

Pre-amp Equalizer and Distortion Control

Senior Project

Brian Jackson

6/4/2010

California Polytechnic State University, San Luis Obispo

This project explores the design of the pre-amp stage of a typical electric guitar amplifier. It requires knowledge of the operation of operational amplifier circuits and RC circuits. A volume control, bass/treble equalizer, and variable distortion were all implemented in this pre-amp design using analog filters and op-amps. The design was formed after research on the Internet of how to design an analog equalizer and distortion circuitry. These features are very common and useful for amplifying guitars. The circuit was first tested using a Pspice simulation. Next, a function generator, DC power supply and oscilloscope were used to test it on a breadboard. After successful testing, a printed circuit board layout was designed and ordered online. The components were then soldered onto the printed circuit board and placed in an enclosure for the final product. This project was a learning experience in design of these pre-amp circuits, as well as the fabrication and manufacturing process that is implemented to produce a final product.

Contents

Figures and Tables	2
Introduction	3
Background	3
Design.....	4
Simulation	9
Design Preparation	14
Development.....	16
Test Results	23
Conclusion.....	33
Bibliography	35
Appendices.....	36
Parts List and Cost:.....	36
Lab Equipment Used:	36
Software Used:.....	37
Time Schedule:.....	37
Specifications:	38

Figures and Tables

Figure 1: Schematic of full Pre-amp Circuit.....	4
Figure 2: Inverting Op-amp	5
Figure 3: Equalizer equivalent circuit at low frequencies	6
Figure 4: Equivalent Equalizer at middle frequencies.....	7
Figure 5: Equivalent equalizer at treble frequencies	7
Figure 6: PSpice frequency sweep with max bass, middle treble	9
Figure 7: PSpice frequency sweep with max treble, middle bass	10
Figure 8: PSpice frequency sweep with bass and treble minimized.....	11
Figure 9: Max Volume, Bass and Treble in middle.....	12
Figure 10: 100% Distorted signal output vs. input at 1000Hz	13
Figure 11: 30% Distortion Output vs. Input	14
Figure 12: Test circuit on breadboard.....	16
Figure 13: Circuit Board layout	18
Figure 14: Unsoldered Printed Circuit Board	19
Figure 15: Printed Circuit Board with parts soldered on	20
Figure 16: Enclosure panel drilling.....	21
Figure 17: Enclosure with pieces mounted.....	22
Figure 18: Front panel of pre-amp.....	22
Figure 19: Back panel of pre-amp	23
Figure 20: Frequency vs. Voltage with Bass max, Treble mid, no distortion	25
Figure 21: Frequency vs. Voltage with Bass mid, Treble max, no distortion	26
Figure 22: Frequency vs. Voltage with Bass min, Treble min, no distortion.....	27
Figure 23: 1kHz input signal with max distortion	29
Figure 24: 1kHz input signal with partial distortion.....	30
Figure 25: 80Hz input with max bass, no dist	30
Figure 26: 80 Hz input with min bass, no dist.....	31
Figure 27: 15kHz input signal with max treble, no dist.....	31
Figure 28: 15kHz input signal with min treble, no dist	32
Figure 29: Testing with guitar and speaker.....	33
Table I: Frequency vs. Voltage with Bass max, Treble mid, no distortion	24
Table II: Frequency vs. Voltage with Bass mid, Treble max, no distortion	25
Table III: Frequency vs. Voltage with Bass min, Treble min, no distortion.....	26
Table IV: Notable Voltage levels and settings.....	28

Introduction

A pre-amp design is present in basically all guitar amplifiers. This project will show the design of a fairly typical pre-amp with equalizer potentiometers and the added effect of a variable distortion. The final design will take an input signal via a ¼ inch audio connector from a guitar, and will output an audio signal to a speaker via a ¼ inch audio connector as well. PSpice will be used to simulate the design before it is put into practice. After PSpice simulations are run, breadboard tests will be made. Following successful breadboard tests, a printed circuit board layout design will be made and ordering. When the printed circuit board is received, components for the design will be soldered into the correct through-holes onto the board. Tests will then be taken on the circuit board. The final step is implementing the design into an enclosure. An enclosure will be bought, and the input and output terminals and potentiometers will be mounted to the enclosure. Finally, extensive lab tests will be run as well as audio tests.

Background

Pre-amps are a stage of amplification present on basically all guitar amplifiers. The input signal from a guitar is always first fed through the pre-amp stage. This stage does a little bit of amplification, but is mostly used for tone adjustments, equalization and any other effects that are desired for the particular amplifier. After a pre-amp stage, there is usually a power amplification stage, which greatly increases the power output of the amp. The power stage is what makes the signal significantly louder before it is outputted from a speaker. This project only focuses on the pre-amp stage, and uses a power amp and speaker that are already built to demonstrate it.

The pre-amp design used in this project applies the concepts of basic operational amplifiers, resistors, capacitors and diodes. Gain across inverting and non-inverting op-amps will be calculated, as well as cutoff frequencies of RC circuits. Potentiometers are used in this project as well. A potentiometer is a resistive device with three terminals and a total resistance across it. The resistance can be shifted left or right of the center node depending on the position of a knob.

Design

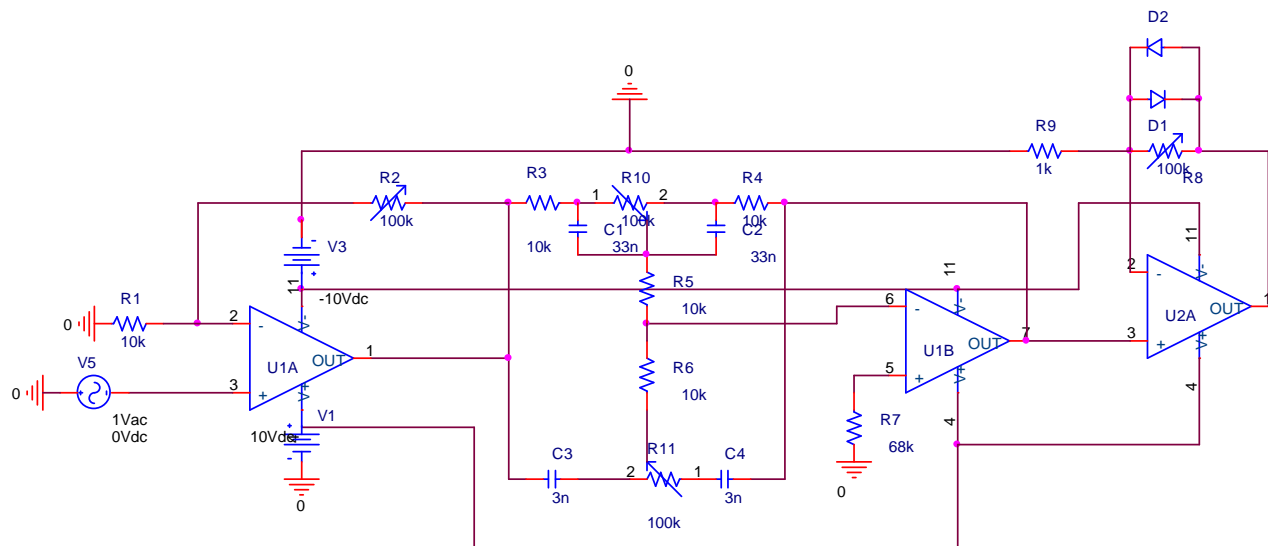


Figure 1: Schematic of full Pre-amp Circuit

The complete equalizer design shown in Figure 1 came largely from the website <http://circuitdiagram-schematic.com/pre-amp-equalizer-using-tl074/>. The design relies on RC circuits and potentiometers that allow the user to adjust the gain of bass and treble frequencies across the second op-amp without adjusting the overall amplitude of the input signal. This is accomplished because there are 2 capacitors in parallel with the bass potentiometer. When the input signal is above a certain frequency equal to $1/(2\pi R_{pot}C)$, these capacitors act as a short

across the potentiometer, leaving the circuit at unity gain due to the 10k ohm resistors on each side of the potentiometer. When there is a high frequency input signal, the capacitors surrounding the treble potentiometer become short circuits, allowing the high frequency signal to be attenuated. The different scenarios can be illustrated as follows:

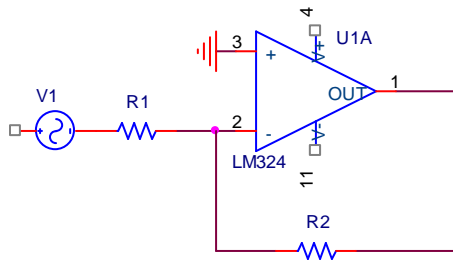


Figure 2: Inverting Op-amp

This equalizer uses an inverting op-amp as shown in Figure 2 to create bass or treble gain. In these circuits,

$$V_{out} = -(R_2/R_1) * V_{in}$$

The bass frequencies in this design can be calculated using the equation $\frac{1}{2\pi * R_{pot} * C}$

$R_{pot} = 100k$ ohms, and the capacitors are 33nF and in series. This makes the total capacitance 16.5nF

So, $\frac{1}{2\pi * 100k * 16.5n} = 96.46Hz$, which is the cutoff frequency, which is fairly typical for bass equalizers. This represents the frequency at which the amplitude is 3dB below the max amplitude.

At a low frequency, Figure 3 shows what the equalizer effectively looks like:

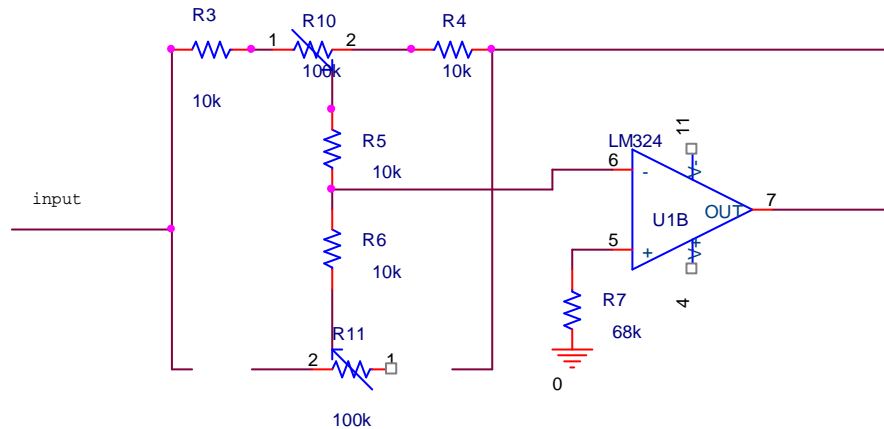


Figure 3: Equalizer equivalent circuit at low frequencies

All the capacitors will act as open circuits at low frequency, and the gain of the signal will be determined by only the bass potentiometer.

In this particular design, the gain of the signal is $V \cdot -(R4 + \text{POTright}) / (R3 + \text{POTleft})$ assuming the signal coming in is at a bass frequency. It depends on the position of the potentiometer. For example, if it is at 80% volume, then 80k ohms of the total 100k ohms of the potentiometer are on the right side, and the gain would be -3. On the other hand, if 80k are on the right side of the potentiometer, the gain would be -1/3.

For the middle frequency signals coming in, the circuit operates differently. Both equalizer potentiometers become effectively open circuits, and these signals will have unity gain. The equivalent circuit seen by middle frequencies is shown in Figure 4:

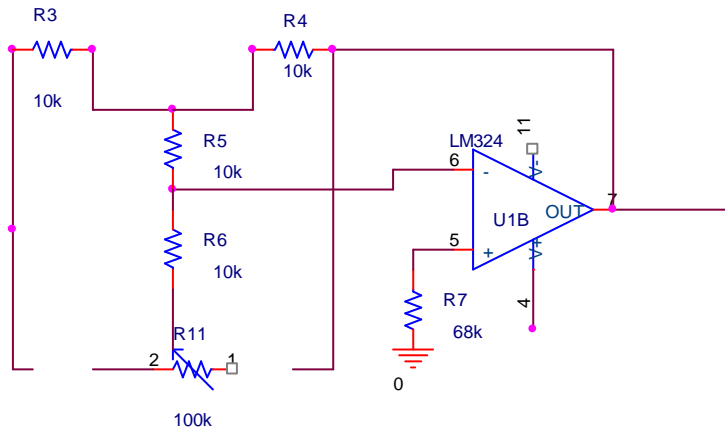


Figure 4: Equivalent Equalizer at middle frequencies

Since the bass capacitors are past their cutoff frequency, they act as short circuits, and the treble capacitors still act as open circuits since they are not past their cutoff. In this scenario, the gain will just be $-(R4/R3)$ which is equal to -1.

If the frequency of the signal is high enough such that it is above the cutoff of the capacitors on the treble side, the bottom capacitors will act as a short circuit, and the treble potentiometer will come into effect. Figure 5 below shows the equivalent circuit:

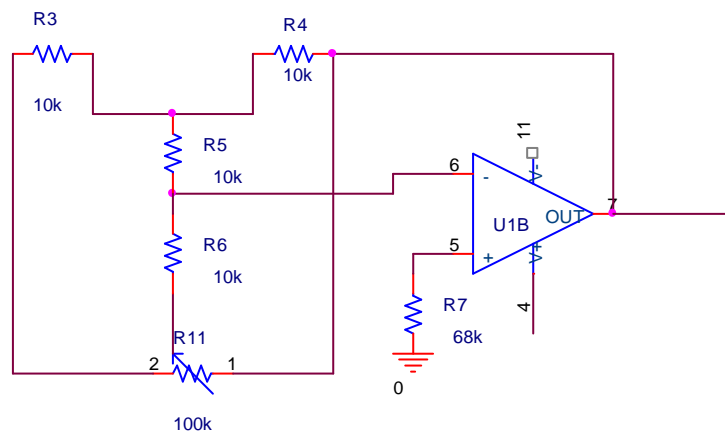


Figure 5: Equivalent equalizer at treble frequencies

In this case, the gain of the circuit is $-\frac{(R4//RPOTright)}{(R3//RPOTleft)} = \frac{-R4 * \frac{RPOTright}{(R3+RPOTright)}}{R3 * \frac{RPOTleft}{(R3+RPOTleft)}}$. So, in this case,

if the potentiometer is at 80% right, the gain will only be -1.8, which is not as powerful as the bass boost, however, still effective.

These capacitors are 3nF and are in series. This would make the total capacitance across the bottom of the circuit 1.5nF, which makes the cutoff of this RC $\frac{1}{2\pi * 100k * 1.5n} = 1061\text{Hz}$. This is a relatively high frequency for a guitar treble since the frequency of the strings on open fret varies from 80Hz for low E to 330Hz for the high E. The treble adjustment will mostly affect the harmonics occurring octaves above the root frequencies.

The third op-amp in the pre-amp stage is to control the distortion output. There are 2 diodes and a variable resistor in parallel with the op-amp. As the value of the potentiometer is increased, the voltage output is increased until that voltage reaches the threshold voltage of the diode. At this point, much of the current goes through the diode instead of the resistor, making the signal flatten out near the positive and negative peak of the AC signal. There is a diode facing in both directions because the signal is alternating and the diodes only allow current to flow in one direction. The basic design for the distortion circuitry came from the website <http://www.gmarts.org/index.php?go=217#top>.

The first op-amp has a potentiometer across it to be used as a volume control. It is just a simple non-inverting op-amp where the gain is equal to $1 + R_{pot}/R1$. This means that the gain is unity if the volume is turned all the way down.

TL072 op-amps were used for this design because they are a very common op-amp used in pre-amp design. They tend to have low noise in small signal circuits, which is important for a good op-amp. 1N4148 diodes were used to create the clipping. This is a common diode used for

this purpose and should create a quality distortion guitar sound. All potentiometers used vary logarithmically, since that will create a more linear sounding increase of gain to a human ear.

Simulation

The first step taken toward implementing the design is digital simulations of the circuit using PSpice. The circuit in figure 1 in the design section was constructed and simulated. AC frequency sweeps with a 0.2Vac signal were simulated to show the effect of the equalizer from 20Hz to 20 kHz since that is the range of frequencies humans can hear. These frequency sweeps show the output amplitude before the signal enters the distortion phase. The results were as follows:

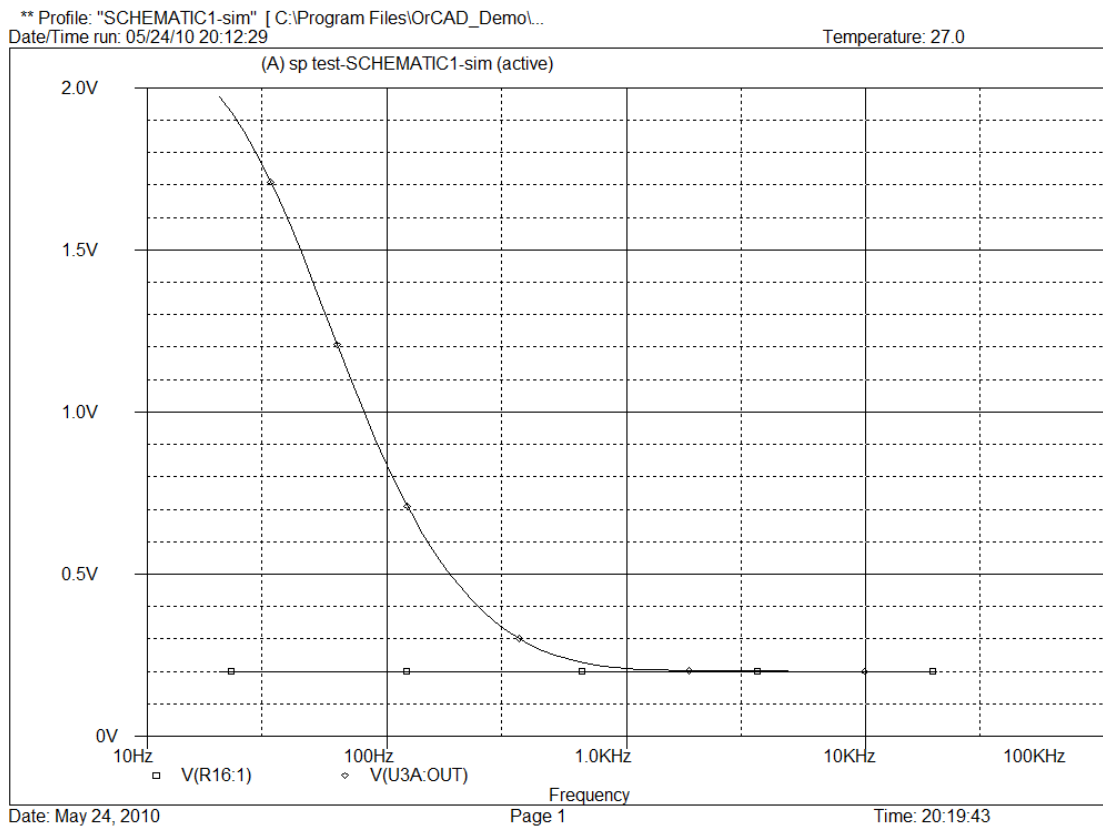


Figure 6: PSpice frequency sweep with max bass, middle treble

Figure 6 demonstrates that the bass potentiometer will significantly affect the magnitude of frequencies up to 200 to 300 Hz, with the gain becoming less significant as the frequency is increased. Everything above about 1 kHz is completely unaffected. The maximum gain at low frequencies is around 10 times the input signal, which is about what should be expected as demonstrated in the design section. The point frequency where about half magnitude is achieved is right around 95 Hz as calculated in the design section. These results are fairly ideal for a bass equalizer.

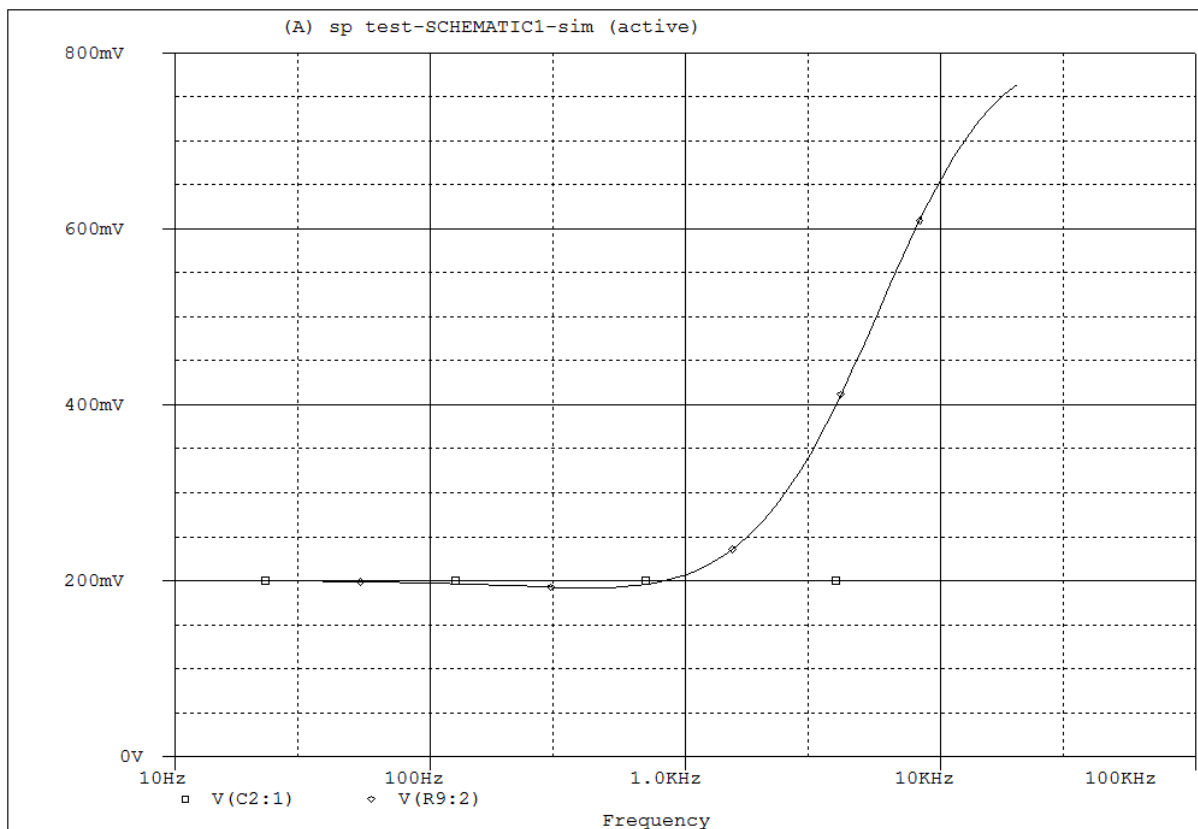


Figure 7: PSpice frequency sweep with max treble, middle bass

Figure 7 also confirms the calculations from the design section. The max treble voltage is not nearly as high as the max bass voltage gets when its potentiometer is maximized.

Next, in Figure 8, the Bass and Treble amplitudes will be minimized:

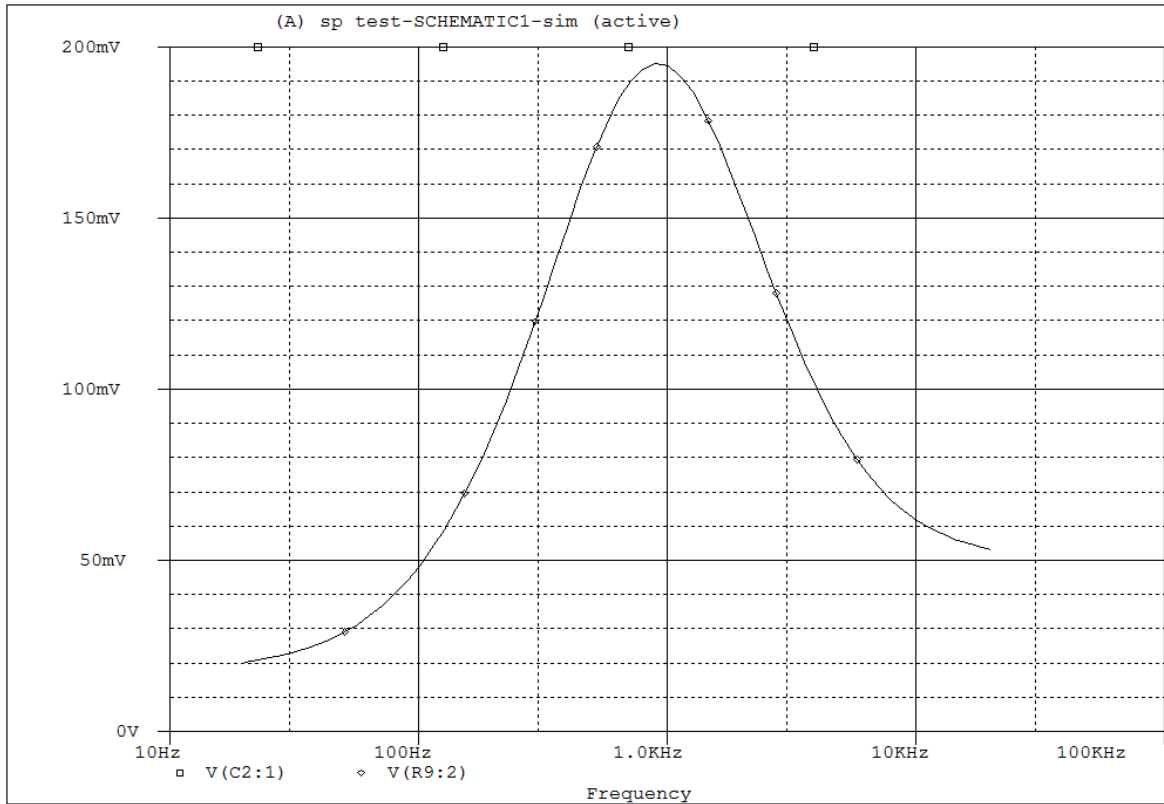


Figure 8: PSPICE frequency sweep with bass and treble minimized

This sweep shows that minimizing the potentiometers nearly eliminates the high and low frequencies completely. The cutoff frequencies are still in approximately the same spots as they were when the bass or treble were maximized.

Figure 9 will show the frequency response with the volume maximized and both equalizers are set in the middle.

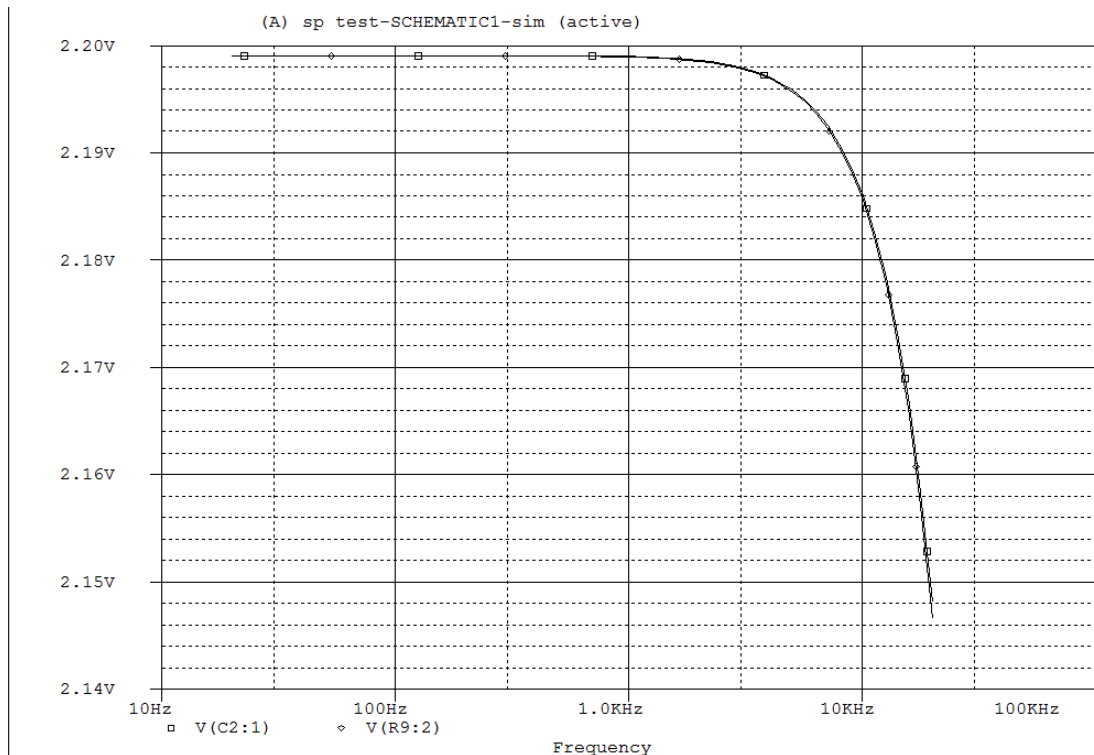


Figure 9: Max Volume, Bass and Treble in middle

The problem with the volume adjustment is that it will not act as it does in the simulation. After going through the distortion circuitry, these parts cannot draw enough current for it to really multiply the input signal by 10. In reality, the volume control will not have very much affect on the amplitude.

Next, to show the affect of the distortion circuitry, the output voltage probe is moved to the output of the third output and a time domain signal will be shown instead of a frequency sweep like the above simulations. It will use a 0.2Vpp sine wave input at 1kHz.

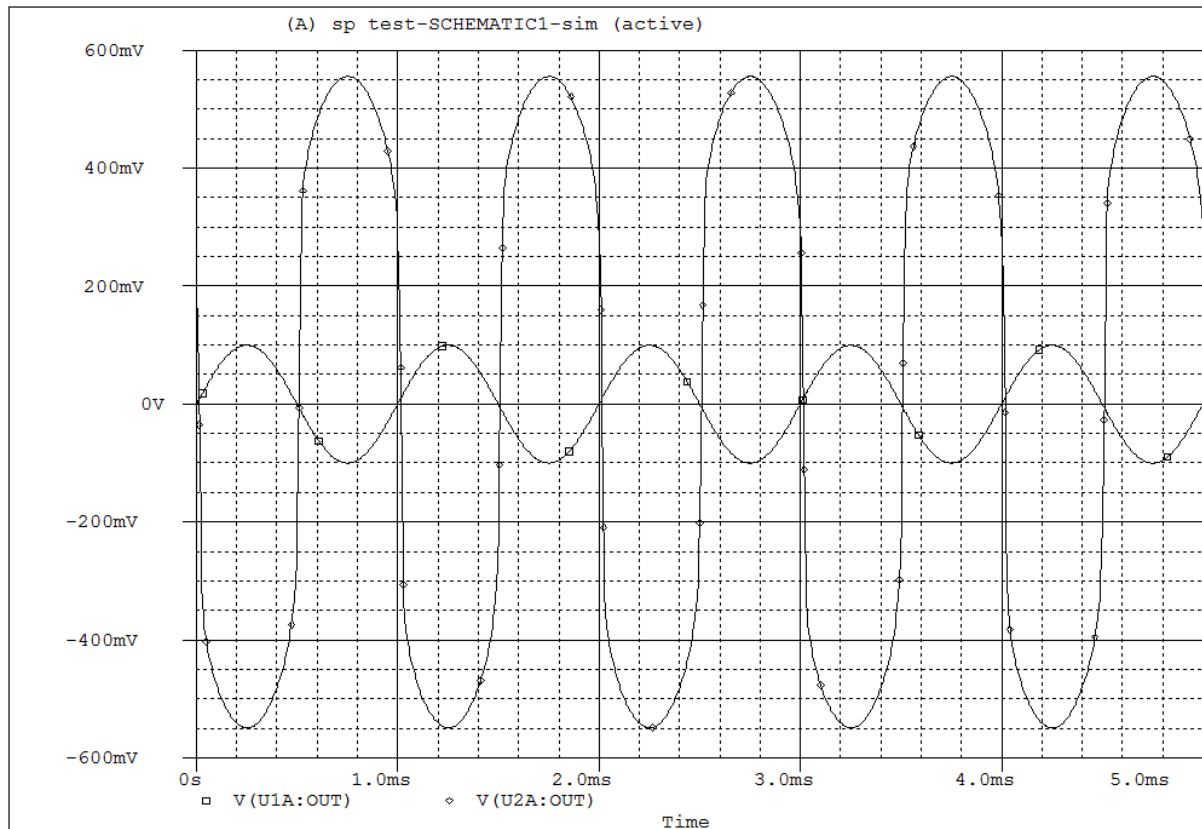


Figure 10: 100% Distorted signal output vs. input at 1000Hz

The larger amplitude signal in Figure 10 is obviously the output. It is 180 degrees out of phase because the second op-amp is an inverting one and the other 2 are non-inverting. The distorted wave form has a steeper slope than the input and flattens out a bit at the top. This type of wave form should create a good, heavily distorted guitar sound. The signal is amplified fairly significantly before the diodes start clipping the sine waves. This is due to the threshold voltage of the diodes, which can vary depending on what diodes are used for the circuit.

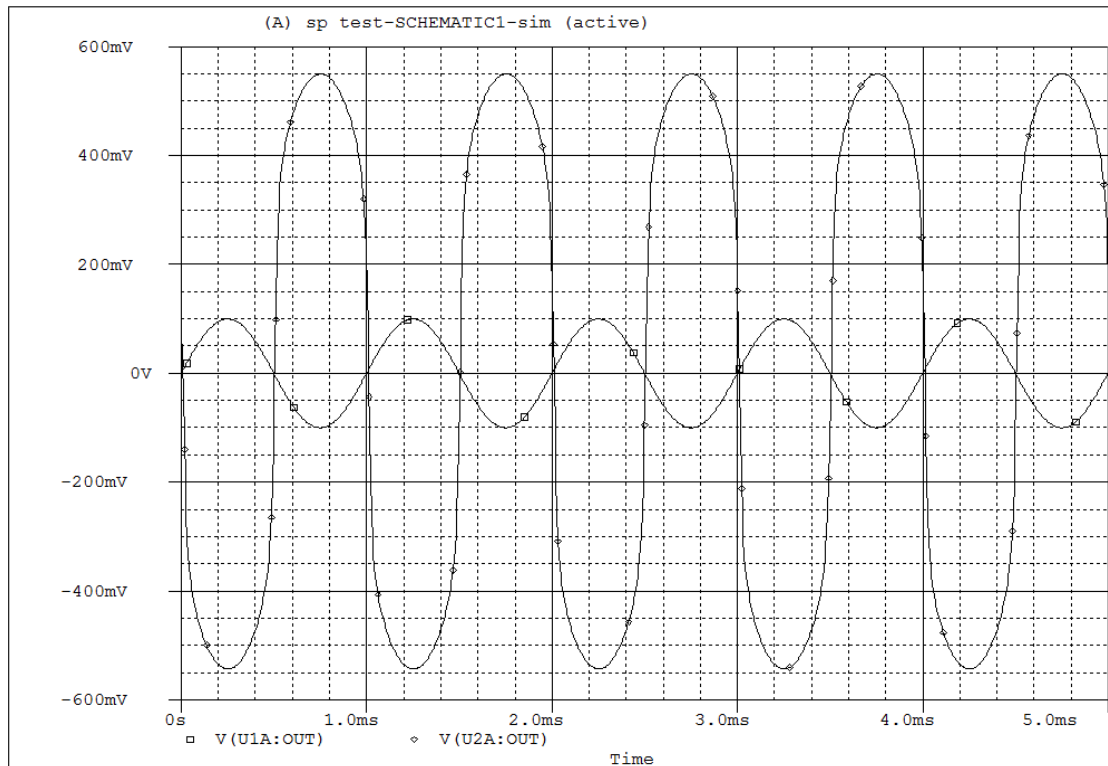


Figure 11: 30% Distortion Output vs. Input

Figure 11 is a result of the simulation done with the distortion potentiometer set to 30k ohms rather than 100k. The difference does not appear to be that vast, but the sloping on the output signal is shallower, and it should create a less distorted sound than the simulation done with a 100k ohm resistor.

Design Preparation

After the successful PSpice simulation, the next step was to order through hole components for testing on a breadboard. Resistors, capacitors, potentiometers, op-amps and diodes were ordered from the website smallbearelec.com to match all of the component values that worked on the PSpice simulation.

Parts were shipped within a week, and were brought into a lab for testing. A circuit identical to the PSpice simulation was constructed on a breadboard using wires and tested on lab equipment. Wires were soldered to the terminals of the potentiometers to make a clean connection between them and the breadboard. To power the op-amps, 2 DC power supplies were used to make a +9V and -9V rail to simulate 2 9V batteries, which will be used in the final product. A Function generator with a 0.2VPP sine wave output was used as the input to simulate sound out of a guitar that the pre-amp is meant to control. An oscilloscope was used to make measurements of the output waveform at various frequencies. The tests run using the lab equipment were made to match the tests made in the PSpice simulation. The tests generated fairly similar results.

After successful lab tests, real audio tests were made using the breadboard. To replace the DC power supplies, 2 9V batteries were connected to the breadboard to power both terminals of the op-amps. ¼ inch audio connectors were connected at the input and output terminals of the circuit. An mp3 player was connected at the input, and speakers were connected at the output. Music files were then played on the mp3 player through the pre-amp design. When the potentiometer knobs were turned, the results were very satisfactory. A clear difference in the bass and treble frequencies could be heard when their respective potentiometers were adjusted. Additionally, the varying of the distortion of the input music was very clear.

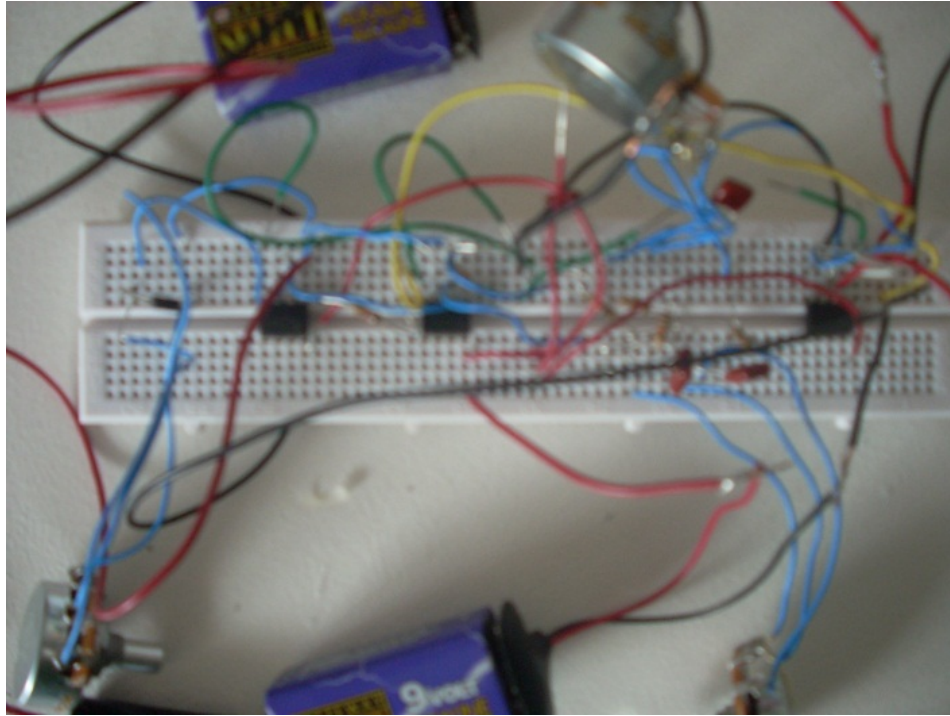


Figure 12: Test circuit on breadboard

Figure 12 is a picture of what the test circuit looked like when powered by 9 volt batteries and tested using an mp3 player and amp speaker. It obviously is not very organized at this point because it is not on a printed circuit board or packaged, however, this was a necessary step in testing the design.

Development

After fairly extensive testing to assure that the design works properly, steps were made toward getting the design printed onto a through-hole printed circuit board that the parts could be soldered on to. A program called “pad2pad” was used to create the circuit board layout. This is a free piece of software put out by the company to be used to send them orders for printed circuit board. When designing the layout, it was important not to make any mistakes on where to connect the traces because the board would not function correctly if it had any minor errors. It

was reviewed several times before ensuring that there were no errors. The design was made so that all input and output through holes on the board were on the outside in order to make implementation of these on the final product easier. It was important to choose proper through-hole spacing for the specific components that were to be soldered to the board so that they would fit properly. The software had features that made this easy to do by offering footprints of different common components. After all of the holes were placed on the board, the program auto-routed the copper tracings on the board using both the top and bottom layer. The program finds the most efficient way to draw the traces without any of them crossing. The design was made for a 3 by 4 inch circuit board. The circuit could have been made more compact, but this seemed to be the standard size and makes for easier soldering when the holes and traces are more spread out. Next, using the software, a silk-screen layer was created to label all of the parts, inputs, and outputs on the circuit board itself. Part labels were matched with the labels on the design schematic in figure 1. This silk screen prevents any mistakes in the soldering process in choosing the right holes to solder parts onto. After the layout design with the copper tracing was completely satisfactory, 3 of these printed circuit boards were ordered for delivery using the software. They were shipped and received about a week and a half later. Figure 13 shows the final circuit board layout:

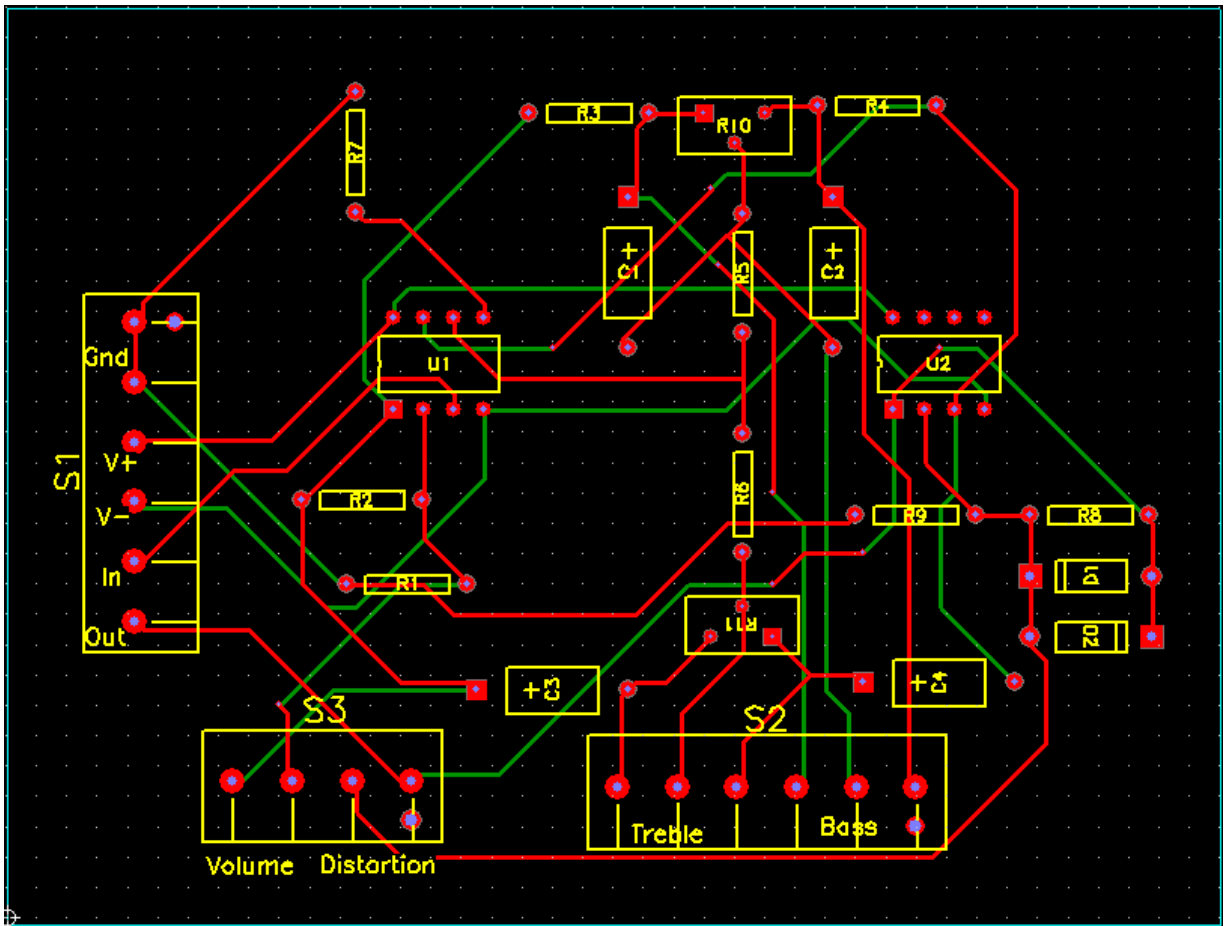


Figure 13: Circuit Board layout

In Figure 13, red tracings are on the top layer, green tracings are on the bottom layer, and everything that is yellow is on the silk screen layer. The resistor hole spacing is 0.4 inches, the hole spacing is 0.5 inches, and the diode hole spacing is 0.4 inches. U1 and U2 are the footprints for the TL072 op-amps. There are only 2 of them since these op-amp IC's each have 2 full op-amps within them, and three total TL072's are needed in the design. They used the footprint of a standard 8-pin integrated circuit. Figure 14 shows a picture of the printed circuit board before it was soldered.

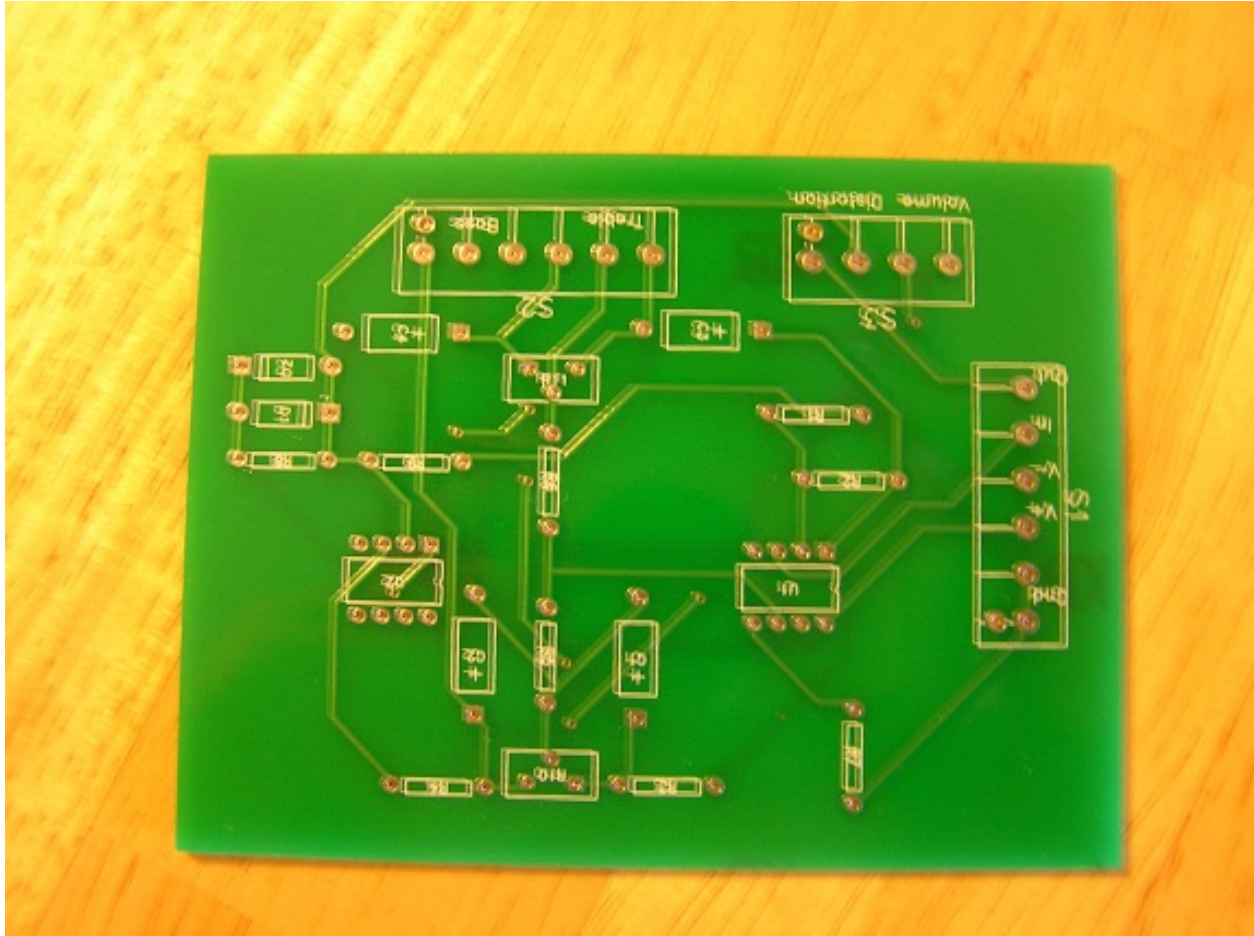


Figure 14: Unsoldered Printed Circuit Board

The next step was to solder all of the components into the circuit board. Wires were soldered to all of the input and output terminals that lead to their potentiometer or source. Before the audio connectors and the battery terminals were connected to the board, the terminal wires were left bare for testing in the lab. The same procedures were performed using the lab equipment as the procedures done for the breadboard test. After this testing, the input connector, output connector, 9 volt battery terminals, and the switch were soldered into place. For the input and output connectors, $\frac{1}{4}$ inch mono audio jacks were used since they are the standard for guitars and amplifiers. Figure 15 shows the soldered board with all of the connectors soldered on.

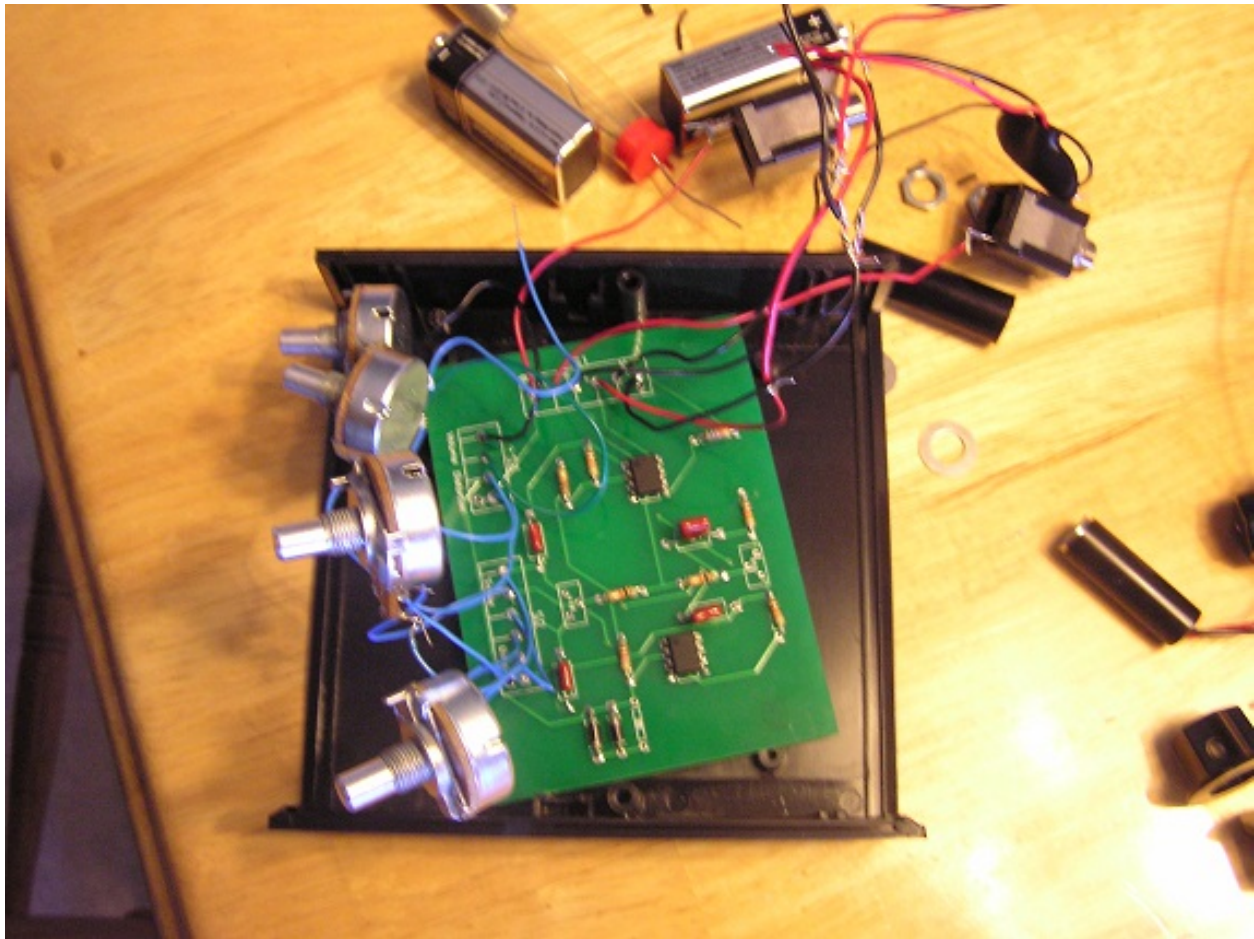


Figure 15: Printed Circuit Board with parts soldered on

The project still looks a bit cluttered at this stage. The next step in the project is to package the pre-amp design into an enclosure to make a final product that looks like an industry device. To find a suitable enclosure, some simple measurements were made to figure out what the dimensions of the case needed to be. It needed to be a bit wider and longer than the dimensions of the circuit board itself in order to fit the batteries, and it needed to be tall enough to mount all of the potentiometers to one side, and the input and output terminals to the other side. A suitable plastic enclosure for this project was found from the website <http://www.pactecenclosures.com/>. 2 of these enclosures were purchased and received within 1

week. 4 holes were measured out and drilled on the front panel of the enclosure for the 4 potentiometers in the design. On the back panel, holes were measured out and drilled for the input terminal, output terminal, and switch. Figure 16 shows the panels being drilled.



Figure 16: Enclosure panel drilling

Once all of the holes had been drilled, all of the inputs and outputs were mounted to their respective holes on the panels. Battery clips were also mounted to the back panel to hold the 2 9 volt batteries in place inside the enclosure. Figure 17 shows the inside of the enclosure with everything mounted:

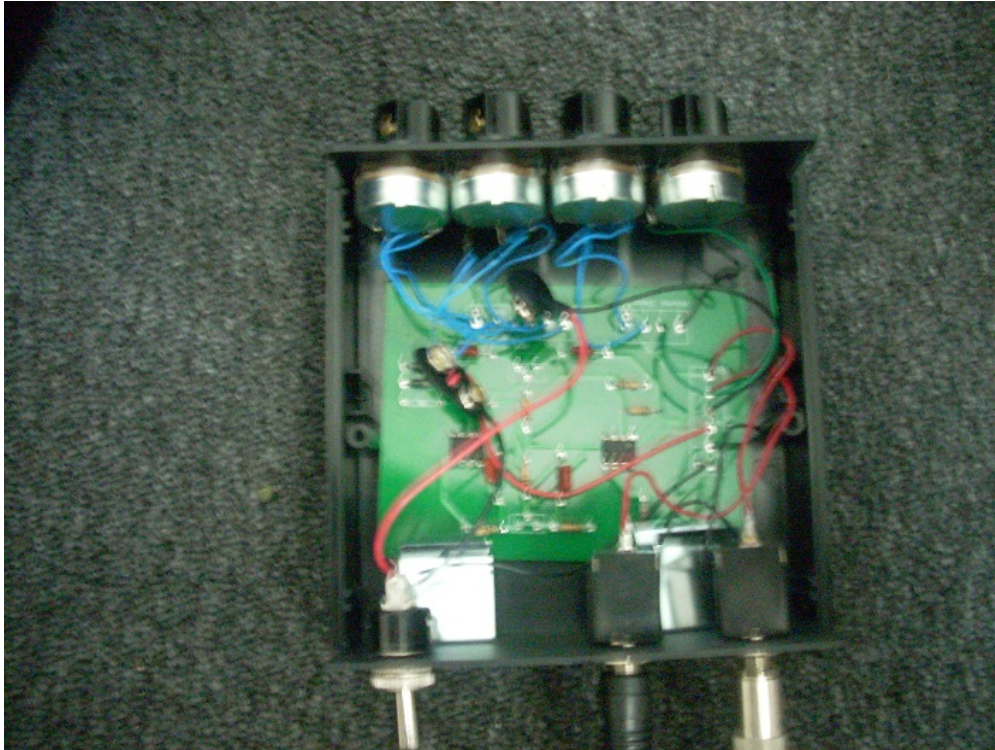


Figure 17: Enclosure with pieces mounted

Figures 18 and 19 show the front and back panels of the device



Figure 18: Front panel of pre-amp



Figure 19: Back panel of pre-amp

In this design, the knobs in Figure 18 from left to right adjust volume, distortion, treble, and bass. In Figure 19, the switch on the left turns the device on or off (up is on, down is off.) The terminal on the right is an output to be sent to a speaker, and the left terminal is the input (from a guitar.) At this stage, the final product is put together, and ready for the final lab tests and audio tests to be ran, and for official data to be taken.

Test Results

The final product of this project was brought into lab to collect sufficient data to show that the device is working properly. Various frequency sweep tests were run, and several images of the output waveform were taken from the oscilloscope. A 0.2V_{pp} sine wave input was connected across the input terminal and an oscilloscope was connected across the output terminal. All tests were run with this amplitude input voltage because that is the approximate

amplitude of the guitar signal the pre-amp is designed for. In these tests, the device was just powered by its 9 volt batteries rather than the lab power supplies. Table I and Figure 20 show the results from a frequency sweep with the bass potentiometer maximized:

Table I: Frequency vs. Voltage with Bass max, Treble mid, no distortion

Frequency(Hz)	Peak to Peak Voltage(V)
50	1.376
60	1.232
70	1.12
80	1.024
90	0.944
100	0.864
120	0.752
150	0.624
200	0.496
250	0.416
300	0.36
400	0.296
500	0.268
700	0.24
1000	0.24
2000	0.2
5000	0.2
10000	0.2
20000	0.2

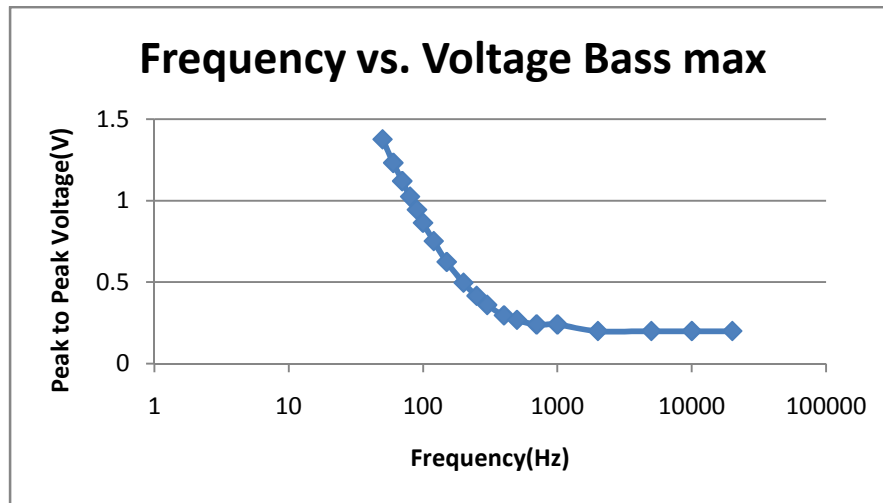


Figure 20: Frequency vs. Voltage with Bass max, Treble mid, no distortion

Figure 20 corresponds fairly well to the PSpice simulation in Figure 6. The voltage gain at the low frequencies is a little smaller than those in the simulation probably due to some internal resistances or losses, but overall, the result is what was expected.

The next frequency sweep was done with the treble potentiometer maximized. Table II and Figure 21 show the results to that test.

Table II: Frequency vs. Voltage with Bass mid, Treble max, no distortion

Frequency(Hz)	Peak to Peak Voltage(V)
50	0.2
100	0.2
200	0.204
500	0.21
1000	0.232
2000	0.308
5000	0.52
7500	0.616
10000	0.68
12000	0.7
15000	0.744
20000	0.76

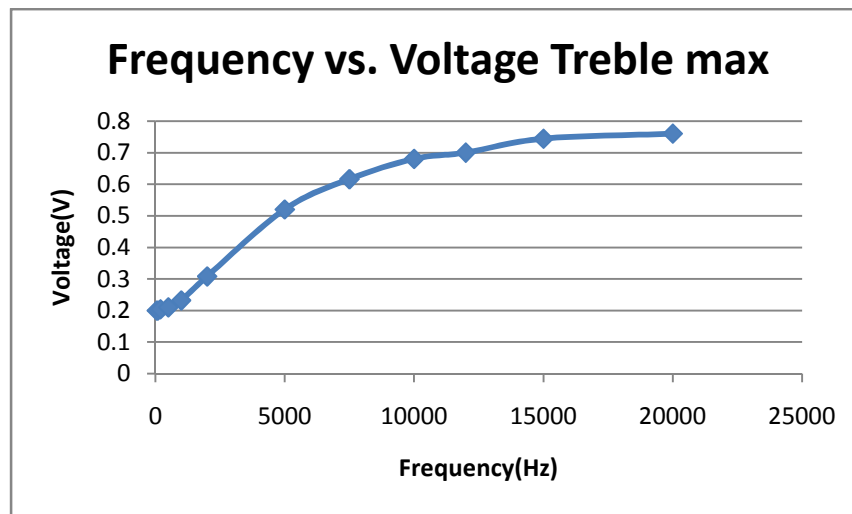


Figure 21: Frequency vs. Voltage with Bass mid, Treble max, no distortion

Again, these results match those of the PSpice simulation fairly well. As expected, the treble potentiometer does not create as much gain on the high frequencies as the bass potentiometer does for the low frequencies.

The last frequency sweep that was done was with both the bass and treble potentiometers set for minimum gain. Table III and Figure 22 demonstrate the results of this sweep:

Table III: Frequency vs. Voltage with Bass min, Treble min, no distortion

Frequency(Hz)	Peak to Peak Voltage(V)
50	0.05
80	0.07
100	0.07
150	0.08
200	0.1
300	0.14
500	0.18
1000	0.2
1500	0.19
2000	0.16
4000	0.108

5000	0.1
8000	0.082
10000	0.08
12000	0.076
15000	0.076
20000	0.076

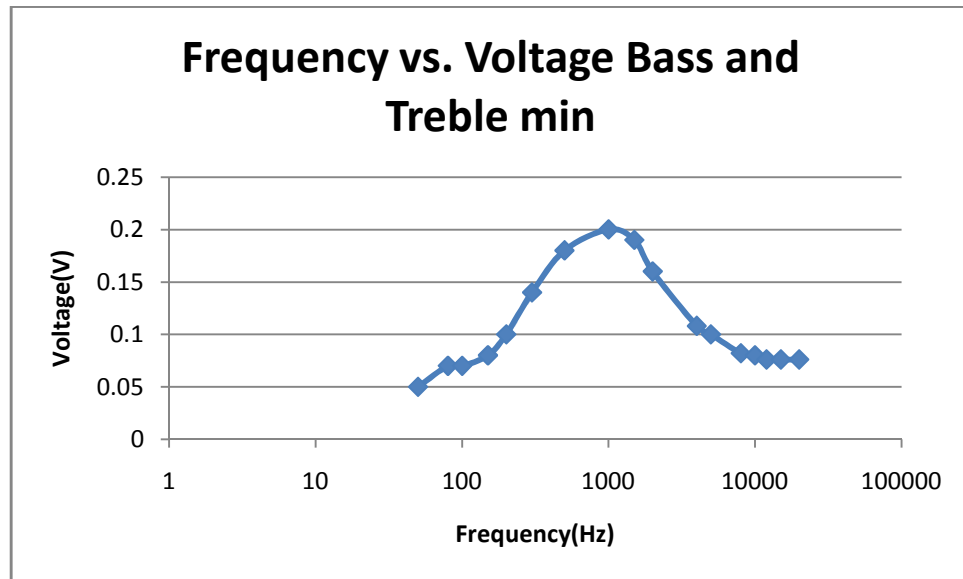


Figure 22: Frequency vs. Voltage with Bass min, Treble min, no distortion

Again, the frequency response here is about what was expected for this test. This is the last frequency sweep test, however there are a view other notable voltage levels that were recorded shown in table IV still using a 0.2Vpp sine wave:

Table IV: Notable Voltage levels and settings

Frequency	Settings	Peak to Peak Voltage
15kHz	max treble, max vol, no dist	1.376V
50Hz	bass max, volume max, no dist	2.5V
2kHz	mid bass, mid treble, max vol, no dist	0.35V
2kHz	mid bass, mid treble, max vol, max dist	1.35V
50 hz	max all	3.68V
15kHz	max all	2.4V

The numbers in Table IV demonstrate the effect of the volume and distortion potentiometers on the output signal. The volume does not create nearly as much gain as shown in the PSpice simulations probably due to that potentiometer being in parallel with the equalizer circuitry. The distortion potentiometer greatly affects the gain as well as the shape of the sine waves. This is because the diodes do not reach their turn-on voltage until there is some gain across the distortion op-amp. This allows the design to distort any input voltage signal, even if it is significantly smaller than 0.2V_{pp}. Many scope images were taken to show what many of these waveforms look like. First, Figure 23 shows what the fully distorted sine wave looks like at middle treble and bass:

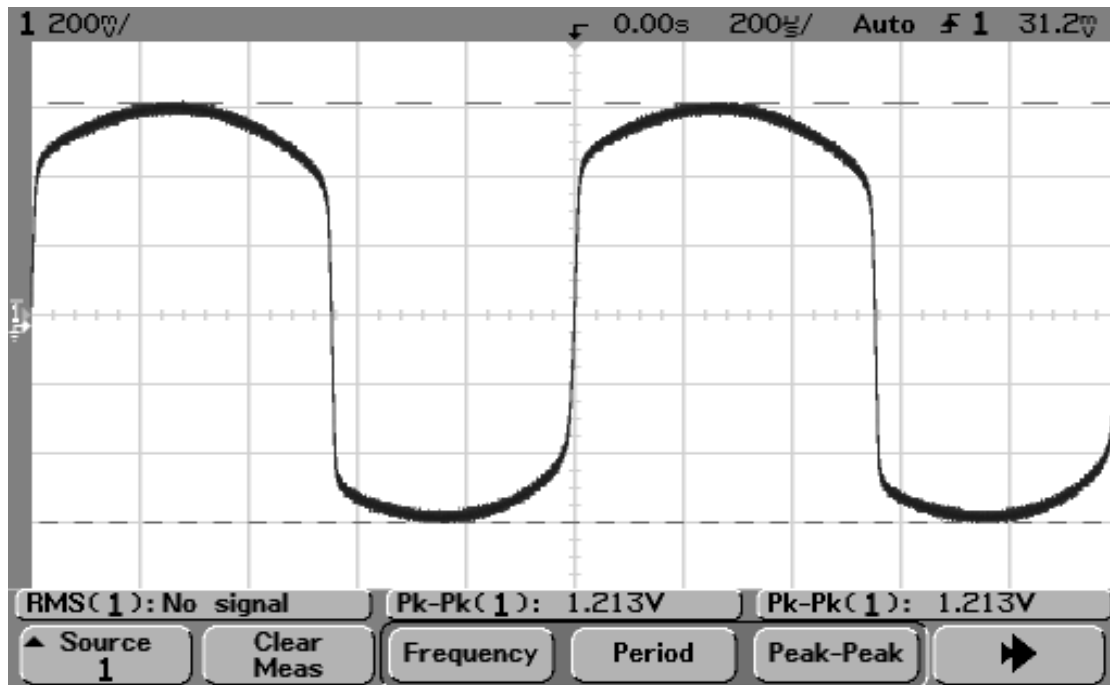


Figure 23: 1kHz input signal with max distortion

This is basically what a distorted waveform is supposed to look like. The closer the waves are to being square, the more distorted the sound is. The wave in Figure 23 is a little uneven between when it is positive and negative. This is probably due to a slight DC offset in the waveform. Figure 24 shows a partially distorted waveform at the same frequency:

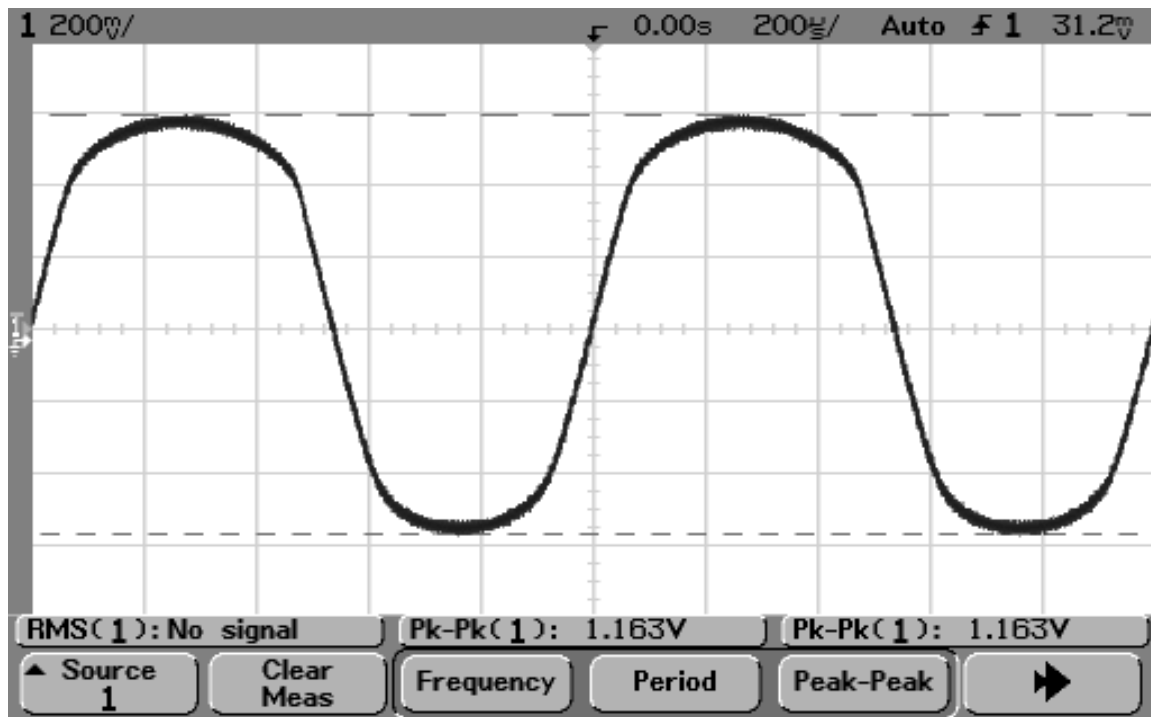


Figure 24: 1kHz input signal with partial distortion

Figure 24 looks much more similar to a sine wave than Figure 23, however it is still a bit squared, so it will create less distortion.

Figure 25 and 26 show an undistorted 80Hz wave with the bass at it's maximum and minimum.

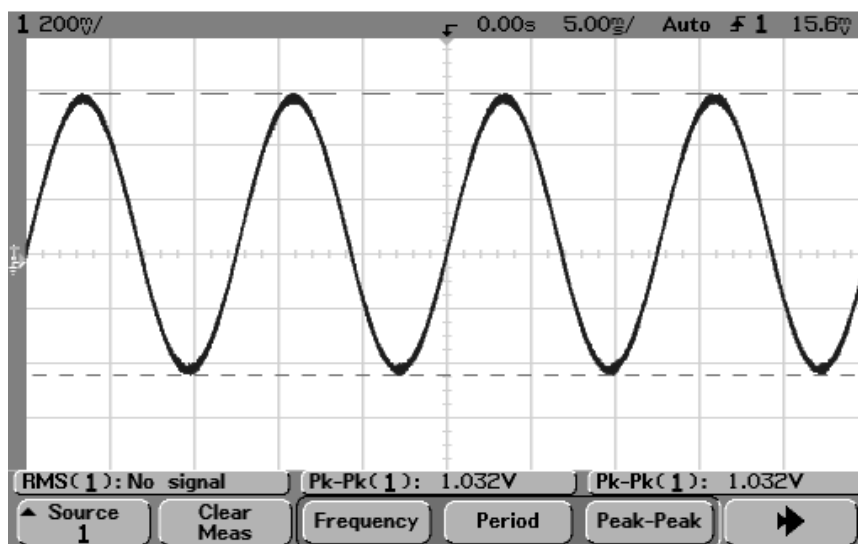


Figure 25: 80Hz input with max bass, no dist

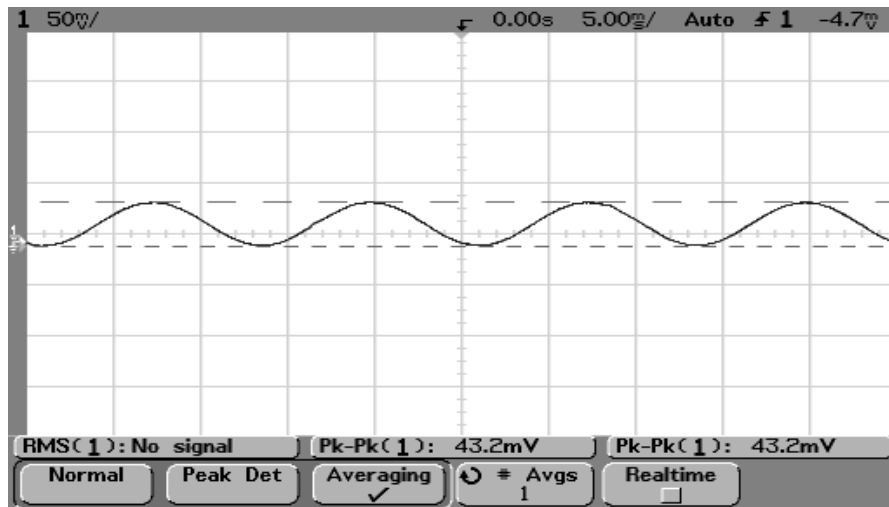


Figure 26: 80 Hz input with min bass, no dist

These 2 figures demonstrate the results recorded in Tables I and III. Next, Figure 27 and 28, demonstrate a 15kHz input signal with maximum treble and then minimum treble.

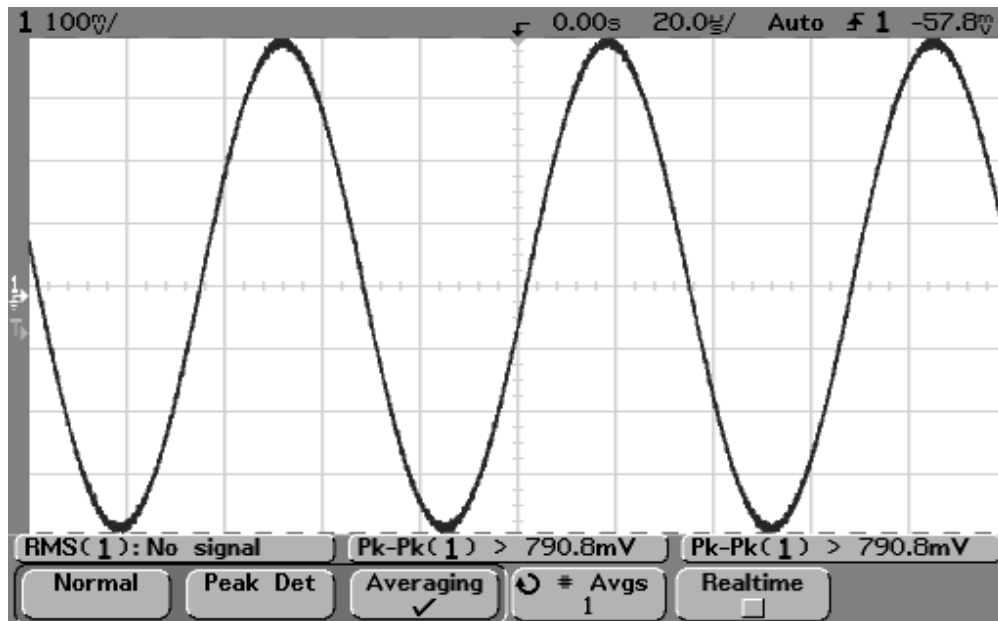


Figure 27: 15kHz input signal with max treble, no dist

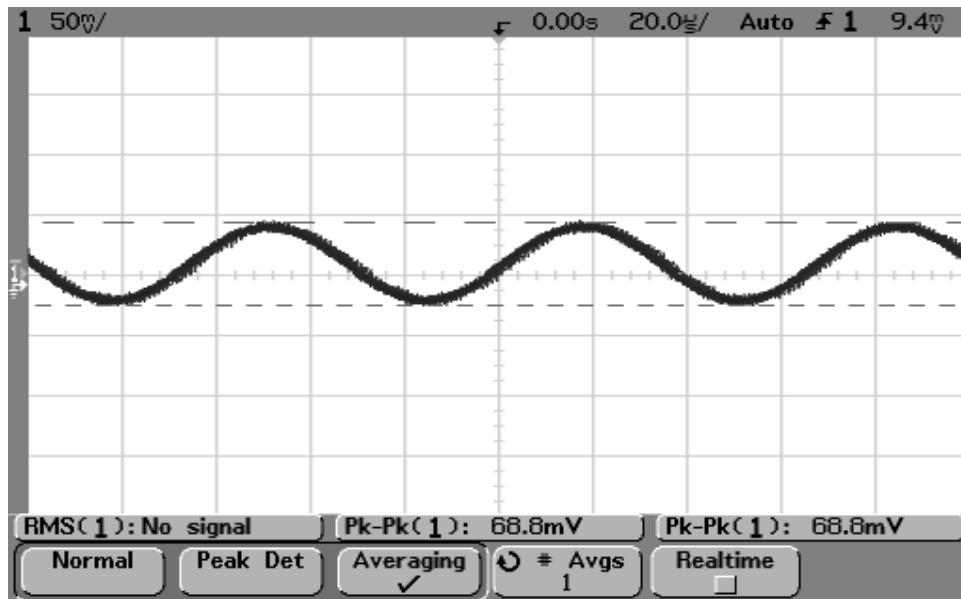


Figure 28: 15kHz input signal with min treble, no dist

These 2 results demonstrate the numbers in Tables I and III.

The last part to testing the final product was to connect a guitar as the input and output it to a speaker. There is no data to show for this, but when bass or treble are increased, a clear difference can be heard from the output signal. The increasing and decreasing of the distortion are also very clear. Figure 29 shows the testing done with the guitar:

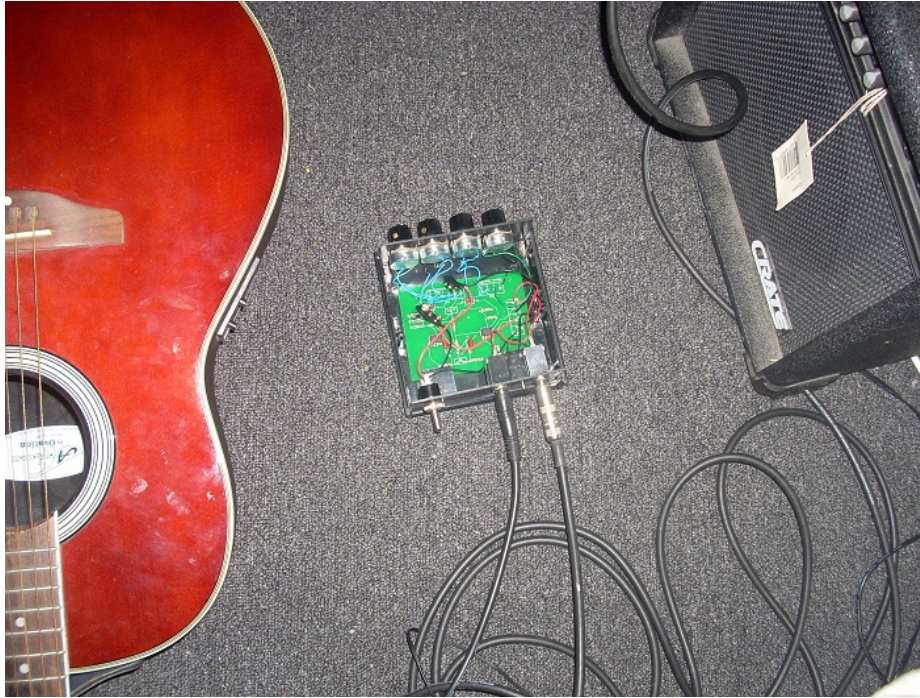


Figure 29: Testing with guitar and speaker

At this point, all testing is completed, and the project is a success.

Conclusion

This Senior Project was a huge success and a great learning experience about pre-amp design. After a good amount of debugging and tweaking the design and details of the project, I ended up with a very good working final project with professional looking packaging. This project taught me a great deal about what goes into guitar amplifier design in the music industry. My project was just a simple example of the kind of things that are constantly being developed to create higher quality sound and different effects settings for guitars. Though the project is fairly basic and fundamental, I feel like it was a great step toward understanding the more complex designs used in more advanced pre-amps.

This project also taught me what it takes to make a quality, polished final product. In my past experiences in labs, the only thing done on circuits was breadboard testing. In my project, I learned how to really complete the design after testing. In industry, a sloppy circuit board with wires going everywhere is never sold. I learned how to use an enclosure to make a professional looking product that could be sold on the market.

Overall, this project was a great experience in designing, testing, and developing a product. All results from the extensive tests made were very close to the expectations formed by the computer simulations. The final tests did not quite perform ideally. There was some DC offset present in some of the tests, and the numbers did not match up perfectly with calculations, however, this sort of thing is to be expected. Electrical components are never quite going to perform ideally, and this is about as close as it can get.

This project could give me a good head start if I choose to work in the audio amplifier business in the future. Having this experience will hopefully give me an advantage over others in the hiring process.

Bibliography

(n.d.).

Elliott, R. (2002, January 27). *100W Guitar Amplifier Mk II*. Retrieved February 20, 2010, from Elliott Sound Products: <http://sound.westhost.com/project27.htm>

Overdrive & Distortion. (n.d.). Retrieved from GM Arts: <http://www.gmarts.org/index.php?go=217#top>

Pre-Amp Equalizer Using TL074. (n.d.). Retrieved from <http://circuitdiagram-schematic.com/pre-amp-equalizer-using-tl074/>

Trent, A. (2003, May 2). *A Study Of The Physical Properties*. Retrieved February 20, 2010, from http://online.physics.uiuc.edu/courses/phys199pom/Student_Reports/Spring03/Amy_Trent/Amy_Trent_P199POM_Final_Paper.pdf

Appendices

Parts List and Cost:

2 3nF Capacitors: \$0.30
2 33nF Capacitors: \$0.30
2 1N4148 Diodes: \$0.30
5 10k ohm resistors: \$0.50
1 1k ohm resistor: \$0.10
1 68k ohm resistor: \$0.10
4 100k ohm logarithmic potentiometers \$3.00
4 Mounting knobs: \$3.00
2 Dual TL 072 op-amps \$1.50
2 ¼ inch mono audio connectors: \$2.00
1 Single Pull Double Throw Switch: \$1.50
2 9 Volt Batteries: \$5.00
1 Printed Circuit Board: \$30.00
1 Pactec CM5 enclosure: \$15.00

Lab Equipment Used:

Dual DC Power supply

Function Generator

Oscilloscope

Digital Multi-meter

Grabber Wires

Breadboard

Soldering Iron

Solder

Drill

Software Used:

Orcad PSpice Capture

Orcad Simulation

Pad2Pad Layout (for PCB ordering)

Time Schedule:

Research: 20 Hours

Design: 15 Hours

PSpice Simulation: 15 Hours

Lab Testing and Troubleshooting: 25 Hours

Layout Design and Ordering: 10 Hours

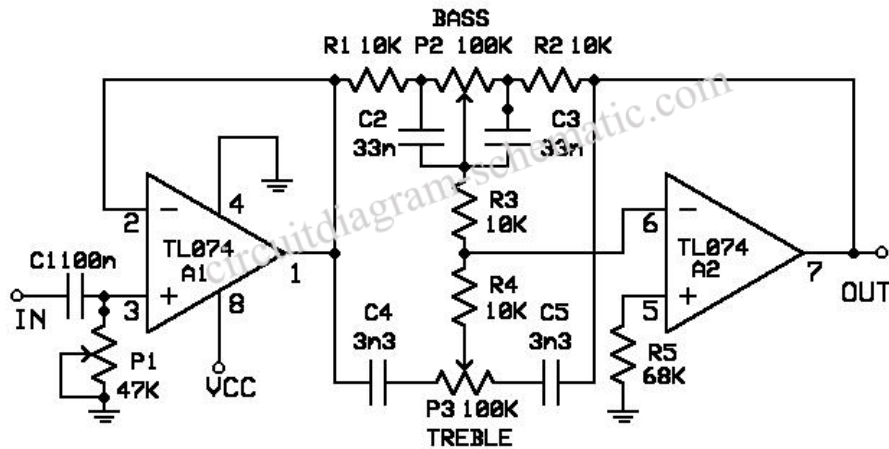
Enclosure Design and Drilling: 8 Hours

Soldering and Mounting: 20 Hours

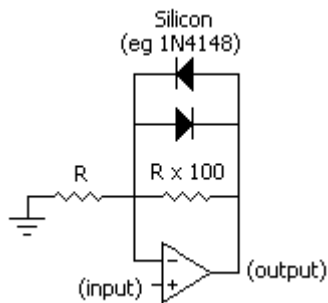
Audio Testing: 3 Hours

Specifications:

Circuits used:



From <http://circuitdiagram-schematic.com/pre-amp-equalizer-using-tl074/>

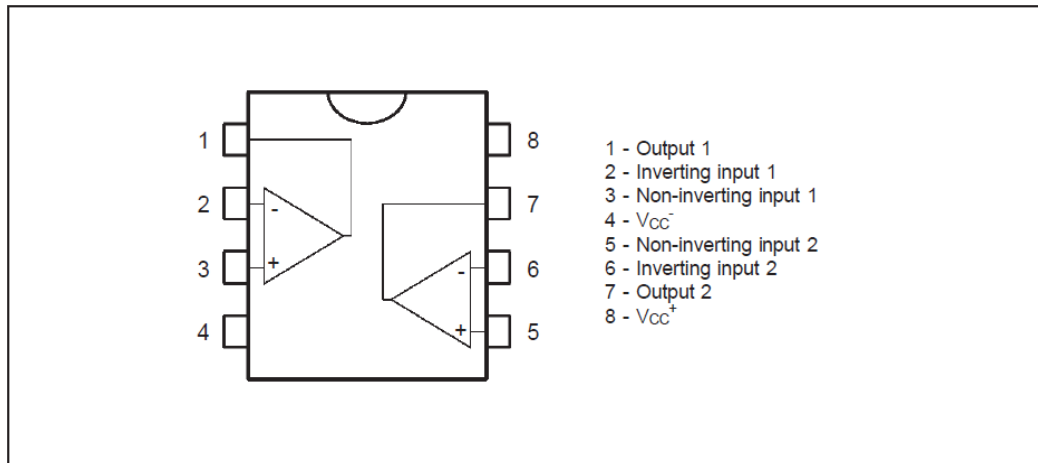


From <http://www.gmart's.org/index.php?go=217#top>

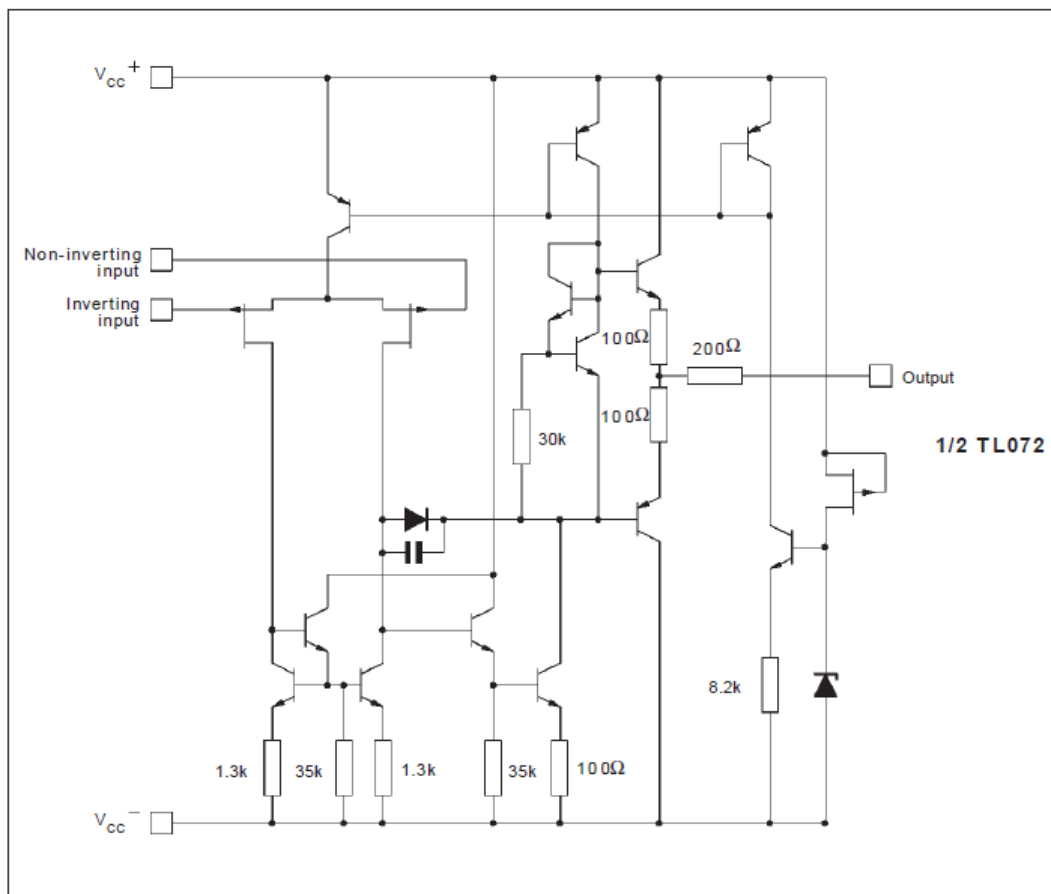
TL 072 specifications from spec sheet at

<http://www.datasheetcatalog.org/datasheet/SGSThompsonMicroelectronics/mXrxvrt.pdf>:

Pin Layout:



Schematic Diagram:



Maximum Ratings:

Symbol	Parameter	Value	Unit
V_{CC}	Supply Voltage - (note 1)	± 18	V
V_i	Input Voltage - (note 3)	± 15	V
V_{id}	Differential Input Voltage - (note 2)	± 30	V
P_{tot}	Power Dissipation	680	mW
	Output Short-circuit Duration - (note 4)	Infinite	
T_{oper}	Operating Free Air Temperature Range TL072C,AC,BC TL072I,AI,BI TL072M,AM,BM	0 to 70 -40 to 105 -55 to 125	°C
T_{stg}	Storage Temperature Range	-65 to 150	°C

Characteristics:

Symbol	Parameter	TL072I,M,AC,AI, AM,BC,BI,BM			TL072C			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
V_{io}	Input Offset Voltage ($R_S = 50\Omega$) $T_{amb} = 25^\circ\text{C}$ $T_{min.} \leq T_{amb} \leq T_{max.}$ TL072 TL072A TL072B TL072 TL072A TL072B		3 3 1	10 6 3 13 7 5		3	10 13	mV
DV_{io}	Input Offset Voltage Drift		10			10		$\mu\text{V}/^\circ\text{C}$
I_{io}	Input Offset Current * $T_{amb} = 25^\circ\text{C}$ $T_{min.} \leq T_{amb} \leq T_{max.}$		5	100 4		5 10	100 10	pA nA
I_{ib}	Input Bias Current * $T_{amb} = 25^\circ\text{C}$ $T_{min.} \leq T_{amb} \leq T_{max.}$		20	200 20		20 20	200 20	pA nA
A_{vd}	Large Signal Voltage Gain ($R_L = 2k\Omega$, $V_O = \pm 10\text{V}$) $T_{amb} = 25^\circ\text{C}$ $T_{min.} \leq T_{amb} \leq T_{max.}$	50 25	200		25 15	200		V/mV
SVR	Supply Voltage Rejection Ratio ($R_S = 50\Omega$) $T_{amb} = 25^\circ\text{C}$ $T_{min.} \leq T_{amb} \leq T_{max.}$	80 80	86		70 70	86		dB
I_{CC}	Supply Current, per Amp, no Load $T_{amb} = 25^\circ\text{C}$ $T_{min.} \leq T_{amb} \leq T_{max.}$		1.4	2.5 2.5		1.4	2.5 2.5	mA
V_{cm}	Input Common Mode Voltage Range	± 11	+15 -12		± 11	+15 -12		V
CMR	Common Mode Rejection Ratio ($R_S = 50\Omega$) $T_{amb} = 25^\circ\text{C}$ $T_{min.} \leq T_{amb} \leq T_{max.}$	80 80	86		70 70	86		dB
I_{os}	Output Short-circuit Current $T_{amb} = 25^\circ\text{C}$ $T_{min.} \leq T_{amb} \leq T_{max.}$	10 10	40	60 60	10 10	40	60 60	mA
$\pm V_{opp}$	Output Voltage Swing $T_{amb} = 25^\circ\text{C}$ $T_{min.} \leq T_{amb} \leq T_{max.}$ $R_L = 2k\Omega$ $R_L = 10k\Omega$ $R_L = 2k\Omega$ $R_L = 10k\Omega$	10 12 10 12	12 13.5		10 12 10 12	12 13.5		V
SR	Slew Rate ($V_{in} = 10\text{V}$, $R_L = 2k\Omega$, $C_L = 100\text{pF}$, $T_{amb} = 25^\circ\text{C}$, unity gain)	8	16		8	16		V/ μs
t_r	Rise Time ($V_{in} = 20\text{mV}$, $R_L = 2k\Omega$, $C_L = 100\text{pF}$, $T_{amb} = 25^\circ\text{C}$, unity gain)		0.1			0.1		μs
K_{OV}	Overshoot ($V_{in} = 20\text{mV}$, $R_L = 2k\Omega$, $C_L = 100\text{pF}$, $T_{amb} = 25^\circ\text{C}$, unity gain)		10			10		%
GBP	Gain Bandwidth Product ($f = 100\text{kHz}$, $T_{amb} = 25^\circ\text{C}$, $V_{in} = 10\text{mV}$, $R_L = 2k\Omega$, $C_L = 100\text{pF}$)	2.5	4		2.5	4		MHz
R_i	Input Resistance		10^{12}			10^{12}		Ω
THD	Total Harmonic Distortion ($f = 1\text{kHz}$, $A_V = 20\text{dB}$, $R_L = 2k\Omega$, $C_L = 100\text{pF}$, $T_{amb} = 25^\circ\text{C}$, $V_O = 2V_{pp}$)		0.01			0.01		%
e_n	Equivalent Input Noise Voltage ($f = 1\text{kHz}$, $R_s = 100\Omega$)		15			15		nV $\sqrt{\text{Hz}}$
ϕ_m	Phase Margin		45			45		Degrees
V_{OI}/V_{O2}	Channel Separation ($A_V = 100$)		120			120		dB

* The input bias currents are junction leakage currents which approximately double for every 10°C increase in the junction temperature.