EE 403W Section 3 Spring 2009

Vacuum Tube Amplifier

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Introduction

The function of an audio amplifier is to amplify low voltage audio signals (several millivolts) to an appropriate level for driving a loudspeaker. Amplification is typically achieved in audio amplifiers using either tube or transistor technology.

Although there are relatively few manufacturers of audio tube amplifiers compared to solid state amplifiers, tubes are often the preferred choice for musicians and audiophiles. Many claim to prefer vacuum tube amplifiers for their unique sound while others may just appreciate the visual effect of the glow [1]. Only tubes can supply the vintage sound that is often sought after.

Beyond subjective preferences, vacuum tubes have a variety of quantifiable advantages over solid state devices even today, when solid state devices have replaced vacuum tubes in modern amplifier designs. The frequency response of vacuum tube designs is highly linear without the negative feedback typically required in transistor designs. [2] Also, circuit designs are often much simpler in vacuum tube designs

After considering all the advantages of vacuum tubes, the objective of this project was to design, construct, and test a high-fidelity vacuum tube amplifier that would be able to reproduce audio over the entire audible frequency range. The amplifier was expected to be comparable in sound quality to solid state and tube amplifiers currently available on the market and also needed to be inexpensive enough for amateur hobbyists.

Team Members

Justin Brooks

Justin will be graduating in May. His primary focus is with software and plans to attend graduate school to obtain his PhD in Computer Science. He has taken courses in circuit design and layout. Justin is also an avid acoustic guitar player and is quite familiar with amplifiers and effects pedals. He has helped family members purchase and set up surround sound home theater systems. Justin was responsible for construction of the power supply and board layout considerations.

Sean Evanuik

Sean is a senior graduating this May. He has taken electives in electronics and power systems. Sean's interest in music and guitar is what led to him pursuing his degree in electrical engineering. Combining his interest for electronics and guitar, Sean successfully constructed a low wattage tube amp with a matching speaker cabinet. His tube project has given him experience with soldering and basic point to point layout design. Sean was responsible for the overall design, component decisions, and oversight of construction.

Dong Jai Lim (Dan)

Daniel is a graduating senior who is specializing in semiconductor physics and devices with a strong background in device characteristics. He decided to participate in this project based on his passion for music, and also under the influence of a friend who is operating an audio company. He has taken a number of electives in analog circuit design, where he learned about class amplifiers as well as frequency response and feedback of amplifier circuits. Dan was responsible for the simulation and testing of the design in Simulink and assisted with construction.

Chien-Wei Lo

Chien-Wei is also a graduating senior who has taken several courses such as engineering circuit design and discrete and signal processing which enable him to analyze signal characteristics. Chien-Wei held an internship position during the summer of 2008 and was performed motherboard circuit analysis and testing. He was responsible for soldering components to tube socket clips, and also assisted with construction.

Requirements and Specifications

The following requirements and specifications serve as a foundation for the design and description of the amplifier.

General requirements:

- Class AB push-pull configuration
- High – Fidelity
- Single Channel, Monoblock
- RCA Input
- Volume Control

Technical specifications included:

	Minimum	Optimum
Frequency Response	30 – 16000Hz	20 – 20000Hz
Total Harmonic Distortion (THD)	Less than 8%	Less than 1%
Output Power	Greater than 5W	10W
Output Load	8 Ω	8 Ω
Signal-to-Ratio (SNR)	80dB	90dB
Cost	Less than $300	Less than $200

The technical specifications were chosen appropriately for the semester time frame and to meet basic quality audio standards. The specifications are based on typical values reported for amplifiers currently on the market. A monoblock design was chosen to keep prototype costs minimal but considerations were given to designs adaptable to a stereo configuration. Testing of these requirements will partly determine the success of the project. Overall, the success of the project will be determined by a qualitative listening comparison with a manufactured high fidelity amplifier.

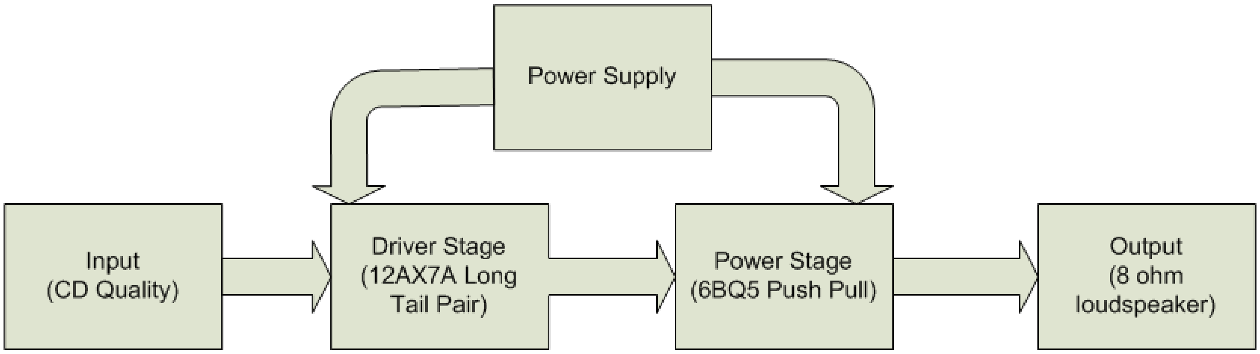
Technical Design

The project was divided into several phases. These phases included design, construction, and testing.

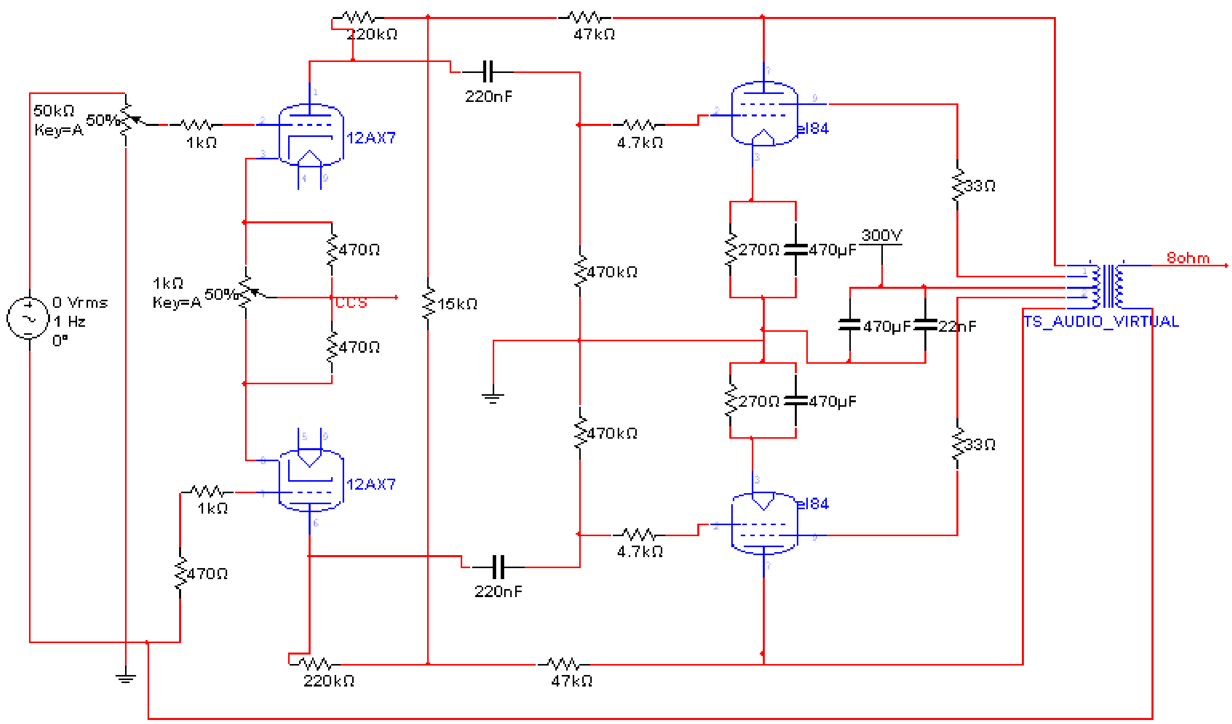
<u>Design</u>

The design phase started with choosing the necessary vacuum tubes needed to design the amplifier around. The 6BQ5 was chosen for the output stage and the 12AX7A was chosen for the driver stage. These tubes were chosen because of availability and the fact they have been used together in various classic amplifier designs.

After choosing the appropriate tubes, a general design was developed. This can be seen in the block diagram below.

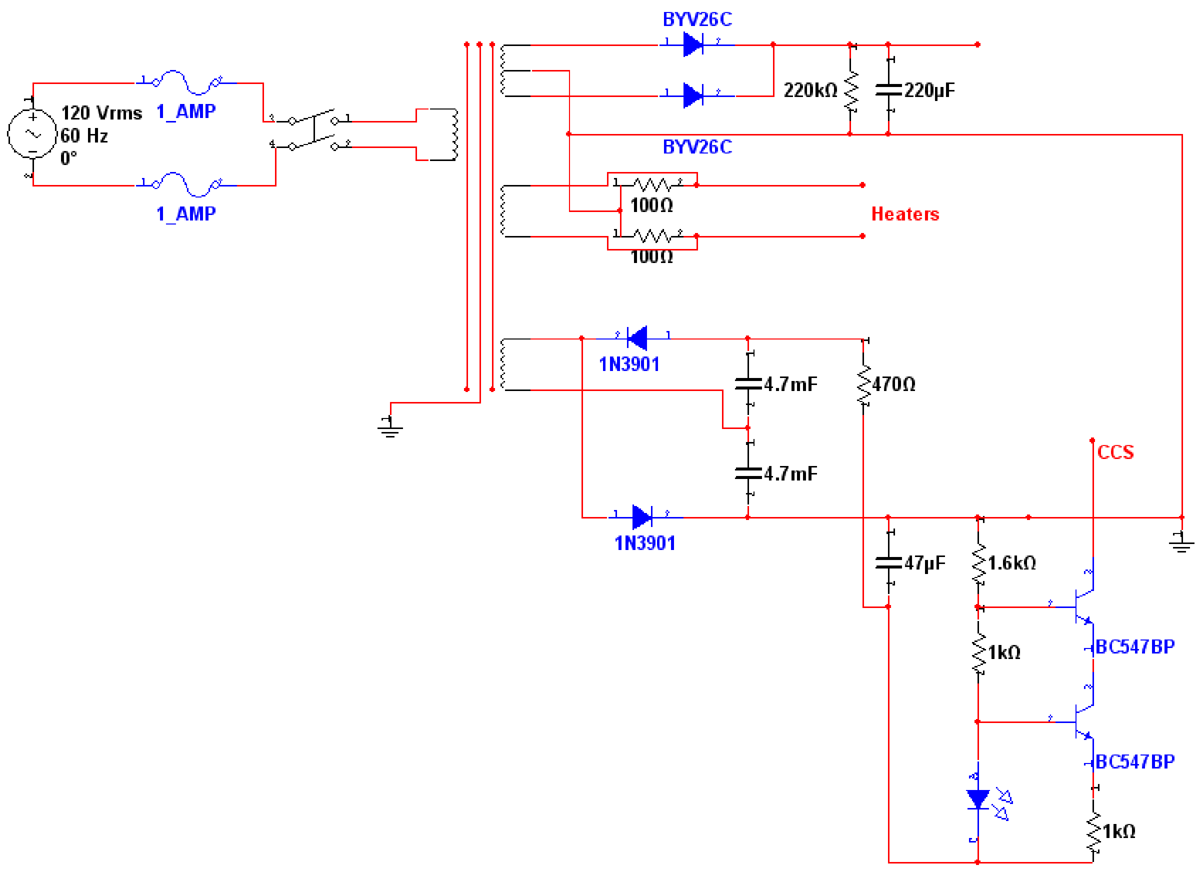


By using a push pull output stage, odd harmonics introduced by the driver stage can be canceled with well matched output tubes. The push pull configuration also increases efficiency and allows for a common output connection known as ultra-linear. Choosing an overall design allowed a tube manual to be referenced for appropriate resistor values for dc biasing and gain settings. The overall design of the amplifier circuit can be seen in the schematic below.



The simple design was adopted from the tube manual. The addition of the 15k resistor was added as local feedback. The reason for this was to help linearize the output signal of the 12AX7A before it entered the push pull stage. It can also be seen in the schematic that the output transformer's primary has several taps. The ultra-linear connection made at these taps allows the amplifier to run in a mode similar to class A and class AB combined. This means the amplifier can achieve the dynamic range typical of a class A amplifier and the linearity and harmonic cancellation effects of a class AB amplifier.

The final design done was the power supply. A power transformer with three secondaries was chosen to allow for three supply voltages. A full wave rectifier was used to achieve the necessary 300V supply



for the tube plates. A constant current source which required 14V was used to bias the differential amplifier. This 14V was achieved by using a voltage doubling circuit with a full wave rectifier. The 6.3 voltage needed for the tube heaters was simply taken from the secondaries without any rectification. The schematic for the power supply and constant current source can be seen below.

<u>Construction</u>

The amplifier was built on a piece of pine board to facilitate construction. Terminal blocks were used to minimize soldering and to allow modifications to be made easy. The components were rated adequately for power dissipation and voltage swings. The exception to this was the filtering cap used in the 300V power supply. Initially, the transformer to be used was to only have a secondary of 240V rms, but do to availability and pricing a 275-0-275 transformer was used. Ideally the capacitor should have been rated for 450V instead of 350V. A decision was made that the capacitor would suffice for this prototype and would still allow for testing of the design. The voltage peak simply will degrade the capacitor dielectric over time, thus making the capacitor only a temporary component. Increasing the capacitor's rated value would be required if the design was to be built for actual use. A picture of the final layout and construction can be seen below.

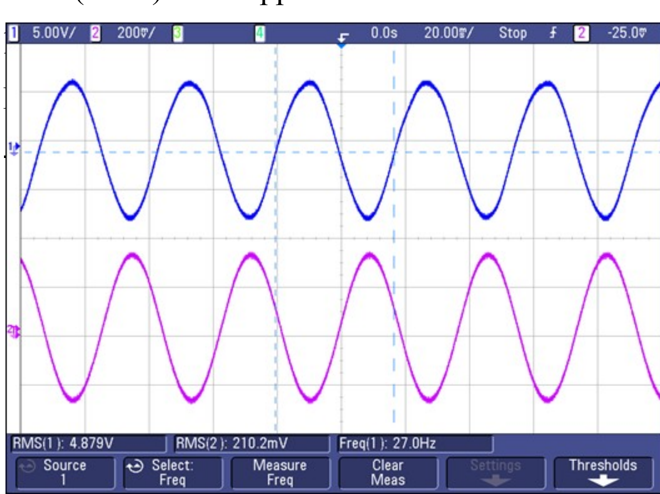
Insert picture here:

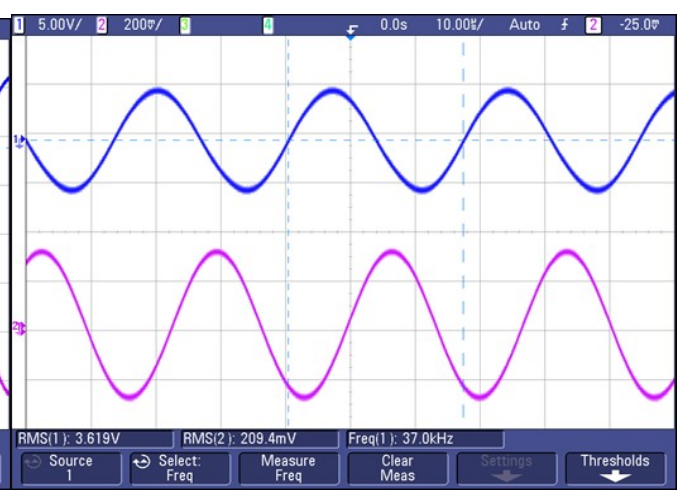
Test and Evaluation

Initially, the evaluation of the amplifier was going to consist of three different tests. This included technical measurements, a comparative listening test, and a blind AB test. Unfortunately, due to time constraints, a blind AB test was not able to be preformed.

The evaluation of measurements included: THD, SNR, amplifier gain, frequency response, and output power. THD was measured using the HP 5461 Dynamic Signal Analyzer. The Analyzer was configured with a bandwidth of 20kHz, a center frequency of 1kHz, and set to measure 10 harmonics. The signal generator itself was found to have a THD value of 0.2%, while the tube amplifier was measured to have a THD value of 1%. The fact the THD value is in a linear scale, it was approximated that the true THD of the amplifier was 0.8%.

The frequency response was determined by manually locating the -3dB points. The amplifier was set at a constant gain of 5V (14dB), and the frequency was varied until the output voltage decreased to 3.6V (11dB). The upper -3dB was found to be 37kHz. Transformer saturation, however, limited the





Output power and gain was measured using a 1kHz input signal at 200mV. The output voltage was measured at 6.5V which is provides 5.28 watts. This was determined from P=V^2/R=6.5^2/8=5.28. This output voltage also determined the voltage gain of the amplifier to be 30.24dB.

For the last test, the designed tube amplifier was compared to a high quality solid state amplifier, the AES McIntosh amplifier. The observations insured the designed tube amplifier was at least of similar audio quality to a manufactured amplifier. The same piece of music from one source, a cell phone, was played through both amplifiers and identical loudspeakers at similar listening levels. The general reaction of the audience was positive and the amplifier exceeded audience expectations.

Actual Specifications:

Desired specifications have been restated for convenience along with what was achieved.

	Desired	Achieved
Frequency Response	20 – 20000Hz	27 – 37000Hz
Total Harmonic Distortion (THD)	Less than 1%	Less than 1%
Output Power	5-10W	>5W
Output Load	8 Ω	4-16 Ω (variable)
Signal-to-Ratio (SNR)	90dB	Not measured
Cost	Less than $200	$168.00

Conclusions and Recommendations

The measured specifications show that the project was a success. The only criteria that was not tested was SNR. This was due to the inability to make the measurement with the equipment available. The frequency response was only below the initial requirements in the lower frequency range. The upper frequency response was well above the audible hearing range. Surprisingly, THD was kept to under 1% even without the addition of negative feedback. Most importantly, the amplifier satisfied the subjective audio quality requirement. This was proven with an inclass demonstration, where peer remarks were highly positive. Comparison with a $4000 amplifier was intimidating, but the simple tube design performed remarkably with the stiff competition. Simple improvements could be made to increase the performance of the amplifier. Placing the amplifier in a metal chassis would help eliminate any interference and noise. Higher quality transformers could be used to help increase frequency response, but that would add to the overall cost of the project. Creating a stereo amplifier would obviously improve the listening experience by allowing music to be reproduced as it was intended.

Much time was devoted to the design of the amplifier to ensure high quality music reproduction. Once the design was complete, actual construction did not take an extensive amount of time. More time would like to have been devoted to testing, especially more thorough listening tests. Overall the effort was adequate enough to produce a successful project, but could have been improved to allow for design adjustments and more testing.

References

[1] Bussey, Stephen W., and Robert M. Haigler. "Tubes Versus Transistors in Electric Guitar Amplifiers." IEEE. May 1981. 26 February 2007.

[2] Barbour, Eric. "The Cool Sound of Tubes." IEEE Spectrum 35.8 (1998).

[3] Hamm, Russell O. "Tubes Vs Transistors: Is there an Audible Difference."AES Journal (1972)