. 07.), we found trans-conductance is 4.9 mA/V. The circuit diagram is as Fig. 08. The amplified signals will then go through output transformer and deliver electrical signal and power to the speaker.

Again we calculate the dynamic plate resistance (rp)

$$r_p = \frac{\partial V_p}{\partial I_p} = \frac{200}{0.115 - 0.100} = 13333\Omega \quad \text{eq. 6}$$

Using the above condition

$$\mu = g_m \times r_p || R_p = 13.33 || 5 \times 4.9 = 17.8 \quad \text{eq. 7}$$

The final voltage across the speaker can be calculated by

$$V_{out} = V_{in} \times \frac{\mu}{\sqrt{\frac{5000}{8}}} = V_{in} \times 48 \times \frac{17.8}{25} = 34.2\ V_{in} \quad \text{eq. 8}$$

And this is what a typical amplifier should look like [7].

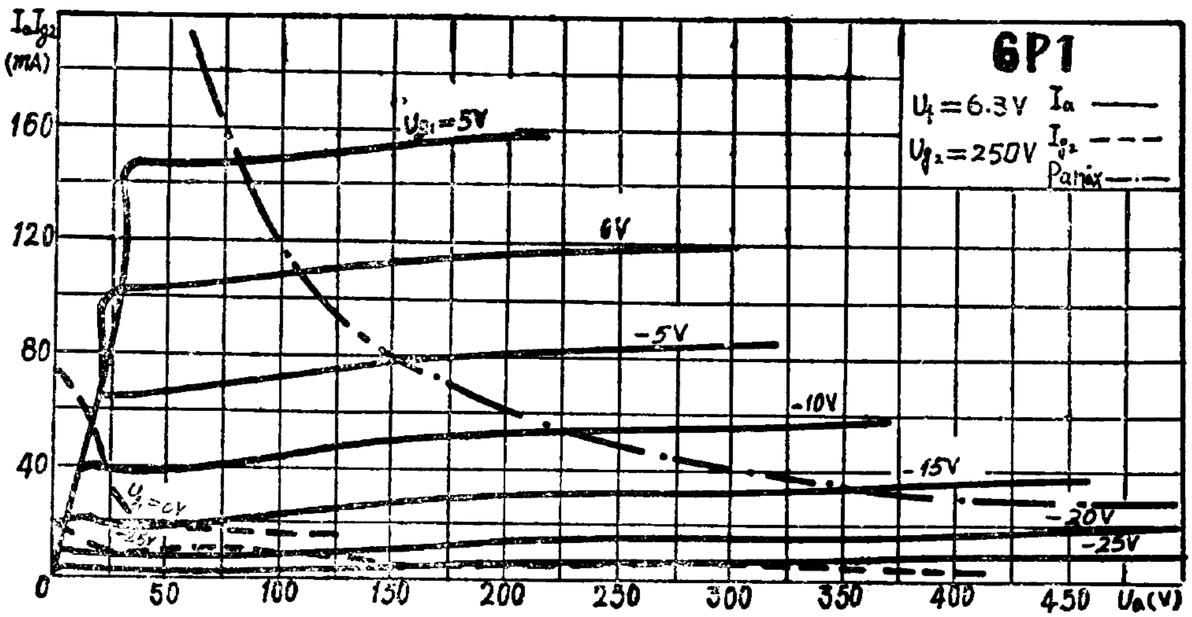

Fig. 08. I-V Curve from 6P1 Datasheet

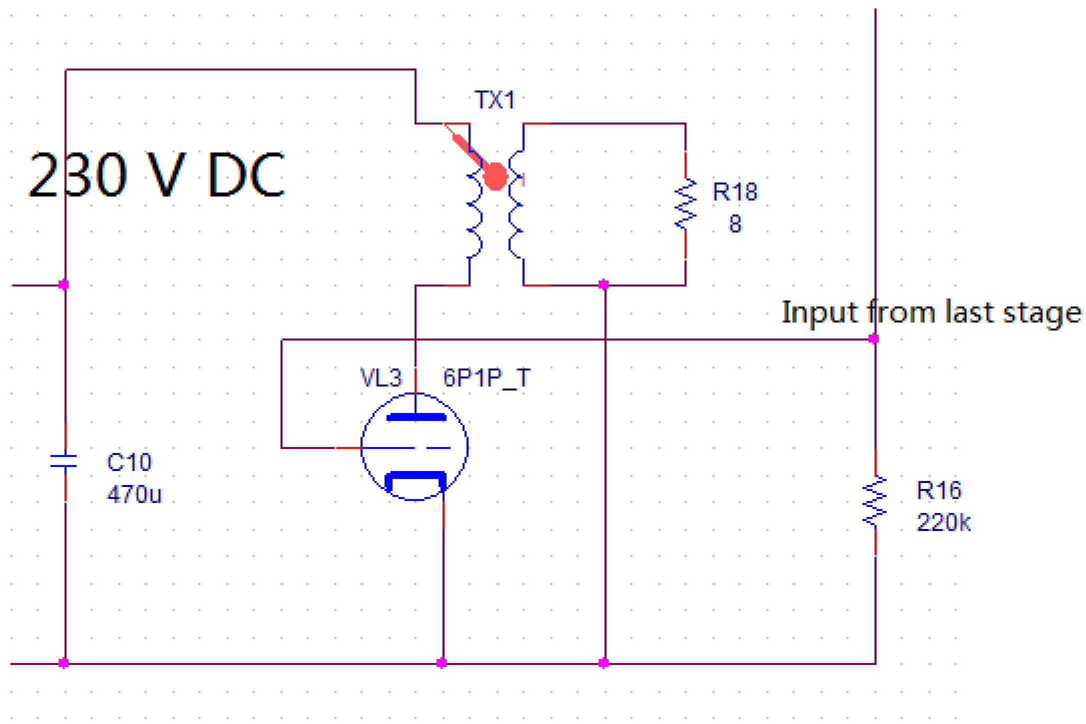

Fig. 09. Circuit Diagram Showing the Power Amp Stage

Requirements	Verification
1. The voltage gain should be greater than 10.	1. A. Connect two terminals of function generator with peak to peak voltage equals 0.1 V to the input of the tube circuit. Connect 2 terminals of oscilloscope to the 2 terminal of primary coil. B. Connect 2 terminal of secondary coil with a 8 Ohm resistor. C. Measure the reading from oscilloscope to make sure the output waveform has a peak to peak voltage greater than 1.0 V.
2. The frequency response should be 40-18.5 kHz minimum	2. A. Connect two terminals of function generator with peak to peak voltage equals 1 V to the input of the tube circuit. Connect 2 terminals of oscilloscope to the plate and ground. B. Sweep the frequency of function generator from 20 to 20 kHz, manually record the output waveform amplitude. C. Plot the data, make sure the 40-18.5 kHz band is at most 3 dB attenuated.
3. The total harmonic distortion (THD) should be less than 3% @ 1 kHz.	3. A. Connect two terminals of function generator with peak to peak voltage equals 1 V to the input of the tube circuit. Connect 2 terminals of oscilloscope to the plate and ground. B. Set the frequency of function generator to 1 kHz, Using the tools on oscilloscope to find the THD.

Our overall circuit schematic will be as Fig. 09.

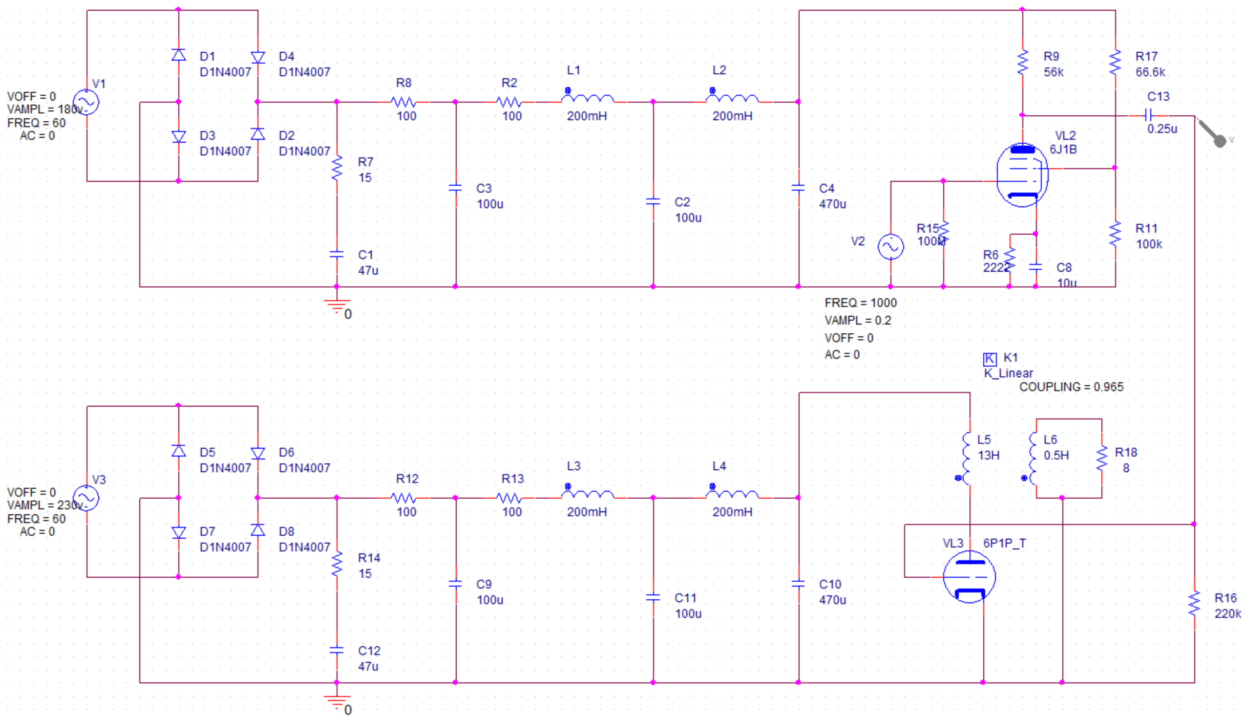

Fig. 10. Overall Circuit Diagram

2.3 Tolerance Analysis

The varying resistances and capacitances will result in a different DC voltage after rectifier, it could also cause a different operating points for the tubes. The result power gain from the system would defer. Lucky, due to the linearity around the operating point, our amplification signal still obtain the same exact waveform with some unavoidable distortions. As a result, the overall power gain in the left and right channel would differ by a mount of:

$$\Delta A_{left} = \frac{\partial A_{left}}{\partial g_{m-6J1}} * \Delta g_{m1} + \frac{\partial A_{left}}{\partial R_{Rout-6J1}} * R_{out-6J1} + \frac{\partial A_{left}}{\partial g_{m-6P1}} * \Delta g_{m-6P1} + \frac{\partial A_{left}}{\partial R_{Rout-6P1}} * R_{out-6P1} \leq \pm 0.042\ A_{left}$$

eq. 9

$$\Delta A_{right} = \frac{\partial A_{right}}{\partial g_{m-6J1}} * \Delta g_{m1} + \frac{\partial A_{right}}{\partial R_{Rout-6J1}} * R_{out-6J1} + \frac{\partial A_{right}}{\partial g_{m-6P1}} * \Delta g_{m-6P1} + \frac{\partial A_{right}}{\partial R_{Rout-6P1}} * R_{out-6P1} \leq \pm 0.042\ A_{right}$$

eq. 10

The Worst-case mismatch in the left and right channel would be:

$$\frac{\frac{A_{left}+\Delta A_{left}}{A_{right}-\Delta A_{right}}-\frac{A_{left}}{A_{right}}}{\frac{A_{left}}{A_{right}}} = 8.77\% \qquad \text{eq. 11}$$

However, the output impedance of tube might not match input impedance of an output transformer. Due to that, the frequency response of output stage might not be ideal. And the power transformer would also differ.

The main tolerance we must maintain is the frequency response of power amplify stage and impedance matching between output resistance of tube and impedance of transformer's primary coil.
We can measure the output and input impedance of the output transformer in 4 ohm configuration, since AC resistance cannot be calculated easily, we use DC resistance as a reference.

Speaker mismatch can be estimated as:

$$\frac{\frac{7.6}{7.5}-1}{1} = 1.3\% \qquad \text{eq. 12}$$

Speaker mismatch can be estimated as:

$$\frac{\frac{1.9}{1.8}-1}{1} = 5.6\% \qquad \text{eq. 13}$$

From this values above, we are able to estimate the power transfer given the power to be to best match the speakers:

	Right Channel		Left Channel	
Case	Speaker Resistance	Transformer Resistance	Speaker Resistance	Transformer Resistance
1	3.8	3.75	3.8	3.6
2	3.8	3.75	3.6	3.8
3	3.75	3.8	3.8	3.6
4	3.75	3.8	3.6	3.8

	Power		Mismatch%
Case	To left channel	To right Channel	
1	5.135	5.033	2.03
2	4.865	5.033	-3.34
3	5.135	4.967	3.38
4	4.868	4.967	-2.05

We can get a minimum of 2% mismatch in the power transfer in right and left channel. We can also use these combination with the left and right channel with the left and right channel gain to further balance the stereo channel.

3. Cost and Schedule

3.1 Cost

The labor cost per hour is estimated to be $50 per person, and the average time into development is estimated to be 8 hours per week. The total labor cost can be calculated as:

$$\$50\ hour^{-1} \times 8\,\frac{\text{hour}}{\text{week}} \times 10\,\frac{week}{person} \times 2\ person = \$\ 8000 \qquad \text{eq. 14}$$

The cost of components is estimated to be:

Component	Cost (Prototype)	Cost (Massive production)
Chassis	$30.9	$8.74
Different values of Capacitors, Resistors and Inductors	$38	$0.73
6J1 Tube*2	$5	$1.33
6P1 Tube*2	$10	$3.0
Tube sockets *4	$3	$0.5
Output Transformer*2	$12.7	$6.36
One voltage and two power transformers	$62.7	$27.3
Inputs and outputs Connectors	$33.2	$6.88
Interconnect wires	$20.4	$3.26
Total	$215.9	$58.1

We add component cost with labor cost:

$215.9 + $8000 = $8215. Which will be our total cost of human resources and prototype.

3.2 Schedule

Since Simulation are almost done at the time we wrote this design document and it is against the safety rules to work on high voltages alone, we will both work on the circuit soldering and testing together as a group.

Feb 12	Design, simulate all rectifier circuit. Build as much as we can.
Feb 19	Design, simulate preamp and power amp circuit. Modify the design if needed. Maximize the theoretical gain in each stage in simulation.
Feb 26	Soldering of Rectifier Circuit. Capture the waveform of three rectifier output voltages by the oscilloscope and perform open circuit test and load test.
Mar 5	Soldering of Voltage Amplification Circuit (one channel). Capture the waveform of output voltage and calculate the voltage gain.
Mar 12	Soldering of Power/Current Amplification Circuit (one channel) and output transformer connection. After safety testing hook it up with 4 ohm resistor to calculate the delivered power.
Mar 19	Building of the Speaker Chamber, Amplifier chassis and build the impedance matching circuit for headphones.
Mar 26	First systematic testing and Measure the frequency response of Speaker (one channel), modify the circuit to keep frequency response flat at 20-20kHz.
April 2	Soldering and testing of the other channel.
April 9	Match the loudness level on both channel and frequency response by tweaking the circuit
April 16	Final debug and testing

4. Ethics and Safety

Since our project involves with voltages that are higher than 200 volts, many components must endure the high voltages. First of all, we need to make sure we did not overload our transformers. The rating of step up 110 volt to 220 volt transformer is 1000VA, thus the maximum current on the high side should not exceed 4.54 A. For the 110 Volt to 6.8 volt transformer, the rating is 50 watts, thus the maximum current on the low side should not exceed 7.35 A. The 110 volt to 180 volt transformer has a rating of 500 VA, thus the current on high side has be limited within 2.77 A.

The rectifier circuit handles a substantial power conversions, which is estimated to be 80 W, thus the rated voltages capacitors are ideally to have more than twice the actual voltage in the circuit to prevent damage to the component. Also, we choose to use resistors that can handle a maximum power of 2 W to maximize the endurance while keep the cost down. If the simulation results in a higher power consumption than 2W, we can either use a combination of resistors instead or make changes to the circuit. The diode are carefully choose to have a forward current of 1 A [8] tolerance and the repetitive reverse breakdown voltage is 1000V, which is lower than any of the transformer values.

In the tube amplifier portion, the tubes are the major power consumption, the circuit design needs to ensure the maximum ratings in currents, voltages and power are not exceeded.

Taking the whole product perspective, according to the first ethic guide of IEEE 7.8 [9], we need to make sure that we will not expose any metal contacts that are powered on to keep ourselves and potential customers safe. A chassis will be utilized to prevent exposure from the high voltages part of the circuit. And we will use insulation gloves if needed. For our project, the circuit part of amplifier must be sealed with good ventilation to prevent circuit and tube overheating. If the passive cooling is not sufficient enough, additional outtake and intake fans will be added.

We will follow all regulations and rules of the senior design lab, in specific:

1. We will never leave any circuits unattended that might cause electric shock or scald.
2. We will always work in pairs.
3. We will make sure that all high voltage lines and equipment are properly insulated and without flaw before use.
4. We will never power on a circuit that’s not finished or still in progress.
5. We will use insulating gloves if we are dealing with high voltages.
6. We will dispose broken tubes properly.

References

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[2] Templeton, J., 'Tube vs Solid-State - Why Do Tubes Sound Better? - thetubestore Blog', 2016. [online]. Available at: http://blog.thetubestore.com/tube-vs-solid-state-why-do-tubes-sound-better/ [Accessed 22 Feb. 2018].

[3] Potuck, M. and Potuck, M., 'Report: Apple's AirPods and wireless Beats take 40% of all recent Bluetooth headphone sales', 2017. [online]. Available at: https://9to5mac.com/2017/01/11/apples-airpods-and-wireless-beats-take-40-of-all-recent-bluetooth-headphone-sales/ [Accessed 22 Feb. 2018].

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[6] McIntoshLabs, 'McIntosh MC275 Vacuum Tube Amplifier', 2018. [online]. Available at: http://www.mcintoshlabs.com/us/Products/pages/ProDuct Details.aspx?CatId=amplifiers&ProductId=MC275B [Accessed 22 Feb. 2018].

[7] Diyaudio.com, 'Typical gain for a power amp - diyAudio', 2012. [online]. Available at: http://www.diyaudio.com/forums/solid-state/205825-typical-gain-power-amp.html [Accessed 23 Feb. 2018].

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[9] Ieee.org, 'IEEE Code of Ethics', 2018. [online]. Available at: https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed 6 Feb.

2018].

Relevant Datasheets

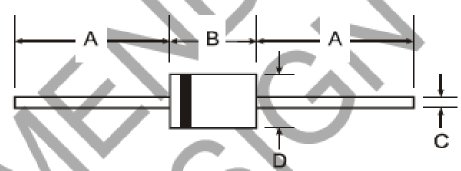
1N4007 Diodes

NOT RECOMMENDED FOR NEW DESIGN
USE S1A-S1M series

1N4001 - 1N4007
1.0A RECTIFIER

Features

- Diffused Junction
- High Current Capability and Low Forward Voltage Drop
- Surge Overload Rating to 30A Peak
- Low Reverse Leakage Current
- **Lead Free Finish, RoHS Compliant (Note 3)**



Dim	DO-41 Plastic	
	Min	Max
A	25.40	—
B	4.06	5.21
C	0.71	0.864
D	2.00	2.72
All Dimensions in mm		

Mechanical Data

- Case: DO-41
- Case Material: Molded Plastic. UL Flammability Classification Rating 94V-0
- Moisture Sensitivity: Level 1 per J-STD-020D
- Terminals: Finish - Bright Tin. Plated Leads Solderable per MIL-STD-202, Method 208
- Polarity: Cathode Band
- Ordering Information: See Page 2
- Marking: Type Number
- Weight: 0.30 grams (Approximate)

Maximum Ratings and Electrical Characteristics (@T_A = +25°C unless otherwise specified.)

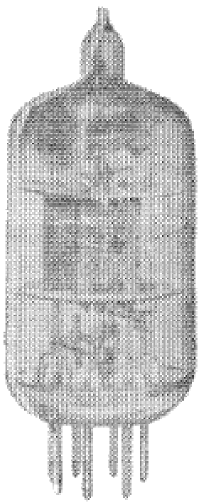
Single phase, half wave, 60Hz, resistive or inductive load.
For capacitive load, derate current by 20%.

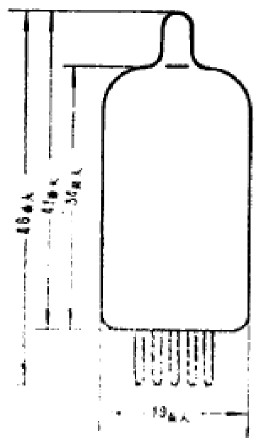
<table>
<tr><th>Characteristic</th><th>Symbol</th><th>1N4001</th><th>1N4002</th><th>1N4003</th><th>1N4004</th><th>1N4005</th><th>1N4006</th><th>1N4007</th><th>Unit</th></tr>
<tr><td>Peak Repetitive Reverse Voltage
Working Peak Reverse Voltage
DC Blocking Voltage</td><td>V_{RRM}
V_{RWM}
V_R</td><td>50</td><td>100</td><td>200</td><td>400</td><td>600</td><td>800</td><td>1000</td><td>V</td></tr>
<tr><td>RMS Reverse Voltage</td><td>$V_{R(RMS)}$</td><td>35</td><td>70</td><td>140</td><td>280</td><td>420</td><td>560</td><td>700</td><td>V</td></tr>
<tr><td>Average Rectified Output Current (Note 1) @ T_A =+75°C</td><td>I_O</td><td colspan="7">1.0</td><td>A</td></tr>
<tr><td>Non-Repetitive Peak Forward Surge Current 8.3ms
Single Half Sine-Wave Superimposed on Rated Load</td><td>I_{FSM}</td><td colspan="7">30</td><td>A</td></tr>
<tr><td>Forward Voltage @ I_F = 1.0A</td><td>V_{FM}</td><td colspan="7">1.0</td><td>V</td></tr>
<tr><td>Peak Reverse Current @T_A = +25°C
at Rated DC Blocking Voltage @ T_A = +100°C</td><td>I_{RM}</td><td colspan="7">5.0
50</td><td>µA</td></tr>
<tr><td>Typical Junction Capacitance (Note 2)</td><td>C_j</td><td colspan="4">15</td><td colspan="3">8</td><td>pF</td></tr>
<tr><td>Typical Thermal Resistance Junction to Ambient</td><td>$R_{\theta JA}$</td><td colspan="7">100</td><td>K/W</td></tr>
<tr><td>Maximum DC Blocking Voltage Temperature</td><td>T_A</td><td colspan="7">+150</td><td>°C</td></tr>
<tr><td>Operating and Storage Temperature Range</td><td>T_J, T_{STG}</td><td colspan="7">-65 to +150</td><td>°C</td></tr>
</table>

Notes:
1. Leads maintained at ambient temperature at a distance of 9.5mm from the case.
2. Measured at 1.0 MHz and applied reverse voltage of 4.0V DC.
3. EU Directive 2002/95/EC (RoHS). All applicable RoHS exemptions applied, see EU Directive 2002/95/EC Annex Notes.

6J1 Tube

6 J 1 型　　锐截式高频五极管





类　　型：旁热式氧化物阴极

用　　途：高频电压放大

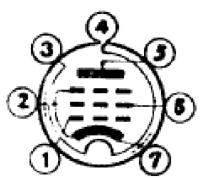
主要电参数

灯丝电压(～或－)	6.3 V
灯丝电流	170±20mV
阳极电压(－)	120 V
第二栅极电压(－)	120 V
阴极电路自给栅偏压电阻	200 Ω
阳极电流	$7.35^{+3.85}_{-2.75}$ mA
第二栅电流	不大于3.2mA
跨导	5.1±1.4 mA/v
内阻	0.1—1.1MΩ
输入电阻	12—25KΩ

极　间　电　容

输入电容	$4.3^{+0.5}_{-0.4}$ PF

电极和管脚连接图



1—第一栅极

2—阴极、第三栅极和屏蔽

3—灯丝

4—灯丝

5—阳极

6—第二栅极

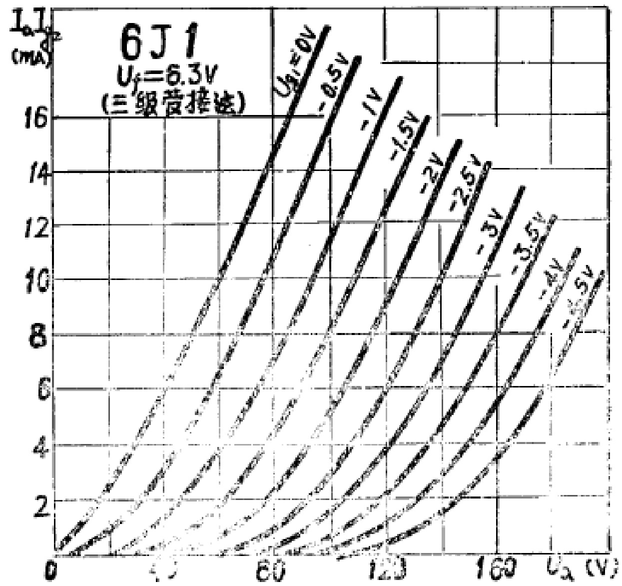
7—阴极、第三栅极和屏蔽

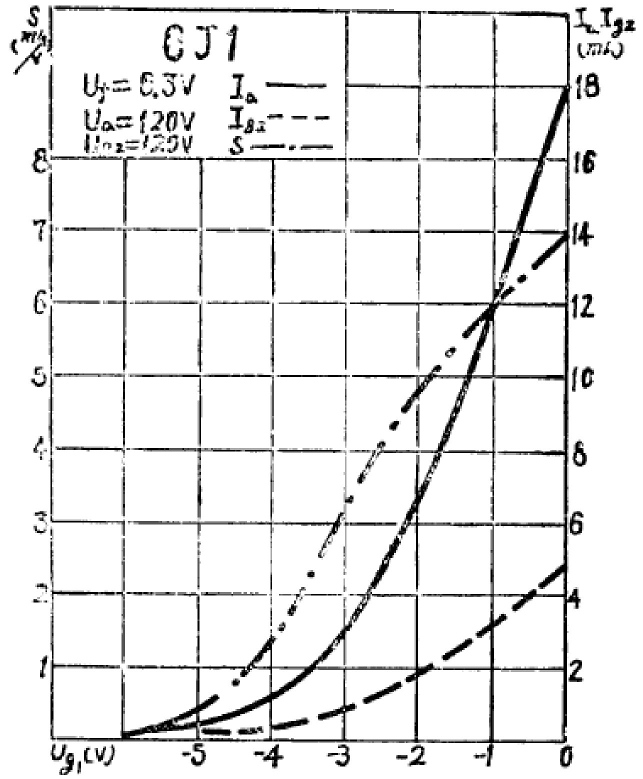
输出电容	2.35±0.25PF
过渡电容	不大于0.02PF
阴极灯丝间电容	不大于4.6PF

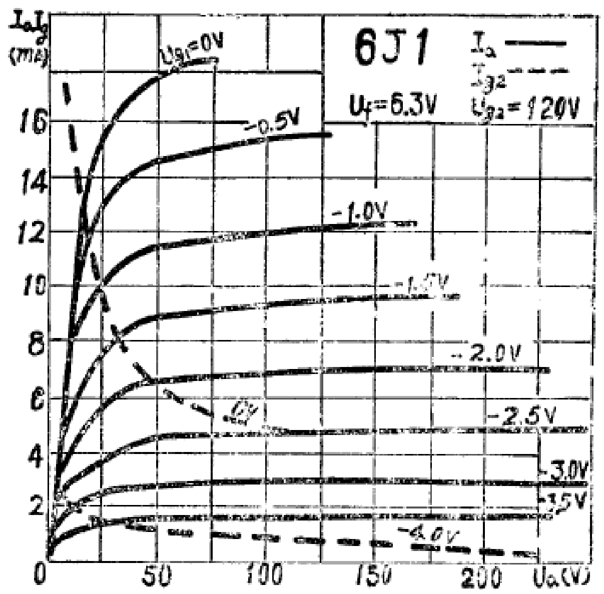
（电容数值系在屏蔽内测量）

极限运用数据

最大灯丝电压（～或－）	6.9 V
最小灯丝电压（～或－）	5.7 V
最大阳极电压（－）	200 V
最大第二栅极电压（－）	150 V
最大阴极电流	20mA
最大阳极损耗功率	1.8W
最大第二栅极损耗功率	0.55W
最大阴极与灯丝间电压	±120 V
最大第一栅极电路电阻	1MΩ



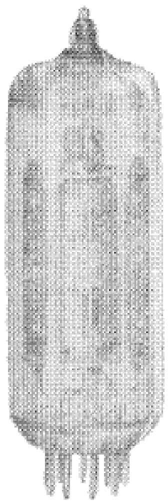

6J1
U_f = 6,3V
U_a = 120V
U_{g2} = 120V
I_a
I_{g2}
S
S (mA/V)
I_a, I_{g2} (mA)
U_{g1} (V)
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
2
4
6
8
10
12
14
16
18

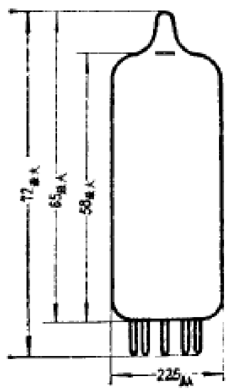


$I_a I_g$ (mA)
U_{g1}=0V
-0.5V
-1.0V
-2.0V
-2.5V
-3.0V
-4.0V
6J1
I_a
I_{g2}
U_f=6.3V
U_{g2}=120V
16
14
12
10
8
6
4
2
0
50
100
150
200
Ua(V)

6P1 Tube

6 P 1 型　输出束射四极管





类　　型：旁热式氧化物阴极

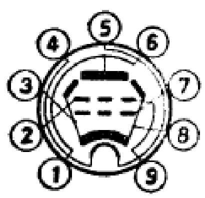
用　　途：低频功率放大

主 要 电 参 数

灯丝电压(～或－)	6.3 V
灯丝电流	500±50mA
阳极电压(－)	250 V
阳极电流	44±11mA
第一栅极电压(－)	－12.5 V
第二栅极电压(－)	250 V
第二栅极电流：	
静态时	不大于 7mA
动态时	不大于12mA
跨导	4.9mA/v
内阻	42.5KΩ
输出功率	不小于3.8W

电极和管脚连接图

1—阳极
2—第二栅极
3—阴极和束射屏
4—灯丝
5—灯丝



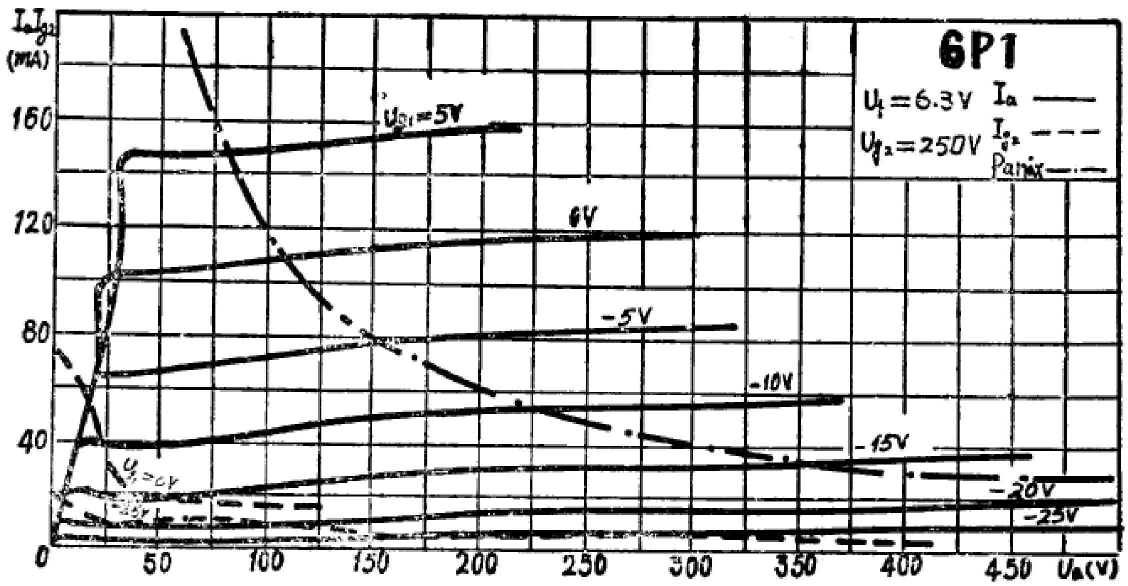
6—阳极
7—第一栅极
8—阴极和束射屏
9—第二栅极

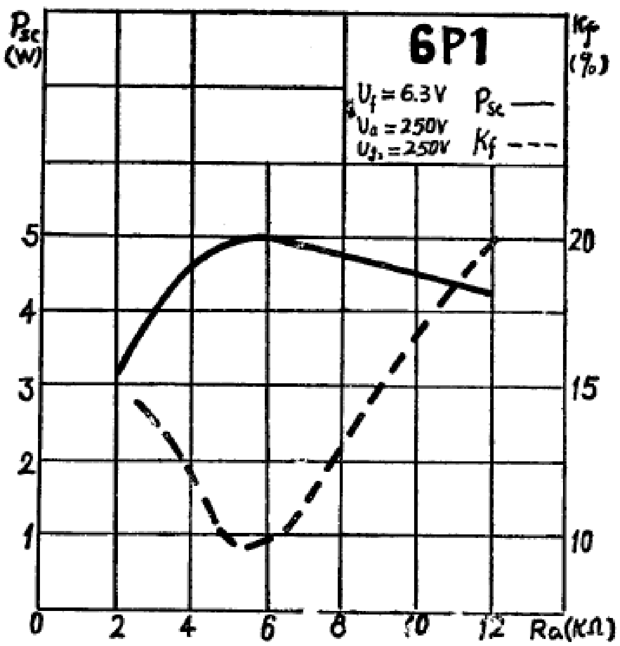
极 间 电 容

输入电容	8PF
输出电容	5PF
过渡电容	不大于0.9PF

极限运用数据

最大灯丝电压(～或－)	6.9 V
最小灯丝电压(～或－)	5.7 V
最大阳极电压(－)	250 V
最大第二栅极电压(－)	250 V
最大阳极损耗功率	12W
最大第二栅极损耗功率	2.5W
最大阴极电流	70mA
最大阴极和灯丝间电压(－)	±100 V


6P1
U_f=6.3V I_a
U_{g2}=250V I_{g2}
Pamax
I_aI_{g2} (mA)
160
120
80
40
0
50
100
150
200
250
300
350
400
450
U_a(V)
U_{g1}=5V
6V
-5V
-10V
-15V
-20V
-25V



6P1
P_{sc} (W)
K_f (%)
$U_f = 6.3V$
$U_a = 250V$
$U_{g_2} = 250V$
P_{sc} ——
K_f - - -
5
4
3
2
1
20
15
10
0
2
4
6
8
10
12
Ra(KΩ)