Vacuum Tube Guitar Amplifier

ANALOG ELECTRONICS CAPSTONE 2014
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Abstract

This semester we designed a vacuum tube guitar amplifier. Despite advances in technology, vacuum tubes remain a popular choice in acoustics and audio amplification. We were interested in researching what gives vacuum tubes their characteristic sound, and how they can be implemented in a circuit. A vacuum tube amplifier is a high performance audio amplifier to deliver the optimum tone to the listener. We set out to design a high performing amplifier which is cheap, portable and sounds great. We were able to properly implement our designed work from simulated circuit to the physical construction of the amplifier. For future work, we would like to design an amplifier without any unwanted humming noise. Furthermore, we would like to design a further optimized circuit using more tubes in the future.

Introduction

When we came together this semester to begin our Capstone Design course, we were all eager to participate in a project that would put our engineering education to good use in a practical and exciting project. As musicians, we were interested in building a circuit that we use in our everyday lives: a guitar amplifier. We had played on amplifiers that use vacuum tubes and noticed a much more clean and powerful tone. Although we had not learned about vacuum tubes in class, we were interested in researching them because of their phenomenal tone.

To make our experiment more challenging and our research more innovative, we decided to build a lightweight and portable amplifier. We would design a circuit to harness the tone of vacuum tubes that all musicians love, but engineer a new circuit with a small and compact design.

The experiment required a team effort for the entirety of the semester. We began with an initial research phase to investigate how tubes work. Once we understood this, we set out to design a driver circuit to amplify our circuit signal. As our circuit design was evolving, we were testing and characterizing
the physical circuit components to optimally amplify a guitar signal. As our research was developing, we realized a need to explain to our colleagues why an engineer might use vacuum tubes in circuit design. The addition of the output stage gave us a circuit that sent a signal through, but with an uneven response. A final debugging phase gave us an optimally engineered amplifier circuit. We are proud to report that our amplifier was physically constructed and produced the tone we had anticipated. Our months of research paid off and we were able to plug in and play music on our amplifier circuit. The output was harmonious and made the guitar sound great. There was, however, some noise in our circuit that we were not able to eliminate. This will be the focus of future work.

**Approach/Methods/Results**

The approach began with the simulation in PSPICE. Our circuit schematic was engineered to provide an output that would be pleasing to the listener. Once the schematic was complete our next step was to physically implement the circuit. Once the circuit was built, we had to complete our procedure with debugging. Problems arose with an uneven signal output in the PSPICE circuit. We tried to solve it by changing the values of the capacitors and the resistors in the circuit and achieved the desired output. At the end of the construction stage, there was a humming sound in the output. Close analysis and the inquiry from our advisor indicated that the problem was coming from the preamp stage in the first tube, and we were advised to rectify it by fixing our first stage. Our system architecture is shown in the block diagram below.

*System Architecture: Block Diagram*
The result of our research was a working amplifier with a great characteristic tube sound. We were able to harness the tone of tube amplifiers and optimize their output in our amplifier circuit.

Cost/Sustainability Analysis

Our amplifier cost $250 dollars to build. This is a very cost effective design. Tube amplification is constructed and sold at a much higher price point for thousands of dollars. This cost effective design was implemented with a simple circuit design and minimum number of parts. This technology could be mass produced cheaply. The cost can be reduced in the future with more effective wiring to cut down costs. One signal transformer in the input caused humming and the amp worked better without it. This cost can be removed to save money.

Vacuum Tube Research

In our engineering education today, we are taught how to design and build microelectronic circuits. We learn about silicon doping, bipolar junction transistors and MOSFET technology. Their benefits in cost and size are undeniable; however the vacuum tube still holds a place in modern electronics.

Vacuum tubes were first introduced in 1906. They were used in everything from televisions to radios and amplifiers. Advances in microelectronics found smaller and more durable alternatives and the vacuum tube became a much less popular choice for circuits.

A vacuum tube has three basic parts: a cathode, a grid and a plate. Essentially, the cathode is heated up and produces a group of electrons. The electrons flow through a grid and onto a plate where the signal is ultimately amplified. It is up to the engineer to properly bias the grids of the tube in order to control the flow of electrons from the cathode to the plate. Biasing the grids with a negative voltage will hold electrons on the cathode while biasing the grids with a positive voltage will draw them towards the
plate. The voltage of the grid acts as a valve for the flow of electrons, which is why tubes are often referred to as valves.

**Why Tubes?**

In terms of circuit analysis, vacuum tubes can produce the same voltage and current characteristic as their transistor analog; however the distortion characteristics are quantifiably different.

An amplifier enters distortion when it is driven past its power rating. During the advent of electric guitars, this became an exploited design flaw. Musicians would play concerts on guitars that are “broken” from an engineering perspective to produce a distorted sound that people wanted to hear. Nowadays, a guitarist can press a button on his amplifier to intentionally distort his output. The real reason the sound becomes distorted is because of the relative strength of the harmonics.

When the guitar is played through the amplifier, what the audience hears is not a single note, but a sum of harmonics of the note that is played on the guitar. How nice the note sounds, or the quality of the tone is determined by the harmonics in the output.

![Standing wave harmonics](image)
When a transistor amplifier is distorted, the dominant distortion product is the third harmonic. The third harmonic is an odd harmonic and is mathematically three times as large as the fundamental frequency. This harmonic is musically equivalent to an octave above the note and also a fifth above the note. Depending on the piece of music, a strong fifth in the output may be a dissonant and unwanted tone.

![Comparative distortion products of transistor amplifier](image)

When a vacuum tube amplifier is distorted, the dominant distortion product is the second harmonic. The second harmonic is musically equivalent to the fundamental frequency. It is exactly twice the frequency of the note played and one octave above the note. To the audience, a second harmonic will sound harmonious and pleasant regardless of its musical context.
Comparative distortion products of vacuum tube amplifier

Tubes vs. Transistors

Despite the fact that valve tube technology is an old technology, it has found its way into modern architectural equipment where it has become extremely beneficial to engineers and to consumers. For this reason, it presents two aspects of advantages to the society: the economic aspect of it and the scientific-engineering aspect of it. Vacuum tube amplifier can be operated in the overload without adding any distortion. It has an ideal sound recording compressor which arises from the combination of both slow rising age and the open harmonic structure of the overload characteristics. Within the safe overload range of 15-20 DB, electrical output of the vacuum tube amplifier increases by only 2-4 DB, hence it acts as a limiter. But since the edge is increasing within this range, the loudness remains uncompressed to the listener’s ears. These characteristics make a tube amplifier to have a high apparent level, even though it is not indicated in the VU meter. Tubes do sound better and have a better signal to noise ratio due its subjective headroom with is absent in the transistor amplifiers.

Vacuum tube amplifier has got a highly linear operation range without experiencing negative feedback. The benefit of this is that it can be used for a lengthy period of time before it drives into
saturation which is likely to distort the quality of the sound. Transistor amplifier unlike the vacuum will become saturated and the quality of the sound reduces, thus it undermines consumes expectation. Vacuum tube amplifier protects the speaker somehow. The entire amplifier is built in isolated structure different from the speaker, and if there is a electrical damage to the amplifier, only the amplifier get affected but the speaker stilt functions. Considering that the speaker is much more expensive than the amplifier, it becomes easier to replace the amplifier that the spear. Transistor amplifier on the other hand, is attached to the speaker and electrical or mechanical damage to it harms both the speaker and the amplifier, thus vacuum tube amplifier presents economic advantages over transistor amplifier in this case. Easier repair in case of damage is another area where vacuum tube amplifier is hugely preferred to transistor’s .Its tube isolation makes it easily to be repaired if it experiences some shortcomings. Because the tubes are isolated from other components, it becomes much easier to simple deal with the faulty component without disturbing other good working parts within its ecosystem. Additionally, this can be easier in that not necessarily experts can do this. This is not the case with the vacuum tube amplifier. In case of its breakdown, the entire ecosystem has to be carefully navigated in repairing it. This action is sometimes challenging and requires experts, which may not be easily available, or if available may not be cheap. Consequently, Vacuum tube still holds an upper hand advantage both economically and scientifically over the transistors.

Driver Circuit

Once we came to understand how a vacuum tube functions in a circuit we set out to design a pre-amplifier circuit, or driver circuit. The main components of our driver were two 12AU7 tubes. The 12AU7s are medium gain twin triode tubes. The first stage of the driver is the cascode stage. The cascode stage takes advantage of the dual triodes to create a high gain. The cathode of the first triode is connected to the plate of the second triode. This creates a large voltage swing, a sought-after trait in
guitar amplifiers. This swing allows players a large dynamic range in their playing as well as a very high maximum volume.

The second stage of the driver circuit is the differential pair. Here, the AC guitar signal input is split into two phases 180° apart. This is installed for noise suppression. In the output stage, any noise in the signal will appear in both of the split signals and will cancel out when recombined in the output stage. In order for our differential pair to be balanced, we added a current sink in place of the biasing resistor. Our plate voltages were unbalanced with the biasing resistor, but by adding a transistor current mirror, we were able to balance the voltages.

The driver circuit schematic is below, including transient and AC analysis.

Driver Stage Schematic and Bias Values
This circuit can be implemented using only two tubes - each tube on the schematic above is only half of a physical tube.

AC analysis reveals the high gain of our circuit design - approximately 400 from 0 Hz to 10 kHz. This gain will of course change as we add to our circuit (primarily the output stage and output transformer), but because we designed the circuit to have more than enough gain, these reductions should not affect the amp’s performance dramatically.

**AC Analysis**

Now we consider a transient analysis of our driver stage design, which demonstrates the soft clipping characteristics we expect from a tube amplifier.
From the figure above we can see that at small input voltages the signal is amplified cleanly and without alteration. This shows that our amplifier is capable of pure amplification without adding any tube characteristic sound to the signal. In the next figure, we see how the tubes can color the sound in a pleasant way.
At 100 mV peak input, we start to see signs of the soft clipping characteristic of tube amplifiers beginning to saturate. In this mode of operation, tube amplifiers begin to produce the pleasing distortion products discussed earlier in this report, most notable the 2nd harmonic (octave). This edge of saturation operation is extremely pleasing musically due to the amplification of the second harmonic; thus, operation in this mode is sought-after for guitarists.

![Graph](image)

*Transient Analysis (200 mV peak input)*

Here the output signal for a 200mV input is shown. 200mV represents the maximum voltage a guitarist can generate using all strings at a high volume. Here, the output begins to show signs of distortion as the output signal is noticeably clipped. Fortunately, the tube amplifiers exhibit smooth clipping in distortion and the result is a pleasant output signal for the listener. The tops of the sinusoidal waves are still smooth and don’t have the hard and sharp corners of the squarewave-like clipping exhibited by transistor amplifiers.
At 1V peak input, we finally see hard clipping. This clipping is more characteristic of transistor amplifiers and is another reason musicians shy away from purchasing transistor amplifiers; the hard clipping sounds harsh and unmusical to many. From this analysis we can see that our amplifier will never exhibit the hard clipping characteristics of a transistor amplifier in the range of normal guitar signal levels (approximately 200 mV peak max).

Characterizing the Transformers

Characterizing transformers were necessary for our PSPICE circuit simulation to get more exact result from it. For the PSPICE transformer modeling, the mutual inductance was measured to find out the coupling coefficients of its transformer. Also, by finding out its specifications and frequency response, we were able to check if those transformers were good enough for our physical circuit implementation or not. There were three types of transformers; Output transformer (8k ohm to 8 ohm),...
10k:10k transformer and 1k:1k transformer. Each transformer was measured carefully by using inductance measurement device and the procedure was given by professor Caggiano.

Measuring mutual inductance of the output transformer

The mutual inductance was measured first, when the circuit is open, next when the each inductor was short and measured the others. For example, if it is an output transformer, then we measure three L1, L2, and L3 when they are open. After that, we short L1, and measure L2, L3 and so on. We discussed which equation to be used for mutual inductances and the corresponding coupling coefficients. Then, we decided to use the Professor Caggiano’s suggestion. Therefore, the equation was used the following for all three transformers. M refers to mutual inductance, and K refers to coupling coefficient.
\[ M_{12} = (L_1 \ast L_2 - L_1 \ast L_{EQ})^{1/2} \]

\[ K_{12} = \frac{M_{12}}{\sqrt{L_1 \ast L_2}} \]

And \( L_{(EQ)} \) could be measured as following,

The results of each transformer

Output transformer (8k ohm to 8 ohm)

\begin{align*}
M_{13} &= .277H \\
M_{12} &= 3.48H \\
M_{23} &= .277H \\
M_{21} &= 3.48H \\
M_{31} &= .276H \\
M_{32} &= .276H
\end{align*}

\begin{align*}
k_{13} &= .984 \\
k_{12} &= .966 \\
k_{23} &= .984 \\
k_{21} &= .966 \\
k_{31} &= .995 \\
k_{32} &= .995
\end{align*}
10k:10k transformer

M12=1.84H  k12=.9914
M13=1.82H  k13=.975
M14=1.85H  k14=.9914

M21=1.89H  k21=1.01
M23=1.82H  k23=.991
M24=1.84H  k24=.989

M31=1.82H  k31=.989
M32=1.82H  k32=.991
M34=1.83H  k34=.991

M41=1.85H  k41=.991
M42=1.84H  k42=.989
M43=1.83H  k43=.992

1k:1k transformer

M12=.35H   k12=.993
M13=.33H   k13=.985
M14=.35H   k14=1.01

M21=.35H   k21=.993
As it is shown above, there are coefficient values which are different but have to be same. For example, our output transformer $k_{13}$ and $k_{31}$ were supposed to have the same values but they were different. In this case, we chose the worst case value which was $k_{13}, 0.984$ for better performance later in real circuit.

**Charge Pump Analysis**

As it fits on our first plan; the light weight, inexpensive tube amplifier, we were thinking of not using the power transformers for the first place where we begin our project. Because a power transformer is typically huge and expansive, eliminating this became our great innovation. That is why the charge pump has become our replacement of this power transformer.

![Charge pump circuit with appropriate load current sink](image)

As it is shown above, this circuit gets input from the wall which has 120RMS (170V\_peak) AC voltage. Then by passing through the capacitors and diodes, at the point where the C10 exists, the voltage becomes doubles and almost like a DC voltage.
Up to the C10 part, this circuit is well known as a half-wave voltage doubler. According to the website, all about circuits; voltage multipliers section,

Half-wave voltage doubler (b) a clamper and (c) a half-wave rectifier

First, C2 charges to 5 on the negative half cycle of AC input. The circuit becomes like (b), a clamper, and the right end is grounded left end is charged at the negative peak of the AC input. During the positive half cycle, the circuit becomes like (C), a half-wave rectifier. At this point, diode D2 becomes just like an open circuit since it is reverse biased. Therefore, C2 is now in series with the voltage source. Thus, rectifier D1 sees a total of 10 V at the peak of the sine wave, 5 V from generator and 5 V from C2. Therefore, after several cycles if input sine wave, the C1 stabilizes at the peak of the voltage.

Here is out output of voltage doubler circuit.

Voltage Doubler Output
This shows the output voltage became almost around 340V, which was doubled from the input peak voltage, with a voltage ripple after few seconds.

Voltage Ripple

The output ripple can be easily seen by having a closer look around the 0.5s. Even though the output voltage was pretty stabilized at this moment, there still exists a voltage ripple.

Lightweight: Signal Transformer and Charge Pump

As this circuit was being created, some of the team was finding the physical devices to realize this circuit. The first device we had to find was a signal transformer to get the signal from our guitar into the circuit. The vast majority of amplifiers will use a power transformer in place of this signal transformer but for the purpose of our research we set out to build ours with a small and inexpensive signal transformer. First of all, we needed to determine the impedance we needed for the transformer. Given that our signal will be coming from an electric guitar, we needed to measure the impedance of the guitar. Electric guitars utilize magnetic coil pickups underneath the string to induce an electrical current.
and send it to the circuit. To measure the impedance, we connected the guitar to an oscilloscope with a substitution box and found impedance that halved the input signal. This was measured to be 10k ohms. We also found a 1k:1k signal transformer for use in the feedback circuit.

Once the transformer arrived, we had to make sure that it would perform well for the whole frequency range of the guitar. To characterize the transformer, we added a 10k ohm resistor in series at the primary coils and shunted a 10k ohm resistor at the output coils to measure frequency vs. output voltage. We determined that the 10k:10k signal transformer was not holding up well for the frequency range of the guitar while the 1k:1k transformer was fairly linear.
We ultimately decided that the 1k:1k transformer would be a great fit in our amplifier. Although some of the low frequencies are attenuated, this will give us a bass boost when used for feedback. The 10k:10k transformer, however, had to be replaced.

This transformer was vital to our experiment. We were designing a lightweight circuit and needed a reliable transformer to handle the input signal. To go along with the signal transformer for isolation, we needed a way to step up the wall voltage to properly amplify our signal. To do this we added a charge pump circuit.

**Output Stage**

Once our driver stage was optimized, we added an output stage to the circuit to amplify the current for the speaker. In this stage we used two 6L6 tubes. The 6L6 tubes are much larger and implement a beam tetrode design to stream and direct the electrons to the plate. We added two coupling capacitors to connect the driver to the output stage. This helps filter out any DC voltage from biasing and only pass AC signal.

![Final Circuit Design and Each Stages in PSPICE](image-url)
Unfortunately, our output was not as even as we would have liked.

The Output Frequency Response of Final Circuit Design

Debugging

With the spike in our output, shown above, we knew we had to change our circuit to get a more flat response. Ideally, each note on the guitar should be output at the same volume so that chords will sound full and harmonious. We tried adjusting the feedback circuit and changing the capacitance in our circuit to optimize the output. Once we reached a result that was nearly linear, we built it.

Construction

We built the circuit using a classic point to point wiring. The circuit was built in a 12”x7”x3” chassis. The first part of the amplifier that we built was the charge pump voltage doubler. We used huge capacitors (47uF, 80uF and 100uF rated at up to 400V) and resistors rated at 5W to handle the high voltage. We took care to wire our power supply carefully and neatly arranged our circuit using 3 selector strips. The wiring of our driver circuit was a bit more challenging. We tried to keep our wiring as neat as possible and even utilized empty tube pins to help us. We used color-coded wires to represent the different voltages in our amplifier and installed a bus ground using a thick ground wire. After some troubleshooting and debugging with the construction, the amplifier was ready for a guitar.
Results

The results of the amplifier were phenomenal. Our design was properly implemented and we were able to enjoy the tone of our experiment. The amplifier had a rich and warm tone. Our output was as linear as we expected and the tone was great all along the fret board. Chords resonated fully for each frequency that composed them. From the low notes to the harmonics at the maximum frequencies, the amplifier held up great. Underneath our tone, there was some noise which we then set out to remove.

Physical Debugging

The most noticeable noise in our amplifier was an oscillating “putt putt” noise. Upon further analysis, we realized that this was due to the fact that we were using BJTs in a circuit with a voltage far too high for them to work properly. To replace this, we reverted to our original design with a single bias resistor and balanced our tubes.

This worked well for awhile, but with the addition of our isolation 10k:10k transformer, a noticeable hum was added to our output. Despite adding capacitance, shielding the transformer and redesigning our ground we were unable to remove the hum. We noticed, however, that removing the first 12AU7 completely removed the hum.

Future Work

Knowing that the hum is entirely in the first stage, our future work will involve redesigning our first stage to eliminate the hum. The problem could be in our ground connections, or an electric field being generated as a result of our circular wiring. Either way, our future plans are to redesign the first stage of the amplifier to have a finished product without any humming.
Conclusion

This experiment was undoubtedly the pinnacle of our engineering education. We were able to take the circuit knowledge we had learned from class and build a circuit that performs a task we enjoy at a professional level. It was amazing to see our engineered circuit light up and amplify our guitar. It was challenging for us to understand how to bias vacuum tubes and use them properly in our circuit. We also faced some challenges with finding the proper parts to implement our theoretical circuit design. Our result was very satisfying and rewarding. We saw how our theoretical circuit design can really be implemented and create our desired tone. We would like to thank Professor Caggiano for his help with our project and hope to build on this experience in future professional settings.

Citations


Individual Contributions

Michael Simio

I began researching after our first meeting and found some articles on vacuum tube amplifiers. I learned how to properly implement and bias vacuum tubes in a circuit. I brought ideas to the group circuit design including using a pull-up resistor to bias the cathodes, bypass capacitors on the cathodes, coupling capacitors to block DC signal and phase splitting for noise cancellation.

I took on the responsibilities of sourcing parts for the project. Once the parts arrived I characterized and found their specifications for our SPICE model. For an initial reading of the transformer, I found turns ratio and impedance ratio. Next, using a derived equation for mutual inductance and coupling coefficient, I found values for M and k. These values were then given to my team members to move our SPICE design forward. I repeated the same process for the 10k:10k signal transformer when it arrived and also for the 1k:1k signal transformer.

I had an active role in our presentations and research. After our first presentation to Dr. Lu, he suggested that we justify our use of vacuum tubes. I browsed audio research to find an engineering result that he was looking for.

When the time came to construct our circuit I worked on soldering and mounting the parts. I also took time to design wiring diagrams to keep our circuit as neat as possible. I worked on initially soldering the charge pump circuit and creating a wiring diagram for the main circuit. I also sourced some more parts to properly construct this circuit. When it came time to build the main circuit, I worked on mounting or input jacks and cables and soldering the circuit together using point to point connections. I was very involved with the final debugging stage to remove the putt-putt and the humming. I experimented with rewiring the circuit, adding extra capacitance and shielding the transformers. I think our best tone came from the bypassed transformer, despite the safety hazards with the lack of isolation.
I had a great experience with this project and really enjoyed my team. Even if I wasn’t working on certain parts of the project, I closely followed their execution and shared any ideas or insight that I had. I feel that I was a very active member of the group and that the team worked well together to meet our goals.

Michael Boan

As someone with experience modifying vacuum tube guitar amplifiers at home as a hobby, I was able to contribute greatly to almost all parts of the project. In the beginning of the semester I designed several versions of a driver stage schematic for a voltage gain of 50. These went unused, but the experience designing them and simulating them in OrCad Capture was invaluable through the rest of the semester. I was able to familiarize myself with the typical operation of vacuum tubes in order to better communicate the details of the circuit design to my team members and to discuss the project with Professor Caggiano. These early designs helped us hone in on our final design by weeding out designs that would not work for our specific application. In particular, we were able to eliminate using the input transformer as a phase-splitting device after I designed several circuits which would not provide the requisite voltage gain. (Note: phase splitting is required for the typical push-pull output stage topology. It also had the added benefit of noise cancellation, a difficult task with our older vacuum tubes). Through several meetings discussing my results with Professor Caggiano, we decided to use a common-mode differential pair topology instead for phase splitting. This was beneficial because it allowed us to use one driver tube solely for voltage gain before the differential pair, as well as getting a significant amount of voltage gain from the differential pair.

I also simulated the circuits I designed, and was able to utilize the software to fine-tune the designs. This was an important part of the design process, since I was able to optimize the hand-drawn circuits—I considered this moving from the rough draft stage to something worth building. Simulating the designs before physically constructing the circuit saved many hours of debugging since I was able to
see the impacts of changing component values without having to solder and re-solder multiple components multiple times. Using the data other group members collected from analyzing the transformers, I was able to see the effects that the real components (rather than the idealized software components) would have on the design. I was confident that, once I finalized the simulations, the amplifier would work well the first time it was powered on.

After finalizing the schematic in the software, I drew wiring diagrams which I could follow while building the circuit. I made several drafts of the wiring diagrams with input from Professor Caggiano, whose experience saved me many hours of re-drilling and re-soldering after I realized some optimization methods for wiring. The charge pump was wired first, and thanks to the wiring diagram I was able to assemble it quickly with the help of my group members. Next was the rest of the circuit, which took considerably longer to construct. After it was powered on for the first time we found it produced a strange putt-putt sound which Professor Caggiano could not diagnose right away. Fortunately, when I tested it at my house I found that it still amplified the guitar signal with an extremely flat frequency response (we had not yet connected the feedback network to implement the bass boost). Professor Caggiano later realized that the source of the putt-putt noise was the improperly-biased current sink we used to bias the differential pair. I removed it and replaced it with a 10k 2-watt resistor and the putt-putt noise was gone.

While the putt-putt noise was gone, some humming and buzzing remained. I trouble-shot the source of this noise with the help of Professor Caggiano and, after eliminating the input transformer and the earth ground, I was able to eliminate it.

I also contributed a great deal to the presentations. After listening to Professor Lu’s feedback on our first presentation, I focused on the areas he suggested we improve in and, along with help from the other group members, I was able to address his concerns. In particular, I was able to synthesize
Gordon’s research in to a coherent and compelling argument for the continued use of vacuum tubes in audio technology from an engineering perspective.

I plan to continue working on the project this summer with continued help from Professor Caggiano. In particular, we plan to revert to our original idea of using the input transformer as a phase-splitting device. We suspect this will work with a slightly new approach – using two differential pair stages rather than amplifying each output from the transformer individually. This innovative approach will provide the voltage gain we need while cancelling the noise that plagued our project thus far. I also plan to add an equalization circuit to the amplifier, but it will likely be op-amp based rather than tube-based to keep the cost and size to a minimum. This will not affect the overall performance of the amplifier because I do not expect the guitar signal to overdrive the equalization circuit, so the unharmonious third harmonic will not be an issue.

Yongseok Kim

When our group first came up with an idea ‘guitar tube amplifier’ as a capstone project, I had no idea where to begin because I did not have any pre-knowledge about tubes and a tube amplifier at all. Although I started it from nowhere, I had a bit confidence to go through this project because of the major classes that I took before; the most confidence was from the experience in Analog Electronics class which I learned a lot about amplifier and how it works in transistors.

I decided to begin from the scratch by knowing how the tube amplifier looks like, what the tube amplifier is and what the tube is. I searched on google other people’s experiences building tube amplifiers by themselves. By looking at others tube amplifier creations I was able to get more used to being friendly about tube amplifiers, and also, those researches gave me lots of ideas and knowledge to start with this project. For example, typically, a tube amplifier has two stages which are pre amplifier and power amplifier stages. At the pre amplifier stage, the signal firstly amplifies, but mostly it gives
stability, and the equalizer, effects, and the volume controllers are implemented here. Then, the power amplifier stage amplifies the signal which was controlled from the pre amplifier stage. However, I saw lots of examples which only had a driver amplifier stage and output. There was also a person who made very simple tube amplifier only 6L6 tubes used. There were lots of difference styles of tube amplifiers which made me excited. Also, tube research gave me more understand how it actually works as an amplifier. Therefore, I was more able to understand when we discuss about our project, and say about the tube’s each part such as, B+ voltage, cathode, plate, and grid. That is how I began our tube amplifier project.

Whenever we were made to meet during the project period, I tried best to be with our group member to work the project together and discuss the problems. Also, I tried best to be on the track of what and why we do the tasks that we were doing. Therefore, I was almost with every single duty what we had to do.

After our tube amplifier’s concept has decided by our group members and professor Caggiano, which was an eliminating the power transformer, and using signal transformers for the isolation, I got the Pspice circuit simulation and analyzing work because I am used to using Pspice program since the beginning of the school. I first found the tube models (12AU7, 6L6GC) from online which were supposed to be used in physical amplifier construction. Then, I drew the driver amplifier stage sketch circuit into the Pspice circuit and simulated. For the first time, the result came out totally wrong. I was not able to get any output signals. Then, I brought this result to other members and discussed what we need for debugging. Later, I found out that there was a mis-reading of the sketch circuit that I got from Mike, but after several discussions and debugging, I was able to get a nice output result with some load resistance.

Output stage simulation went through the same procedure. I implemented the sketch circuit into the Pspice circuit, and did the transformer Pspice modeling corresponding to the data from the
measurement. At this time, there was also a difficulty. Somehow, the circuit did not work because the 6L6GC tube Pspice model did not give us a correct current flowing. This could be fixed by me after several trials of Pspice modeling and re-construction of the Pspice circuit. After we had several discussions and suggestions for the better output frequency response, I was able to finalize the circuit simulation.

During the time I was dealing with the circuit simulation, I also tried to find out physical characteristics for our guitar impedance and the signal, output transformers. I was willing to bring my guitar into the lab to see how the guitar pick-up impedance would be. By using an oscilloscope, I found out the maximum input voltage, which was about 210mV, and found out the input impedance, which was ok for the 10k:10k signal transformer. Next, I characterized the output transformer’s specifications for my Pspice modeling. This procedure was done by using a device which we can easily read the mutual inductance from. I repeated this process for the 10k:10k signal transformer and 1k:1k signal transformer too. Then later, I visualized nicely by using excel program, and made some nice graphs for these transformers to see their characteristics.

In presentation, I participated in our group presentation preparation meeting and brought out some ideas and suggestions such as what the contents need to be included. In why tube section, I researched and brought the THD (total harmonic distortion) idea to our group members. Also, on the presentation day, not only I had my speaking part, but also did I write down the advices from prof. Lu, and Caggiano. Then I organized well the advices and changes, and distributed to our group members for reminder in later time presentation.

Unfortunately, I was not able to participate the actual physical tube amplifier construction. I participated all the time in debugging process after when it is once wired all and had a putt-putt sound. Once, other member broke the circuit by bypassing a capacitor in a wrong way, I de-soldered the charge
pump circuit, and checked if the diode is ok or the input resistor is ok. Fortunately, we found out the reason, and the circuit came back to work again.

Lastly, I really think this was a great project that I ever experienced in my life. I cannot forget the moment when I heard the sound which our tube amplifier actually worked and amplified the guitar sound so nicely (even though there was a little noise). I could not stop smiling while it was making sounds because this was my first experience that I actually made a circuit device, and it is working in real life. I am willing to keep moving on of our project removing completely the hum and white noise. Also, I have a deep thank for our project advisor professor Caggiano, who gave a lot help on this, and our group members Mike Boan, Mike Simio, Gordon Odira.

Gordon Odira

Working in this capstone project, was a challenging experience, but hugely rewarding at the end. I had only read about vacuum tube amplifier, but had never seen any. So, when the opportunity arose for the project, I became glad that I will be finally be building one. I started off by doing a research on the entire project entailed: from the overdraft of work layout to the expected final results. I contributed to the group by offering the structural design of the amplifier using a simple by efficient technological schematic outlay. I took part in sourcing the parts of the components from the local stores. I participated in finding mutual inductance and coupling coefficient of the sourced signal transformers-the values of both M and K. Also, I was instrumental in testing all the components that we were to use to ensure that they are valid and could function within the required specifications and ranges, for instance the capacitors. Throughout the cases of presentations, three with Prof. Lu, and the last during the Capstone Day, I was at the forefront of all the layout plans: organization, delivery and ensuring efficiency of the entire exercise. In the previous instances before presentation, I contributed in making the report analysis needed for the presentation. On the software, I participated in PSPICE simulation of the fine tuning of the results, where we were experimenting with different values of
resistors and capacitors to achieve a desired effect. There was a physical part, real amplifier construction that we started off by drilling holes in chasse board and the real project work began. We followed the fine tuned schematic picture we had (courtesy of Mike Boan) to connect the components: capacitors, resistors and transformers. Once the layout was complete, our amplifier could not work and in the case that it did, it had some noise that required debugging, and changing other components. Several proposal were put forth by Prof. Caggiano, this remains a work to be done.