Sergejs Popovs

Modern Vacuum Tube Amplifier

VFD as a triode

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Abstract

The goal of this thesis is to apply knowledge of analogue circuits to demonstrate performance of VFD based triode Nutube designed by Korg. After reading this material, the user is able to understand advantages and disadvantages of this component and further development problems.

This study includes information of vacuum tubes history and circuit design, theory of amplifiers design and audio measurements methods, which can be useful for further work of audio engineers. Study discusses the main principles of amplification of signal in the low frequency range (of audible frequency).

The result of the project is an amplifiers based on Nutube 6p1 and its measurements which will demonstrate efficiency and benefits of this component and analysis of future perspectives of the device.

The prime goal of the project was achieved successfully. Four amplifiers for different purposes was designed and measured. Modern VFD vacuum tube demonstrated itself as a tube which can provide “tube sound” with low supply voltages. However, there are problems with Nutube 6p1 which makes it useless in audio systems with high fidelity.

Keywords	Audio, Low Frequency, THD, Noise, Vacuum tube, Circuit design, PCB design

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Contents

Abbreviations

Hi-Fi - High Fidelity

VFD - Vacuum Fluorescent Display

dB - Decibels

Hz - Hertz

PCB - Printed Circuit Board

SNR - Signal-to-Noise Ratio

JFET - Junction Gate Field-Effect Transistor

DC - Direct Current

NF - Noise Figure

IC - Integrated Circuit

THD - Total Harmonic Distorti

1 Introduction

In the beginning of the third millennium, not a lot of people remember that in the history of electronic devices vacuum tubes was one of the most important components. It was used in wide range of devices such as radio, TVs, telephone networks and even computers.

In 1950s vacuum tubes started to lose position on the market because semiconductors were introduced. Since then there was no much development in this field. They were still used in the military sector, microwave devices and audio equipment.

In 2014, a company called KORG presented new vacuum tube which has same advantages as a normal vacuum tube but got a new design and fixed problems of lifetime, power consumption and size. These disadvantages have removed tubes from this field and they were replaced by solid state components.

The goal of this project is to investigate characteristics of this component, develop an amplifier, explore can it be used in HiFi equipment and based on results find possible applications where it will suit.

1.1 A Brief History

In the world's history vacuum tubes played a pivotal role in many events and changed everyday life significantly. History of vacuum tubes started in the middle of 19^{th} century.

1855 - Geissler tube was invented in Germany by Heinrich Geissler. It was not vacuumed tube but evacuated gas discharge tube. The pressure inside of them vary from 40 to 0.03mmHg and it gives different visual effects. It was used to demonstrate the principles of electrical glow discharge. [1]

1875 - Photoelectric cell was introduced. It was vacuum or gas-filled tube which was sensitive to the light. It was used for the long term in the different application until photo resistors were invented. [3]

1897 - CRT oscilloscope was created. It consists of Braun Tube which was used in 1907 by Boris Rosing to display geometric shapes on the screen and it was the start of television and radar tubes. [3]

1904 - 'Fleming Valve' was invented by John Ambrose Fleming. It is first practical electron tube and diode as well. IEEE called it as "*one of the most important developments* *in the history of electronics*". It was used to rectify high-frequency oscillations and thus detect wireless signals. [2]

1906 - invented the triode. In the beginning, it was called audion. It was the first device which could amplify the signal. Name triode is coming from its structure, consisting of three electrodes – plate, the filament (also known as anode and cathode) and a grid. [2]

1926 - Hull and Williams co-created the tetrode. It was triode with one additional grid. This tubes had greater amplification coefficient and greater input impedance, but they didn't get popular because of decreasing of the quality of the signal, due to secondary emission from the anode to screen-grid. The Same year was introduced pentode, by Philips and it could amplify power without any distortion. [3]

1938 - Klystron tube was developed by Americans Russell and Sigurd Varian. It is devices which can amplify signals from radio frequencies up to microwave frequencies. It is used even nowadays because it can produce more power on the high frequencies than solid state microwave can do. [3]

1.2 Tubes in Audio Equipment

As part of electronics field, audio equipment was influenced by valves (vacuum tubes in British English) a lot. It is also called low-frequency devices. First audio amplifiers were massive and used only in public address systems and movie theatres. In course of time, they became smaller and affordable.

In 1927 first portable amplifiers came to the market. They had bad quality and didn't have any tune control. In that time guitars got more and more popular and musicians wanted to get loud sound from their instruments. This way guitar amplifier's market was formed. In this year's main structure of amplifiers was stated. It consists of pre-amplifier, control block and power amplifier.

In the 1970s, solid state components started to take over. Transistor amplifiers became cheaper, smaller. They started to develop very fast. Since 1980s mid-priced guitar amplifiers were usually using solid-state components. High-end amplifiers were using tubes because most of the musicians didn't like "transistor sound" and they were telling that tube amps has "warm tube sound" and more natural distortion effect which used by rock band guitar players.

Nowadays, most of HiFi equipment is based on transistors, but musicians and audio recording companies prefer tube amplifiers. Companies like Fender, Vox, Marshall and Blackstar produce amplifiers with tubes. It is “all-tube” design or combined, tube preamplifier with solid state power amplifier. However, most high-end amplifiers which are used in the gigs or recording studios uses tubes. All these tube amplifiers cost much more than modern solid state amplifiers.

1.3 Audio Standards

Audio devices can vary a lot, with price, output power and the technologies which are used in them. To understand which device is good and which is not was applied some standards. They directed developers to reach some minimum requirements so they can mark their equipment as HiFi device.

HiFi stands for High Fidelity which means that this device has a high-quality reproduction of sound. Ideally, HiFi device has inaudible noise and distortion, and infinite frequency response.

Each type of audio equipment has their own minimum requirement. Some countries have their own standard as well. For example, German have their own standard - DIN 45500 which was formed in 1974. International Electrotechnical Commission has their own standard called IEC 60581. Russia has GOST 24388-88 and India has IS 9551.

Some of these standards are opened like Russian or Indian and some of them need to buy. They have almost similar minimum requirements and minor differences in measuring conditions.

Table 1. Comparison of available standards

Standard	DIN 45500	GOST 24388-88	IS 9551
Balance Control	>8 dB for each channel	If more than 1 channel , >8dB Variation for each	Each Channel, >8dB Variation
Effective Frequency range	40 Hz to 16 kHz Permissible deviation for 1 kHz 1.5 dB with linear input	40 Hz to 16 kHz/ 20 Hz to 25 kHz/ 10 Hz to 40kHz, Permissible deviation for 1 kHz	40 Hz to 16 kHz, Permissible deviations for 1 kHz 1.5 dB Non-equalized input

		1.5/0.5/0.3 dB in be-tween 20 Hz and 20 kHz	2.0 dB Equalized in-put
Gain Alignment	>3dB gain difference between channels, at frequencies from 40 Hz to 16 kHz	4dB/1dB/ between channels, at fre-quencies from 40 Hz to 16 kHz 0.5dB	250 Hz to 6300 Hz gain difference be-tween channels <4dB
Total Harmonic Dis-tortion	40 Hz to 12.5 kHz >1%	1%/0.5%/0.25%	40 Hz to 16 kHz for: Pre-amp 0.7% Power Amp 0.7% Integrated Amp 1%
Rated Output Power	None	None	At least 10W
Overload Source emf	Non-equalized input 1.5V	None	Non-equalized input 2V Equalized inputs 30mV
Over-all cross-talk attenuation	>30 dB in range of 250 Hz to 16 kHz	None	250 Hz to 10 kHz >30dB and at 1 kHz >40dB
Wideband signal-to-noise ratio	Pre-Amp > 55 dB Power Amp > 70 dB	Pre-Amp >58dB Power Amp >81dB	Pre-Amp >55 dB Power Amp >70 dB Integrated >55 dB

1.4 Nutube and VFD

Like a vacuum tube, a typical VFD, Vacuum Fluorescent Display, consists of a glass container from which all the air has been removed. Because VFDs are display devices, the glass envelope tends to be somewhat flat and rectangular in shape. The display characters, i.e. the symbols, words, and segments that actually light up - are composed of electrodes called anodes that are coated with phosphorescent chemicals. Typically, these chemicals contain zinc, selenium, sulfur, and other trace materials. [4]

Stretched across the interior of the container, suspended above the display characters, are several filament wires. These wires are powered by a low-voltage supply to heat them.

While the purpose of a VFD is very different than that of the average radio tube, there are similar structures in both. Both contain an electron source, the filament. Both contain a positively charged target. In the VFD, this electrode is called an "anode," and takes the form of a phosphor-coated word, symbol, or display segment. Finally, each device contains a grid structure, which is used to control the flow of electrons from the filament to the anode/plate. This similarity between VFDs and the triode tubes made enthusiast wonder if a VFD could be used as an amplifier.

At the end of the May 2016, Korg announced Nutube. In the fall of 2016, Korg started to sell Nutube and opened a website with more details about it.

Figure 1. Nutube 6P1 produced by Noritake for Korg. [15]

Nutube 6P1, is a VFD which was designed to use it as a double triode. Nutube got main advantages of VFD's – low operating voltages, long lifespan, and miniature size, but remain general benefits of vacuum tube triode, as “tube sound” and rich harmonics.

Korg asserts that new vacuum tube uses less the 2% of the power required by conventional vacuum tubes and making it easy to power the unit on batteries. It expands a lot of applications where it can be used. Now it occupies less than 30% of the volume of a conventional vacuum tube. Its small size and low thermal output allow it to be easily mounted directly on a high-density circuit board without using a socket. And the High reliability and long life of Nutube gives to costumers up to 30,000 hours of continuous operating life and the possibility to attach it directly to the circuit board with confidence knowing that it will not need to be replaced regularly like a 12AX7.

1.4.1 Nutube 6P1 Datasheet

According to datasheet Nutube 6p1 has significantly small amplification factor (μ). For Nutube it is 14.5 while other tubes such as ECC83 and 6L6, which is widely used, have 100 and 130 accordingly. The transconductance of Nutube is 54 mS and it is much bigger than other tubes has. The usual value for triodes used in preamps is 6 mS. [14]

Filament voltage and the current for its operating is crucial low. Typical current and voltage for Nutube is 0.7 V and 17 mA. As a result, Nutube have only 0,0119 W loss on the filament. On the other hand, is old tubes which have 6.3 V and 0.3 A for the filament. As a result power loss of 1.89 W. It is around 160 greater than Nutube's. [14]

Voltage amplification of Nutube is between 3.7 and 6.4, but the typical value is 5. This value allows using Nutube as the first stage of the amplifier (Preamp) how it is stated in some of Korg's articles.

1.4.2 Nutube 6P1 Application Notes

Nutube 6P1 was designed to be common with DIP chip. It consists of glass as normal vacuum tube and has a rectangular form with sharp edges. It has 10 Pins with not common distance from each other. It is 2 mm, normal DIP components have 2.54 mm.

Nutube delivers excellent linearity on different voltage levels. It is close to the linearity of an ideal twin triode. This linearity ease to design schematics for different supply voltages. It gives good gain alignment and decreases non-linear distortions.

On the figure 2, is visible that output power of triode is very low. It operates with anode currents below 200 uA. Average output power of it is 1.7mW. This disadvantage can be solved by using JFET buffer or op amp buffer.

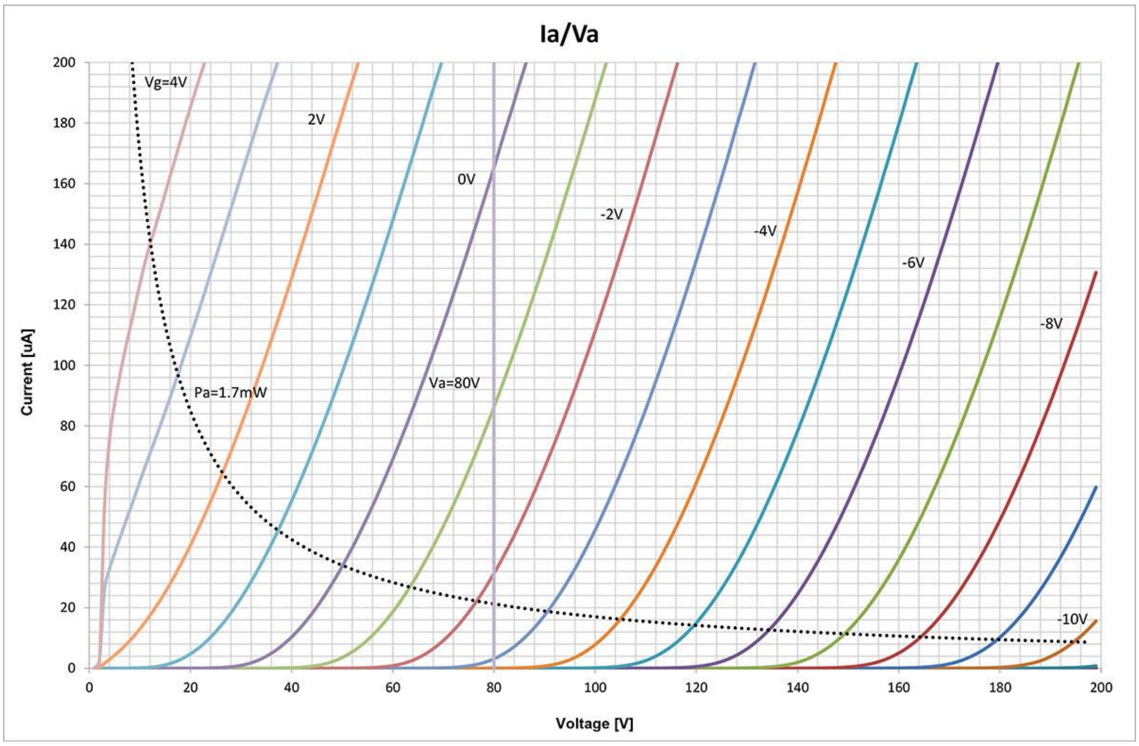

Figure 2. Anode characteristics of Nutube. Dependence of anode current on anode voltage [14]

It is possible to supply filament with the current 2 ways - with parallel or with a series connection. Parallel connection of filament enables to have each filament to have the same voltage. To reduce power consumption and increase the battery life of an amplifier it is possible to supply filament current in series. This way filament current is half of that of parallel connection.

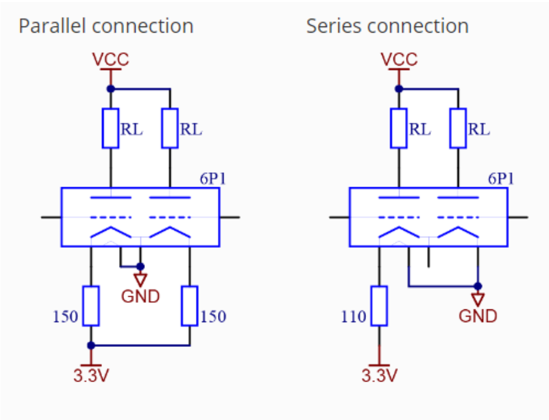

Figure 3. Filament connection in parallel and in series. [15]

1.4.3 Microphonic Noises

The microphonic response of different types of vacuum tubes to the same mechanical agitation covers a 70 dB range of levels. Tubes of the same type, on the average, cover a range of about 30 dB. [5]

As a direct-heating tube, it does suffer from microphonic noise more than indirectly heated cathode tube. To prevent Nutube 6P1 from the microphonic noise it is needed to remove any vibrations around it.

Circuit board vibration can be removed by wiring Nutube to the main circuit board instead of connecting it with the solid connector. Wired Nutube board is needed to mount to main board with some cushioning, for instance, sponge or cotton.

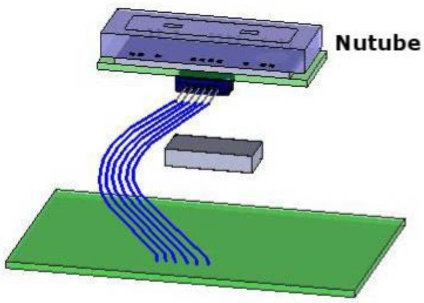

Figure 4. Preventing microphonic noises from the main board. [15]

The vibration of the air (sound) reaching the surface glass of Nutube can cause the microphonic noise especially high frequencies (a metallic sound). Placing Nutube in a protective box/case helps prevent such vibrations. Using the acoustic material in the chassis further reduces the noise. Placing a heavy metal plate (e.g. lead) on the surface of a Nutube can also reduce noise.

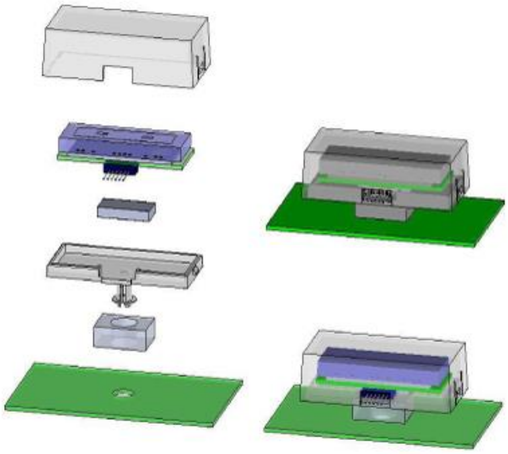

Figure 5. Preventing microphonic noises from the air(sound). [15]

2 Theoretical Background

2.1 Working Principle of a Vacuum tube

The vacuum tube is an electronic device which consists of glass, metal, metal-ceramics or ceramics bulb which is filled with vacuum. In this vacuum, the bulb is soldered electrodes which have different forms depending on the tasks they were designed for. All vacuum tubes have cathode and anode. In tubes where is more than 2 electrodes, additional grids are located in between of anode and cathode.

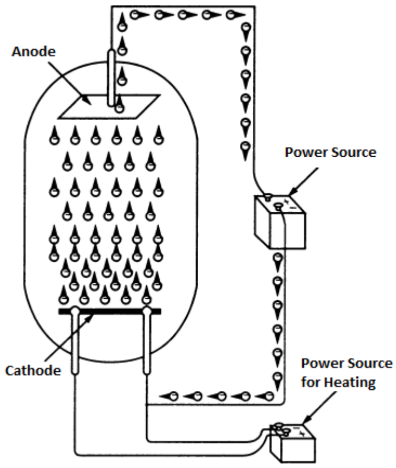

Figure 6. Electron movement inside vacuum tube [12]

The basic working principle of the vacuum tube is based on electrons thermionic emission of electrons from a hot filament or a cathode heated by the filament. By heating, cathode/hot filament material receives thermal energy which weakening connection between atom and electron. It starts loose elections and in the vacuum, they start to move in the directions of electric fields. Anode normally has a higher potential and it is struck by electrons. As a result, there is a current in between anode and cathode.

Control grids in between of cathode and anode are placed to control fields inside of tubes. By applying positive voltage on them, electric field intensity between cathode and grid will change significantly. Electrons will receive additional acceleration, but because of high potential difference between anode and grid, these electrons will pass control grid. Anode current will increase this way.

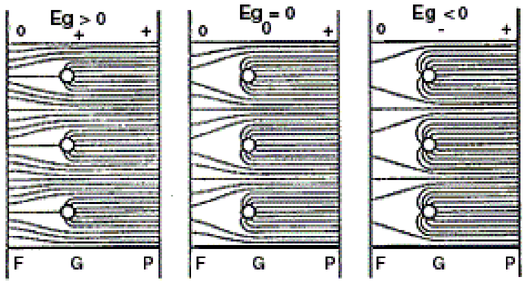

Figure 7. Change of current flow through the grid, depending on voltage on the grid [12]

Other tubes work the same way but there are more additional electrodes in the tube. For instance, pentode is vacuum tube with 3 additional electrodes: control grid, suppressor grid, screen grid. The function of them is to increase output current and reduce distortions caused by secondary emission.

2.2 Amplifiers Theory

Usually audio amplifiers, or low-frequency amplifiers, are designed to work in hearing range frequencies. It is commonly given from 20 Hz to 20 kHz, but this range can vary between individuals. Most of the amplifiers have an effective frequency range between 10-15 Hz to 18-20 kHz.

Audio amplifiers are supposed to receive low-frequency signal, it can be microphone or guitar pickup for instance. Depending on the input source, the input signal can have an amplitude of few millivolts up to volts. After amplification, the output signal is connected to the load, it can be other power amplifier or acoustic systems (cabinets for guitar amplifiers).

Almost none of amplifiers have 1 amplification stage. Usually, it is multi-stage amplifiers where each stage is developed for certain needs. The first stage of the amplifier is used for inputting signal to the amplifier. The final stage of the amplifier, returns amplified signal, it can be connected to the audio system to hear the result of amplification.

Total amplification is the product of gain on each stage. It is usually provided in decibels for clearer understanding. There are 2 kinds of amplification, voltage and power. Voltage amplification is the ratio between output and input voltage, while power amplification is the ratio between output and input powers.

$$G_t = G_1 \times G_2 \times G_3$$

$$G_{t(dB)} = 20 \times log_{10}(G_t) \quad (Voltage)$$

$$G_{t(dB)} = 10 \times log_{10}(G_t) \quad (Power)$$

First stage amplifier or pre-amplifier amplify voltage. It is designed to have high input impedance, small SNR and high gain coefficient. Final stage amplifier, also called power amplifier, amplify the power of signal so it could be fed to the acoustic system, headphones, cabinets, home theatre.

In between of pre and power amplifiers is located control block. With this control block, it is possible to change volume, tone, equalisation etc. The structure of this kind of amplifier is presented in figure 8.

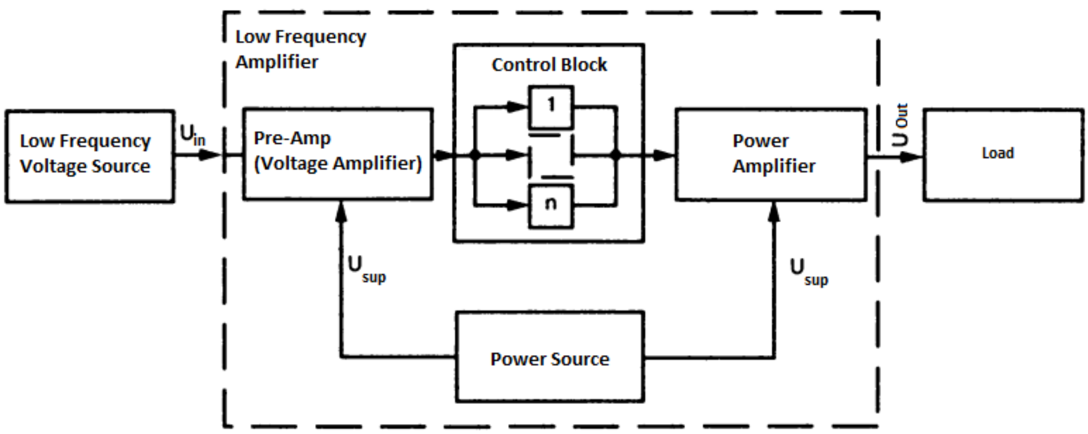

Figure 8. The structure of multistage low-frequency amplifier with control block. [12]

In low-frequency Hi-Fi amplifiers, sometimes is used other structure. In these amplifiers, each channel got separated on different frequencies in control block and each this frequency channel has its own power amplifier stage. An amplifier designed this way can have very flat gain alignment and cost a lot. Usually, they have two to five different frequency channels. The structure of this amplifier is presented in figure 9.

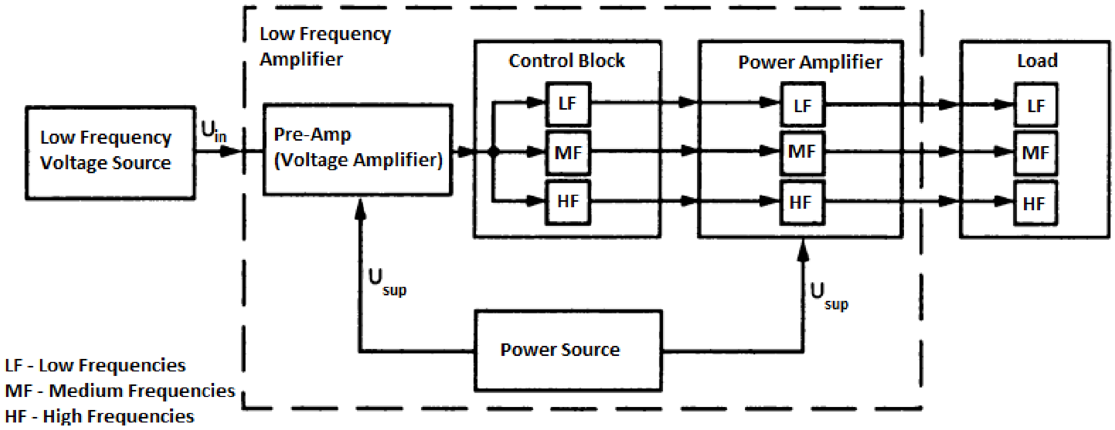

Figure 9. The structure of multistage low-frequency amplifier with control block which separates signal on different frequency channels. [12]

3 Design the Prototype

After releasing and start of sales of Nutube, Korg started providing datasheets. There are example amplifier circuit and more data. As a target of this project, is to create amplifiers which will approach the minimum requirements of Hi-Fi amplifiers. Also, to design an amplifier which will have a distortion on the output as guitar amplifier does.

For developing PCB, PADs software was used because it got common during studies. For generating LMD file from milling machine was used CircuitCAM software and for milling the board was used, BoardMaster.

3.1 Nutube Board

To prevent microphonic noises and ease moving Nutube 6P1 from one amplifier circuit to another was designed Nutube board. Nutube has 10 pins. This 10 pins is connected with SIP 10 connector as an output of this board. This board will protect flexible Nutube pins from its bending and braking.

To do it was needed to design new PCB decal which has 2mm distance between pins and print the board.

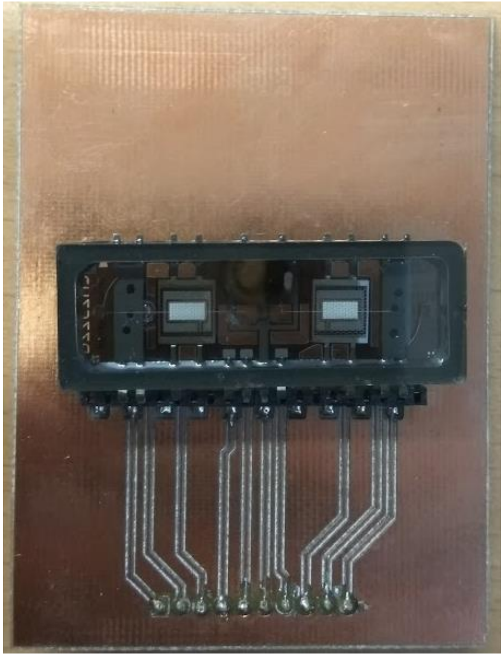

Figure 10. Nutube mounting board.

3.2 Capacitors Selection

Capacitors in amplifiers are used for filtering, power supplies and audio coupling. In case of audio coupling, it can play a significant role. For audio coupling usually are used electrolytic, tantalum or ceramic capacitors.

Ceramic capacitors are cheap and small. However, they suffer from microphonic noises and their value can decrees with the time as much as 50%. They are not very good in audio coupling because they are not very linear and can cause non-linear distortion to the amplifier.

Tantalum capacitors are expensive and they are not available in many values. They are linear in an audio path and can be used for audio coupling. Audiophiles state that they sound not as good as electrolytic capacitors.

Electrolytic capacitors are the best for audio coupling. They have low equivalent series resistance and small package. Special purpose capacitors for audio equipment is usually electrolytic capacitors. They are cheaper than tantalum capacitors. Only theirs disadvantage, compare with other capacitors types is the size, they are bigger than competitors.

In this application, electrolytic capacitors are used for audio coupling because the purpose of the project is to get an audio amplifier with highest possible fidelity. For voltage stabilisation and noise reducing will be used ceramic capacitors.

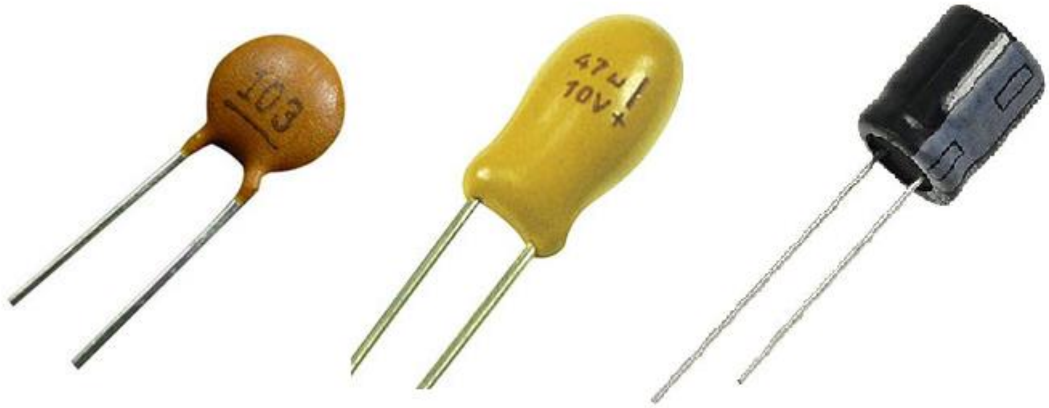

Figure 11. 3 types of capacitors widely used for audio coupling: ceramic, tantalum and electrolytic (from left to right).

3.3 Single Amplifier by Korg

It is an reference designed amplifier of a designed by Korg and attached to datasheets. It has 3 stages of amplification. It consists of 2 JFETs and one triode. It requires 2 voltage sources - 12 V and 3.3 V. First stage of an amplifier is voltage buffer. It is used to protect very low power input signal. JFET is used in this case because it has a large input impedance which is around 10 GOhm. This Impedance comes in parallel with 1M resistor what makes input impedance equal 1M, what is high enough. The second stage is Nutube. The last stage of the amplifier is one more JFET as a buffer. It is used one more time because of the very high output impedance of Nutube.

Figure 12. Block Scheme of Single Stage Nutube Amplifier by Korg

This Amplifier is very simple but gives a clearer understanding of Nutube applications. To prevent future development problems it is needed to design PCB of this amplifier first. This way will be understandable difficulties which are needed to withstand while designing.

For the grid of Nutube amplifier, it is needed to use the biasing circuit. It must be fed with 3.3 V maximum. This biasing voltage can be tuned by a variable resistor and fed to the grid through 33k ohm resistor.

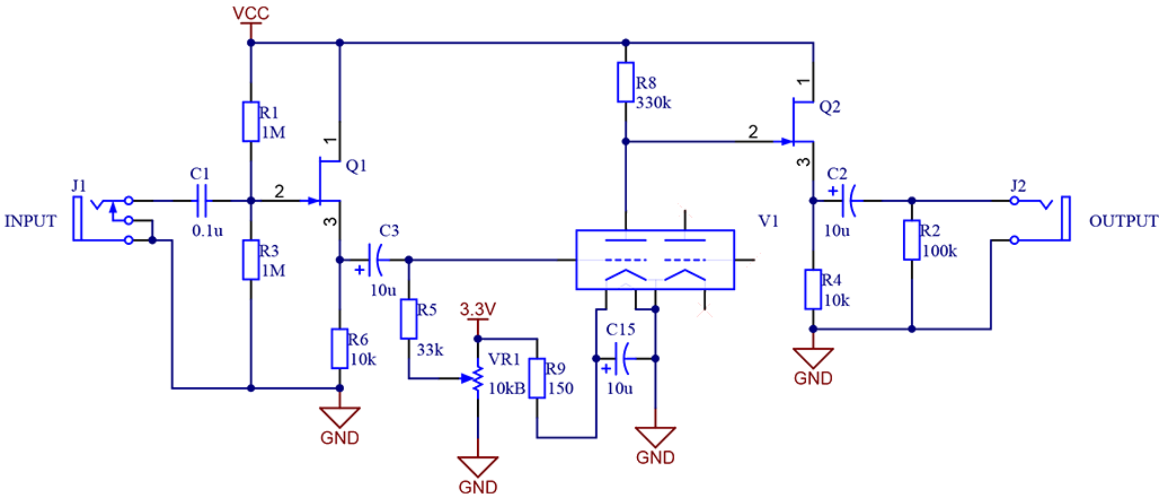

Figure 13. Schematic of single Nutube 6P1 amplifier by Korg.

This Amplifier does not have any volume/balance control. It is single channel amplifier. As well it didn't have a high gain level. Amplification of the signal should be around 14 dB. Output power is low because output stage of an amplifier is JFET buffer. To increase maximum output power is needed to use IC power amplifier. An alternative of it is valve power amplifier based on pentodes. It is still widely used in Hi-End devices despite on the oldness of this solution.

3.3.1 Schematics and Layout of Components

In the case of simplicity of this amplifier, it will be possible to implement everything on 1 layer and use other as a ground layer. As an input and output of the signal, is used standard 6.3 mm, Jack. It is widely used in the music industry and in guitar amplifiers. As a JFET was used BF245. It is usually used in High Frequencies amplifier but in this application, it fits well and preliminary test on breadboard proofed it.

This amplifier requires 2 voltage sources so in this case it was needed to use a voltage regulator. In this application LM1117 3.3 V SMD Voltage regulator is used. For inputting power was used typical DC 5.5mm x 2.1mm Jack and its connector. As a passive component was used here electrolytic capacitors (one ceramic capacitor was used for voltage stabilisation) and both, film and carbon resistors or carbon resistors.

To make device useable it is needed to follow standard component placing. All components which are used to tune the signal must be placed in the front of the board. Input signal must come from the left part of the board and the output must be returned from opposite side. Voltage input must be placed somewhere on the edges of the amplifier as well. Other amplifiers follow the same components placement rules.

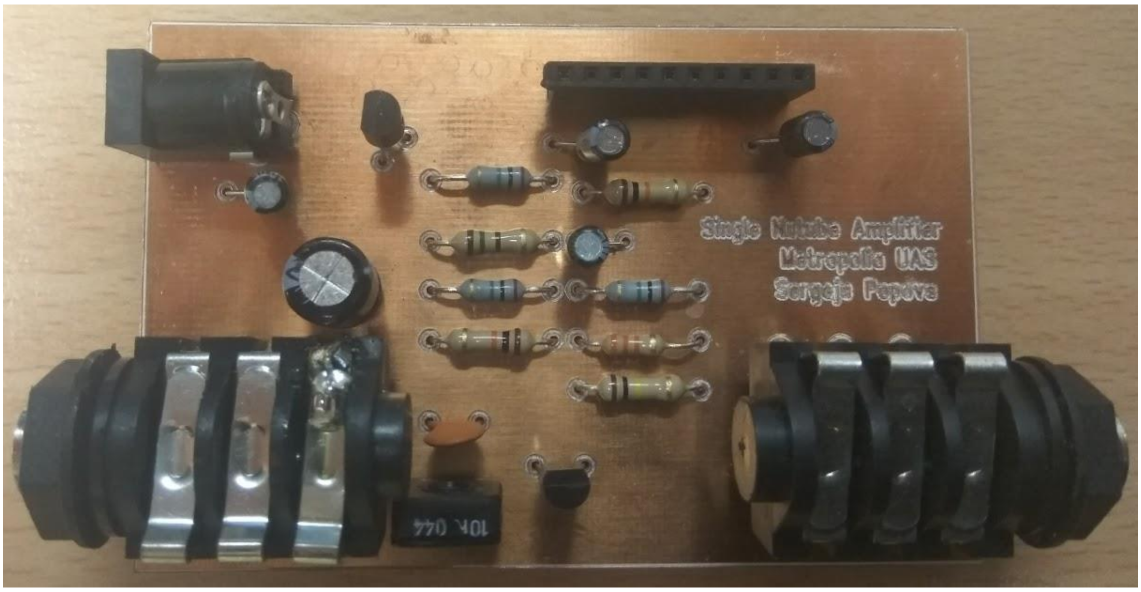

Figure 14. Single stage, single channel Nutube amplifier.

3.4 Double Stage Nutube Amplifier

For higher gain levels is needed to use more amplification stages. Nutube is double triode and in a single stage, Nutube amplifier designed by Korg is used only one triode and second is unused.

The first stage of the amplifier is JFET buffer. It will rise input impedance to the high level. The second stage is a Nutube 6P1. It will give 14 dB amplification. After Nutube is used as voltage buffer because the output impedance of a triode is meaningfully high. For this case, Hi-Fi op-amp is used. It has very high input impedance and won’t bring a lot of total harmonic distortion and noises. As a second step is used the second triode of Nutube. It brings to the system 14 dB amplification more and the total is 28 dB on this stage. On the last stage of an amplifier used second channel of Hi-Fi op-amp. [14]

As a HiFi op-amp is used TL072. It has typical total harmonic distortion 0.003% what is expressively low for audio equipment and using it twice in one channel won't distort sound quality.

A total gain of the system will be 28dB because only Nutube stages bring voltage amplification to the system. 28dB is equal to 25 times higher amplitude.

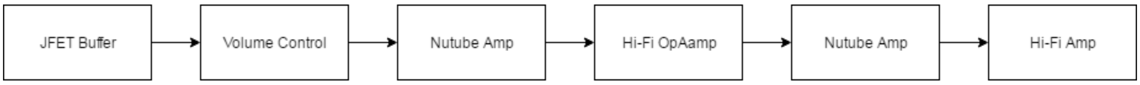

Figure 15. Block Scheme of double stage Nutube preamp.

This gain level can create a distortion on the output if the input signal will be high enough. One of the benefits of a tube amplifier is "tube sound" and its soft clipping distortion.

Soft clipping distortion is an effect which releases when output signal got amplified and it exceeded maximum voltage peak-to-peak but its edges remain smooth. Opposite of soft clipping distortion is hard clipping distortion, it is more common for solid state devices.

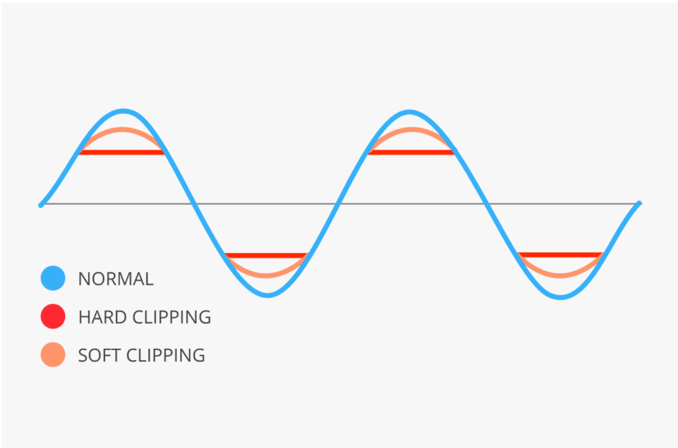

Figure 16. Sine wave under hard clipping and soft clipping distortion.

This amplifier can be used as effect pedal for guitar as well. It is a simple and easy way to get tube sound or tube distortion for guitar. It is possible to create this circuit to work with the 9V battery.

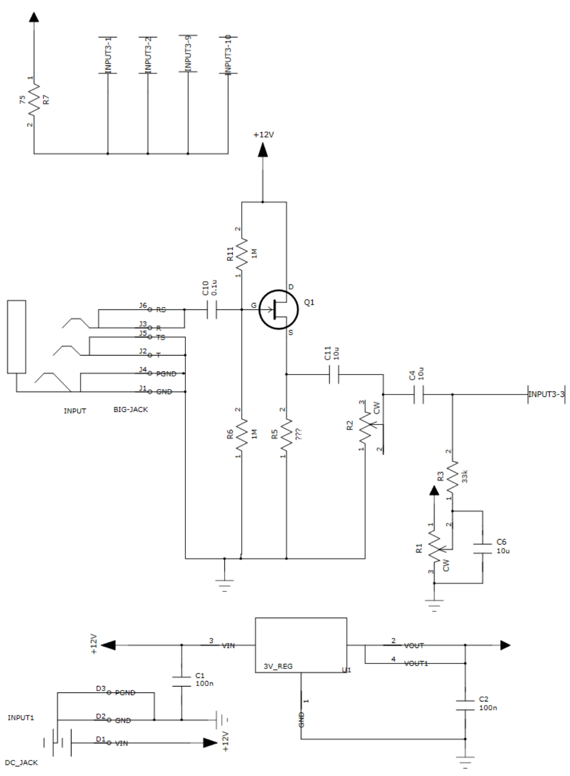

Figure 17. Schematic of double stage Nutube PreAmp.

3.5 Nutube Amplifier with Power Stage

Nutube amplifier must have balance control and some tunings to approach Hi-Fi standards. As well it must have a power amplifier on the final stage to pass minimum requirements of Hi-Fi power output.

The first stage of this amplifier will be a JFET buffer, similar to a single Nutube amplifier by Korg has. It provides high enough input impedance and does not cause noises. On the second stage is used balance control/volume block. For volume, the block is used a simple variable resistor. Next stage is a Nutube and after will come audio Op-amp buffer. As a final stage of this amplifier used power amplifier. Whole amplifier system will be stereo so it uses two channels for all stages.

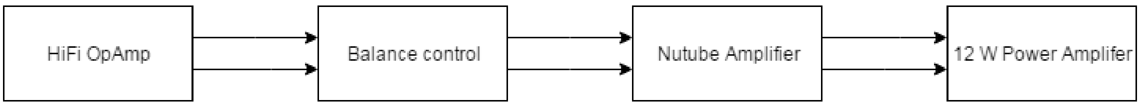

Figure 18. The structure of a stereo amplifier with power amplifier on the last stage.

As a power amplifier is used TDA2616. It is IC power amplifier by Philips Semiconductors. It is stereo amplifier so it is needed one chip for both channels. It passed Hi-Fi test in accordance with IEC 268 and DIN 45500 for IC amplifiers. The output of this amplifier is 12W for each channel. It makes this amplifier heats a lot. It is needed to use a heat sink to reduce the temperature in the chip. Heatsink must have thermal resistance around 3.3 K/W according to datasheet [10]. It must be supplied by at least 15V. Total harmonic distortion of this amplifier is typically 0.15%

In this circuit there is 3 different voltage levels. It is 12, 3.3, -12 V. This range of voltage is needed to use because of TDA2616 is required dual polar voltage and 3.3 V is needed for biasing. [10]

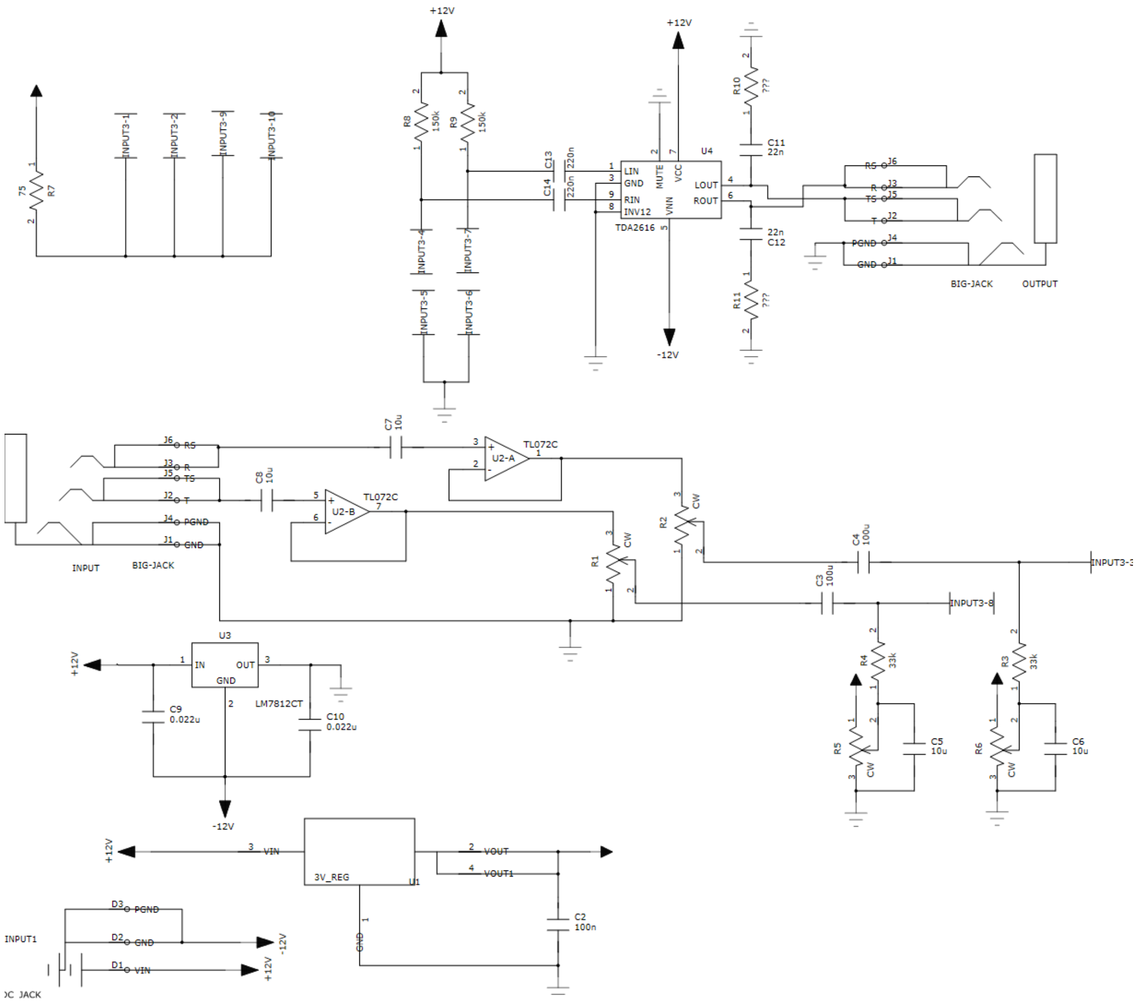

Figure 19. Stereo 12W amplifier with Nutube preamp.

Power amplifier brings difficulties to the PCB design. It is needed to take into account high currents for supplying TDA2616. This current can exceed 2 A and it is needed to use wider traces. [10]

The voltage gain of an amplifier will be around 44 dB. 14 dB on the Nutube amplifier stage and 30 dB for TDA2616. It is about 160 times higher amplitude.

3.6 Portable Double Stage Nutube Amplifier with Power Stage

One of the benefits of Nutube valve is a reduced power consumption. Comparing to the other tubes, it uses only 0.625% power of normal tube. This advantage gives the possibility to design portable vacuum tube amplifier. [14]

Because of the low maximum output power of Nutube, it is needed to use power amplifier stage as it was done in paragraph 3.3. It means that this amplifier won't be completely valve amplifier, but combined solution with JFET buffers and IC power amplifier.

Power supply for this amplifier will be 9V battery or power adapter with 9V output. It is enough voltage for the anode of Nutube. Almost none of old vacuum tubes could work with this low anode voltage.

As a power amplifier, in this application is used LM386. It is widely used power amplifier in portable audio equipment. Maximum output power varies from 500 to 700 mW with 9 V power supplied. It is enough for a small speaker for the portable amplifier. Speaker must be connected to this amplifier in series with 250 uF capacitor and in parallel with RC circuit according to the LM386 datasheet [11].

For better usability, this amplifier will have tone control block. Tone control blocks usually placed before power amplifier stage. It will have 2 controls, for basses (lowest frequencies of audible spectre) and treble (highest frequencies of audible spectre). The Baxandall tone control circuit fits great for this application. It works like parallel adjustable low pass and high pass filter. [13]

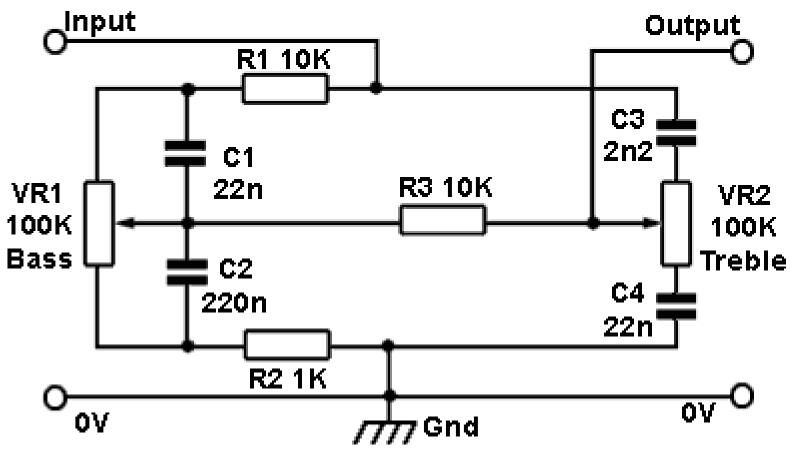

Figure 20. Baxandall tone control circuit [13]

Mid band attenuation of Baxandall tone control circuit is about 20 dB. With full boost applied on treble or bass potentiometer minimum attenuation is about 3 dB. Maximum attenuation with bass and treble cut is 40 dB. The curve of Baxandall frequency response is in the figure 21. [13]

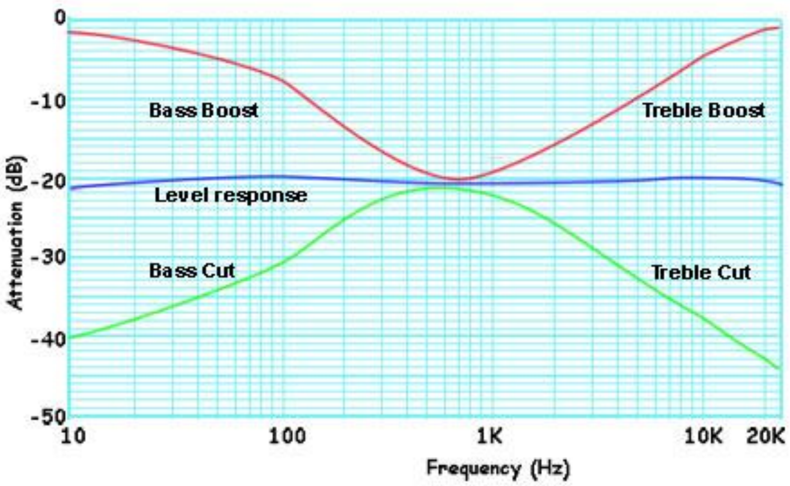

Figure 21. Baxandall frequency response curve [13]

This amplifier is single channel because it is designed as a guitar amplifier. Here will be used both triodes of Nutube. With 9 V fed by battery, amplification of both valves is 26 dB. For getting distortion on tube stage of an amplifier, with 100 mV peak-to-peak input signal, it is needed to use additional pre amplifier stage. According to testing 800 mV coming on Nutube stage is enough to get tube distortion with soft-clipping effect, Pre-amp of this amplifier must have 18 dB before tube stage and must work with 9 or 3.3 V. For this application MCP6279 op amp can be used. This preamplifier stage must have variable gain, to control distortion level. In between of the valves is used JFET buffers to increase the output power of valves.

The whole structure of designed portable Nutube amplifier is on figure 22. Total maximum amplification of the signal can be 50 dB. It is 316 time, with this amplification and 100 mV input signal, the output signal will be distorted not only with vacuum tube but also power amplifier. It means that it will be needed to reduce signal amplitude on volume control stage.

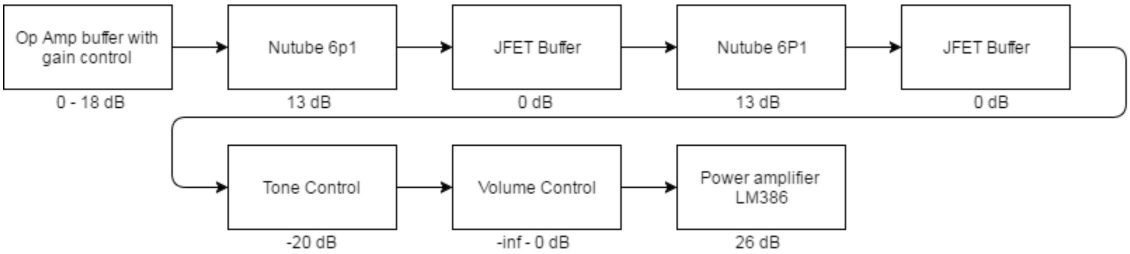

Figure 22. Block diagram of portable Nutube amplifier with valve distortion

To increase working life with the battery, in this application is used serial filament connection, with 110 ohm resistor. [14]

In this amplifier, there are two voltage levels. It is 9 and 3.3 V, which comes from the voltage regulator. For switching on and off the amplifier, is used the switch in between the 9V battery and power input of the circuit.

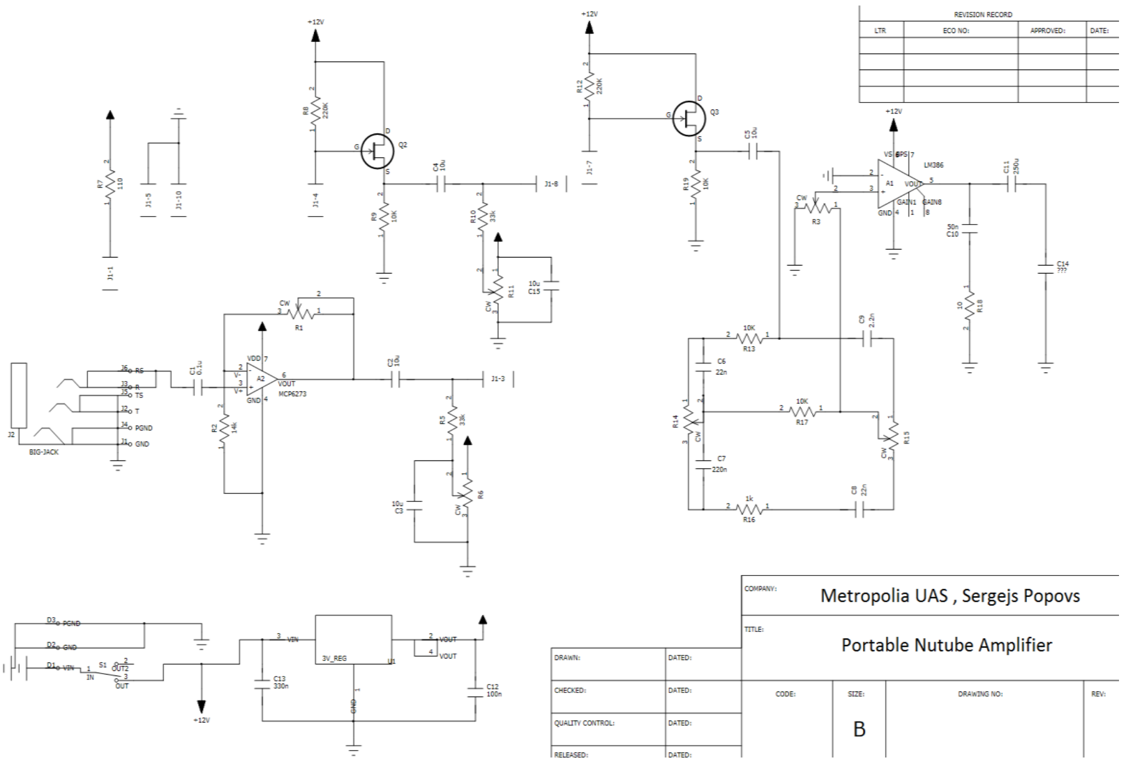

Figure 23. Schematic of Portable Nutube Amplifier

As a result, this amplifier will have powers switch, 4 controls: volume, gain, bass and treble. As an output is used 8 ohm 0.5 W speaker. As a power input is used 9 V battery. As an input of the signal is used common 6.3 mm audio Jack.

4 Measurements

4.1 Output power

Amplifiers of this project can be divided into 2 groups: preamps and amplifiers with power amplifier stages. Preamplifiers shouldn't have high power output, because they are not used to reproduce sound through speakers. Amplifiers with power stages are designed to connect with speakers.

HiFi standard minimum requirement for non-preamp is 10W. Stereo Nutube amplifier has output power 12W per channel and it means that it passed HiFi requirements. This is enough power for TV or car audio amplifiers. Portable Nutube amplifier is using LM386 with output power 700 mW. It is enough for a portable speaker this power is not matching with IS 9551 standard.

4.2 Effective Frequency Range

The audio amplifier must work in whole auditable frequency range identically well. In the case of Hi-Fi and Hi-End equipment, signal output have to be the same as input because otherwise it can change the sound and reduce fidelity.

To measure effective frequency range it is needed to input sine wave signal to the amplifier and compare with the output signal. Then change the frequency in the whole auditable frequency range. If the ratio of the output signal and input signal does not change and remain reasonably constant, this range called effective frequency range

If the amplifier has timbre block or tone control it can reduce effective frequency range. This tone control works as filters which can reduce output amplitude to get the sound which user wants.

To pass Hi-Fi standard minimum requirements amplifier's effective frequency range must be at least 40 Hz to 16 kHz. In this range, the signal can change for 1 dB in 1 kHz bandwidth. It doesn't cover whole audible spectre but in real life, our hearing effective frequency range is not flat as well. Human ear won't define any differences in the highest frequencies of audible spectre.

	Single Nutube Amplifier	Double Stage Nutube Amplifier	Stereo Nutube 12W Amplifier	Portable Nutube Amplifier
Effective Frequency Range	10 Hz - 17 kHz 1 dB difference 8 Hz - 21 kHz 1.5 dB difference	10 Hz - 16 kHz 1dB difference 5 Hz - 19.5 kHz 1.5 dB difference	10 Hz - 16.5 kHz 1 dB difference 8 Hz - 19 kHz 1.5 dB difference	2 Hz - 21 kHz 2 dB difference equalized input It reaches 2 dB difference on 100 Hz frequency

Table 2. Effective frequency ranges of different Nutube amplifiers.

The frequency characteristic of Nutube is relatively good. In most of applications and tests, it was passing Hi-Fi minimum requirements. For portable Nutube amplifier EFR suffered because of tone control block, but with precise tuning it is possible to get flat output in the audible frequency range.

4.3 Total Harmonic Distortion (THD)

Total harmonic distortion is the summation of all harmonic components of the voltage waveform compared against the fundamental component of the voltage. The ideal sine wave has zero harmonic components. During amplification, some non-linear characteristics of an amplifier can cause parasitic harmonic components.

As well these parasitic components can come from amplifiers output amplitude limitations, frequency response, applied a load, circuit board layout and grounding.

Harmonic distortion may be measured by applying a spectrally clean sine wave voltage signal to the input of the amplifier under test. Next, adjust the input power level to the amplifier for a desired output power level and then looking at the output harmonic spectrums (second, third, and fourth harmonics, etc.) of the amplifier on a spectrum analyzer.

Total Harmonic Distortion (THD) is expressed in Root-Sum-Square (RSS) in percentage. The THD is usually calculated by taking the root sum of the squares of the first five or six harmonics of the fundamental. [6]

$$THD(\%) = 100\ \times \sqrt{\frac{V_2^2+V_3^2+V_4^2+\cdots+V_n^2}{V_1}} \quad [9]$$

Values on the spectrum analyzer can be showed as dBm, dBV, dBW, V or W. On figure 24 is demonstrated signal with high harmonic distortion level.

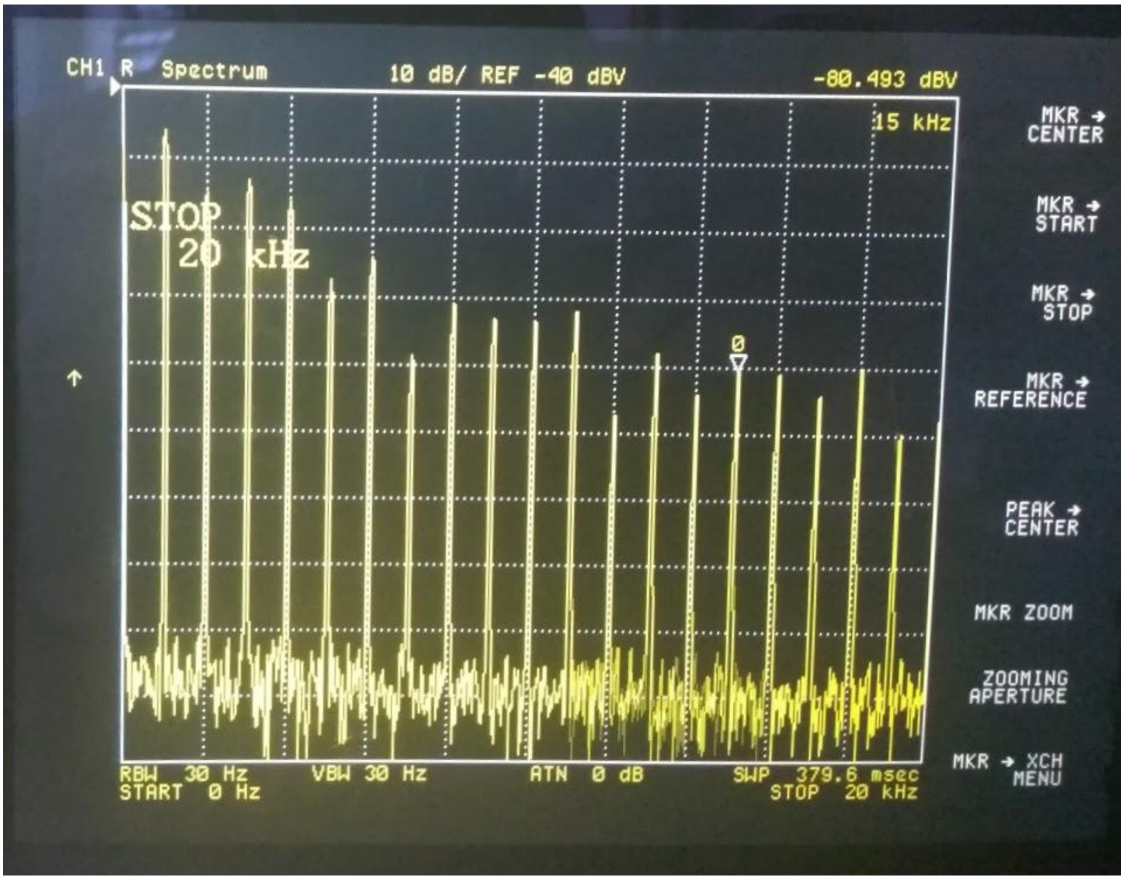

Figure 24. The output of the spectrum analyzer with input signal frequency of 1 kHz.

For audio equipment, is important only low-frequency components which are the part of the hearable frequency range from 20 Hz to 20 kHz. For these purposes are used spectrum analyzers which can handle low frequencies. For measuring THD in this project was used Agient 4395A network/spectrum/impedance analyzer. It works in the range of 10 Hz to the 500 MHz and it covers whole auditable spectre.

Smaller THD is better for the amplifier. For HiFi standard DIN 45500 minimum requirements, THD must be smaller than 1%, for GOST 24388-88 standard it should be smaller then 1%/0.5%/0.25% in respect of audio device class and for Indian standard, it must be smaller than 0.7%, both for the preamplifier and power amplifier.

	Single Nutube Amplifier	Double Stage Nutube Amplifier	Stereo Nutube 12W Amplifier	Portable Nutube Amplifier
Total Harmonic Distortion (THD)	Max - 0.28% Typical - 0.21%	Max - 0.51 % Typical - 0.48 %	Max - 0.49% Typical - 0.44%	Max - 0.54 % Typical – 1.23%

Table 3. Total Harmonic Distortion level of different Nutube amplifiers

With increasing of input voltage amplitude THD level is increasing. It is needed to decrease gain/volume level to negotiate distortion which comes from voltage level limitation. To get tube distortion it is needed to increase input level without decreasing gain/volume level. In this case THD level will be high, up to 15%.

These amplifiers passed minimum requirement levels of Hi-Fi systems. Main reason why it is so, is low amplification level of amplifiers. Other devices on the market usually has higher gain and higher THD level.

4.4 Noise Figure and Signal-to-Noise Ratio

The noise factor is defined as the ratio of the output noise power of a device to the portion thereof attributable to thermal noise in the input termination at standard noise temperature T_0 (usually 290 K). The noise factor is thus the ratio of actual output noise to that which would remain if the device itself did not introduce noise, or the ratio of input SNR to output SNR.

Noise figure is a very important to point in audio equipment. High Fidelity audio equipment ideally should have 0 noise but it is impossible because of noise sources. There is five basic noise sources for amplifiers: [8]

- Thermal noise
- Shot noise
- Flicker (1/f) noise
- Burst noise
- Avalanche noise

Burst noise and Avalanche noise is not the case of vacuum tubes, it is more related to semiconductors. Modern one does not suffer so much from these sources. [8]

Flicker noise is a low-frequency effect and it can bring some damage to signal in audio amplifiers, this noise can be caused not only in semiconductors but also in resistors and vacuum tubes. [8]

Shot noise is a noise produced from discrete nature of electric charge. It was first introduced in 1918 when Walter Schottky has studied currents in vacuum tubes. This noise is white, it means that it is frequency independent. [8]

Thermal noise is a constant energy per unit bandwidth and is generated by the thermal agitation of electrons in a conductor. It is white noise as well, so it can make an influence on the audio spectrum also. [8]

There is lots of specific equipment which can be used to measure noise level. It can be also done by using spectrum analyzers which were used to measure THD.

There are few methods of measuring noise. They are called Gain method, Y-factor method and Noise Figure Meter method. In Metropolia's laboratory, there is no noise figure meter which is used for last method, and no calibrated noise source which is used in the Y-factor method. In this thesis, a gain method is used. It is very simple but accurate method to use. [7]

To measure noise with the gain method it is needed to left amplifiers input terminal disconnected and spectrum analyzer connects to the output of the amplifier. It is needed to take an average of the spectrum analyzer and measure noise figure. After it is needed to subtract it with the noised thermal power and gain of the amplifier. The result of this simple calculation is noise figure. [7]

$$NF = P_{nout} + 174\, dBm/Hz - Gain \quad [7]$$

The signal to noise ratio for an amplifier is the ratio between the maximum output signal and the noise floor at zero output level. To measure it, first is needed to measure maximum output signal voltage. Secondly, it is needed to measure noise floor and after take the ratio between these 2 values. [9]

Hi-Fi standards minimum requirement for the preamp is 55 dB or higher. For power amplifier signal-to-noise ratio must be higher than 70 dB. For power amplifier this minimum requirement is much higher because power amplifier stage amplify signal much higher and this way increase signal amplitude and signal power and as a result.

	Single Nutube Amplifier	Double Stage Nutube Amplifier	Stereo Nutube 12W Amplifier	Portable Nutube Amplifier
Noise Figure	23 dB - with amplification level 15.6 dB	14 dB - with amplification level 30 dB	28 dB - with amplification level 44 dB	36 dB - with amplification level 58 dB
Signal-to-noise ratio	44 dB	42 dB	47 dB	38 dB

Table 4. Noise Figure and SNR of Nutube amplifiers

The noise level of all Nutube amplifiers is very high. As it was mentioned before, Hi-Fi standard minimum requirement is 55 dB and none of the amplifiers reach that. Stereo Nutube 12W amplifier, which considered to have high SNR, because it uses Hi-Fi power amplifier with SNR which passed IC power amplifier requirements in IEC 268 and DIN 45500 standards.

This noise definitely comes from Nutube. Some of the noise comes from the voltage buffer, the noise figure of BF245a which is used in these stages is 1.5 dB. In most of the amplifiers, this JFET is used 2 or 3 times.

4.5 Over-all cross-talk attenuation

Cross talk coupling is an effect can be found in amplifiers with more than one channel. It is an undesired effect which usually caused by capacitive, inductive or conductive coupling between traces of PCB, IC components and wires.

This effect is not very important on modern simple audio systems and more related in studio equipment. It is important in amplifiers with a structure similar to figure 9 has and multi-channel audio amplifiers In this type of amplifiers, it is possible to have a big amount of channels. This noise also can be caused by ground currents.

To test this effect it is needed to apply a signal to one of the channels and connect the second channel to the ground. After it is needed to measure both channels on the output of the amplifier. A ratio is formed by dividing unwanted signal amplitude on the signal channel amplitude. It is expressed in decibels and it depends on the frequency. With the increase of the frequency, cross talk attenuation usually increases as well because of capacitive and inductive coupling effect increases.

Only one amplifier in this project has two channels and in this amplifier, it is possible to measure cross-talk attenuation and build a graph with different frequency. (Figure 25)

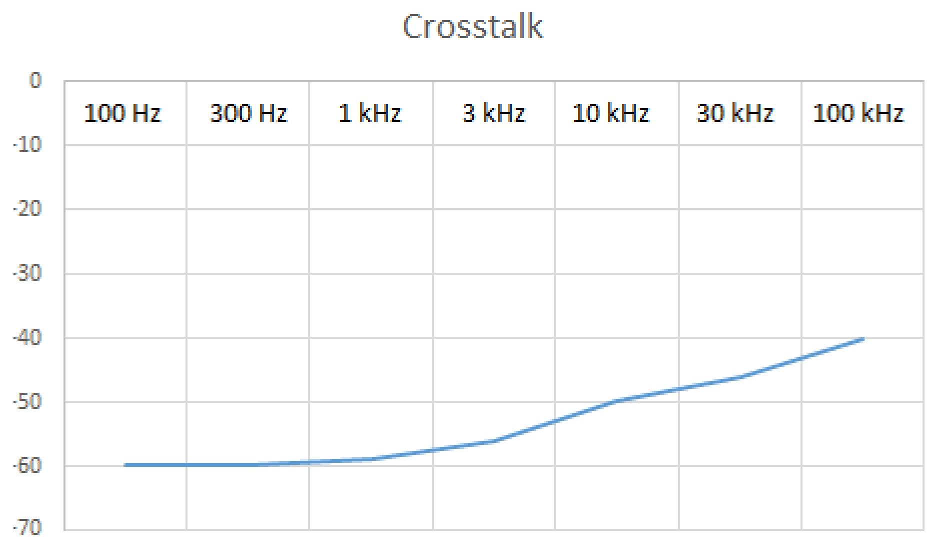

Figure 25. Graph of crosstalk attenuation on Nutube 6p1 stereo 12W Nutube amplifier.

Measured crosstalk attenuation is around 56 dB in Nutube Stereo 12W amplifier. HiFi minimum requirement is >30 dB for 250 Hz and >40 dB for 10 kHz. In this case, stereo amplifier passes minimum requirements. With frequency increasing this ratio is increasing, because output voltage amplitude decreases as well and this amplifier works as low pass filter because it’s auditable effective frequency range.

5 Results and Discussion

After having preliminary testing and measurements of amplifiers were made following observations.

In most of the audio measurement, Nutube performed well. It has very good effective frequency range. It does cover whole audible frequency range with flat amplification curve. As well this component provides low total harmonic distortion level and does not have any problems with cross-talk attenuation. After some gain level, Nutube can produce “tube distortion” with soft clipping effect which can be used in guitar amplifiers.

The main flaw of all amplifiers is noise level. Amplifiers suffered from noises and by measuring and datasheets it comes from Nutube 6p1. Korg provided different solutions how to reduce noise levels of Nutube but some of them is hard to implement, such as microphonic noises. Until Nutube will get some update or new model of it will be released by Korg, this component will affect on the noise level of the amplifier. Maybe it is the main reason why there is no any audio devices on the market which are using Nutube as voltage amplifier stage.

On the other hand, Nutube 6p1 is a great solution for amplifiers with low supply voltage or which working from the battery. It consumes very small amount of power compare with other normal tubes. As well it requires very small anode voltage, starting from 5V. This high supply voltage range which starts from low voltages provides the possibility to use this component in the application where it was impossible to use valves. A possible application is car amplifiers, portable amplifiers, guitar pedals, guitar active pickup voltage amplifier.

On more disadvantage of Nutube is low power output of valve. It means that amplifier must have several solid-state components in its schematic. As a result of this disadvantage is combined (valve + solid state) design. It will lose part of the possible market if some applications will be released.

Nutube has modern design and in some stages of designing applications is needed take it in account. Flexible pins of Nutube is one of the major disadvantages of this package. Strange pinout also makes an application based on Nutube a bit odd. If all the active pins could be placed on the same distance or have standard distance between of them 2.54 mm as SIP connector has.

Nutube 6p1 definitely cannot be used in Hi-Fi equipment because the requirement for this audio equipment is too high for this component. However, devices which uses Nutube 6p1 can get Hi-End marking. This label does not need any minimum requirement but they must use some innovative solutions. In this point of view this component can look interesting and some people can buy applications based on it, because it is vacuum tube and it looks modern.

6 Conclusion

Nutube is a good step to renovate tube market and brings new products to it. It can be used in some applications and the best field is portable amplifiers and low voltage amplifiers as it is visible from the measurements and design articles above. With decent design and marketing products based on Nutube can take part of the audio amplifiers market. It does fix most of the problems valves had, such as heating, power consumption and life span.

As a component as it is now, it won't be used in audio equipment. It has high noise level and it is expensive compared to the other tubes. It is not possible to assemble complete valve amplifier with it and potential consumers will prefer old style tubes.

Korg should continue developing new products and components based on same principles of Nutube. They are not first who found VFD as an audio triode, but they are first company who implemented it as a ready to use component with proper audio characteristics. If it could be possible to recreate this triode based on VFD principles, and it will have lower noise level, it could be a great solution for audiophiles and recording studios as well.

The price of this component is 50 euro per each valve and it is costly for final products. Final products will be more expensive than other solutions because other valves or solid state devices cost less, and on this part of amplifier market is lots of solutions which use solid state devices and few of them uses valves or combined design. In this case, Korg can be successful because of theirs brand and long experience.

However, it is a good component for amateur audio electronics designers. Already now it is possible to find preamps and headphones amplifiers based on Nutube, which was designed by a single person and sells as a kit for assembling.

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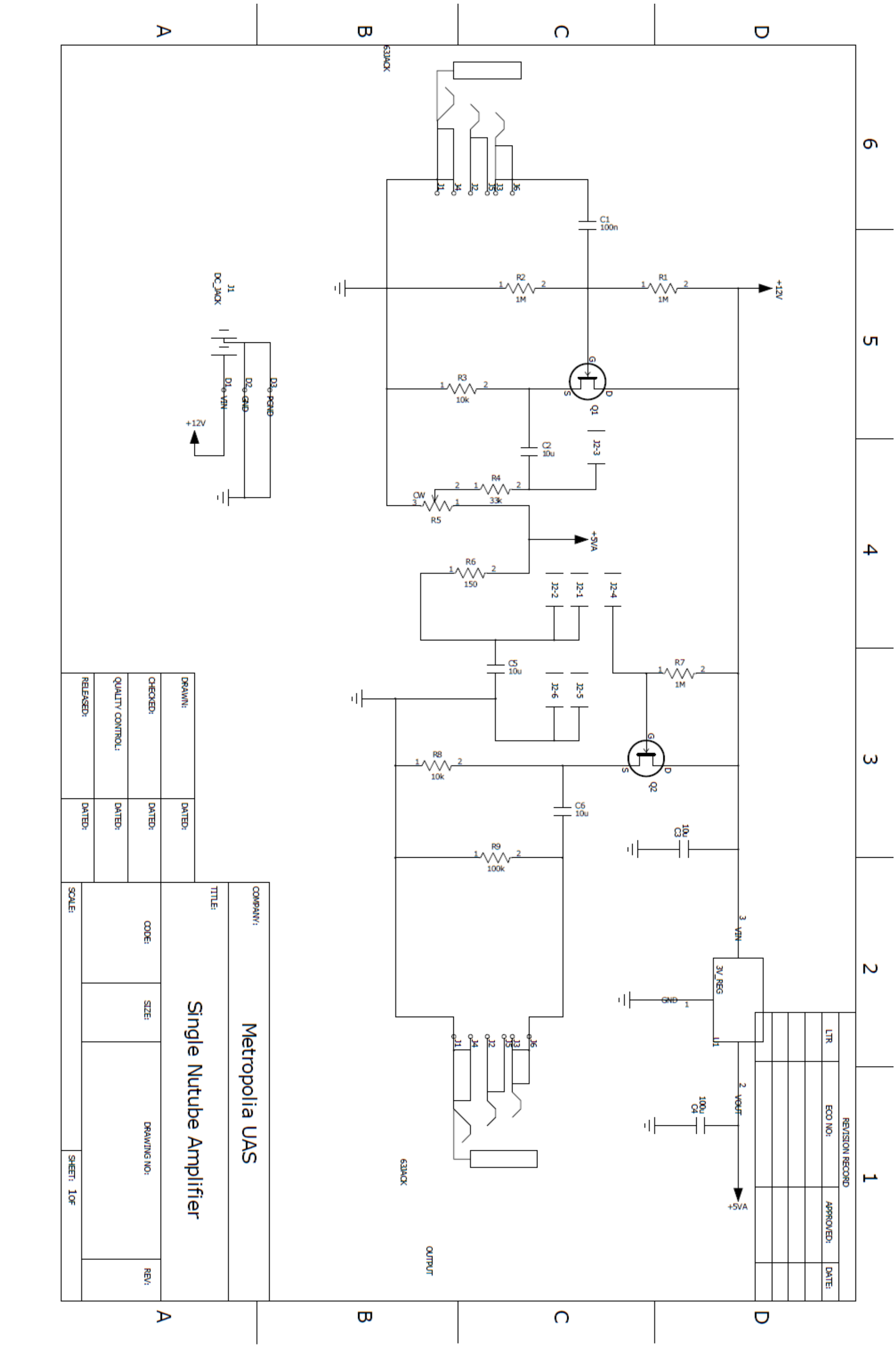
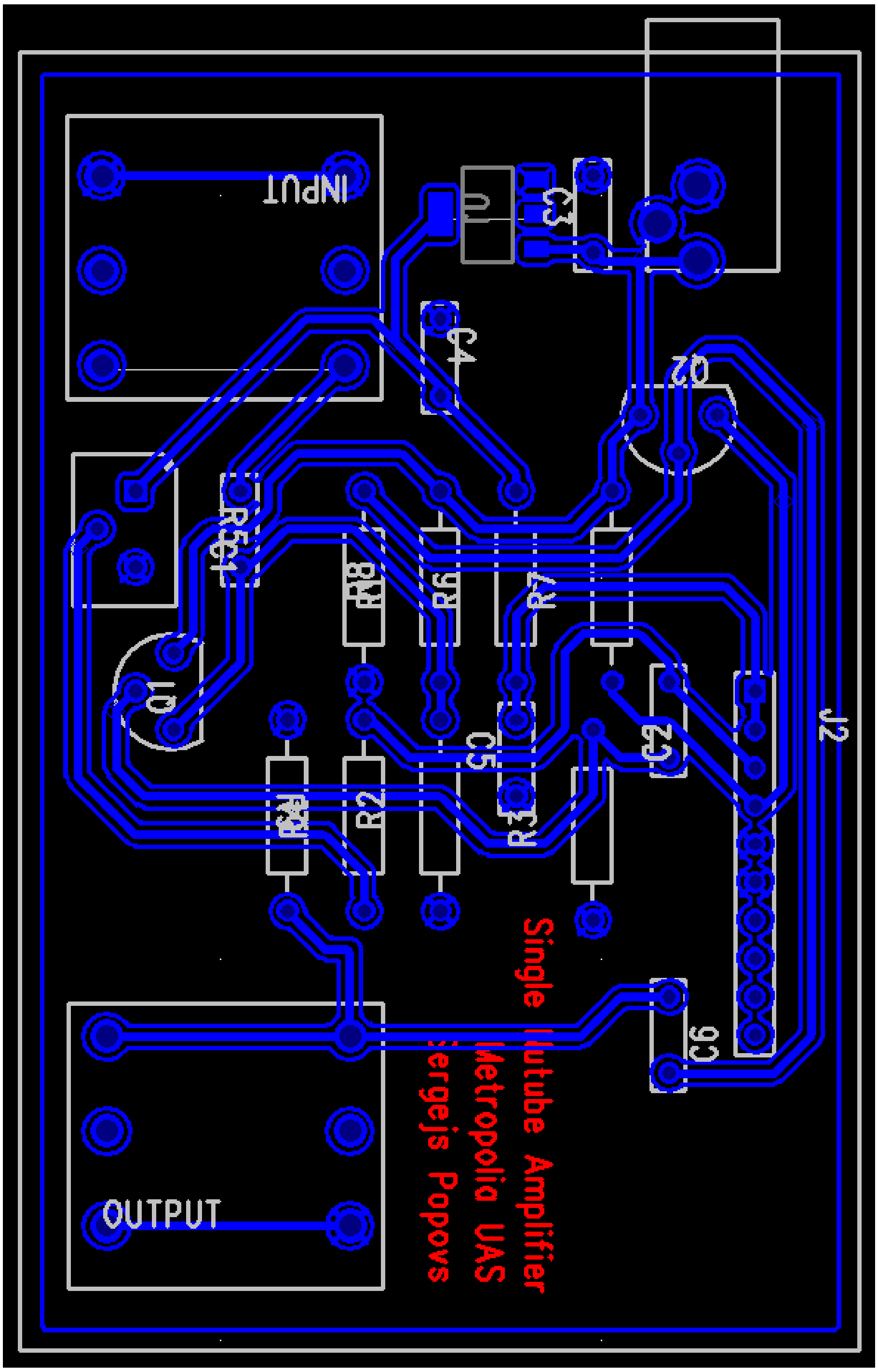
Appendix 1. Single Nutube Amplifier Schematic



Appendix 2. Single Nutube Amplifier Layout

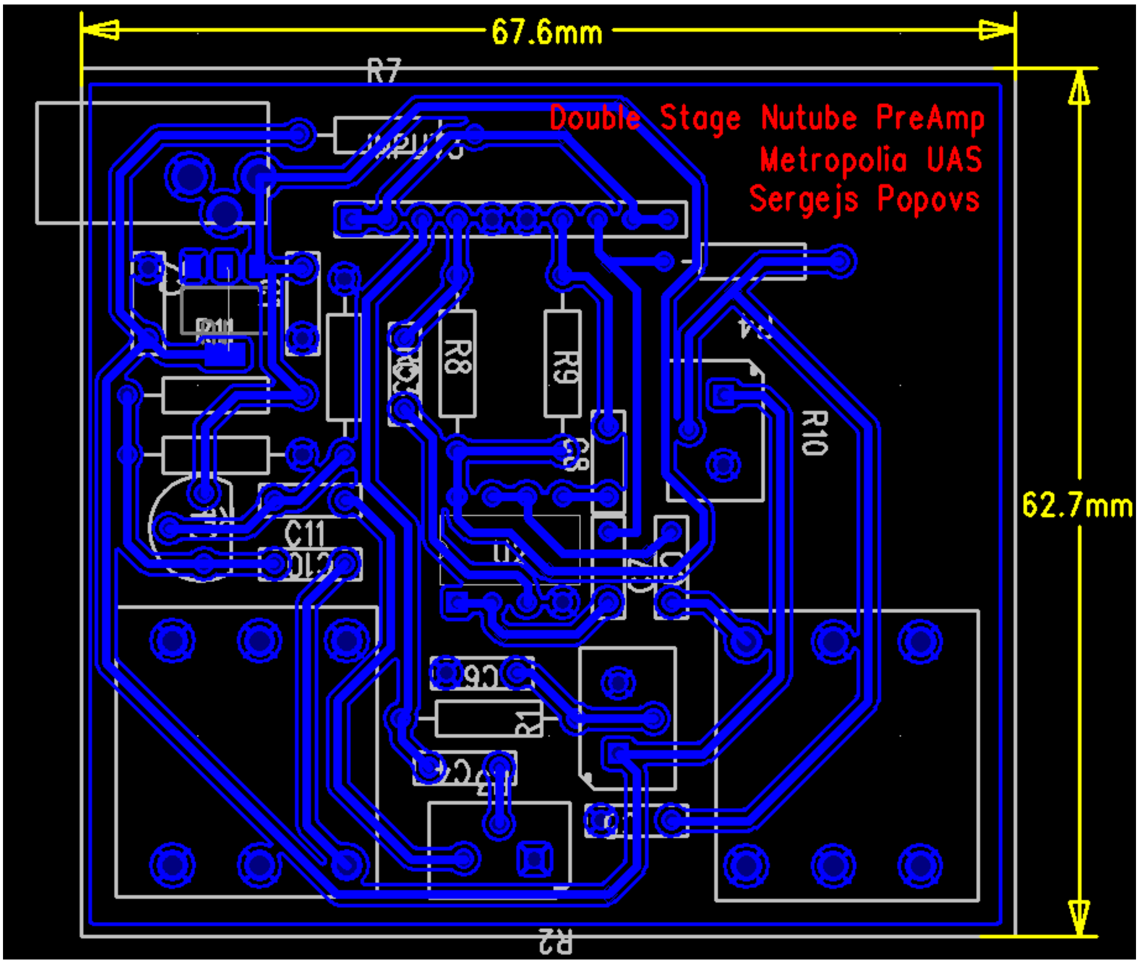


Appendix 3. Single Nutube Amplifier Bill of Materials

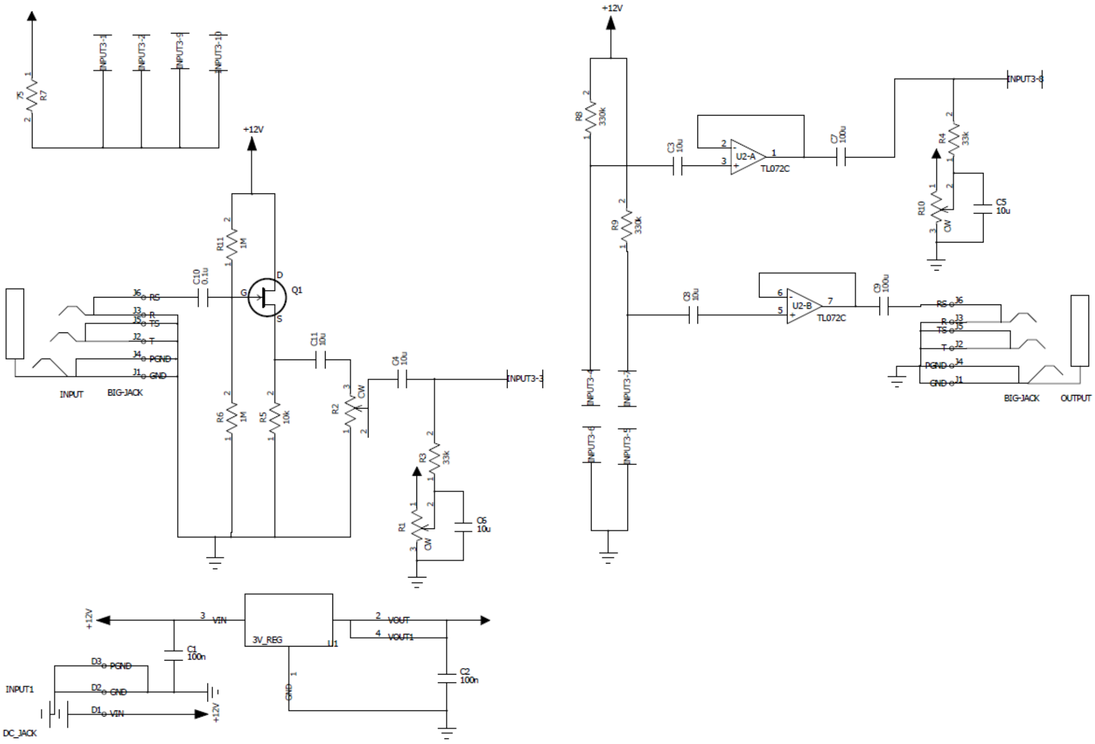
Bill Of Materials for SingleAmpli.sch on Fri May 05 14:46:18 2017

Item	Qty	Reference	Part Name	Manufacturer	Description
1	1	U1	3V_REG		
2	2	INPUT OUTPUT	63JACK		
3	2	Q1-2	BF245A	MOTOROLA	N-CHANNEL,DEPLETION MODE, VHF/UHF AMPLIFIER JFET
4	1	C1	CAP-CC06,100n,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
5	1	C4	CAP-CC06,100u,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
6	4	C2-3 C5-6	CAP-CC06,10u,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
7	1	J2	CON-SIP-10P		GENERIC 10 PIN SIP HEADER .100 CENTERS
8	1	J1	DC_JACK		
9	1	R9	RES-1/4W,100k		RES BODY:100 CENTERS:500
10	2	R3 R8	RES-1/4W,10k		RES BODY:100 CENTERS:500
11	1	R6	RES-1/4W,150		RES BODY:100 CENTERS:500
12	3	R1-2 R7	RES-1/4W,1M		RES BODY:100 CENTERS:500
13	1	R4	RES-1/4W,33k		RES BODY:100 CENTERS:500
14	1	R5	VRES		VARIABLE RESISTOR (POT)

Appendix 4. Double Nutube Amplifier Layout



Appendix 5. Double Nutube Amplifier Schematic

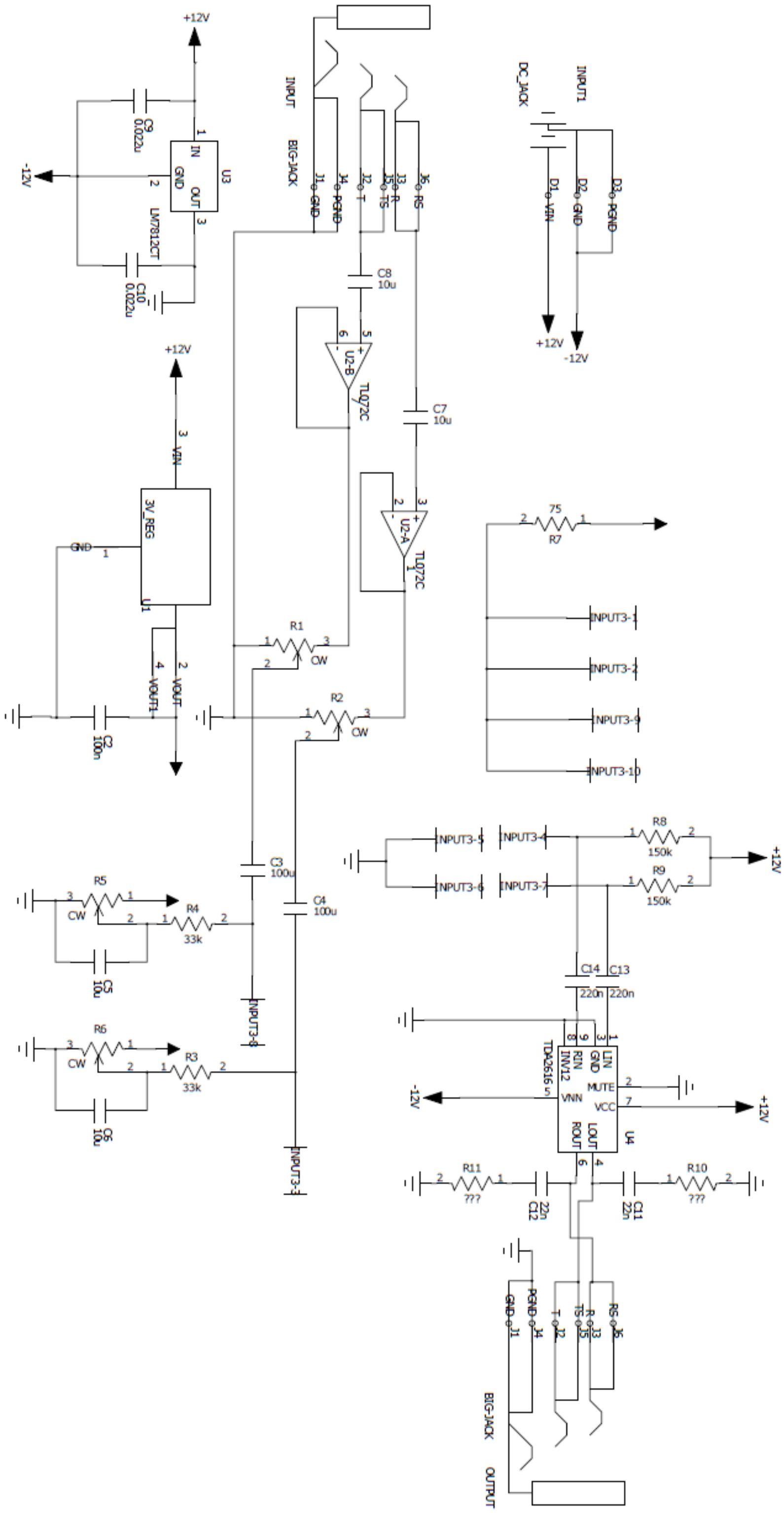


Appendix 6. Double Nutube Amplifier Bill of Material

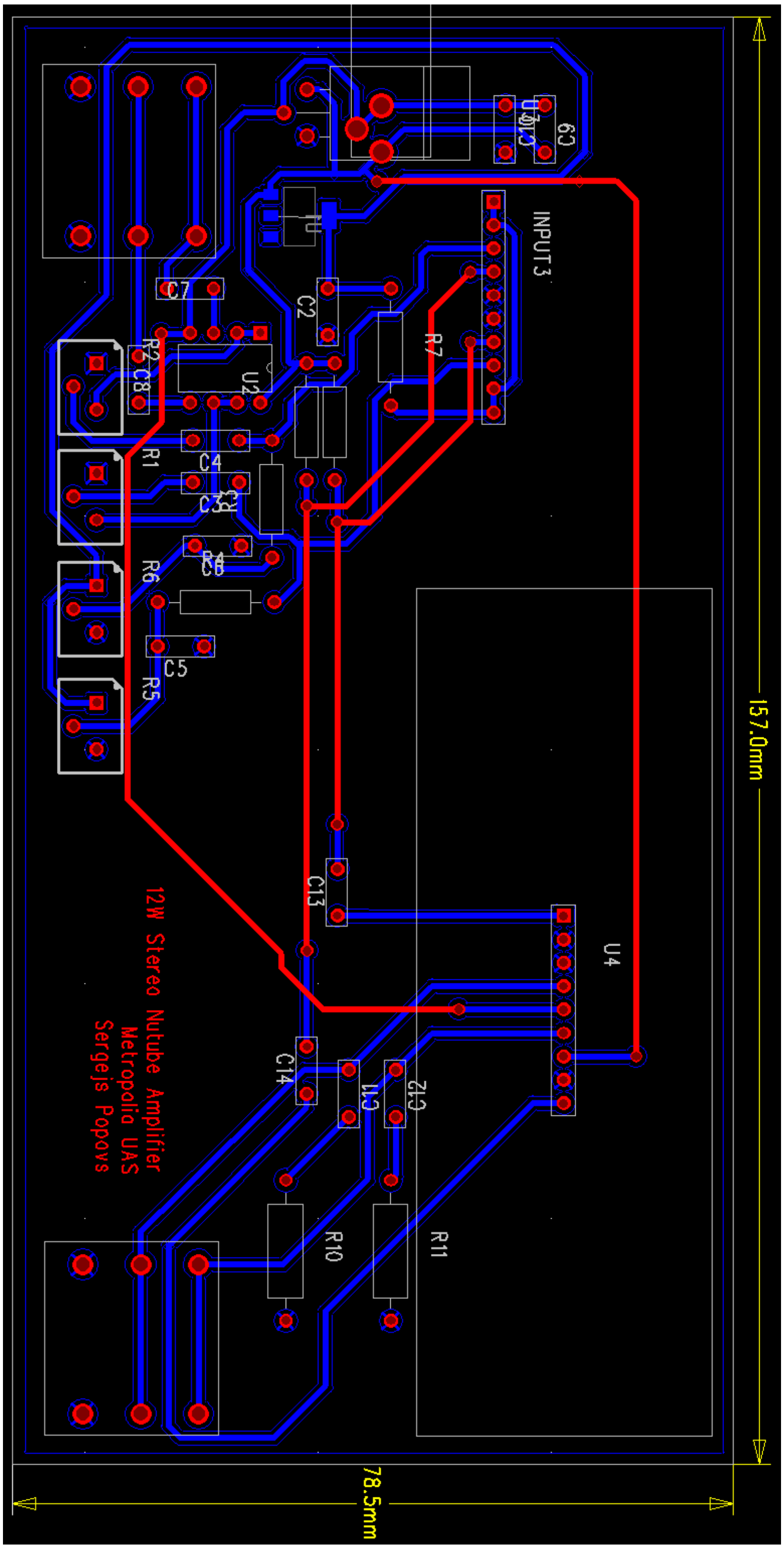
Bill Of Materials for DoubleNutubeAmplifier.sch on Fri May 05 14:54:38 2017

Item	Qty	Reference	Part Name	Manufacturer	Description
1	1	U1	3V_REG		
2	1	Q1	BF245B	MOTOROLA	N-CHANNEL,DEPLETION MODE, VHF/UHF AMPLIFIER JFET
3	2	INPUT OUTPUT	BIG-JACK		
4	1	C10	CAP-CC06,0.1u,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
5	2	C1-2	CAP-CC06,100n,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
6	2	C7 C9	CAP-CC06,100u,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
7	6	C3-6 C8 C11	CAP-CC06,10u,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
8	1	INPUT3	CON-SIP-10P		GENERIC 10 PIN SIP HEADER .100 CENTERS
9	1	INPUT1	DC_JACK		
10	1	R5	RES-1/4W,10k		RES BODY:100 CENTERS:500
11	2	R6 R11	RES-1/4W,1M		RES BODY:100 CENTERS:500
12	2	R8-9	RES-1/4W,330k		RES BODY:100 CENTERS:500
13	2	R3-4	RES-1/4W,33k		RES BODY:100 CENTERS:500
14	1	R7	RES-1/4W,75		RES BODY:100 CENTERS:500
15	1	U2	TL072C	MOTOROLA	LOW NOISE,JFET INPUT, OPERATIONAL AMPLIFIER
16	3	R1-2 R10	VRES		VARIABLE RESISTOR (POT)

Appendix 7. Stereo Nutube Amplifier Schematic



Appendix 8. Stereo Nutube Amplifier Layout

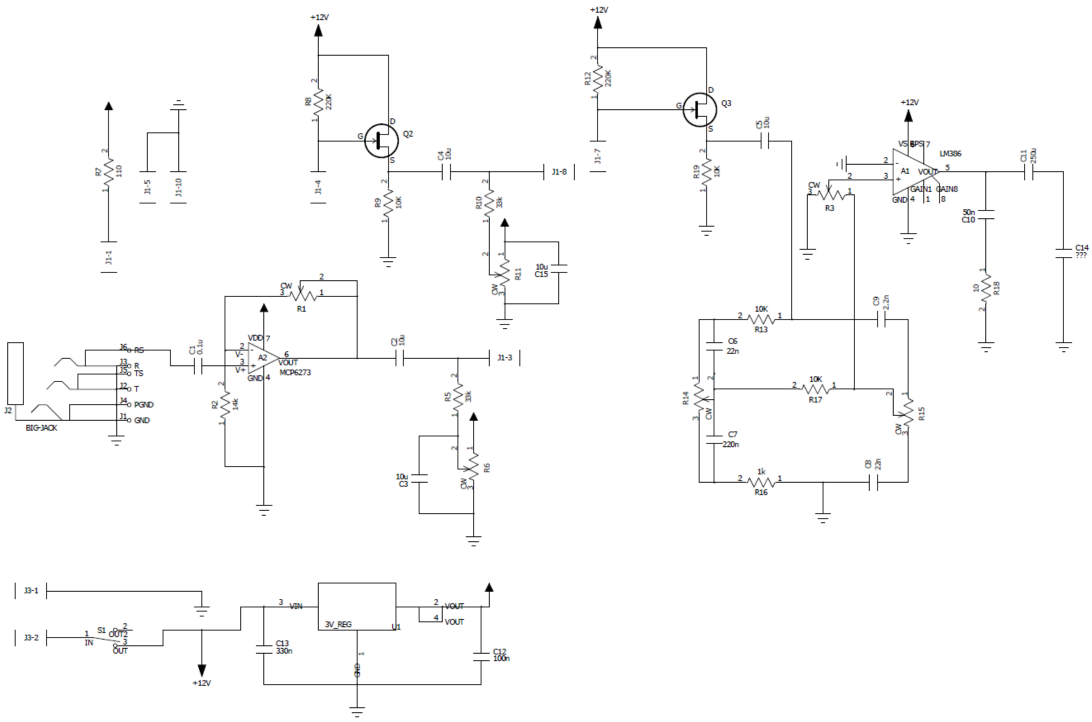


Appendix 9. Stereo Nutube Amplifier Bill of Materials

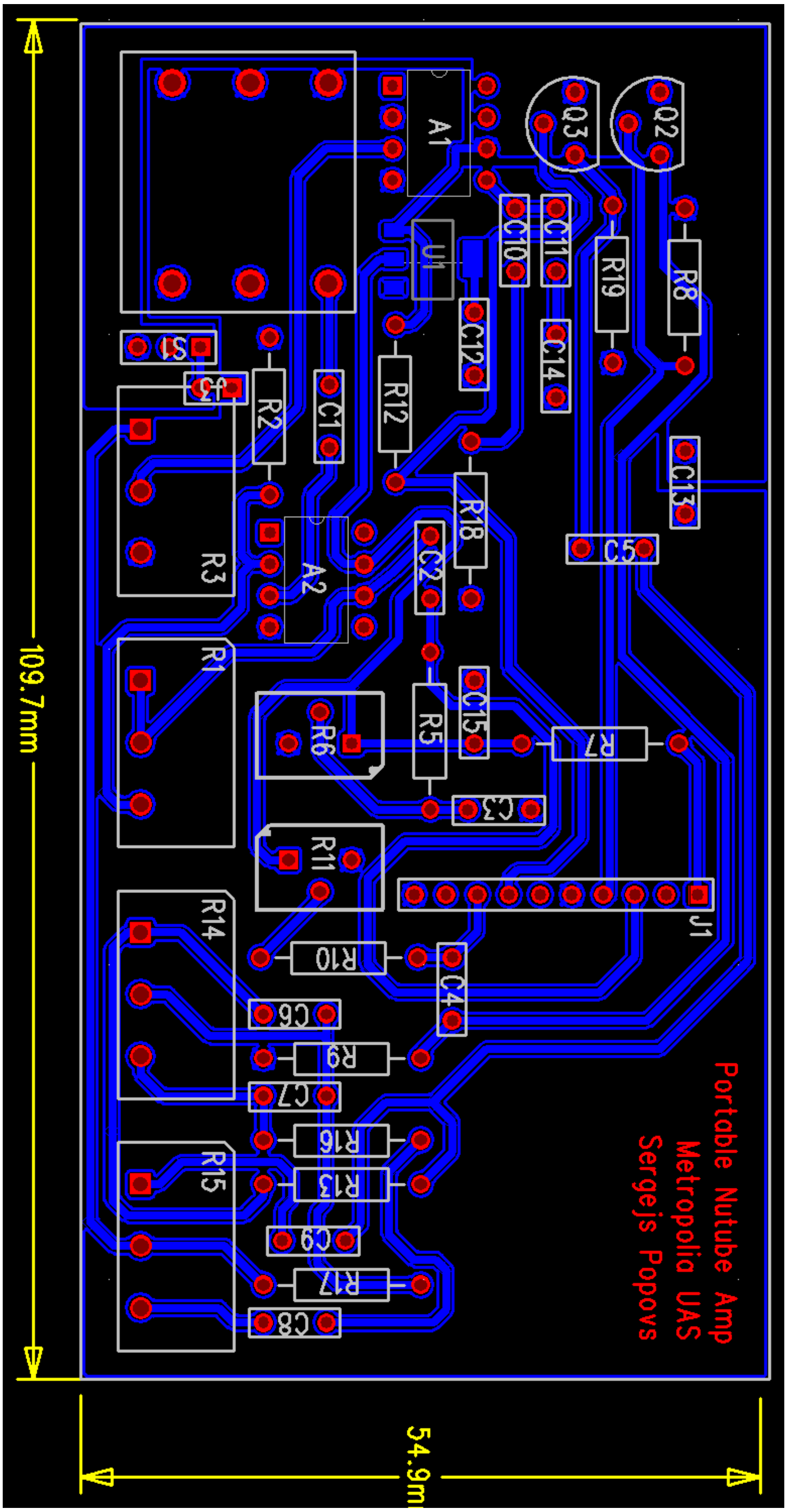
Bill Of Materials for 12WAmplifier.sch on Fri May 05 14:58:37 2017

Item	Qty	Reference	Part Name	Manufacturer	Description
1	1	U1	3V_REG		
2	2	INPUT OUTPUT	BIG-JACK		
3	2	C9-10	CAP-CC06, 0.022u	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
4	1	C2	CAP-CC06,100n,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
5	2	C3-4	CAP-CC06,100u,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
6	4	C5-8	CAP-CC06,10u,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
7	2	C13-14	CAP-CC06,220n,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
8	2	C11-12	CAP-CC06,22n,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
9	1	INPUT3	CON-SIP-10P		GENERIC 10 PIN SIP HEADER .100 CENTERS
10	1	INPUT1	DC_JACK		
11	1	U3	LM7812CT	NATIONAL SEMICONDUCTOR	12 VOLT, VOLTAGE REGULATOR
12	2	R10-11	RES-1/2W,16		RES BODY:150 CENTERS:600
13	2	R8-9	RES-1/4W,150k		RES BODY:100 CENTERS:500
14	2	R3-4	RES-1/4W,33k		RES BODY:100 CENTERS:500
15	1	R7	RES-1/4W,75		RES BODY:100 CENTERS:500
16	1	U4	TDA2616		
17	1	U2	TL072C	MOTOROLA	LOW NOISE,JFET INPUT, OPERATIONAL AMPLIFIER
18	4	R1-2 R5-6	VRES		VARIABLE RESISTOR (POT)

Appendix 10. Portable Nutube Amplifier Schematic



Appendix 11. Portable Nutube Amplifier Layout



Appendix 12. Portable Nutube Amplifier Bill of Materials

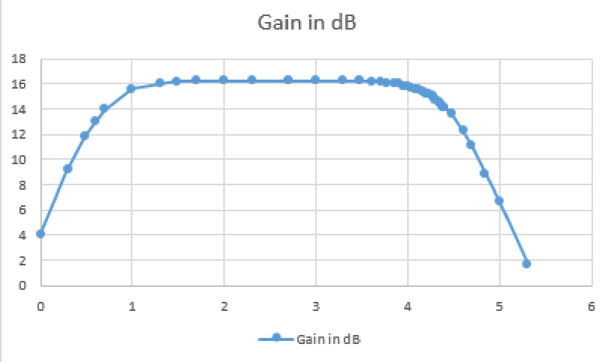
Bill Of Materials for FinalAmpDoublePower.sch on Fri May 05 15:01:47 2017

Item	Qty	Reference	Part Name	Manufacturer	Description
1	1	U1	3V_REG		
2	2	Q2-3	BF246B	MOTOROLA	N-CHANNEL,DEPLETION MODE, SWITCHING JFET
3	1	J2	BIG-JACK		
4	1	C1	CAP-CC06,0.1u,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
5	1	C12	CAP-CC06,100n,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
6	5	C2-5 C15	CAP-CC06,10u,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
7	1	C9	CAP-CC06,2.2n,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
8	1	C7	CAP-CC06,220n,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
9	2	C6 C8	CAP-CC06,22n,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
10	1	C11	CAP-CC06,250u,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
11	1	C13	CAP-CC06,330n,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
12	1	C10	CAP-CC06,50n,	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
13	1	C14	Output	KEMET	RADIAL CERAMIC CAPACITOR, MIL-SPEC SIZE CK06
14	1	J1	CON-SIP-10P		GENERIC 10 PIN SIP HEADER .100 CENTERS
15	1	J3	CON-SIP-2P		GENERIC 2 PIN SIP HEADER .100 CENTERS
16	1	A1	LM386		
17	1	A2	MCP6273		
18	1	R18	RES-1/4W,10		RES BODY:100 CENTERS:500
19	4	R9 R13 R17 R19	RES-1/4W,10K		RES BODY:100 CENTERS:500
20	1	R7	RES-1/4W,110		RES BODY:100 CENTERS:500
21	1	R2	RES-1/4W,14k		RES BODY:100 CENTERS:500
22	1	R16	RES-1/4W,1k		RES BODY:100 CENTERS:500
23	2	R8 R12	RES-1/4W,220K		RES BODY:100 CENTERS:500
24	2	R5 R10	RES-1/4W,33k		RES BODY:100 CENTERS:500
25	1	S1	SWITCH		
26	2	R6 R11	VRES		VARIABLE RESISTOR (POT)
27	4	R1 R3 R14-15	VRES-TOP-ADJ		VARIABLE RESISTOR (TOP ADJUST TYPE)

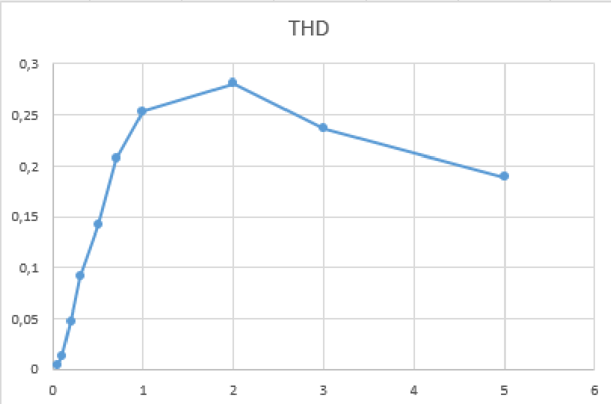
Appendix 13. Measurements of Single Nutube Amplifier

Frequency Response Single Nutube Amplifier

Freq	log of freq			gain	Gain in dB
1	0	0,1	0,16	1,6	4,0824
2	0,30103	0,1	0,29	2,9	9,24796
3	0,477121	0,1	0,39	3,9	11,82129
4	0,60206	0,1	0,45	4,5	13,06425
5	0,69897	0,1	0,5	5	13,9794
10	1	0,1	0,6	6	15,56303
20	1,30103	0,1	0,63	6,3	15,98681
30	1,477121	0,1	0,645	6,45	16,19119
50	1,69897	0,1	0,65	6,5	16,25827
100	2	0,1	0,65	6,5	16,25827
200	2,30103	0,1	0,65	6,5	16,25827
500	2,69897	0,1	0,65	6,5	16,25827
1000	3	0,1	0,65	6,5	16,25827
2000	3,30103	0,1	0,65	6,5	16,25827
3000	3,477121	0,1	0,65	6,5	16,25827
4000	3,60206	0,1	0,645	6,45	16,19119
5000	3,69897	0,1	0,643	6,43	16,16422
6000	3,778151	0,1	0,635	6,35	16,05547
7000	3,845098	0,1	0,63	6,3	15,98681
8000	3,90309	0,1	0,63	6,3	15,98681
9000	3,954243	0,1	0,62	6,2	15,84783
10000	4	0,1	0,615	6,15	15,7775
11000	4,041393	0,1	0,608	6,08	15,67807
12000	4,079181	0,1	0,603	6,03	15,60635
13000	4,113943	0,1	0,599	5,99	15,54854
14000	4,146128	0,1	0,591	5,91	15,43175
15000	4,176091	0,1	0,583	5,83	15,31337
16000	4,20412	0,1	0,578	5,78	15,23856
17000	4,230449	0,1	0,575	5,75	15,19336
18000	4,255273	0,1	0,567	5,67	15,07166
19000	4,278754	0,1	0,559	5,59	14,94824
20000	4,30103	0,1	0,547	5,47	14,75975
21000	4,322219	0,1	0,535	5,35	14,56708
22000	4,342423	0,1	0,531	5,31	14,50189
23000	4,361728	0,1	0,519	5,19	14,30335
24000	4,380211	0,1	0,511	5,11	14,16842
25000	4,39794	0,1	0,507	5,07	14,10016
30000	4,477121	0,1	0,482	4,82	13,66094
40000	4,60206	0,1	0,41	4,1	12,25568
50000	4,69897	0,1	0,358	3,58	11,07766
70000	4,845098	0,1	0,277	2,77	8,849595
100000	5	0,1	0,217	2,17	6,729195
200000	5,30103	0,1	0,121	1,21	1,655707



Vin	THD
0,05	0,003343
0,1	0,012663
0,2	0,047459
0,3	0,091141
0,5	0,141884
0,7	0,206935
1	0,253542
2	0,28083
3	0,236368
5	0,188835



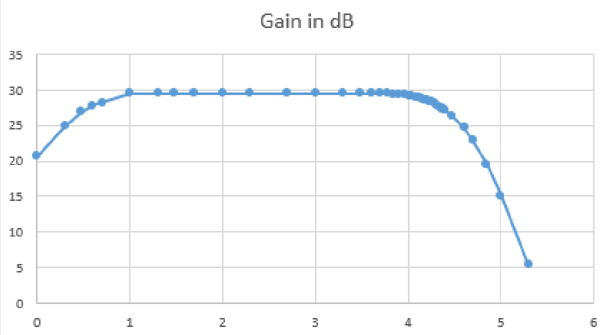
noise amplitude with no input signal	SNR	SNR dB
0,055	160,1818	44,09226

Appendix 14. Measurements of Double Stage Nutube Amplifier

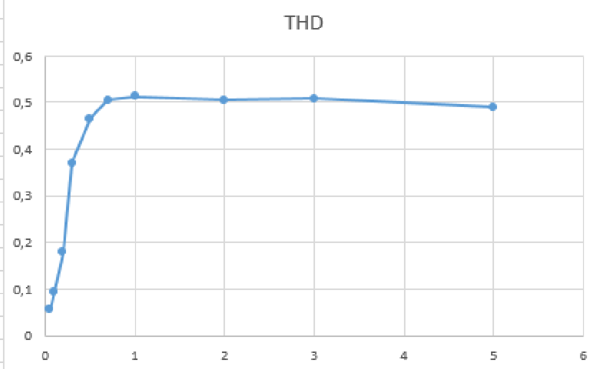
Frequency Response of Double Stage Nutube Amplifier

Freq	log of freq	Vin	Vout	gain	Gain in dB
1	0	0,1	1,08	10,8	20,66848
2	0,30103	0,1	1,75	17,5	24,86076
3	0,477121	0,1	2,21	22,1	26,88785
4	0,60206	0,1	2,45	24,5	27,78332
5	0,69897	0,1	2,56	25,6	28,1648
10	1	0,1	2,98	29,8	29,48433
20	1,30103	0,1	3	30	29,54243
30	1,477121	0,1	3	30	29,54243
50	1,69897	0,1	3	30	29,54243
100	2	0,1	3	30	29,54243
200	2,30103	0,1	3	30	29,54243
500	2,69897	0,1	3	30	29,54243
1000	3	0,1	3	30	29,54243
2000	3,30103	0,1	3	30	29,54243
3000	3,477121	0,1	3	30	29,54243
4000	3,60206	0,1	3	30	29,54243
5000	3,69897	0,1	3	30	29,54243
6000	3,778151	0,1	3	30	29,54243
7000	3,845098	0,1	2,97	29,7	29,45513
8000	3,90309	0,1	2,95	29,5	29,39644
9000	3,954243	0,1	2,92	29,2	29,30766
10000	4	0,1	2,89	28,9	29,21796
11000	4,041393	0,1	2,85	28,5	29,0969
12000	4,079181	0,1	2,81	28,1	28,97413
13000	4,113943	0,1	2,78	27,8	28,8809
14000	4,146128	0,1	2,74	27,4	28,75501
15000	4,176091	0,1	2,71	27,1	28,65939
16000	4,20412	0,1	2,67	26,7	28,53023
17000	4,230449	0,1	2,63	26,3	28,39911
18000	4,255273	0,1	2,6	26	28,29947
19000	4,278754	0,1	2,56	25,6	28,1648
20000	4,30103	0,1	2,5	25	27,9588
21000	4,322219	0,1	2,43	24,3	27,71213
22000	4,342423	0,1	2,38	23,8	27,53154
23000	4,361728	0,1	2,34	23,4	27,38432
24000	4,380211	0,1	2,31	23,1	27,27224
25000	4,39794	0,1	2,26	22,6	27,08217
30000	4,477121	0,1	2,07	20,7	26,31941
40000	4,60206	0,1	1,71	17,1	24,65992
50000	4,69897	0,1	1,4	14	22,92256
70000	4,845098	0,1	0,95	9,5	19,55447
100000	5	0,1	0,572	5,72	15,14792
200000	5,30103	0,1	0,187	1,87	5,436832

Noise amplitude with no input signal				SNR	SNR dB
0,075	V			129,8667	42,26995

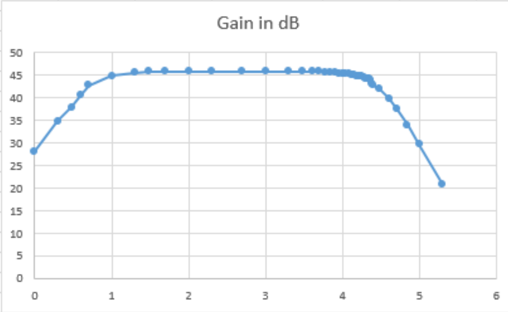


Vin	THD
0,05	0,057288
0,1	0,094524
0,2	0,178369
0,3	0,370071
0,5	0,465022
0,7	0,505341
1	0,512774
2	0,505481
3	0,508383
5	0,489574

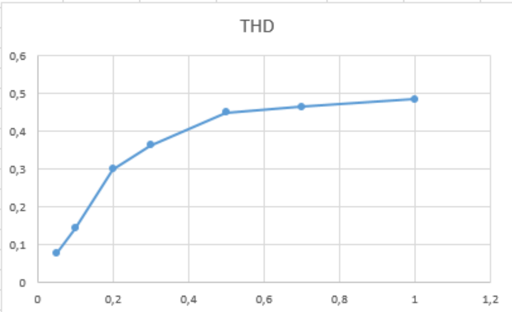


Appendix 15. Measurements of Stereo 12W Nutube Amplifier

0,1 Vpp						
Freq	log of freq				gain	Gain in dB
1	0	0,1	0,16	2,56	25,6	28,16479931
2	0,30103	0,1	0,29	5,51	55,1	34,82303198
3	0,477121	0,1	0,39	7,8	78	37,84189205
4	0,60206	0,1	0,45	10,8	108	40,66847511
5	0,69897	0,1	0,5	13,75	137,5	42,76605396
10	1	0,1	0,6	17,4	174	44,81098497
20	1,30103	0,1	0,63	18,9	189	45,52923608
30	1,477121	0,1	0,645	19,35	193,5	45,73361939
50	1,69897	0,1	0,65	19,5	195	45,80069223
100	2	0,1	0,65	19,5	195	45,80069223
200	2,30103	0,1	0,65	19,5	195	45,80069223
500	2,69897	0,1	0,65	19,5	195	45,80069223
1000	3	0,1	0,65	19,5	195	45,80069223
2000	3,30103	0,1	0,65	19,5	195	45,80069223
3000	3,477121	0,1	0,65	19,5	195	45,80069223
4000	3,60206	0,1	0,645	19,35	193,5	45,73361939
5000	3,69897	0,1	0,643	19,29	192,9	45,70664455
6000	3,778151	0,1	0,635	19,05	190,5	45,5978996
7000	3,845098	0,1	0,63	18,9	189	45,52923608
8000	3,90309	0,1	0,63	18,9	189	45,52923608
9000	3,954243	0,1	0,62	18,6	186	45,39025888
10000	4	0,1	0,615	18,45	184,5	45,31992741
11000	4,041393	0,1	0,608	18,24	182,4	45,22049668
12000	4,079181	0,1	0,603	18,09	180,9	45,14877134
13000	4,113943	0,1	0,599	17,97	179,7	45,09096154
14000	4,146128	0,1	0,591	17,73	177,3	44,97417471
15000	4,176091	0,1	0,583	17,49	174,9	44,85579619
16000	4,20412	0,1	0,578	17,34	173,4	44,78098186
17000	4,230449	0,1	0,575	17,25	172,5	44,73578199
18000	4,255273	0,1	0,567	17,01	170,1	44,61408627
19000	4,278754	0,1	0,559	16,77	167,7	44,49066125
20000	4,30103	0,1	0,547	16,41	164,1	44,30217162
21000	4,322219	0,1	0,535	16,05	160,5	44,10950073
22000	4,342423	0,1	0,531	15,93	159,3	44,04431552
23000	4,361728	0,1	0,519	15,57	155,7	43,84577225
24000	4,380211	0,1	0,511	14,308	143,08	43,11157863
25000	4,39794	0,1	0,507	13,689	136,89	42,72743447
30000	4,477121	0,1	0,482	12,532	125,32	41,96040772
40000	4,60206	0,1	0,41	9,84	98,4	39,85990197
50000	4,69897	0,1	0,358	7,518	75,18	37,52204643
70000	4,845098	0,1	0,277	4,986	49,86	33,95504548
100000	5	0,1	0,217	3,038	30,38	29,65175539
200000	5,30103	0,1	0,121	1,089	10,89	20,7405576
Noise Amplitude with No Input Signal				SNR	SNR dB	
0,1				224	47 dB	

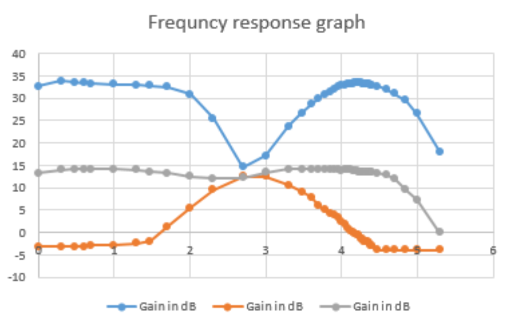


Vin	THD
0,05	0,074844
0,1	0,14208
0,2	0,299444
0,3	0,362837
0,5	0,448678
0,7	0,46327
1	0,484673

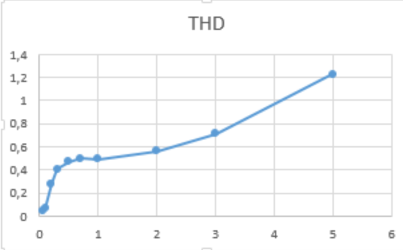


Appendix 16. Measurements of Portable Nutube Amplifier

Frequency Response of Portable Nutube Amplifier											
0,1 Vpp			Max trble and bass			Minimum trible and bass			Tuned for flat freq. response		
Freq	log of freq			gain	Gain in dB		gain	Gain in dB		gain	Gain in dB
1	0	0,1	4,3	43	32,66937	0,07	0,7	-3,09804	0,46	4,6	13,25516
2	0,30103	0,1	4,95	49,5	33,8921	0,07	0,7	-3,09804	0,5	5	13,9794
3	0,477121	0,1	4,78	47,8	33,58856	0,07	0,7	-3,09804	0,51	5,1	14,1514
4	0,60206	0,1	4,68	46,8	33,40492	0,07	0,7	-3,09804	0,51	5,1	14,1514
5	0,69897	0,1	4,58	45,8	33,21731	0,072	0,72	-2,85335	0,51	5,1	14,1514
10	1	0,1	4,52	45,2	33,10277	0,072	0,72	-2,85335	0,51	5,1	14,1514
20	1,30103	0,1	4,44	44,4	32,94766	0,076	0,76	-2,38373	0,5	5	13,9794
30	1,477121	0,1	4,35	43,5	32,76979	0,08	0,8	-1,9382	0,48	4,8	13,62482
50	1,69897	0,1	4,26	42,6	32,58819	0,117	1,17	1,363717	0,46	4,6	13,25516
100	2	0,1	3,5	35	30,88136	0,189	1,89	5,529236	0,42	4,2	12,46499
200	2,30103	0,1	1,9	19	25,57507	0,3	3	9,542425	0,4	4	12,0412
500	2,69897	0,1	0,54	5,4	14,64788	0,42	4,2	12,46499	0,41	4,1	12,25568
1000	3	0,1	0,72	7,2	17,14665	0,42	4,2	12,46499	0,47	4,7	13,44196
2000	3,30103	0,1	1,53	15,3	23,69383	0,34	3,4	10,62958	0,51	5,1	14,1514
3000	3,477121	0,1	2,17	21,7	26,72919	0,285	2,85	9,096897	0,51	5,1	14,1514
4000	3,60206	0,1	2,69	26,9	28,59505	0,25	2,5	7,9588	0,51	5,1	14,1514
5000	3,69897	0,1	3,14	31,4	29,93859	0,2	2	6,0206	0,51	5,1	14,1514
6000	3,778151	0,1	3,5	35	30,88136	0,18	1,8	5,10545	0,51	5,1	14,1514
7000	3,845098	0,1	3,78	37,8	31,54984	0,165	1,65	4,349679	0,51	5,1	14,1514
8000	3,90309	0,1	4	40	32,0412	0,157	1,57	3,917993	0,51	5,1	14,1514
9000	3,954243	0,1	4,22	42,2	32,50625	0,145	1,45	3,22736	0,5	5	13,9794
10000	4	0,1	4,34	43,4	32,74979	0,133	1,33	2,477033	0,49	4,9	13,80392
11000	4,041393	0,1	4,42	44,2	32,90845	0,122	1,22	1,727197	0,5	5	13,9794
12000	4,079181	0,1	4,5	45	33,06425	0,112	1,12	0,98436	0,5	5	13,9794
13000	4,113943	0,1	4,58	45,8	33,21731	0,105	1,05	0,423786	0,5	5	13,9794
14000	4,146128	0,1	4,64	46,4	33,33036	0,1	1	0	0,49	4,9	13,80392
15000	4,176091	0,1	4,66	46,6	33,36772	0,098	0,98	-0,17548	0,49	4,9	13,80392
16000	4,20412	0,1	4,66	46,6	33,36772	0,095	0,95	-0,44553	0,49	4,9	13,80392
17000	4,230449	0,1	4,66	46,6	33,36772	0,095	0,95	-0,44553	0,48	4,8	13,62482
18000	4,255273	0,1	4,66	46,6	33,36772	0,085	0,85	-1,41162	0,47	4,7	13,44196
19000	4,278754	0,1	4,6	46	33,25516	0,085	0,85	-1,41162	0,47	4,7	13,44196
20000	4,30103	0,1	4,58	45,8	33,21731	0,08	0,8	-1,9382	0,48	4,8	13,62482
21000	4,322219	0,1	4,58	45,8	33,21731	0,08	0,8	-1,9382	0,48	4,8	13,62482
22000	4,342423	0,1	4,52	45,2	33,10277	0,078	0,78	-2,15811	0,48	4,8	13,62482
23000	4,361728	0,1	4,5	45	33,06425	0,076	0,76	-2,38373	0,48	4,8	13,62482
24000	4,380211	0,1	4,46	44,6	32,9867	0,072	0,72	-2,85335	0,47	4,7	13,44196
25000	4,39794	0,1	4,46	44,6	32,9867	0,072	0,72	-2,85335	0,47	4,7	13,44196
30000	4,477121	0,1	4,3	43	32,66937	0,064	0,64	-3,8764	0,46	4,6	13,25516
40000	4,60206	0,1	3,98	39,8	31,99766	0,064	0,64	-3,8764	0,44	4,4	12,86905
50000	4,69897	0,1	3,58	35,8	31,07766	0,064	0,64	-3,8764	0,4	4	12,0412
70000	4,845098	0,1	3,02	30,2	29,60014	0,064	0,64	-3,8764	0,3	3	9,542425
100000	5	0,1	2,13	21,3	26,56759	0,064	0,64	-3,8764	0,23	2,3	7,234557
200000	5,30103	0,1	0,8	8	18,0618	0,064	0,64	-3,8764	0,1	1	0



Vin	THD
0,05	0,042595
0,1	0,064982
0,2	0,275701
0,3	0,408587
0,5	0,471043
0,7	0,496637
1	0,492324
2	0,564575
3	0,710758
5	1,228282



Noise Amplitude with no input signal	SNR	SNR dB
0,1	84	38,48559