The Garage Band Lightshow

By

Jason DeScenzo

Senior Project

ELECTRICAL ENGINEERING DEPARTMENT

California Polytechnic State University

San Luis Obispo

March 2014

Table of Contents

List of Tables and Figures

Abstract

The expenses musicians accrue make it hard to afford all the different equipment needed to perform and very unlikely that the average start up band or artist can afford the luxury of a musical light show in their early performances. The Garage Band Lightshow provides an easily set up and affordable way for musicians to use concert lighting in their performances. The Garage Band Lightshow provides one LED box. The light box responds to an audio signal and provides varying pulses and colors of light depending on the high, mid, and low frequencies of the audio signal. The Garage Band Lightshow provides a professional concert lightshow without the use of expensive software or a light technician. Instead, the musician can create the custom lightshow by simply playing music.

Chapter I: Introduction

The motivation behind the Garage Band Lightshow stems from the expensive nature of all musical equipment and accessories. As a musician in a band, I want to provide as professional of a show as possible. One way of doing this involves using lights in the performance. The goal of this project is to provide an inexpensive way for amateur musicians to get the equipment needed to add a powerful visual lightshow to their performance. Also, visual representations of audio have a powerful effect on the viewer/listener and providing such a representation can greatly help the amateur musician in gaining fans. Similar systems can run as much as five to six hundred dollars and feature much more complicated control systems [1][2]. Some require software or DMX controllers that need an operator adjusting controls [1]. These products include more features, such as customizable programs, dimming, and strobe effects, but are more complicated than the plug and play design of the Garage Band Lightshow. Figures 1 and 2 show some of these similar products.

Figure 1: Similar product for comparison, Chauvet COLORado 3P IP [1]

Figure 2: Similar product for comparison, American DJ LED UV Go [2]

Most lighting systems of a similar nature do not feature a direct hands free control, or a control through the use of musical equipment, like the Garage Band Lightshow, and instead have knobs and switches that control the brightness of the lights. Because of these reasons, the Garage Band Lightshow has a lower price and control of the lights by means of simply playing music.

This report contains the marketing requirements and engineering specifications for the Garage Band Lightshow. It also contains a functional decomposition of the system down to level 1, cost estimates, and time allocation. Later chapters outline the design process and the decisions made throughout the multiple design, build, and test cycles resulting in the final product. Finally, the end of the report compares the final product with the original engineering specifications and discusses the future plans for the product.

Chapter II: Requirements and Specifications

This chapter outlines the marketing requirements and engineering specifications for the Garage Band Lightshow. Table 1 (page 4) includes engineering specifications with their corresponding marketing requirements and a justification for each specification. This chapter also includes a discussion of the contents of Table 1.

Table 1: GARAGE BAND LIGHTSHOW REQUIREMENTS AND SPECIFICATIONS

Marketing Requirements	Engineering Specifications	Justification
2	Production and Labor costs do not exceed $350.	Based on pricing of similar products and assumed budget of the average consumer.
1	Physical setup of audio and power connections does not exceed 1minute.	Audio and power connections shouldn't require more than just plugging them in.
1,4	The system has ¼ inch, XLR, and RCA inputs.	Transmission of audio signals uses many types of cables.
3	The system withstands a drop of 6 feet and has water resistance in terms of minor liquid splashes and spills, but not complete submersion.	System used in a stage setting surrounded by larger equipment and must withstand transportation abuse and liquid spills.
5	System output response should have delay of less than a millisecond.	Output response must stay in time with input for system to serve its purpose.
4	Processes and filters frequencies in the range of 20Hz to 20kHz.	The audible frequency range for humans.
6	Output contains multiple colors of LED, and Can lighting with brightness in the range of 800-2000 millicandles.	This provides a variety of lighting options for the user.
5,6,7	System output provides pulsing and flashing lights in response to low(20-350Hz), low-mid(350-2kHz), high-mid(2kHz-5kHz), and high(5kHz-20kHz)[5] frequency bandwidths from the audio input signal	System ultimately used to gain a visual response from an audio signal
4,6,7	Input signal frequencies trigger blue and purple lights for low frequencies, lighter blue, green, and orange lights for the middle frequencies, and red and yellow lights for the high frequencies.	Designed to incite multi-color responses based on frequencies in 4 different bandwidth ranges.
1,6	Removable and replaceable output lighting units physically separate from input filter unit, requiring only the disconnection of wires for removal and replacement.	Allows for the upgrade and customization of product as well as creating a system that provides easy transport and set-up.
8	Visible warning label, stating the flashing light hazard pertaining to photosensitive epilepsy	Flashing and pulsing light patterns are known to trigger photosensitive seizures. A sufficient warning label can alert epileptics and educate them on the hazard of the system.
9.	System fully enclosed. No outside access to internal components without dismantling.	Prevents user from accidentally electrocuting self, or shorting components and causing a fire.

Marketing Requirements

1. Easy to setup and use.
2. Low cost
3. Durable
4. Highly compatible with audio equipment
5. System output should synchronize with input
6. Output provides multiple lighting options.
7. Provides visual response from audio.
8. Safety hazard warning
9. No outside electrical signal contact

The Garage Band Lightshow requires a low cost and an easy to use platform for the consumer. For this reason, the product must remain under $350 dollars. When compared to similar light products, just one responsive light can cost as much $280-300 and not have as sensitive a response as the Garage Band Lightshow [3]. Similar units may also require an external controller operated physically by another person [4]. The multiple input ports provide compatibility and ease of use. Similar products do not posses multiple inputs and instead only provide a DMX control input [4]. Bands or other live sound producers prefer the ¼ in. or XLR inputs, and for a DJ or personal use, the RCA inputs provide an easy way to connect an mp3 player or computer. The frequency bandwidths reflect average bandwidth ranges used in audio applications. The bandwidth range flexibility allows for precision equalizing and varies from product to product; therefore, the chosen range reflects an average range with high compatibility to input equipment and EQ [5].

The next chapter introduces block diagrams and the functional decomposition of the Garage Band Lightshow. It also includes schematics for the different modules of the system.

Chapter III: Functional Decomposition

This Chapter includes the functional decomposition of the Garage Band Lightshow. Figures 3, 4, and 5 show the level 0, level 1, and revised level 1 block diagrams, and Tables 2, 3, and 4 breakdown the functional decomposition for the level 0, level 1, and revised level 1 block diagrams.

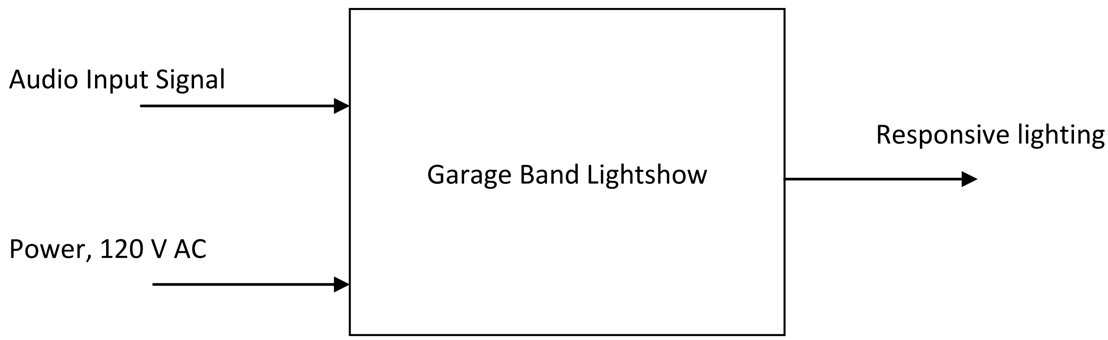


Figure 3: Level 0 Block Diagram for the Garage Band Lightshow

Table 2: Level 0 functional decomposition

Module:	Garage Band Lightshow
Inputs:	Audio Input Signal(Song file .mp3 .wav etc.), Power (120 V AC)
Outputs:	Flashing and pulsing lighting (LED, Can)
Functionality:	Take the audio input signal and produce a lighting output that responds to the input signal.

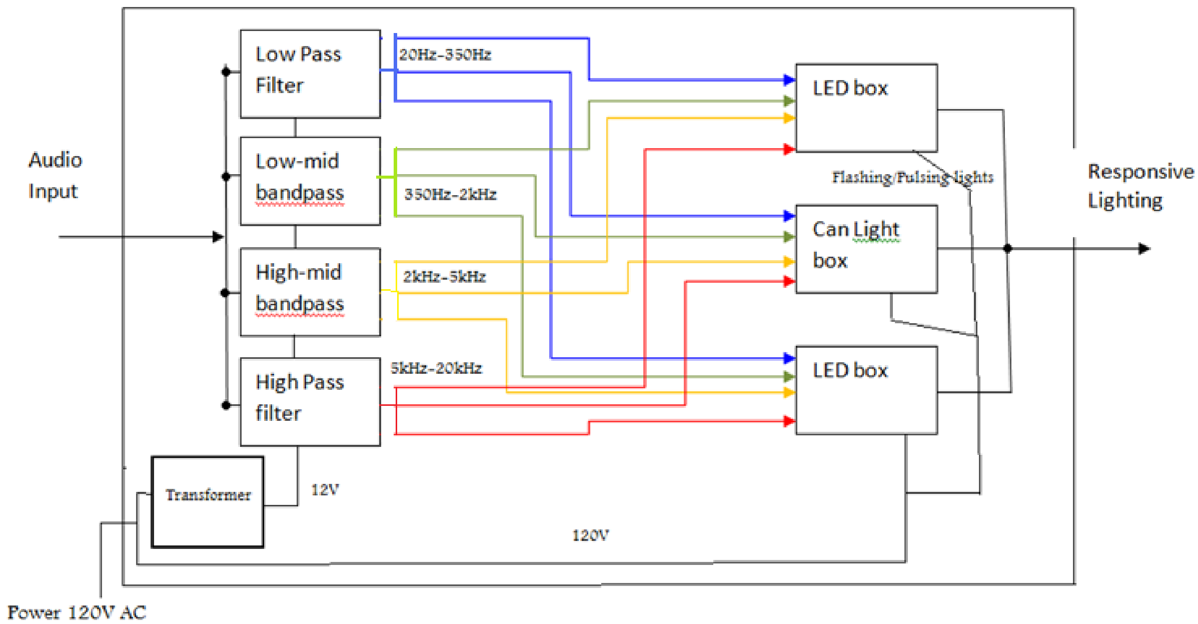


Figure 4: Level 1 Block Diagram

Table 3: Level 1 Functional Decomposition

Module:	Low Pass Filter
Inputs:	Audio input signal(varying amplitude and frequency), 12V DC
Outputs:	Audio signal frequencies 20-350Hz
Functionality:	Take audio input signal and produce filtered output in the desired frequency range
Module:	Low-Mid bandpass filter
Inputs:	Audio input signal(varying amplitude and frequency), 12V DC
Outputs:	Audio signal frequencies 350Hz-2kHz
Functionality:	Take audio input signal and produce filtered output signal in the desired frequency range
Module:	High-mid bandpass filter
Inputs:	Audio input signal(varying amplitude and frequency), 12V DC
Outputs:	Audio signal frequencies 2kHz-5kHz
Functionality:	Take audio input signal and produce filtered output signal in the desired frequency range
Module:	High Pass filter
Inputs:	Audio input signal(varying amplitude and frequency), 12V DC
Outputs:	Audio signal frequencies 5kHz-20kHz
Functionality:	Take audio input signal and produce filtered output signal in the desired frequency range
Module:	LED Box
Inputs:	Filtered audio signals from each of the 4 preceding filters, 120V DC
Outputs:	Flashing/blinking/pulsing LED light in response to the 4 filtered audio signals
Functionality:	Provide lighting output that is responsive to an audio signal broken up into 4 different frequency bands
Module:	Can Light Box
Inputs:	Filtered audio signals from each of the 4 preceding filters, 120V DC
Outputs:	Flashing/blinking/pulsing Can lights in response to the 4 filtered audio signals
Functionality:	Provide lighting output that is responsive to an audio signal broken up into the 4 different frequency bands
Module:	AC-DC step down transformer
Inputs:	120V AC
Outputs:	12V DC/120V DC
Functionality:	Take 120V AC power from wall socket and convert to 12V DC to power the filter circuit’s rail.

Figure 4 and Table 3 show that the audio signal input which varies in frequency and amplitude enters into four filters varying in frequency bandwidth that filter the audio signal, and provide four separate outputs of the audio signal. The filters output a signal that consists of the original audio signal, but only the parts of the audio that fall into the desired range. The ranges include low consisting of 20-350Hz, low-mid consisting of 350-2kHz, high-mid consisting of 2kHz-5kHz, and high consisting of 5kHz-20kHz [5]. These four audio outputs in their respective frequency range connect with the lighting circuit that provides a pulsing and flashing response in blue, purple, green, orange, red and yellow colors depending on the respective frequency range.

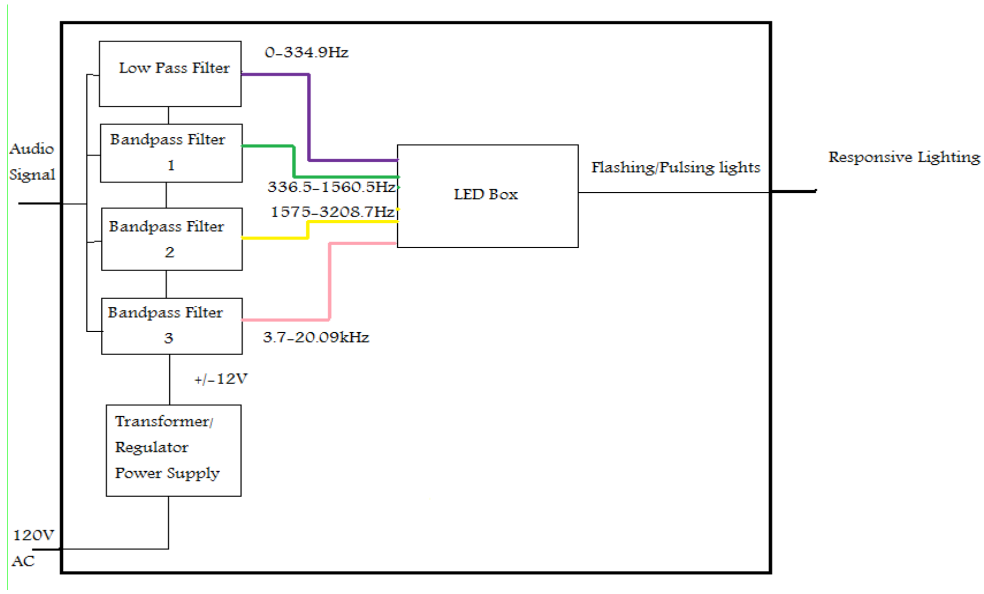


Figure 5: Revised Level 1 Block Diagram for Final Design

Table 4: Functional Decomposition for Revised Level 1 Block Diagram

Module:	Low Pass Filter
Inputs:	Audio input signal(varying amplitude and frequency), 12V DC
Outputs:	Audio signal frequencies 0-334.9Hz
Functionality:	Take audio input signal and produce filtered output in the desired frequency range
Module:	Low-Mid bandpass filter
Inputs:	Audio input signal(varying amplitude and frequency), 12V DC
Outputs:	Audio signal frequencies 336.5Hz-1560.5Hz
Functionality:	Take audio input signal and produce filtered output signal in the desired frequency range
Module:	High-mid bandpass filter
Inputs:	Audio input signal(varying amplitude and frequency), 12V DC
Outputs:	Audio signal frequencies 1575Hz-3208.7Hz
Functionality:	Take audio input signal and produce filtered output signal in the desired frequency range
Module:	High Pass filter
Inputs:	Audio input signal(varying amplitude and frequency), 12V DC
Outputs:	Audio signal frequencies 3.7kHz-20.09kHz
Functionality:	Take audio input signal and produce filtered output signal in the desired frequency range
Module:	LED Box
Inputs:	Filtered audio signals from each of the 4 preceding filters, 120V DC
Outputs:	Flashing/blinking/pulsing LED light in response to the 4 filtered audio signals
Functionality:	Provide lighting output that is responsive to an audio signal broken up into 4 different frequency bands
Module:	AC-DC step down transformer/Linear voltage regulator
Inputs:	120V AC
Outputs:	+/-12V DC
Functionality:	Take 120V AC power from wall socket and convert to 12V DC to power the filter circuit's rail.

Chapter IV: 1st Design, Build, and Test Cycle

The 1st design cycle focuses on the design of each of the four filters. Active filters provide gain if needed and prevent loading on the output. A low pass, two bandpass, and a highpass filter provide the four separate frequency band signals. Figures 6a-c contain the basic schematic for each filter.

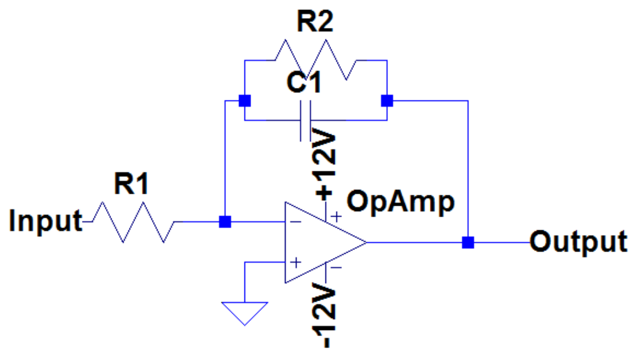


Figure 6a: Active Low Pass Filter

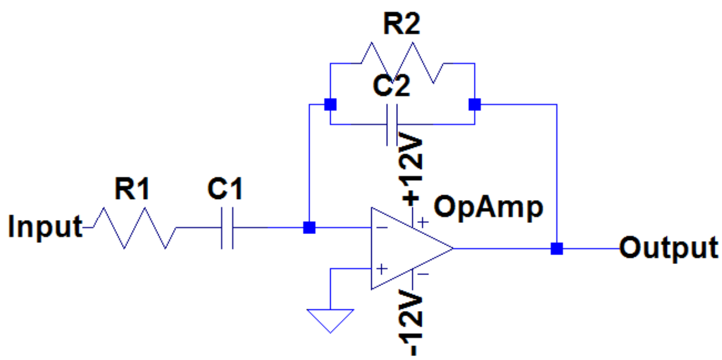


Figure 6b: Active Bandpass Filter

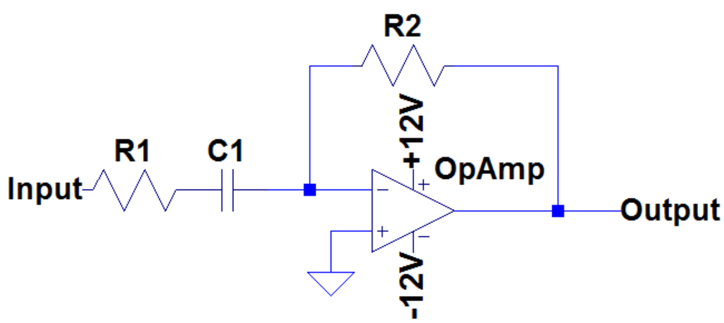


Figure 6c: Active High Pass Filter

I selected the resistor and capacitor values for each filter based on the desired frequency ranges of 0-350Hz, 350Hz-2000Hz, 2000Hz-5000Hz, and 5000Hz and above. To make for fewer parts, I used standard capacitor values along with the frequencies to find the correct resistors. Table 5 outlines the selected and calculated values for each filter.

Table 5: Filter Resistor and Capacitor values

Filter	Frequency Range	R1	C1	R2	C2
Low Pass	<350Hz	1900Ω	.47uF	1900Ω	--
Bandpass 1	350-2000Hz	1900Ω	.47uF	2300Ω	.068uF
Bandpass 2	2000-5000Hz	2300Ω	.068uF	1900Ω	.033uF
High Pass	>5000Hz	1900Ω	.033uF	1900Ω	--

For the operational amplifiers, I considered the LM386N and the TL082. The LM386N has the label of an audio amplifier [18]. The TL082 has low harmonic distortion, very high input impedance, and an eight pin package that contains two op-amps [19]. Initial tests with the LM386N revealed that the built in 20 dB gain was too large for the application so I selected the TL082 [18].

Signal noise became a problem in the beginning design stages. Figure 7 shows the input signal (on top) and the resulting noisy output signal (on the bottom). I fixed the problem by adding capacitors on the power rails of the op-amps. A very small value capacitor placed a tenth of an inch away from the op-amp, and a larger value capacitor placed in parallel with it act as a filter that reduces high frequency AC noise. The capacitors do this by bypassing the high frequency signals to ground, and allowing the DC signal through. Figure 8 shows the schematic of a filter with capacitors on the rail.

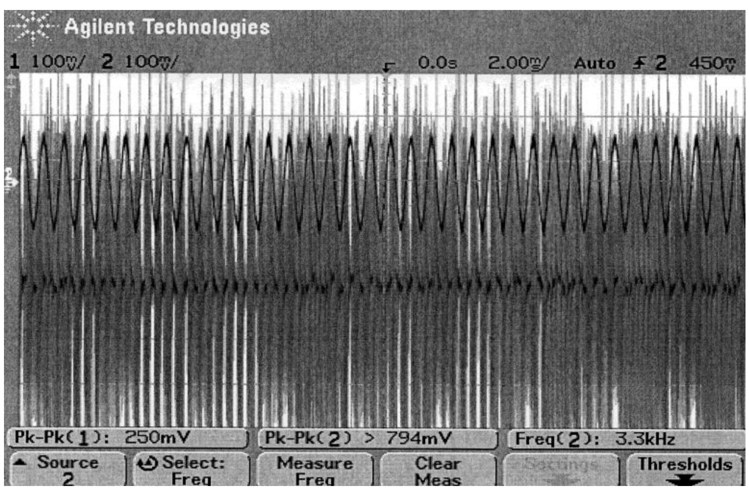


Figure 7: Scope capture of noise on output signal

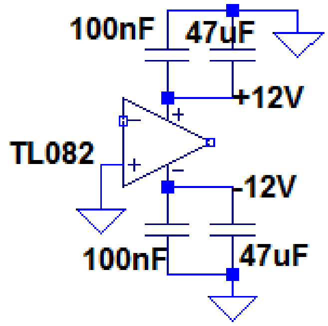


Figure 8: Capacitor configuration on power rails to reduce signal noise.

The next step in the process involved performing frequency sweeps for each filter testing for corner frequencies and attenuation. Starting with the low pass filter, I performed a frequency sweep of 10Hz to 1kHz. The output of the low pass filter exhibited attenuation as it surpassed the center frequency of 350Hz. Next I compared the output signal with the input signal at three different frequencies and measured amplitudes. This data gave me a relative idea of the functionality of the low pass filter. I repeated this process for the two bandpass filters, and the high pass filter. Figures 9a-d show the frequency sweep of the low pass filter, and the amplitude of the output at 10Hz, 350Hz, and 1kHz. Figures 6b-d also show a phase shift in the output signal.

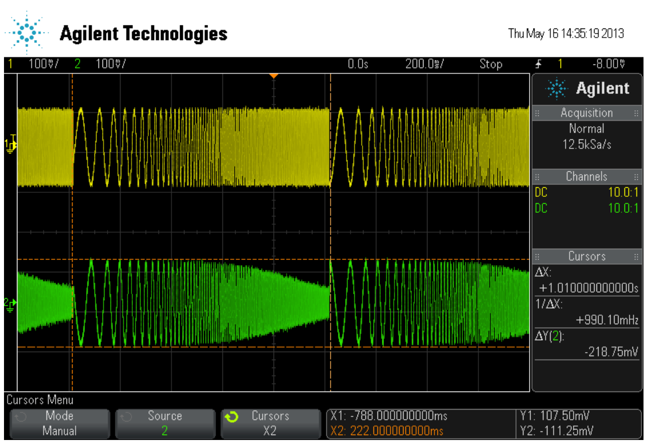


Figure 9a: Low pass sweep (10-1kHz) **Y**-input,**G**-output

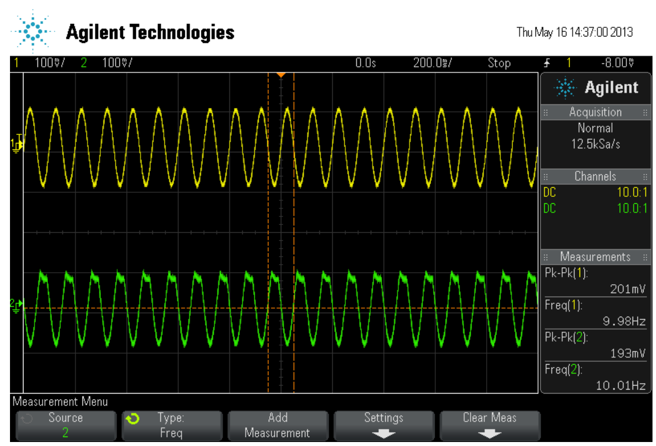


Figure 9b: Low pass at 10Hz **Y**-input,**G**-output

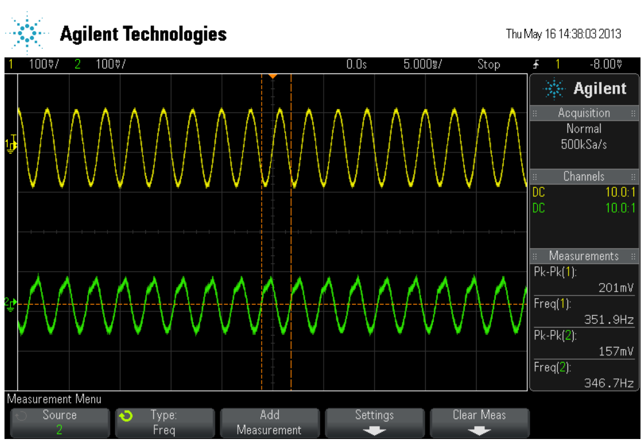


Figure 9c: Low pass at 350Hz **Y**-input,**G-**output

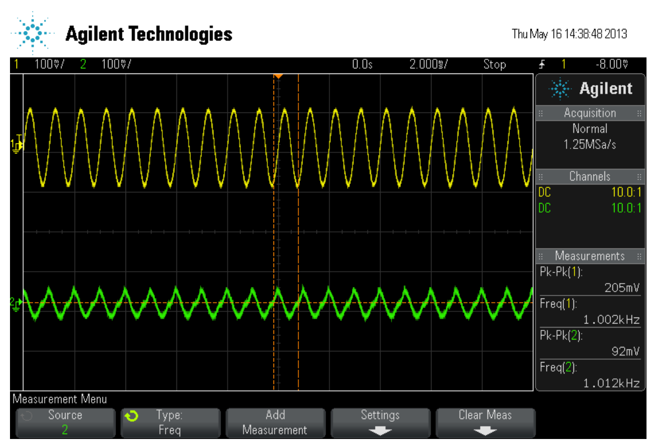


Figure 9d: Low pass at 1000Hz **Y**-input,**G**-output

For the first bandpass filter (350-2000Hz), the sweep of 100-3kHz showed attenuation at the first corner frequency but showed none at the second corner frequency. The output signals at different frequencies also exhibited a slight phase shift. Figures 10a-d shows the frequency sweep of 100Hz to 3kHz and the amplitude of the output at 100Hz, 1.2kHz, and 3kHz.

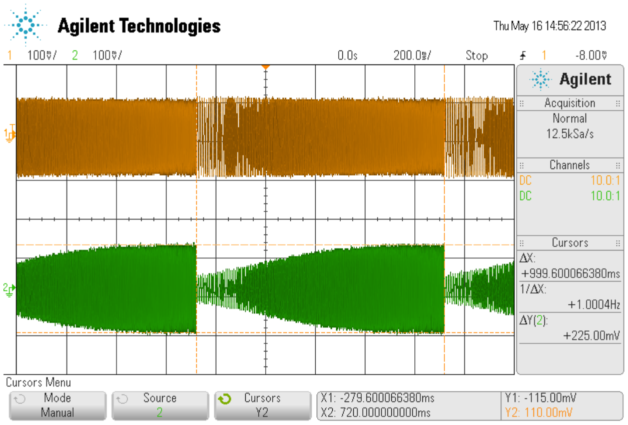


Figure 10a: Bandpass 1 frequency sweep (100-3kHz) **Y**-input,**G-**output

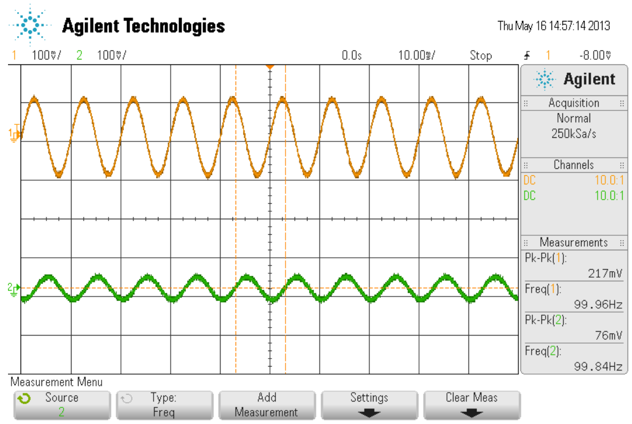


Figure 10b: Bandpass 1 at 100Hz **Y**-input,**G-**output

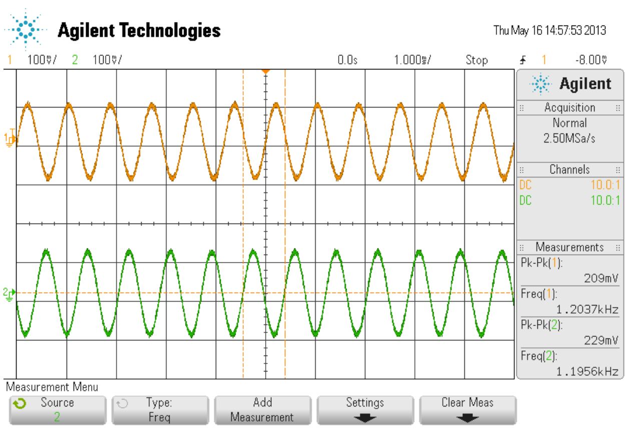


Figure 10c: Bandpass 1 at 1200Hz **Y**-input,**G-**output

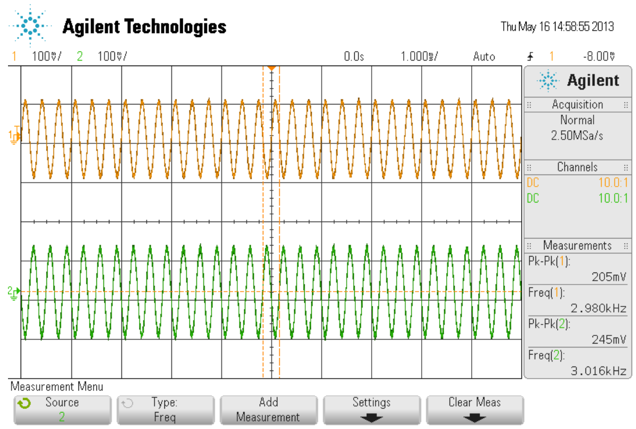
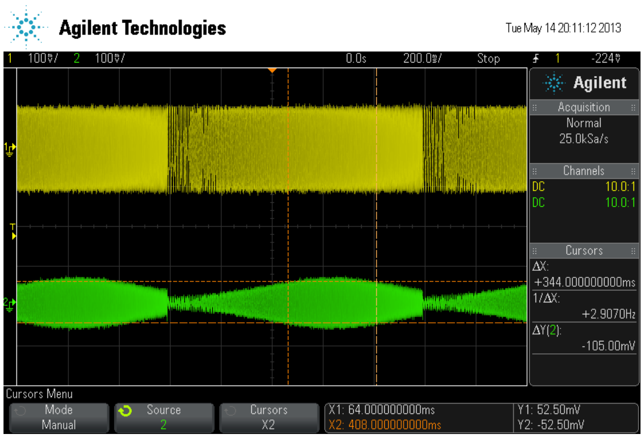


Figure 10d: Bandpass at 3000Hz **Y**-input,**G-**output

For the second bandpass filter (2000-5000Hz), the sweep showed significant attenuation throughout the range of frequencies, and the output signal at multiple frequencies showed a slight phase shifted. Figures 11a-d shows the frequency sweep from 1kHz to 7kHz, and amplitude at 1.8kHz, 2.4kHz, and 5kHz.



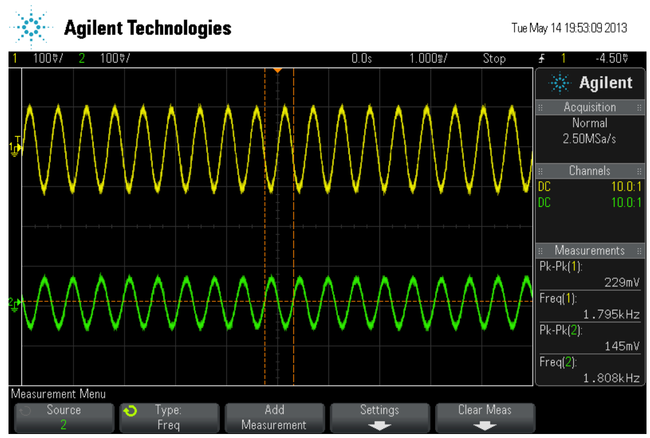
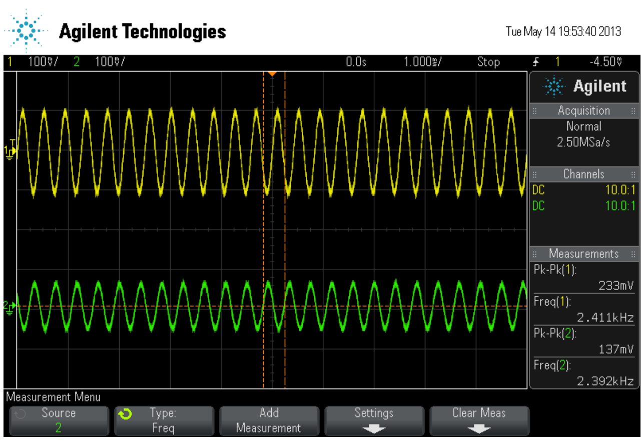


Figure 11a: Bandpass 2 sweep (1kHz-7kHz)
Y-input,**G**-output

Figure 11b: Bandpass 2 at 1800Hz
Y-input,**G**-output



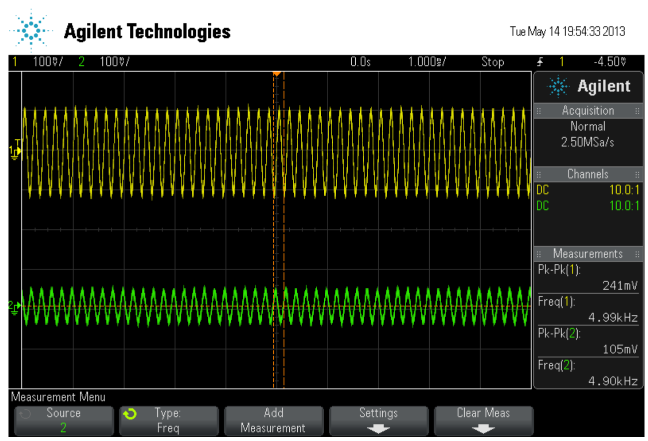
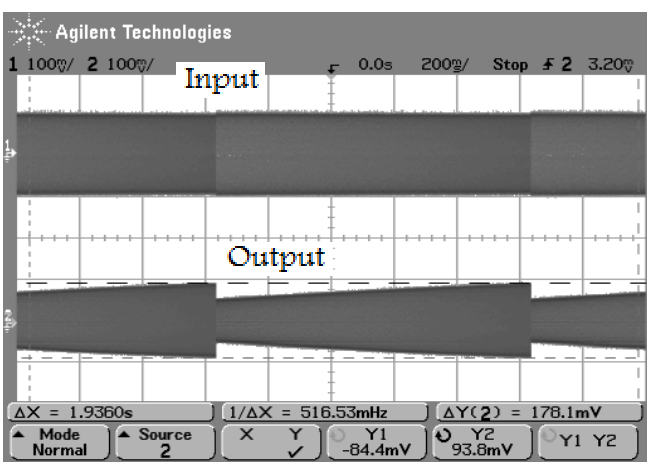


Figure 11c: Bandpass 2 at 2400Hz **Y**-input,**G**-output **Figure 11d:** Bandpass 2 at 5000Hz **Y**-input,**G**-output

For the High pass filter (>5kHz), the sweep showed a gradual attenuation on the output signal even with frequencies well above the center frequency. The output signal also showed a slight phase shift. Figures 12a-d show the sweep from 3kHz-10kHz and the amplitudes of the output at 3kHz, 5kHz, and 10kHz. The top signal shows the input and the bottom signal shows the output.



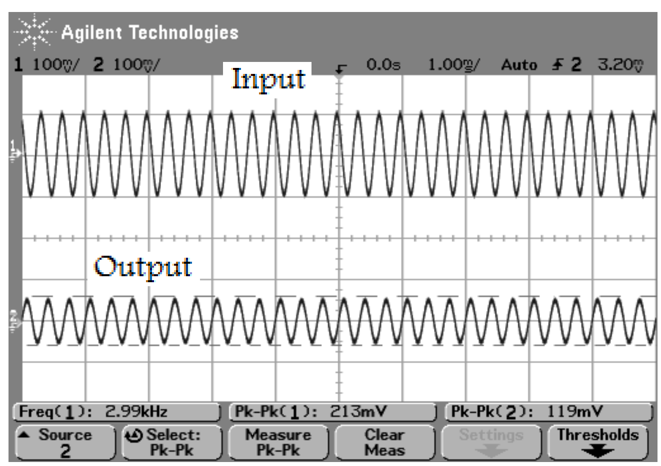


Figure 12a: High pass sweep (3kHz-10kHz)

Figure 12b: High pass at 3kHz

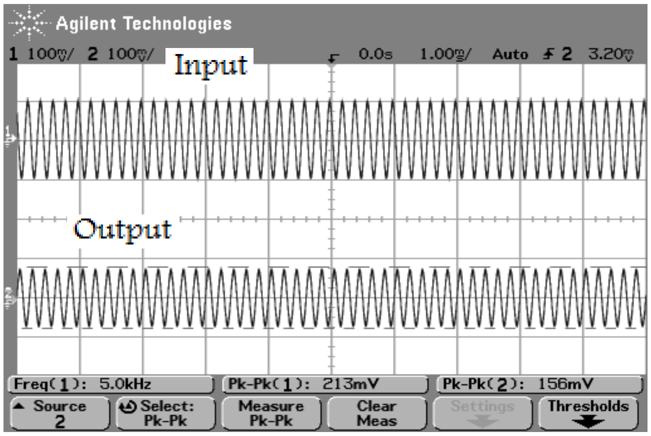


Figure 12c: High pass at 5kHz

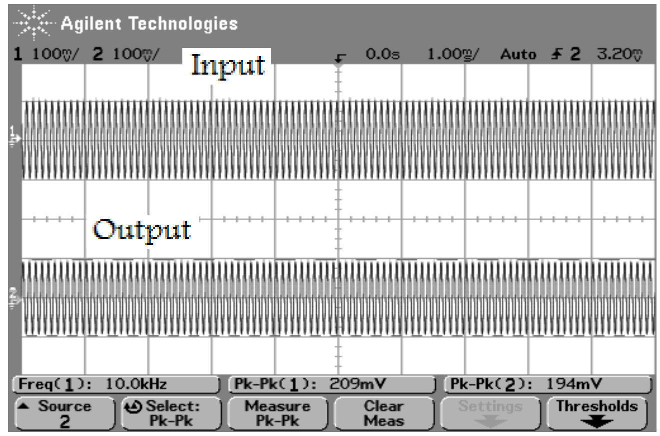


Figure 12d: High pass at 10kHz

I made a passive bandpass filter of 1kHz-2.5kHz out of available parts to compare the output response with that of the active filters. The output signal of the passive filter showed a large attenuation at all frequencies tested, and when compared to an active bandpass filter with the same frequency band, the output signal showed no attenuation. Figures 13a-f shows scope captures of the input and output signals for the passive filter and active filter at various frequencies. Again the top signal shows the input and the bottom signal shows the output.

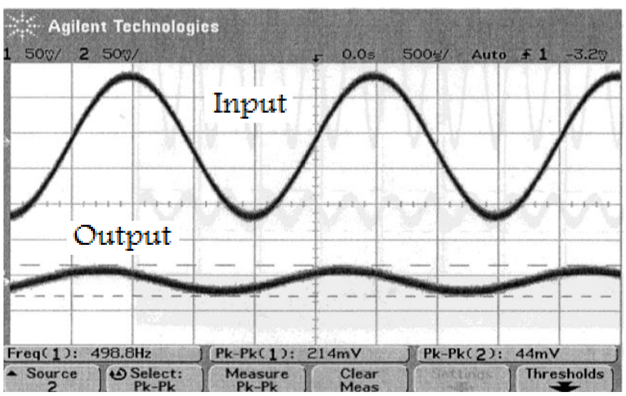


Figure 13a: Passive filter at 500Hz

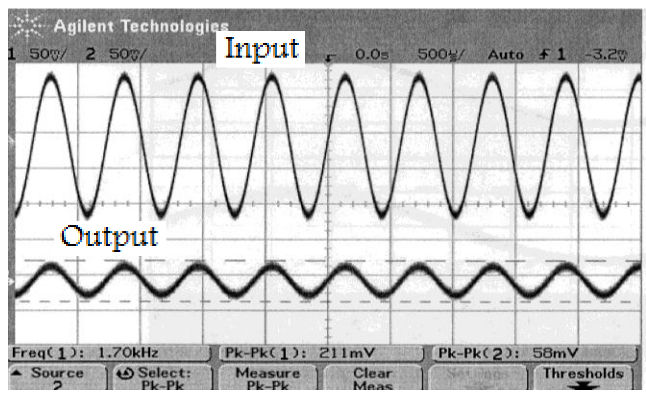


Figure 13b: Passive filter at 1.7kHz

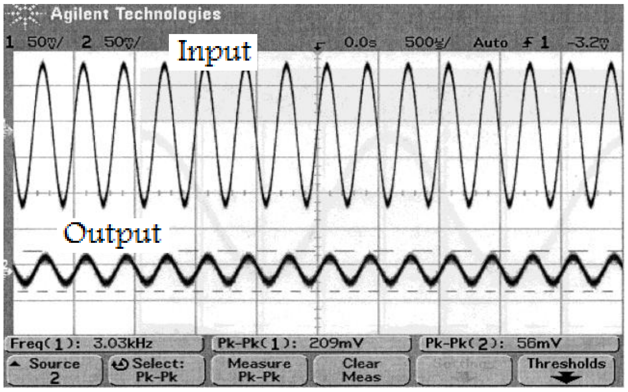


Figure 13c: Passive filter at 3kHz

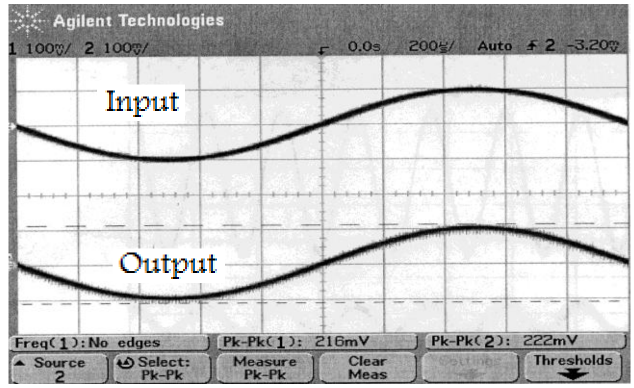


Figure13d: Active filter (1kHz-2.5kHz) at 500Hz

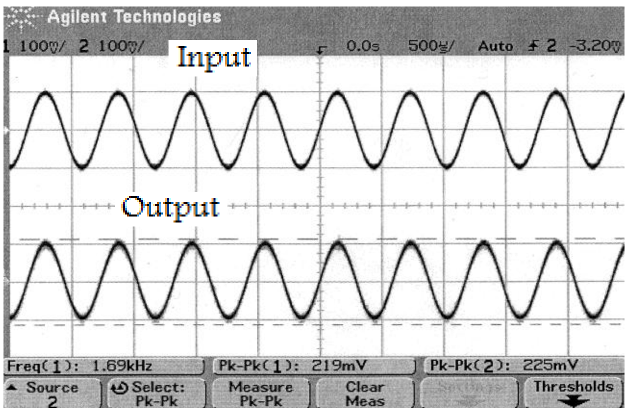


Figure 13e: Active filter at 1.7kHz

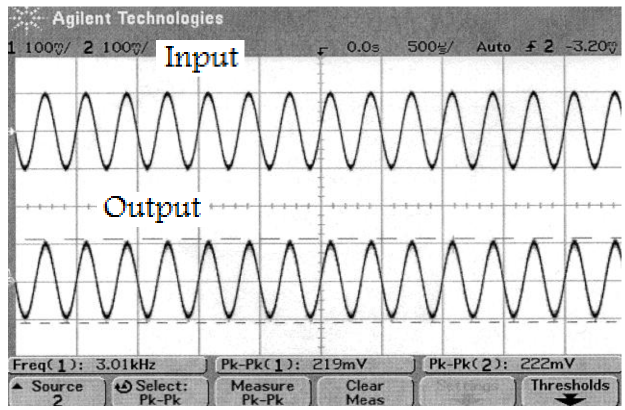


Figure13f: Active filter at 3kHz

To fix the problem, I recalculated the resistor and capacitor values for the filters. This time I selected 20kohm resistors for each resistor value, and calculated the capacitor values using the desired frequency bands. Table 6 outlines the resistor and capacitor values.

Table 6: Re-calculated Resistor and Capacitor values

Filter	Frequency Range	R1	C1	R2	C2
Low Pass	<350Hz	20kΩ	.022uF	20kΩ	--
Bandpass 1	350-2000Hz	20kΩ	.022uF	20kΩ	.004uF
Bandpass 2	2000-5000Hz	20kΩ	.004uF	20kΩ	1.6nF
High Pass	>5000Hz	20kΩ	.1.6nF	20kΩ	--

With the re-calculated component values, I calculated multiple gain values at multiple frequency points for each filter. I then plotted these values on bode magnitude plots and used them to find the -3dB points of each. Figures 14a-d show the magnitude plots for the low, high, and bandpass filters. For the low pass and both of the bandpass filters, the -3dB frequencies came very close to the desired corner frequencies. The low pass -3dB frequency came within 50Hz. The first bandpass filter -3dB frequencies came within 50 to 100Hz. The second bandpass filter -3dB frequencies came within 100Hz, and the high pass filter -3db Frequency undershot the desired frequency by about 3kHz.

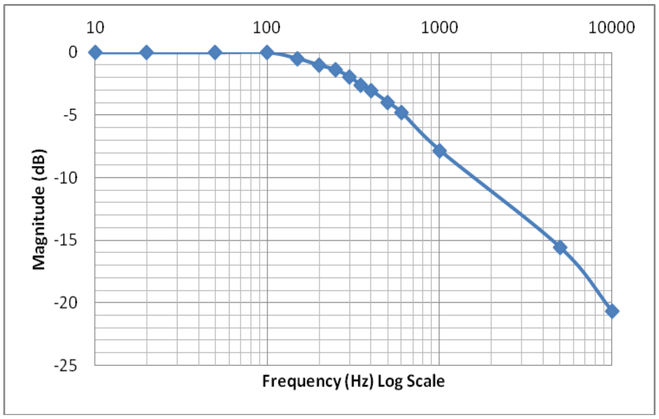


Figure 14a: Magnitude plot for low pass filter

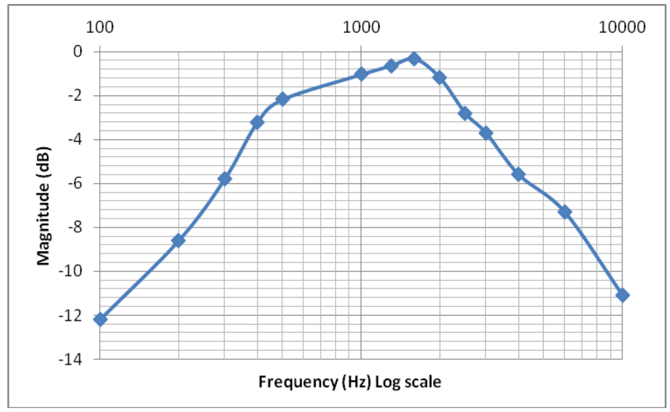


Figure 14b: Magnitude plot for bandpass 1

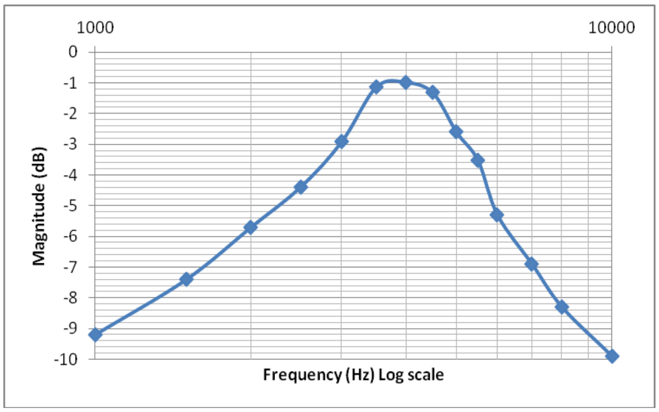


Figure 14c: Magnitude plot for Bandpass 2

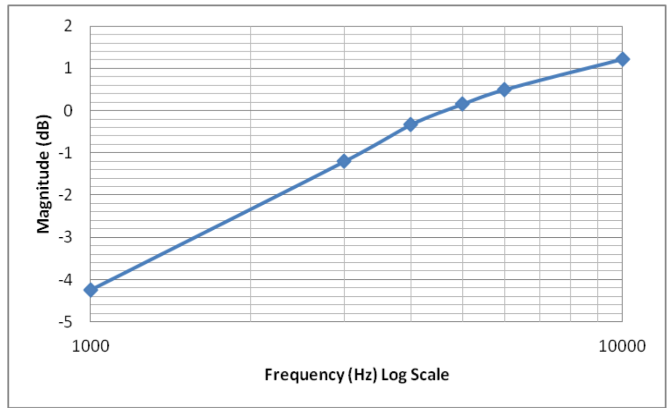


Figure 14d: Magnitude plot for High pass filter

Table 7: Desired and Actual -3dB Frequencies for first build from magnitude plots (Figures 14a-d)

-3 dB Frequencies	Desired	Actual
Low Pass	350 Hz	400 Hz
Bandpass 1	350, 2500 Hz	400, 2600 Hz
Bandpass 2	2500, 5000 Hz	3000, 5200 Hz
High Pass	5000 Hz	2000 Hz

With the low pass and two bandpass filters working, I added the design of the light response test circuit. I wanted to move forward to make sure that the light response circuit would work as planned before spending more time on the filters and having to do a complete redesign. Figure 15 shows the schematic for the light response test circuit. I connected the output of each filter to the base of a TIP31 NPN transistor [20]. The transistor acts as a switch, and when the audio signal input voltage reaches the threshold the transistor goes into forward active mode allowing current to flow from the supply voltage through the LED's to ground on the emitter. This turns on the lights with the peaks in the audio signal and turns them off when the voltage at the base emitter junction does not reach the turn-on voltage. The filters only allow their respective bandwidths through which creates a separate flashing response for each filter. Coupled with different color LED's, four sets of different colored LED's each responding to a different frequency band of the audio signal provides the end result. Figure 16 shows the entire testing circuit schematic.

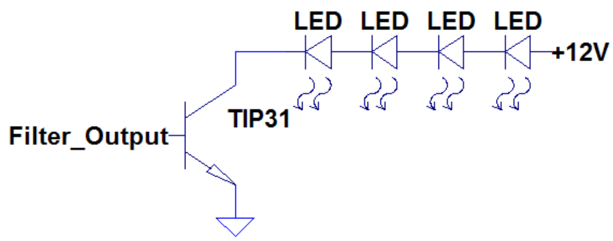


Figure 15: LED light response test circuit

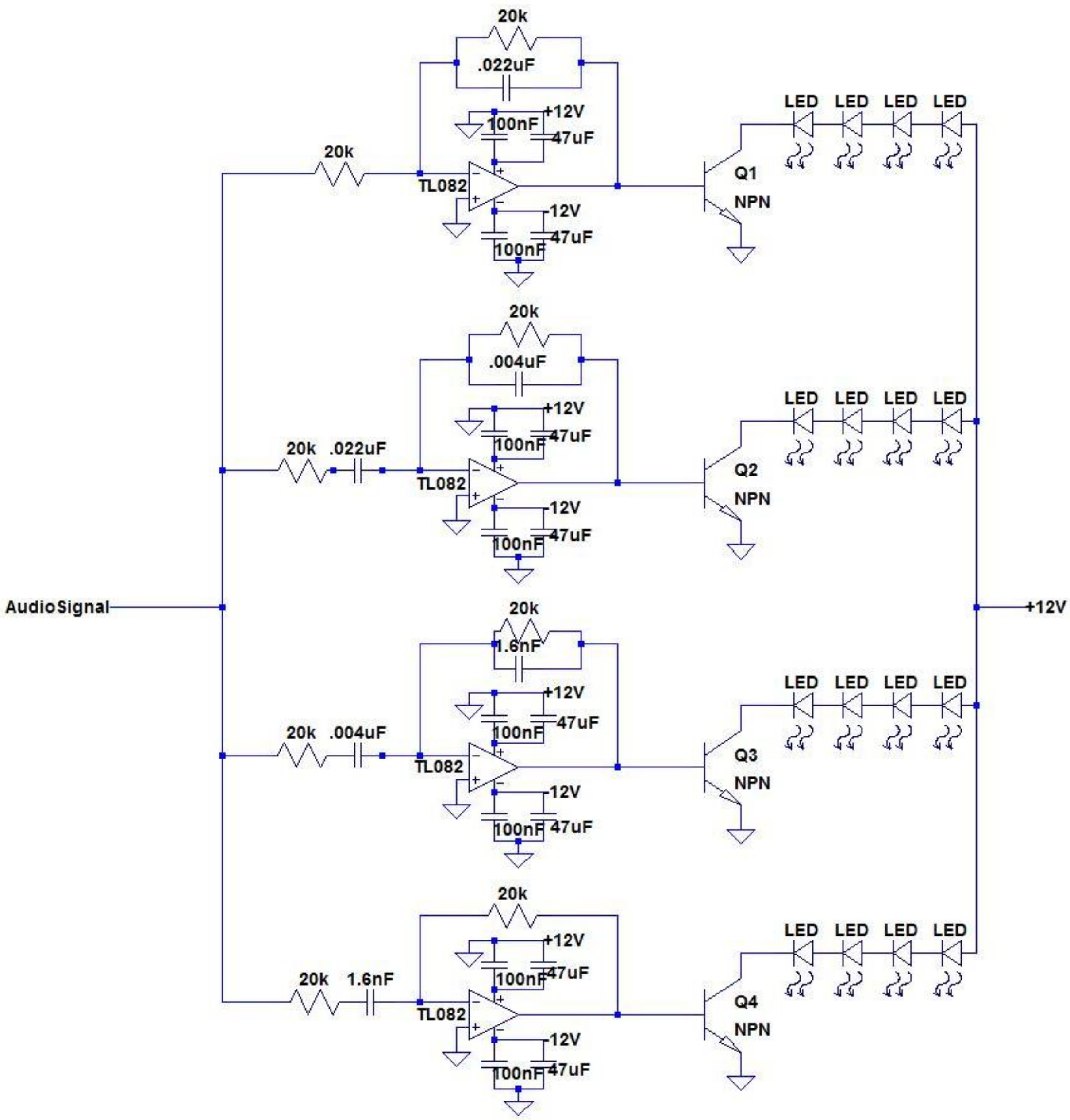


Figure 16: Full test circuit including 4 active filters and 4 light response test circuits

When tested, the light response test circuits attached to the low pass, and two bandpass filters, all exhibited flashing and pulsing lights. Some lights pulsed brighter than others due to different Turn-on voltages for the different colored LED's. The light response test circuit attached to the high pass filter however, displayed LED's that stayed on without an input audio signal. The LED's remained on because the high pass filter allowed high frequency noise through. The noise's amplitude provided a large enough voltage to turn on the BJT and therefore the LED's.

The next chapter explains the redesign of the test circuit in Figure 16, as well as the building and testing of the circuit. It addresses the problems presented in this chapter and discusses the proposed solutions.

Chapter V: 2nd Design, Build, and Test Cycle

This chapter chronicles the second design, build, and test cycle for the Garage Band Lightshow. This second iteration uses data collected from the first cycle to re-evaluate the design and get the test circuit working properly. Chapter five focuses on the high pass filter redesign and component selection. It also touches on the design of a power supply for the filters.

At this stage in the design process I decided to use components for the resistors and capacitors, instead of continuing the use of switchable resistor and capacitor boxes. Component selection at this stage became limited by the available supplies. Figure 17 and table 8 show the resulting redesign and component value selection. I replaced the high pass filter from the test circuit in figure 16 with a bandpass filter to remove the high frequency noise that caused the LED's to remain on. The LED's selected for the new test circuit all have the same turn-on voltage to account for the uneven voltage drop in the previous design. Figure 25 in Appendix C (page 43) shows a picture of the circuit in figure 17 built on a breadboard.

Table 8: Resistor and Capacitor Values for filters in Figure 17 and their corner frequencies

low pass		**bandpass 1**		**bandpass 2**		**bandpass 3**	
R15	21.6 kΩ	**R17**	21.5 kΩ	**R19**	21.5 kΩ	**R21**	21.5kΩ
R16	21.6 kΩ	**C17**	0.022 uF	**C19**	0.0047 uF	**C21**	0.002 uF
C16	0.022 uF	**R18**	21.7 kΩ	**R20**	24.8 kΩ	**R22**	19.8 kΩ
fc1	334.9 Hz	**C18**	0.0047 uF	**C20**	0.002 uF	**C22**	0.4 nF
		fc1	336.5 Hz	**fc1**	1575 Hz	**fc1**	3701.2 Hz
		fc2	1560.5 Hz	**fc2**	3208.7 Hz	**fc2**	20,095.3 Hz

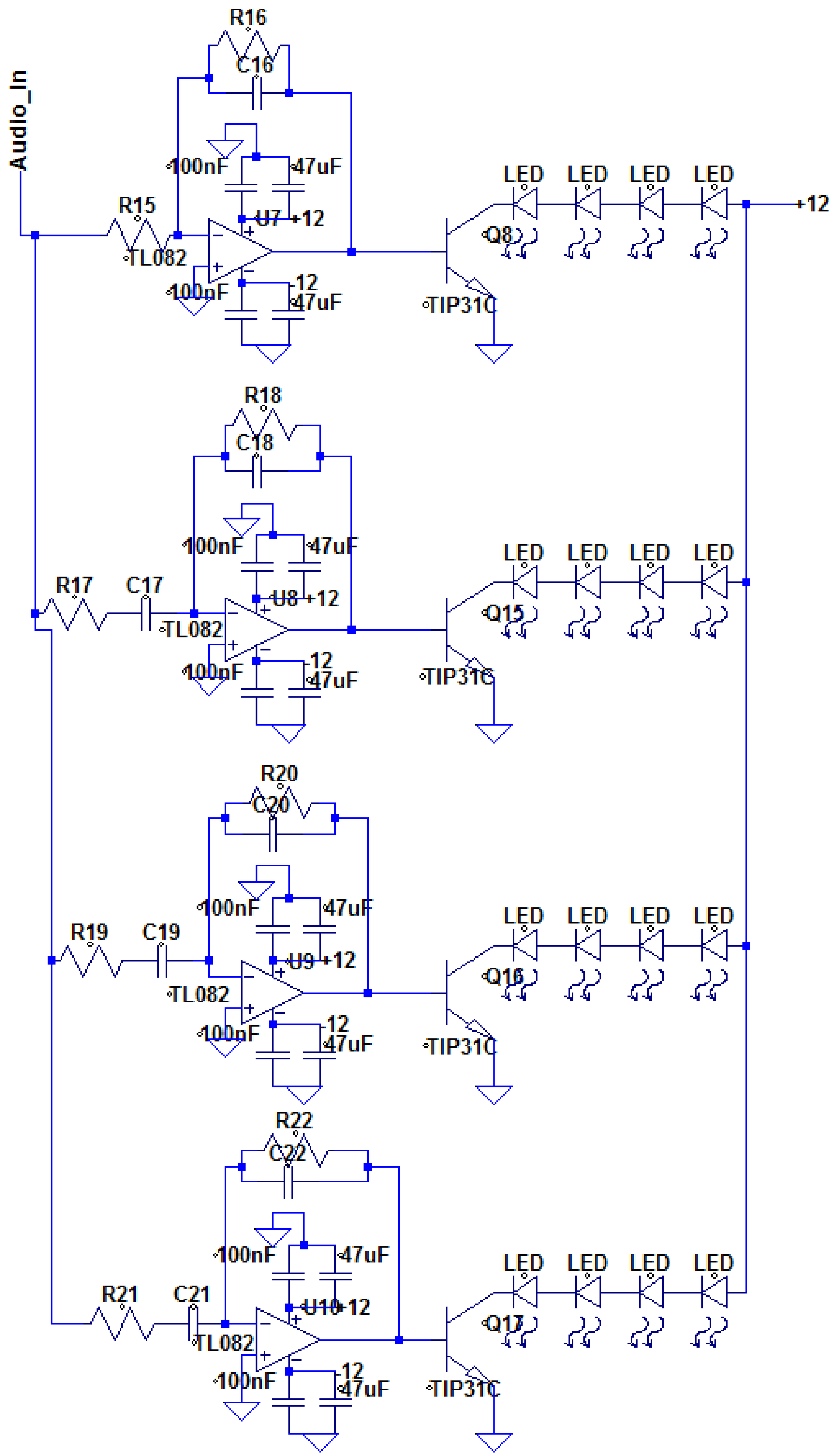


Figure 17: Test circuit after redesign with resistor and capacitor component values

With the four light response test circuits now providing different light flashing patterns, the next step in the process became powering the TL082 op-amps. I designed a power supply to provide +/-12 volts DC. With +/-12V required, the LM7812 and LM7912 regulators seemed like the best options. These regulators are designed specifically for +/- 12V therefore making them the optimum choice [21] [22]. The LM7812 became the positive voltage regulator, but since the LM7912 was not readily available, the LM337 became the second choice for the negative voltage regulator [23]. Figure 18 shows the original power supply design. The circuit also contains a fuse and a switch; I did not include these in Figure 18.

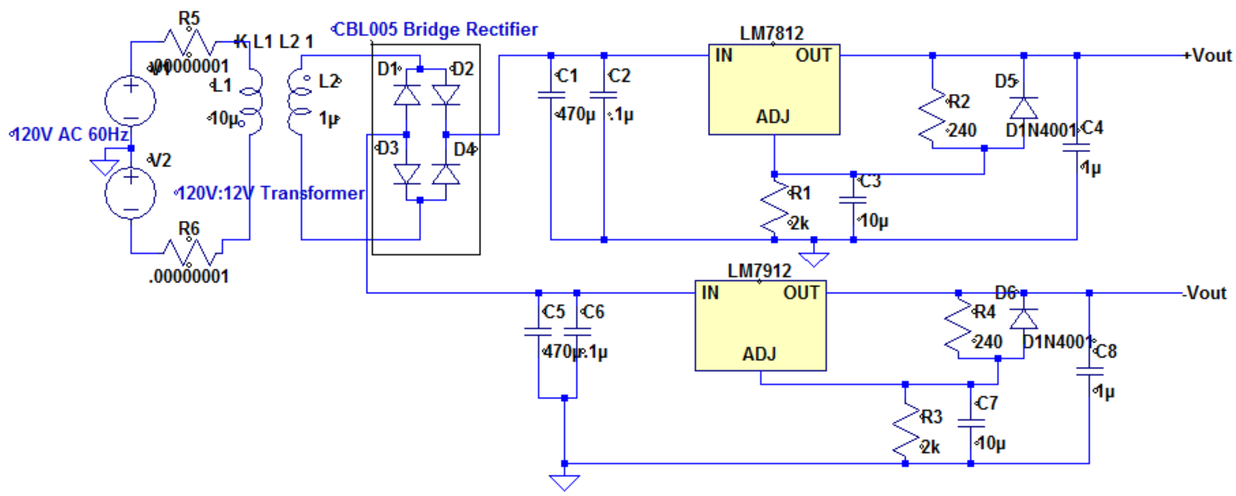


Figure 18: Original power supply design

With the LM7912 not available, I replaced it with the LM337 in the design, and built the circuit in figure 18. I measured the output voltages and got values of 16-17V from the LM7812, and -11V from the LM337. Further investigation uncovered that the LM7812 should not have capacitor C3 from figure 18. With this capacitor removed, the power supply output +/- 11 volts. Figure 19 shows the final power supply circuit. Once again, I did not included the switch and fuse in the circuit schematic. Figure 26 in Appendix C (page 43) shows the circuit in figure 19 built by connecting the regulator circuit, built on a breadboard, to a transformer mounted in a metal box.

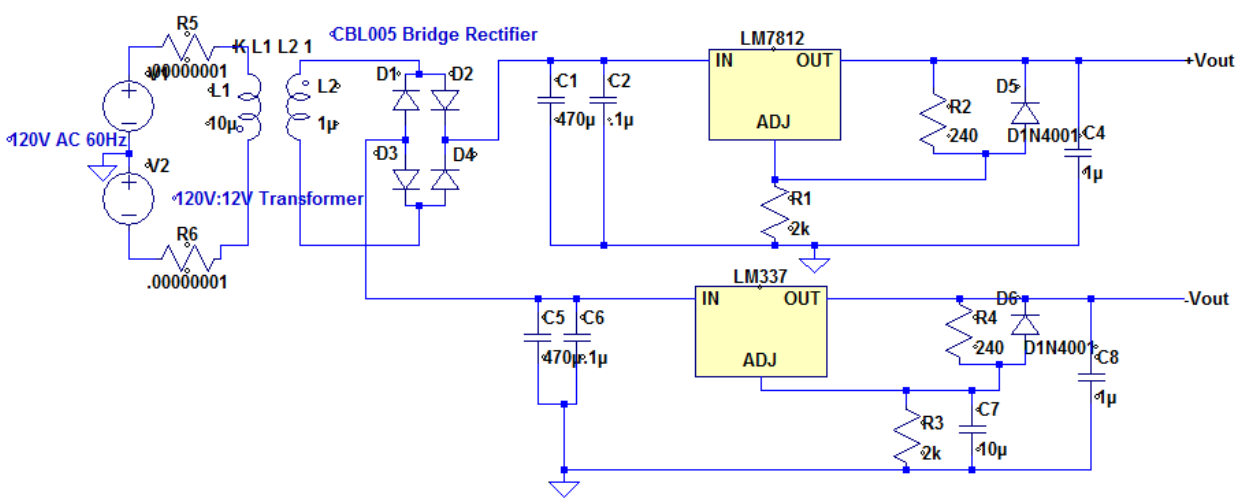


Figure 19: Final power supply design

Chapter 6 discusses the final design, build, and test cycle of the Garage Band Lightshow. The issue of powering the LED's gets looked into, and I outline the full scale prototype construction process.

Chapter VI: Final Design, Build, and Test Cycle

With the main components of the Garage Band Lightshow working, the next step in the process involved designing and building a full scale prototype. I address the problem of how to power the LED's later since I could not make a final decision on how, until I had a completed the design for the full scale prototype.

For the full scale prototype, the power supply and filters from the second design, build, and test cycle remain the same, but I replaced the light response test circuit. When deciding on the design for the final light response circuit, I drew ideas from different products I had seen, along with the idea I saw in my head. I knew that I wanted a large number of LED's to provide the most light possible. The sizing of the final light response circuit came from the size of an 8 ½"X11" piece of paper. I used the paper to layout and get an idea of the pattern and orientation of the LED's. Figure 28 in Appendix C (page 45) shows the original drawing and figure 30 (page 47) shows the LED layout on the completed prototype. The next question became how to power 84 LED's for the final light response circuit. The three options considered included, using the power supply for the op-amps, building a new power supply for the LED's, or using batteries. The problem with the first option became the required number of transistors for the response circuit. With only 11-12 volts supplying the LED's the design would require six to seven more transistors. Building a new power supply requires extra parts, such as transformers and regulators, and without manufacturing capabilities, building a power supply also did not seem feasible for the space provided. This made the logical choice batteries. I chose two 9V batteries put in series to create an 18V power source for the LED's. Figure 29 in Appendix C (page 46) shows the back of the completed prototype and the battery mount. This brought the number of transistors required to thirteen, without requiring an excessive amount of batteries. Figure 20 shows the layout of the light response circuit.

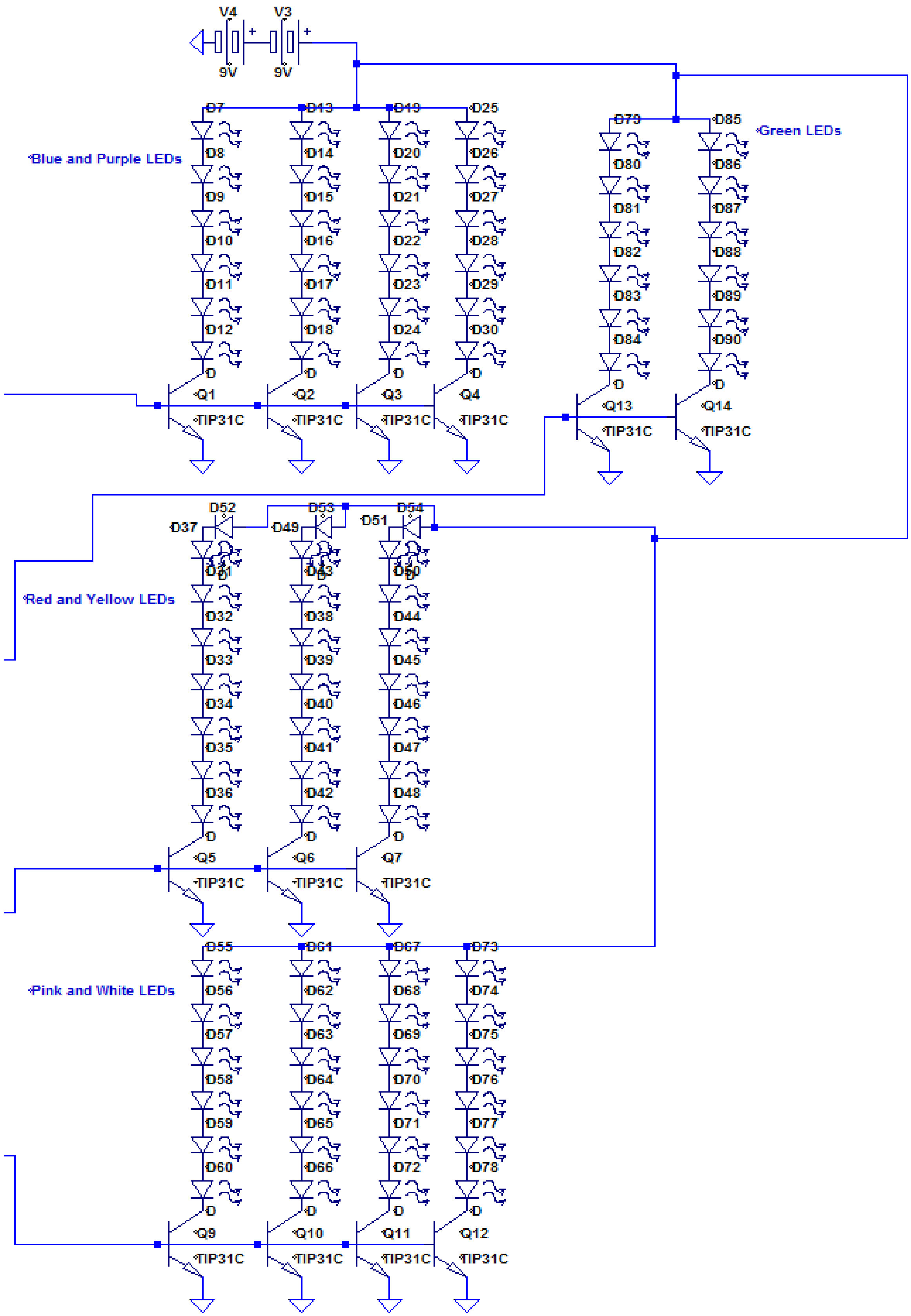


Figure 20: Final light response circuit

I selected the colors of the LED's based on available colors in the 10mm size, and based on my personal preference. I could not find the pink LED's in the 10mm size so I accepted the 5mm size. The on voltages for the LED's determined the arrangement of the LED's with their corresponding transistor. Since Red and Yellow LED's have a lower on voltage, I put more of them in series for each transistor. With the design of the circuit completed, the final design became how to house the light response circuit. With the tools available to me, wood seemed the best option. I used particle board to mount all of the LED's, and pine wood constructed into a frame to hold the particle board mount and house the electronics. Figure 21 shows Particle board used for mounting the LED's. Figures 25-33 in Appendix C shows pictures of the final prototype.

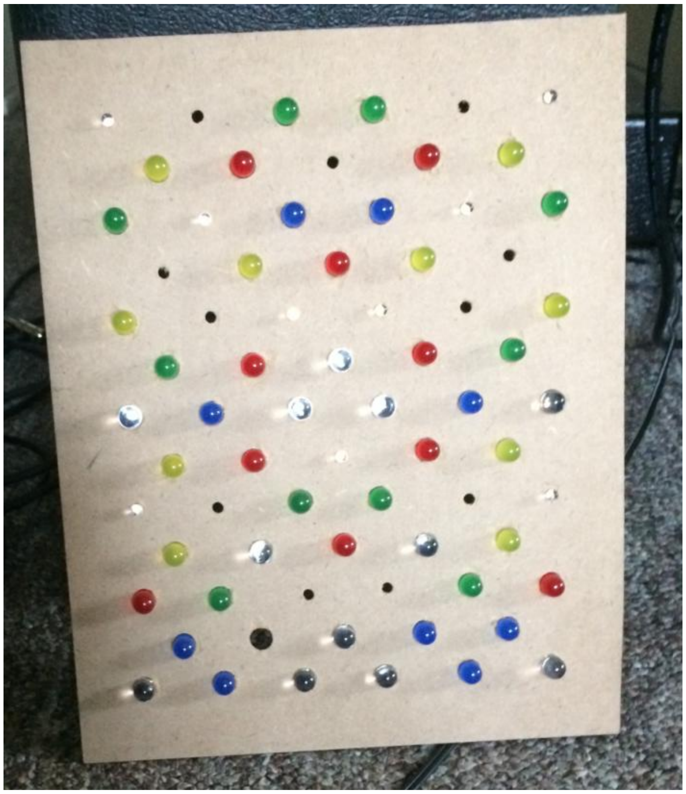


Figure 21: Particle board mount for LEDs

Chapter VII: Conclusion

In this chapter I start by discussing the engineering specifications set out in Chapter 2, and how the final product of this project addresses them. I talk about things I learned during the duration of this project, some troubleshooting and final problems that I ran into with the final prototype, and future plans for the Garage Band Lightshow.

The first engineering specification requires a production and Labor cost of less than 350 dollars. Table 10 shows that the part cost for two boxes comes out to 235.24 dollars, with assembly included, the cost exceeds 350 dollars. As mentioned in Appendix B, establishing the ability to manufacture the product and produce large numbers of Garage Band Lightshows brings the cost within the 350 dollar requirement. The second specification requires a setup time, of the power and audio cables, of a minute or less. The final prototype includes detachable power and audio cables making setup time within the desired range. Figure 32 in Appendix C (page 48) shows the detachable wires that transmit the filtered audio signals to the light response circuit. The third specification called for three different audio input jacks. The final prototype does not include any of the specified jacks, and instead uses a 3.5mm input jack. For the final product I will add the other jacks, but for the testing process and the prototype construction, the 3.5mm input jack sufficed. The next specification requires the Garage Band Lightshow to withstand a drop of six feet and minimal liquid exposure. With the power supply and LED boxes enclosed, minimal liquid exposure does not cause damage. This also prevents access to internal electronics and the safety hazard of electrocution. The metal and wood box constructions of the power supply ensure that six foot drop does not cause damage. I did not fully test the drop, but accidentally did when one of the boxes fell approximately three feet due to a failure in the mounting apparatus. The next few specifications require filtering at different frequency bandwidths and a minimal delay from input to output. The final product produced bandwidths around the ranges specified, and the pulsing light output matches the audio output, verifying a minimal delay from input to output. The LED's chosen all fell within the specified millicandle range of 800-2000 millicandles [24-30]. The colors of the LED's with respect to the frequencies mentioned in the engineering specifications, ended up different, based on personal preference and available colors. I used purple and blue for the lower frequencies, red, yellow, and green for the middle frequencies, and pink and white for the high frequencies. The LED boxes are also detachable from the power supply. I have not included a warning label yet but since I have not put the product on the market for sale, I did not find it necessary at this point. The final product met seven out of twelve of the engineering specifications.

Throughout my education in electrical engineering, the curriculum focused mainly on the theoretical aspects of circuit design and analysis. When I began this project, I ran into problems derived from my lack of knowledge involving real world applications. I address these problems in earlier chapters and the solutions I used, but they all stemmed from my application of theoretical analysis and design. I learned that with design, the theoretical knowledge supplies a good base for the beginning of design, but real world conditions must be expected and accounted for.

The final prototype for the Garage Band Lightshow began to malfunction after multiple hours of functional use. This became the final troubleshooting necessary for the completion of the project. With the power from the power supply on, the lights in the LED box turned on. Without an audio signal input to the system, I recognized the problem had to come from a short circuit in either the LED box itself, or the filters circuit. After inspection of the LED box, I found no obvious short circuit. When I disconnected the wires from the filters to the LED box, the LED's turned off. I therefore recognized the short circuit happened in filter circuits. I switched the components of the filter circuits to a new breadboard and the Garage Band Lightshow began to work again. Figure 33 in Appendix C (page 49) shows the Garage Band Light show functioning.

My future plans for the Garage Band Lightshow involve the addition of features. Adding potentiometers in place of the filter resistors provides adjustable frequency bands. This allows for customization of frequency bands which means customization of the flashing light response. Replacing the wiring from the filters to the LED boxes with a wireless system would allow for unrestricted placement of the LED boxes.

Chapter VIII: References

[1] http://www.stagelightingstore.com/Chauvet-COLORado-3P-IP?sc=25&category=809514, Chauvet COLORado 3P IP.

-Similar product that shows pricing comparisons for one unit that the Garage Band Lightshow comes with

[2] http://www.stagelightingstore.com/American-DJ-LED-UV-Go?sc=25&category=825214, American DJ LED UV Go.

-Similar product that shows pricing comparisons for another unit that the Garage Band Lightshow comes with

[3] Chauvet, http://www.musiciansfriend.com/pro-audio/chauvet-4bar-led-system, 4-bar LED system.

-leading sight for musicians to purchase most musical needs at warehouse prices.

[4] http://www.stagelightingstore.com/Shop-By-Brand/MBT-Sound-Responsive-Effect-Lighting/MBT-LED-Color-Mixing-Flat-Screen, LED mixed color light-board.

-Similar product that shows pricing comparisons for one unit that the Garage Band Lightshow comes with

[5] C. Crane Company, "Sound Frequency Response," 2013, http://www.centerpointaudio.com/HowToUnderstandSoundFrequencyResponseGraph.aspx

-Article describing different frequency EQ bandwidths, article comes from a company that sells audio equipment and should have a reliable understanding of frequency ranges. Also this information matched up with similar information found on multiple forums.

[6] R. Ford and C. Coulston, Design for Electrical and Computer Engineers, McGraw-Hill, 2007, p. 37

-Helps with the process of design for engineers and gives guidelines and steps on the design process.
-Both authors have Ph.D.'s, one in electrical engineering and one in computer science and engineering. Both authors have industry experience in design working for IBM

[7] IEEE Std 1233, 1998 Edition, p. 4 (10/36), DOI: 10.1109/IEEESTD.1998.88826

-Standards that electrical engineers follow

-A standard put in place by the IEEE

[8] American Opto Plus LED, “8mm LED Lamp-Green Diffused Lens,” American Opto Plus LED, datasheet L-813GD.

-This type of LED or a similar one provides one option of output for the system.
-American Opto Plus LED is a leading LED manufacturer that has existed for 30 years and still manufactures them, first company to release the award winning Phosphor-free white LED.

[9] R.C. Mills, D.D. McCabe, “Analog LED Controller,” U.S. Patent 8362705, 2013.

-Patent for an analog LED controller that has multiple ways of controlling LED’s including audio.
-Cites 19 different references, references include U.S. Patents dating from the 1970’s to 2011.

[10] P. Ahgren, “Acoustic Echo Cancellation and Doubletalk Detection Using Estimated Loudspeaker Impulse Responses,” *IEEE Transactions on Speech and Audio Processing,* vol. 13, no. 6, pp. 1231-1237, Nov. 2005.

-Echo and doubletalk in a live performance setting could give undesired results to the output due to extra noise picked up on the input from the output sound.
-References consist mostly of other IEEE Transactions on journal articles, and also contain a reference from Bell Systems and a few from publisher Prentice-Hall.

[11] D. Susan, “Analog Filters Using Simulated Inductor,” Presented at the *Mechanical and Electrical Technology (ICMET), 2010 2nd International Conference on,* S. Jayalalitha, Sept. 2010.

-Possible approach taken when designing filters to use simulated inductors.
-References include many published textbooks as well as an IEEE journal of solid state electronics article.

[12] Wing Yan Leung, “A high-power-LED driver with power-efficient LED-current sensing circuit,” Presented at the *Solid-State Circuits Conference, 2008. ESSCIRC 2008. 34th European*, Tsz Yin Man, Mansun Chan, Sept. 2008.

-I plan to use a large amount of high powered LED’s and need to drive all of them to give max output lighting power.
-References a number of well known manufacturer datasheets from Texas instruments, Maxim, and National Semiconductor.

[13] Yu-Sheng Chan, “Study and implementation of high frequency pulse LED driver with self-oscillating circuit,” Presented at the *Circuits and Systems (ISCAS), 2011 IEEE International Symposium on,* Tsong Juu Liang, Kai-Hui Chen, and Jer-Nan Juang, May 2011.

-Talks about LEDs driven in this case specifically by a high frequency pulse, I plan to drive LEDs using multiple frequency ranges.

-Has 10 references which include IEEE journals, IEEE transactions on, U.S. Patents, and datasheets

[14] P. K. Dhar, "Design and Implementation of digital filters for audio signal processing," Presented at the *Strategic Technologies, 2008. IFOST 2008. Third International Forum on,* Hee-Sung Jun, Jong-Myon Kim, June 2008.

-another approach to implementing filters in the Garage Band Lightshow might involve digital filters.
-References a few second edition books

[15] Don Lancaster, "Psychedelia 1: Color Organs Designed for the 70's Opens New Vistas in Display of Sound," *Popular Electronics Magazine*, vol. 31, no. 3, pp. 29-44, Sept. 1969.

-Comparison of music visualize circuits designed and used in the 1970's to what I am designing with modern technology.
-A magazine published for almost 50 years and held the title of the World's Largest Selling Electronics Magazine.

[16] Sergio Franco, "Design With Operational Amplifiers and Analog Integrated Circuits," 3rd ed. New York, NY, McGraw Hill, 2002.

-Contains design information on synthetic inductors, audio filters, and amplifiers.
-15 different editors, Author is author of multiple textbooks, Author has extensive industrial experience and has worked and published in areas of electronic music, IC design, and consumer electronics.

[17] Dittke, Susanne, "The Health and Environmental Impacts of e-Waste," http://inece.org/ewaste/01_dittke.pdf

-Chemical Engineer and Environmental Consultant presentation.

[18] National Semiconductor, "LM386 Low Voltage Audio Power Amplifier," Texas Instruments, August 2000, datasheet SNAS545A.

-Datasheet for LM386 amplifier

[19] Texas Instruments, "TL082 JFET-input Operational Amplifier," Texas Instruments, September 2004, datasheet SLOS081G.

[20] Fairchild Semiconductor, "TIP31 NPN Epitaxial Silicon Transistor," Fairchild Semiconductor, July 2008, datasheet TIP31.

[21] Fairchild Semiconductor, "LM78XX/LM78XXA 3-Terminal 1 A Positive Voltage Regulator," Fairchild Semiconductor, August 2013, datasheet LM7812.

[22] Fairchild Semiconductor, “KA79XX/KA79XXA/LM79XX 3-Terminal 1 A Negative Voltage Regulator,” Fairchild Semiconductor, August 2013, datasheet LM7912.

[23] Texas Instruments, “LM237, LM337 3-Terminal Adjustable Regulators,” Texas Instruments, November 1981, Revised November 2007, datasheet LM337.

[24] Lighthouse LEDs, http://lighthouseleds.com/10mm-led-uv-purple-ultra-bright-5-000-mcd.html, 10mm Round Top UV/Purple LED-Ultra Bright.

[25] Electron.com, http://www.electron.com/led-10mm-cool-white-1025pwc.html, LED 10mm Cool White – 1025PWC.

[26] Electron.com, http://www.electron.com/led-10mm-blue-105xb7d.html, LED 10mm Blue – 105XB7D.

[27] Electron.com, http://www.electron.com/led-10mm-green-105xg2d.html, LED 10mm Green – 105XG2D.

[28] Electron.com, http://www.electron.com/led-10mm-red-105mr2d.html, LED 10mm RED – 105MR2D.

[29] Electron.com, http://www.electron.com/led-10mm-yellow-amber-105my8d.html, LED 10mm Yellow (Amber) – 105MY8D.

[30] Electron.com, http://www.electron.com/led-5mm-pink-530jpkc.html, LED 5mm Pink – 530JPKC.

[31] epilepsyfoundation.org, http://www.epilepsyfoundation.org/aboutepilepsy/seizures/photosensitivity/, Photosensitivity and Seizures.

Appendix A—Analysis of Senior Project Design

Project Title: Garage Band Lightshow

Students Name: Jason DeScenzo
Students Signature:

Advisor's Name: David Braun
Advisor's Initials:
Date:

1. **Summary of Functional Requirements**
   The Garage Band Lightshow system takes an audio input and produces a synchronized lighting output. The output provides a flashing and pulsing response of the lights that directly respond to the multiple frequency ranges of an audio signal. When a live mix is used as the audio input, the Garage Band Lightshow produces a custom lightshow for the band or artist playing the live mix. Refer to **Table 1** (page 3) for more information.

2. **Primary Constraints**
   The Garage Band Lightshow has cost as a big limiting factor. Its design requires affordability for musicians and my design approach and construction ideas for the product become heavily affected by the cost constraint. Operating conditions of the Garage Band Lightshow become another limiting factor. Since start up musicians looking for an affordable way to provide a live music lightshow at their performance make up the consumer, the Garage Band Lightshow requires durability and ease of use. Because of these requirements the connections for input and output provide easy connection and disconnection, and the housing used requires rigidity made of a durable metal that can withstand being tossed around. My confidence in analog over digital electronics shaped the design of the Garage Band Lightshow. This shaped the design into a fully analog system.

3. **Economic**
   Economic impacts include human, financial, manufactured, and natural capital. The human capital for the Garage Band Lightshow is made up of the hours of work that I put in, in the design and construction of project. Because I provide the only direct human capital, all hours invested come from my free time which can lengthen the project. The financial capital provided by me comes from a job that I put human capital into. The amount of hours I put into work results in the amount of financial capital I receive to put toward the project. The manufactured capital comes from the companies that provide circuit components and other parts necessary for the project in exchange for financial capital. The required financial capital for the manufactured capital impacts the results of the manufactured capital greatly since factors considered when choosing the manufactured capital consist of good quality and low cost. The natural capital impact for the Garage Band Lightshow is small because of the abundance of silicon, and the amount of other components used is minimal when compared to the consumption of these similar natural resources in other applications.
   The costs for this project start to accrue at the beginning of EE 460. I invested human capital in the project planning process and it continues to accrue as financial, manufactured, and natural capital become invested at the design and build stages of the project.

The benefits of the project do not appear until completed and the project made into a manufactured product.
The inputs required for the project consists of hours of time to design, build, and test, as well as money to purchase all the parts required. I payed for the project and its total cost comes to about $241.
Products emerge once manufactured and exists for at least a year or more before upgraded versions become available. Maintenance costs only require the possible need for new cables for input, output, and power connections. Operations cost would include the amount of kW/hr used and the price per kW/hr.
The original estimated development time came to about 11 months.
After the project ends the final product testing consists of use by a band in a live setting, and its subsequent response determines the future of the product.
Refer to **Appendix-B** for more information on cost estimates and time allocation.

4. If Manufactured on a Commercial basis

If advertised well, 250 units will be sold per year. The estimated manufacturing cost not including the design costs comes to $250. With the estimated purchase price at around $350 the profit per year comes to about $25,000. I have not yet determined the power consumption, but cost for operation of unit by user would depend on the amount of time used and if used in a place where the user pays for electricity.

5. Environmental

The environmental impact of the Garage Band Lightshow involves the power consumption, component parts, and the length of use. Since the Garage Band Lightshow draws its power from the power grid, no personal batteries get used to power it, and thus, no batteries due to this product become waste thrown away into the environment. When discarded, electrical components cause large amounts of pollution in ground water, and, for this reason, the Garage Band Lightshow design leaves room for upgrades rather than entire system replacement. Natural resources my project uses include silicon and copper for component parts and aluminum for the housing. Indirectly, it uses natural fuels burned to create the energy at the power plants that it uses when plugged into a wall socket. If the system gets thrown away instead of recycled the metals in the components could harm whatever ecosystems they get dumped into, especially near water. Improper recycling techniques such as burning e-waste can also make the problem worse by releasing the toxic metals into the ecosystem [16]. While the project does not directly impact another species, unless they like to attend concerts, indirectly a trashed system dumped into an ecosystem can pollute it, and affect whatever species lives there in a negative way.

6. Manufacturability

If the Garage Band Lightshow becomes a manufactured product, it would make it easier in a number of aspects. The circuits used to get the desired response could be manufactured onto PCB's or, possibly, even into specific IC's and would take up less space. Also, all connecting cords could have color codes and attach in a way to make less output wiring. Purchasing components in bulk quantities would also lower the cost per component, which in turn, could lower the consumer price or boost the profit.

7. Sustainability

The maintenance of the Garage Band Lightshow would mostly consist of replacing connecting wiring. Cables, especially ones used in live audio applications, take a considerable amount of wear and tear in their everyday use. This wear and tear usually occurs on the inside of the cable insulation making it hard to find and repair. Because of this, at some point the Garage Band Lightshow may require replacement wiring. I designed an accessible housing so that if a failure occurs in a component on the inside, the user could possibly fix it if they possess some knowledge of circuits.

The project mostly consists of electrical components housed in an aluminum box. This project should be mostly recyclable if brought to a legitimate recycling place and broken down into parts.

Upgrades that could improve the project include adding more output connections to provide more lighting effects. This would prove fairly easy and most likely use an extra purchased attachment to the output that would provide extra output slots. Another upgrade entails getting the system to respond to specific instruments instead of frequency. This would possibly require a complete redesign and might not apply to an upgrade of the existing product.

8. Ethical

IEEE Code of ethics:

The main goal of the project is to provide a working product at a low cost. When manufactured and sold, it will be for a reasonable price that reflects the work and cost put into it. The product design provides the safest possible product with all connections made with strong wires, and clean connections to prevent electric shock. The misuse of this product to induce seizures in people with epilepsy is an example of one way this product can be used unethically. In the correct use at a concert setting with one's own music being used it does not seem to produce anything unethical about the product use. All specifications such as power consumption, voltage, and amperage are disclosed so that all information about the product becomes available to the consumer.

Utilitarianism:

Utilitarianism or providing the greatest good for the greatest number of people applies to the Garage Band Lightshow. Because of the great diversity amongst the consumers of this product, it becomes necessary to provide the greatest good for the greatest number. The community and location of the consumers determines the need for the product. If the consumers have many nearby venues with stage lighting, they may reconsider the need for such a system. The low cost of the item might draw them to make the purchase anyway, which also applies to the many economic backgrounds of the consumers. The low cost provides an alternative to more expensive products for the consumers with less money. Also, the skill level of the consumer as well as their position in the music community determines the consumers' overall need for the system. The low cost and feature of direct visual response from audio, provides the system with the ability to appeal and work for all the people in these range of backgrounds. Therefore, the Garage Band Lightshow applies to the greatest good for the greatest number of people.

9. Health and Safety

The design of this system for safety purposes focuses mainly on heat dissipation. The biggest concern for a product that uses a number of lights is the large amount of power consumption and heat which could, if designed poorly, start a fire. In the manufacturing process the inhalation of solder fumes could pose a health risk, and working with 120 V AC power from a wall socket always possesses the risk of electric shock.

The completed product poses another risk involving the purple/UV LED's. Since the Garage Band Lightshow is designed to use in a low light setting, the dark atmosphere causes viewers pupils to dilate. This admits more light into the eyes, which becomes a risk with UV lights involved. UV light is known to damage the eyes with prolonged exposure, and with more of it absorbed through the dilated pupils it poses a health risk to viewers. Since the amount of UV light used in the Garage Band Lightshow is significantly less than the amount used in similar night club settings, the risk becomes minimal, but still worth mentioning.

The flashing and pulsing lights of the Garage Band Light show also pose the risk of inducing seizures in people afflicted by photosensitive epilepsy [31]. The light patterns that trigger photosensitive seizures are not specifically known, and the random patterns that the Garage Band Light produces might pose a risk.

10. Social and Political

Products similar to this one get manufactured every day. Because of this, the Garage Band Lightshow has an effect on any manufacturer or company that produces a similar product. The biggest impact would be competition in the market. It would create competition for similar manufacturers and cause them to seek designs targeted towards a similar consumer. The direct stakeholders consist of the component manufacturers and the consumers. The component manufacturers get affected by the amount of components purchased from them, and the consumer is affected by the creation and availability of the product. Indirectly, it affects competing companies in the audio and lighting business. It benefits component manufacturers by providing them with business and it benefits the consumers by providing them with an inexpensive alternative to provide stage lighting. It can either benefit or harm similar product manufacturers by providing them with competition, which could put them out of business or provide the drive to create another possibly better alternative product. Another stakeholder either directly or indirectly consists of the venues that offer live music. If the venue has performers that own the Garage Band Lightshow then their own stage lighting could become unnecessary, or the venues could purchase the Garage Band lightshow as an alternative to the more expensive stage lighting products. The consumer as a stakeholder varies greatly in community, location, economic power and skills. For this reason, the Garage Band Lightshow's design provides a system that produces the least amount of inequities amongst the diverse group of consumers.

11. Development

In earlier electrical engineering classes, we analyze basic passive analog filters, but further forms and techniques do not get introduced till later on. In this project, I analyze and develop more advanced active filters for the system. Also, I explore the circuitry that controls the lights and makes them respond to the multiple frequencies, another subject that has not yet been touched on. I performed a literature search that also helped in development. See Chapter 8 for references.

Appendix B—Cost estimate and Gantt chart

Table 9: Initial Cost estimates for Garage Band Lightshow

Garage Band Lightshow Cost Estimate			
Parts Costs			
	LED's	$43	Using equation(6) the average LED cost came out to $.86 (want about 50)
	Can Lights	$20	average cost about $5 (want 3-4 of them)
	Wiring	$33	Using equation(6) the average cost for 100ft of speaker wire was about $33
	Input/Output Jacks	$35	3 different types of input jacks and 3 output jacks in the range of $5-6
	Power Cords	$20	estimated 4 power cords need, 1 for circuit box and 1 for each light box
	Circuit Components	$55	resistors/transistors/capacitors/amplifiers etc.(just estimated don't know exact number of components yet
	Housing	$35	Sheet metal boxes/wooden boxes estimated prices
Labor Costs $25/hr			
	Design Hours	25+ per design stage	Estimated 3 design stages at $1875
	Build Hours	15+ for first build 10+ for 2nd and 3rd	Estimated 3 build stages at $875
	Test Hours	15+ per test stage	Estimated 3 test stages at $1125
Total Cost			
	$4,116		

Cost=(CostLow+(4*CostMid)+CostHigh)/6

Equation(6) from Ford and Coulston's Design for Electrical and Computer Engineers [1]

Table 10: Final Costs for Garage Band Lightshow

Part Costs		One Box	Two Boxes
LED's		$15.84	$31.68
Wiring		$4	$7
Input/Output Jacks		$39.40	$75.30
Circuit Components		$61.36	$67.26
Housing		$22	$34
Shipping		$20.00	$20.00
Labor Costs $25/hour			
Design hours	35+ for 1st, 30+ for 2nd, 20+ for 3rd	$2,125.00	$2,125
Build Stage	10+ for 1st, 10+ for 2nd, 15+ for 3rd	$875.00	$1,000
Test Stage	20+ for 1st, 20+ for 2nd, 10+ for 3rd	$1,250.00	$1,250
Total Cost		$4,412.60	$4,610.24

The final cost for the Garage Band Lightshow exceeded the initial cost estimates made at the beginning of the project by about 500 dollars. This final cost does not include the original can light box included in the initial cost estimates. Adding can lights to the final project would increase the final cost by about another 161 dollars. I expected an increase in cost from the initial cost estimates because I made the initial estimates before I produced any designs. Unforeseen problems occurred that I did not account for in the Labor Cost estimates, and I also did not include shipping costs. If the Garage Band Lightshow became a manufactured product, the time and cost for assembly would decrease significantly. Also ordering circuit components, LED's, input/output jacks, and wiring in excess of 1000 units, for the assembly of many products, would greatly reduce the cost of each individual component included in the Garage Band Lightshow.

Figure 22: Garage Band Lightshow Gantt Chart

Figure 23: Re-assessed Gantt Chart

Figure 24: Final Gantt Chart

Appendix C – Project Pictures

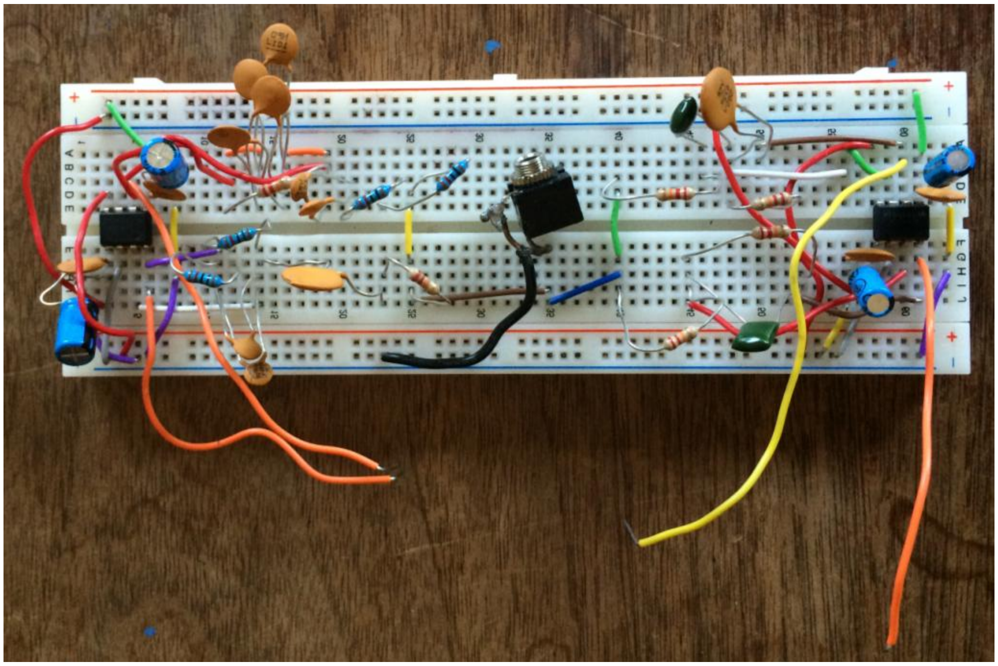


Figure 25: Circuit for the 4 filters on a breadboard

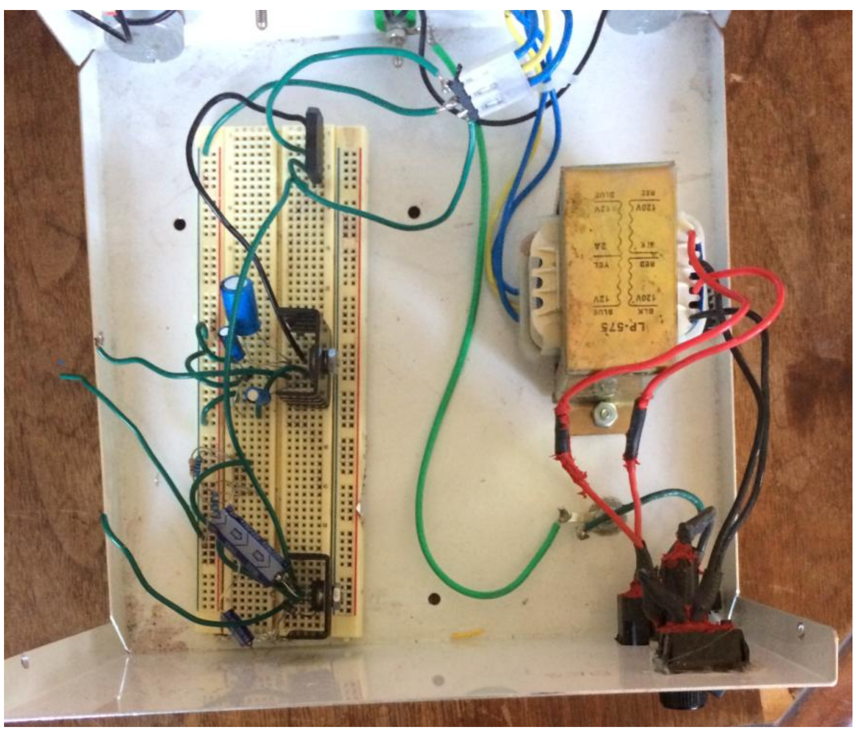


Figure 26: Transformer and Voltage regulator circuit

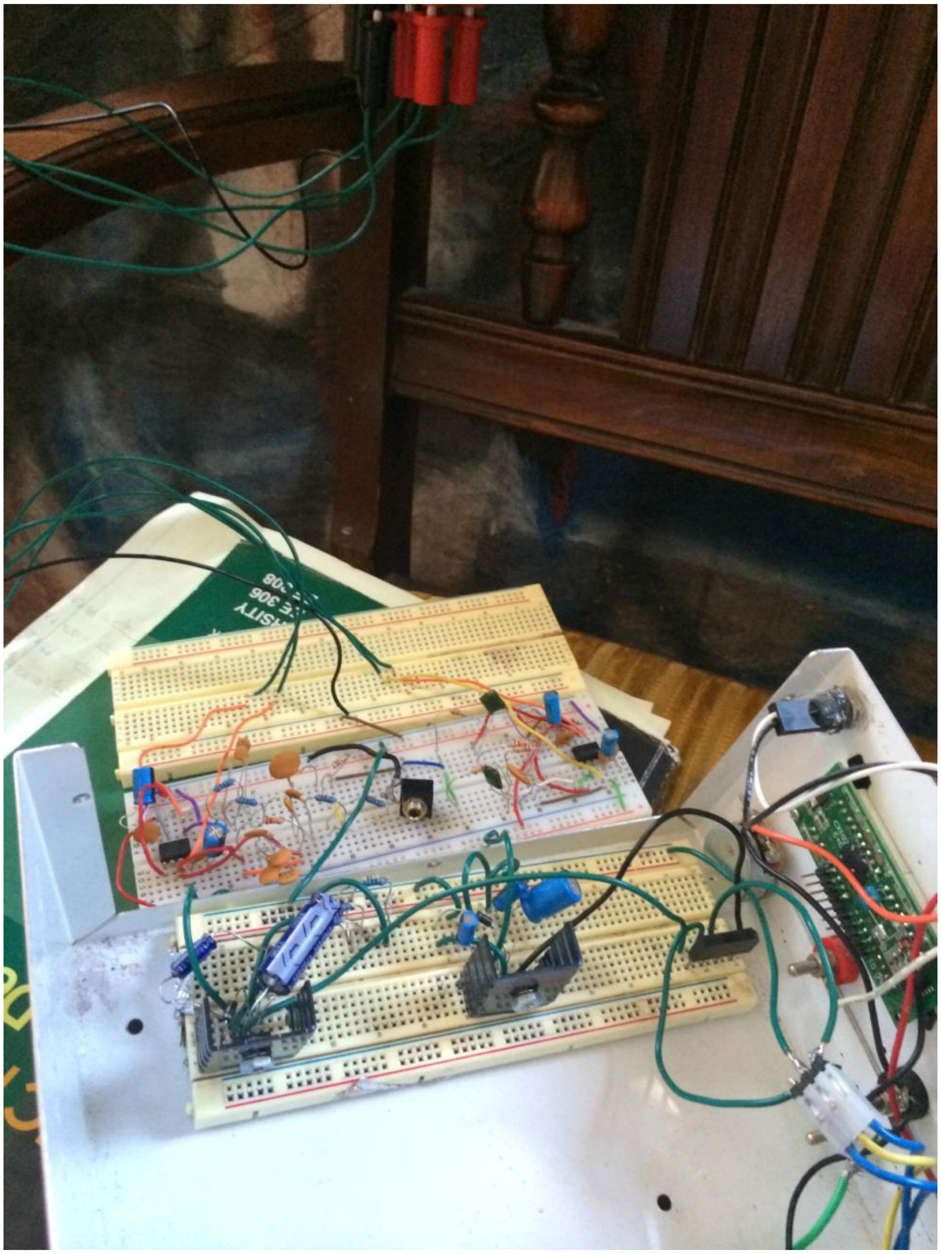


Figure 27: Voltage Regulator power Active Filters

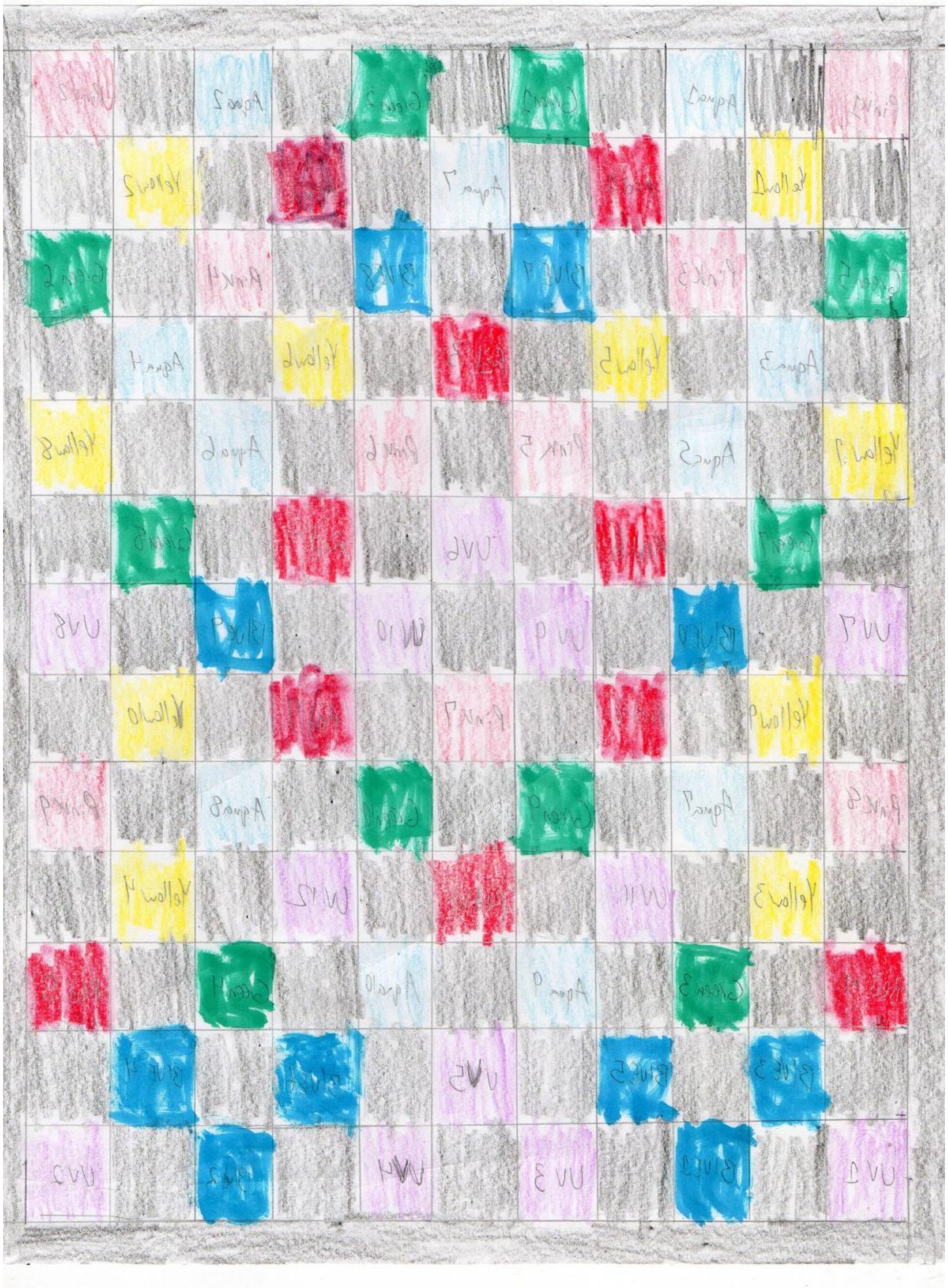


Figure 28: Original drawing/plan for LED layout

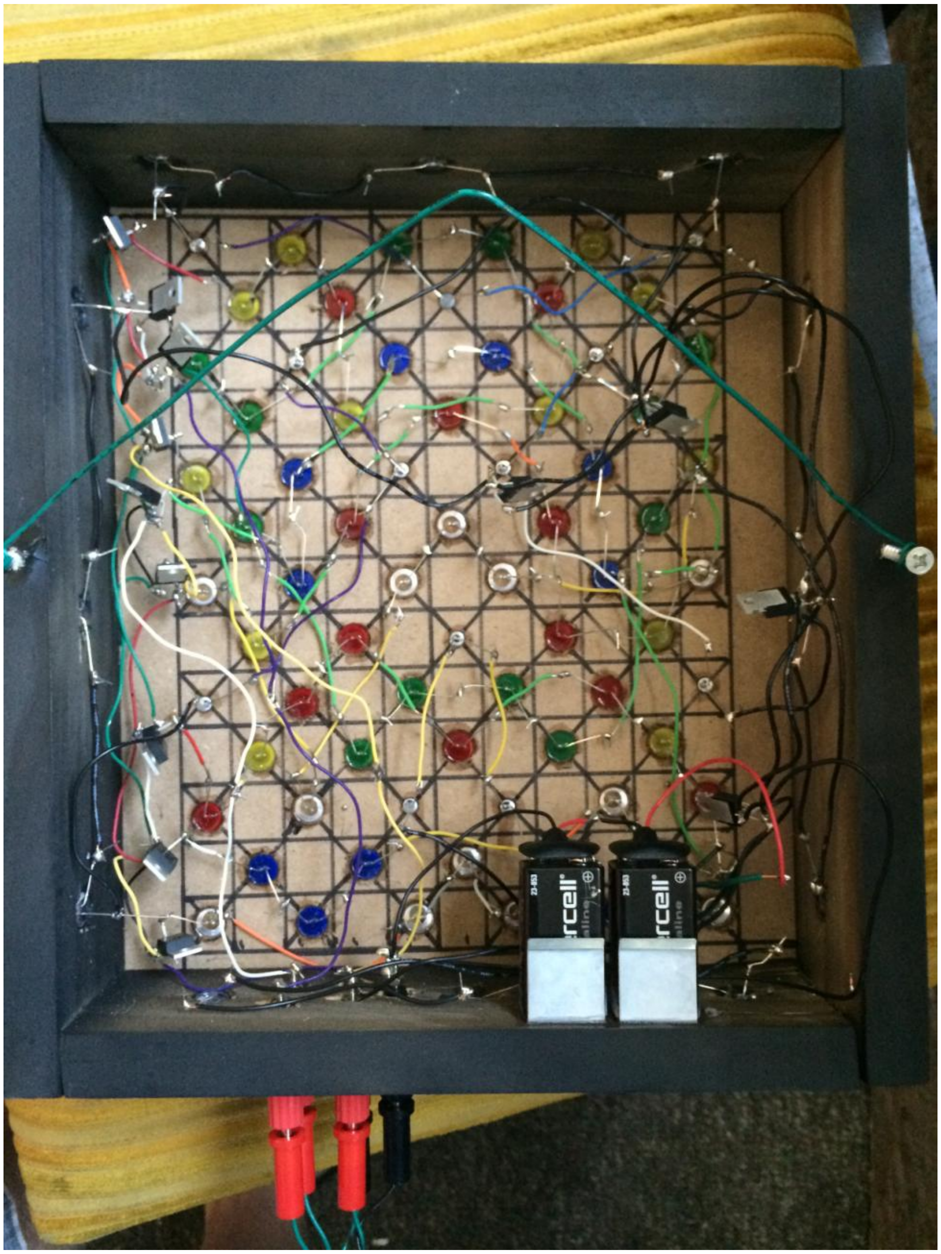


Figure 29: Back view of completed LED box

Figure 30: Front view of completed LED box

Figure 31: Side view of completed LED box

Figure 32: Bottom view of completed LED box, connecting wires from filter output

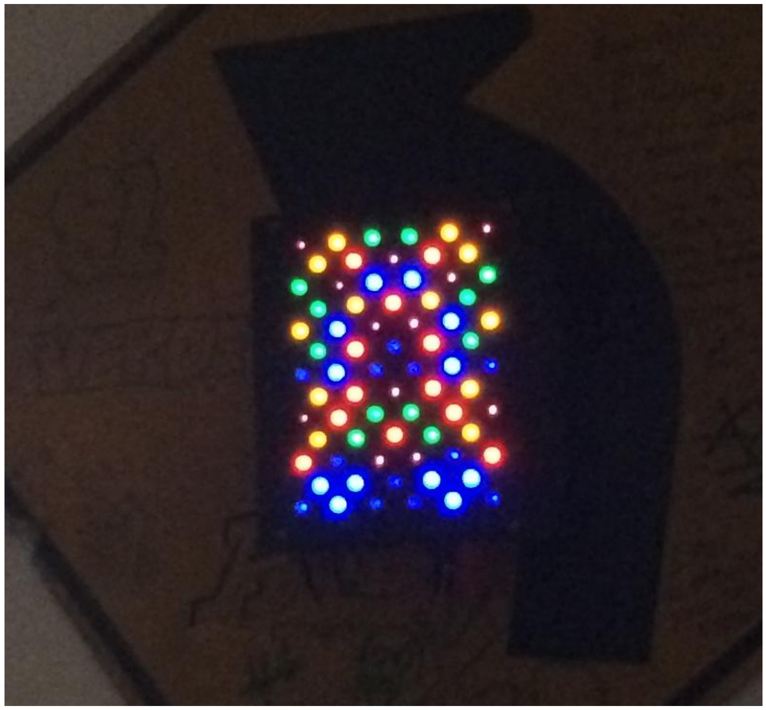


Figure 33: Functioning LED Box