Beam It (A Li-Fi Enabled System)

Group 8

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Summer 2019

Project Summary

With the exponentially increasing data demand but limited available radio spectrum, alternatives will be necessary to accommodate the needs of wire-free communication systems. Visible light communication is a technology that can be used to accommodate the need for faster and better wireless communications in the coming years. The basic idea is that instead of using traditional methods of communication over cables or radio frequencies, VLC systems send data by turning light on (logic 1) and off (logic 0).

As visible light communication technology is relatively new, our team will be working on creating a prototype to test out this technology and demonstrate its possible capabilities. We will be using Two MSP430S (in which one will act as a transmitter and the other as a receiver), one HC-05 bluetooth module ,one TXINLEI 250mW laser module, and one WINGONEER photoresistor. We will use these main components and design a printed circuit board to connect the system on a sleek design. These components and modules will allow us to create a fully functioning visual light communication (VLC) system to transmit properly.

The transmitter will have a Bluetooth module and connect to a phone that will allow the user to choose the data they wish to send through VLC. The second microcontroller will have the photoresistor that will be responsible for reading the visual light data which the microcontroller will then decode and perform a task. Lastly, we will begin preparing a file of string of bytes for data transmission.

Table of Contents

List of Figures

List of Tables

1 INTRODUCTION

1.1 Background

Visible Light Communications is essentially communication by means of optical light. It falls under the category of free-space optical communications. Transmitting data via light is achieved by having the light source flicker on and off to represent a logic high and logic low signal respectively [9]. A receiver will detect the light coming from the transmitter and will interpret the signal. When the receiver detects light, it is represented as a logic high and when it detects no light at all from the transmitter, it is represented as a logic low. By turning the light on and off, the transmitter can transmit 0s and 1s. This is the simplest method that visual light can be used for digital communication[9].

With VLC technology improving and becoming more prominent in the world, Li-Fi, a subset of VLC is becoming more of a reality. Li-Fi is built upon VLC and is a high-speed bidirectional wireless network similar to Wi-Fi. This is achieved by having a transmitter and receiver built in each device where it transmits light and receives incoming light from another device. However, most VLC systems today are unidirectional. As time progresses, more bidirectional VLC systems will emerge[9].

In 2003, a team at the Nakagawa Laboratory located at Keio University in Japan used LEDs to transmit data via visible light [8]. This is the first account of transmitting digital information via LEDs. In 2010, a collaboration between researchers from Siemens and from Heinrich Hertz Institute in Berlin were able to transmit at a speed of 500 Mbit/s over a distance of 5 meters and transfer at 100 Mbit/s over an even longer distance with 5 white LEDs manufactured by Ostar [10].

In July 2011, at TED Global, there was a demonstration of the D-light project, a VLC project led by Harald Haas, a professor at the University of Edinburgh [11]. The demonstration showed a HD video being transmitted from a standard LED lamp. The data rate of the VLC system was approximately 10 Mbps which is roughly the data rate of a DVD playing back [12], [13]. As time passes by, VLC is expected to grow immensely and is expected to be a possible method of providing the Internet of Things.

1.2 Problem Description & Significance

Today, there is an increasing demand for a faster and more secure wireless communication. There is a pressing need for a new medium of wireless communication as the radio spectrum is already crowded. Visible light is a medium that can address both of these needs. Visible Light Communications (or Li-Fi) is a relatively new technology that we will be exploring in Beam It (VLC). Li-Fi is a new type of wireless communication that uses LED lights to transmit data wirelessly.

Transmission of data is one of the most important day-to-day activities we have today. The current wireless networks that connect us to the Internet can become slow when multiple devices are connected. As users increase the number of devices which access the Internet, the availability of fixed bandwidth makes it much more difficult to enjoy high data transfer rates and to connect a secure network.

The spectrum used for Radio Frequency (RF) is not only costly but also has a limitation in bandwidth. As a result, Radio Frequency cannot support the growth in demand for high data rates and the large numbers of communication systems. Figure 1 shown below illustrates the frequency allocations of the radio spectrum in the United States.

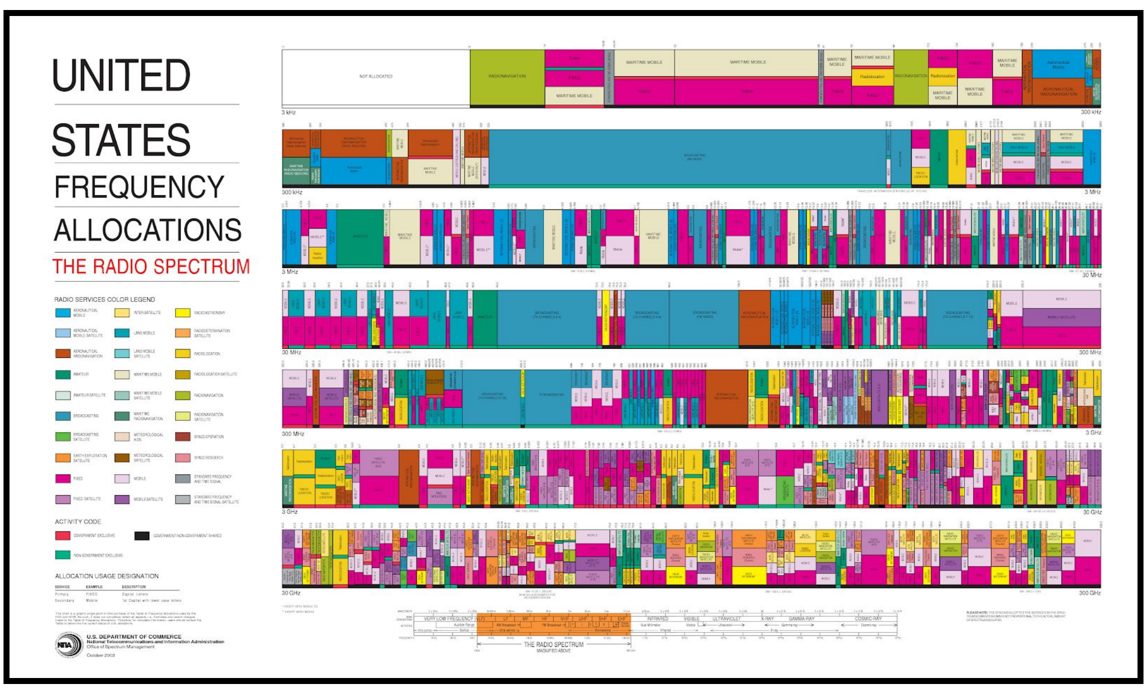


Figure 1: US Frequency Allocations

Source:https://upload.wikimedia.org/wikipedia/commons/6/65/United_States_Frequency_Allocations_Chart_2003_-_The_Radio_Spectrum.png

2.1 Overview of the Solution

Li-Fi has got a much broader spectrum for transmission compared to conventional methods of wireless communications that rely on radio waves. Li-Fi known as Light Fidelity is a bidirectional and wireless mode of communication using light. It uses the unused visible spectrum and reduces the load on radio spectrum. Instead of using modems, Li-Fi uses LED bulbs with a transceiver. Data transmission in Li-Fi is expected to be about 100 times faster than Wi-Fi. In our project, "Beam It (VLC)" will explore the need for Li-Fi and its applications.

2.2 Goals and Objectives

Our objective is to design and implement a laser transmitter that can connect to a phone via Bluetooth to program the text data to be sent. This data can then be sent through a laser beam to a receiver, using visual light communication. This will allow the user to have a secure way to communicate with devices without having to sync or pair a connection like other wireless communicators. The user simply points the laser, and their message is relayed to the receiver(s). Our goal is to have a fully functioning system by the end of the summer.

2.3 Literature & Market Research

To build our system platform, we began by evaluating existing patents and solutions; below is a set of two patents our team reviewed.

Researcher: Giannina Duran
Title: LIFI COMMUNICATION SYSTEM
Patent Number: US 2016/0218807 A1
Inventor: Bao Tran, Saratoga, CA (US)
Held by: Bao Tran, Saratoga, CA (US)
Date Granted: Jul. 28, 2016

Summary: "A communication system includes a light source to generate light; a broadband light transmitter control electronics to modulate a light signal and provide broadband optical data transmission network using the light source; a broadband light receiver control electronics to demodulate a received light signal from the broadband optical data transmission network; and a wired network transceiver coupled to the light (63) Continuation of application No. 13/845,056, filed on transmitter/receiver to receive and transmit data between the Mar. 17, 2013, now Pat. No. 9,310,064. optical data transmission network and a wired circuit.[2]"

Researcher: Josh Sohan
Title: VISIBLE LIGHT COMMUNICATION TRANSMITTER AND VISIBLE LIGHT COMMUNICATION SYSTEM
Patent Number: US 8,526,825 B2
Inventor: Masashi Yamada, Tokyo (JP): Kousuke Nakamura, Tokyo (JP)
Held by: Taiyo Yuden Co., Ltd., Tokyo (JP)
Date Granted: Sep. 3, 2013

Summary: “Visible light data communication with a sufficient transmission speed is performed using a general-purpose and cost advantageous blue-light-excitation-type white LED without using a blue color filter while preventing the element from being damaged. When transmission data is inputted to a driving waveform generation unit (110) in a transmitter (100), the driving waveform generation unit (110) and a multi-grayscale driving unit (120) generate a multi-grayScale driving signal, which is Supplied to the blue-light-excitation-type white LED (140) and allows the blue-light-excitation-type white LED (140) to emit light. A light signal outputted from the blue-light-excitation-type white LED (140) is collected by a lens or the like, is made incident into a PD (210) in a receiver (200), and is converted to a current signal. The current signal is converted into a Voltage signal in a transimpedance amplifier (212). Further, the light signal is subjected to equalization processing in an equalizer (214) and then is digitized by a limiting amplifier (216), thereby obtaining output data.[1]”

2.4 Alternative Solutions

Infrared Wireless (IrDA)

IrDA was introduced in the early 1990s and is still in use today by some companies. It supports the transfer of data from laptops and personal digital assistants (PDAs) to printers as well as other short-range PANs [14].

Induction Wireless

It transmits data by way of magnetic induction, which is one of two fields that comprise a radio signal. Electric is the other field. It relies on a coiled transmitter that delivers the magnetic induction signal that is then picked up by another device. The technology was developed and patented by Aura Communications [14].

2.5 Evaluation

Infrared Wireless (IrDA)

While it does seem like a great because it is tried and tested as far back as the 1990’s. However, it has limitations on the speed of data it can transfer and can only reach up to 10 FT.

Induction Wireless

Similarly to IrDA, this method of communication also has a small range of communication. It also has the possibility of interfering with sensitive equipment because it is fluctuation and manipulation magnetic fields.

2.6 Decision

We have come to the conclusion that Visual Light Communication(VLC) is the best method to solve our problem. Compared to the alternatives, it requires a lower cost, has a further range, and faster speeds. Because this technology does require line-of-sight to transmit data, it is extremely secure. Where the other methods such as Bluetooth and WiFi can be accessed from out of the room, VLC keeps data contained to a room. This can be great for moving sensitive data.

3 PLAN OF IMPLEMENTATION

3.1 Project Requirements

Sending text, photos, videos or any data at a certain distance and speed by using visual light communication is our main objective. Based on our system diagram describing the tasks required to accomplish this project, we will need the following components :

- Two Mini Arduino Nano V3.0 ATmega328P Microcontroller Board
- Two Photoresistors (Photoresistor modules can also be used)
- Two Mini Laser Dot Diodes 650 nm 5V 5 mW
- One PAM8403 Digital Power Amplifier Board 23W Class D 2.5-5V USB Power
- One medium solar panel
- Two 10K potentiometers
- One 4x4 Matrix Array 16 Key Membrane Switch Keypad Keyboard for Arduino
- Sunfounder LCD1602 Module with 3.3V Backlight for Arduino
- LM358 Op-Amp
- Multiple Resistors (330Ohm, 3.3KOhm, 220 Ohm, 10KOhm)
- Speakers
- Wires (Male-to-Female)

We will also be using the following tools:

- Soldering station with solder & flux
- PCB Boards, breadboards ,veroboards
- Needle-nose pliers
- Multimeters
- Power supplies

3.2 Hardware Components

A. ARDUINO NANO

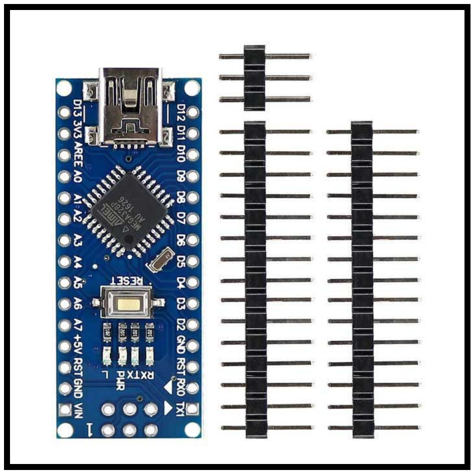


Figure 2: Mini Arduino Nano

“The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328P (Arduino Nano 3.x). It has more or less the same functionality of the Arduino Duemilanove, but in a different package. It lacks only a DC power jack, and works with a Mini-B USB cable instead of a standard one.”

Source: https://store.arduino.cc/usa/arduino-nano

B. LASER MODULE

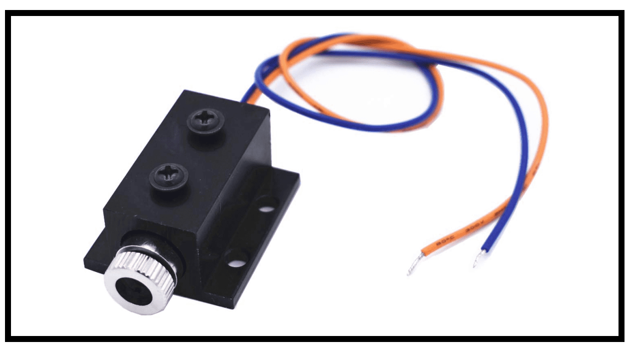


Figure 3: Laser Module

The image above is a laser module used as visible light output or optical output power. It needs between 3 to 5 VDC and a current of 20 mA to function properly. Its output power is in a range of 200 to 250 mw. It can reach at least 25 feet.

C. WINGONEER PHOTORESISTORS

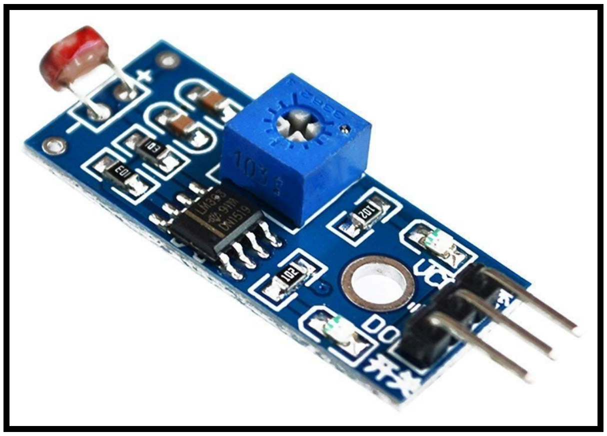


Figure 4: Photoresistor Module

The image above shows a photoresistor used for sensing the level of ambient light. To function properly, it needs a 150-volt DC and 100 mW power and a resistance of 0.5 M ohm. We can also use single photoresistors without the need of the module, but we will need a potentiometer that is able to control the resistance.

D. LCD SCREEN (1602)

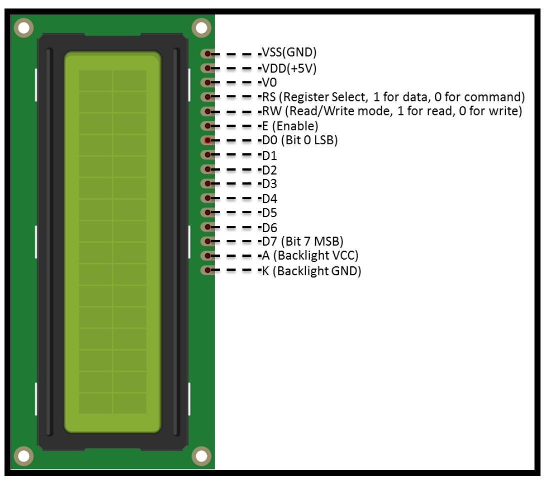


Figure 5: LCD Screen

The LCDs have a parallel interface, meaning that the microcontroller has to manipulate several interface pins at once to control the display. The interface consists of the following pins:

1. A register select (RS) pin that controls where in the LCD's memory you're writing data to. You can select either the data register, which holds what goes on the screen, or an instruction register, which is where the LCD's controller looks for instructions on what to do next.
2. A Read/Write (R/W) pin that selects reading mode or writing mode

3. An Enable pin that enables writing to the registers
4. 8 data pins (D0 -D7). The states of these pins (high or low) are the bits that you're writing to a register when you write, or the values you're reading when you read.
5. There is also a display contrast pin (Vo), power supply pins (+5V and Gnd) and LED Backlight (Bklt+ and BKlt-) pins that you can use to power the LCD, control the display contrast, and turn on and off the LED backlight, respectively.
6. The process of controlling the display involves putting the data that form the image of what you want to display into the data registers, then putting instructions in the instruction register. The LiquidCrystal Library simplifies this for you so you don't need to know the low-level instructions

Source: https://www.arduino.cc/en/Tutorial/HelloWorld

3.3 Software - Josh

We will be programming in language C++ for the two Arduino nanos. The transmitter will be responsible for getting the text data from the keypad and then display the values on LCD and serializing that data to pin 11. These 1s and 0s of the serialized data turns into high and low which will then turn on and off the laser light at the baud rate of 400. The receiver will then receive this binary data from the blinking light via the photoresistor. This data will then be converted back into text and displayed on the receiver.

3.4 Research & Functionality of Device

Based on certain factors, like accuracy of our components, our desire is to send data by using visual light communication. In the first transmitter, we will send audio data (analog). The second transmitter will send text data (digital). In both circuits, the transmitter will send the data to the receiver through the laser. The first transmitter will be connected to an aux cord (which is connected to a phone) and its corresponding receiver (which will have audio speakers connected) will play the audio tone out loud. The second transmitter will have an LCD screen as will its corresponding receiver. Both units will show simultaneously the data being sent and received. For this project, our goals will be the following:

- Send text at a distance of approximately 14 feet and at a baud rate of 400.
- Send audio at a distance of approximately 14 feet.
- Design two functioning PCB boards.

3.5 System Design

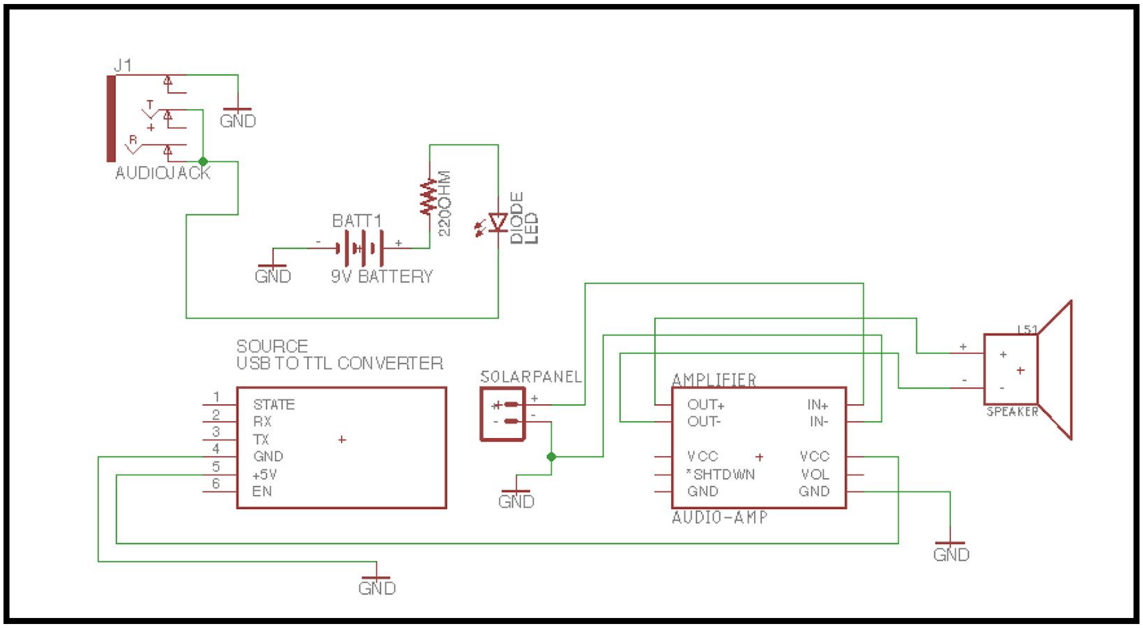


Figure 6: System Design of Beam It (Analog Transmitter & Receiver)

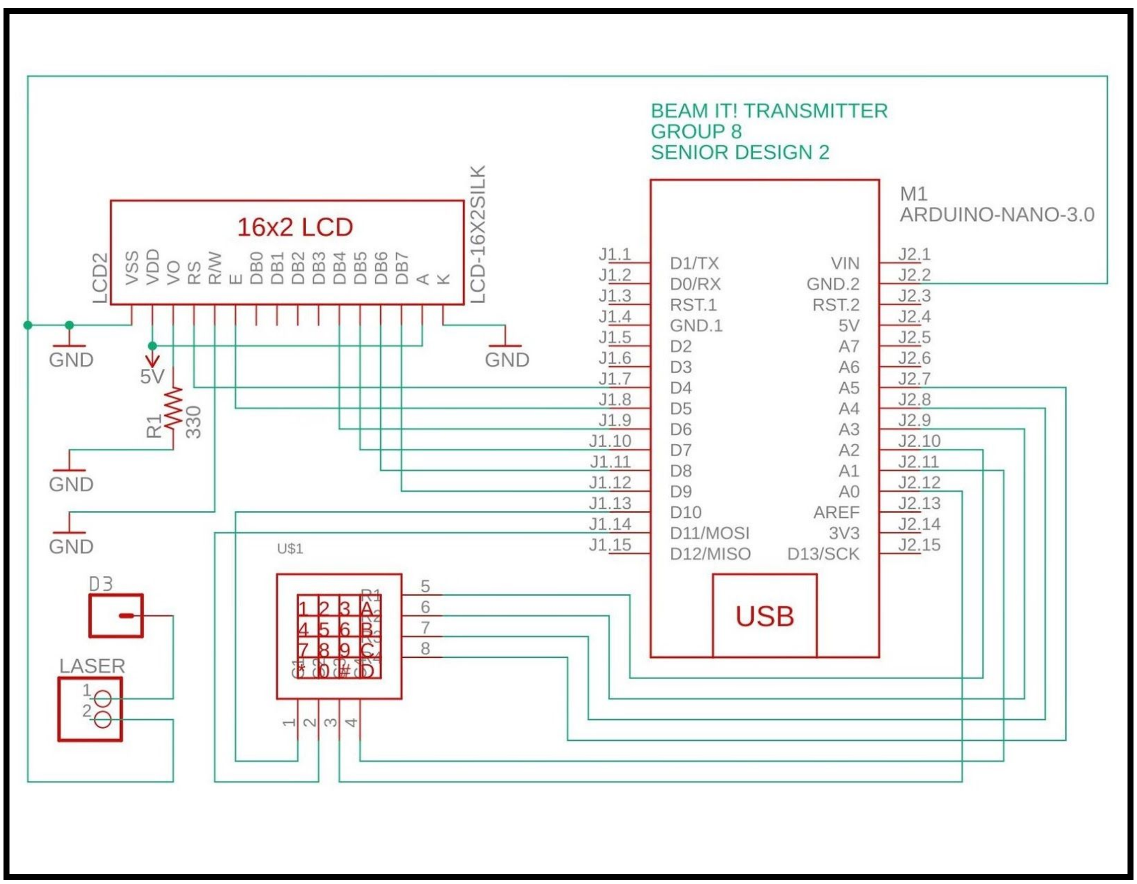


Figure 7: System Design of Beam It (Digital Transmitter)

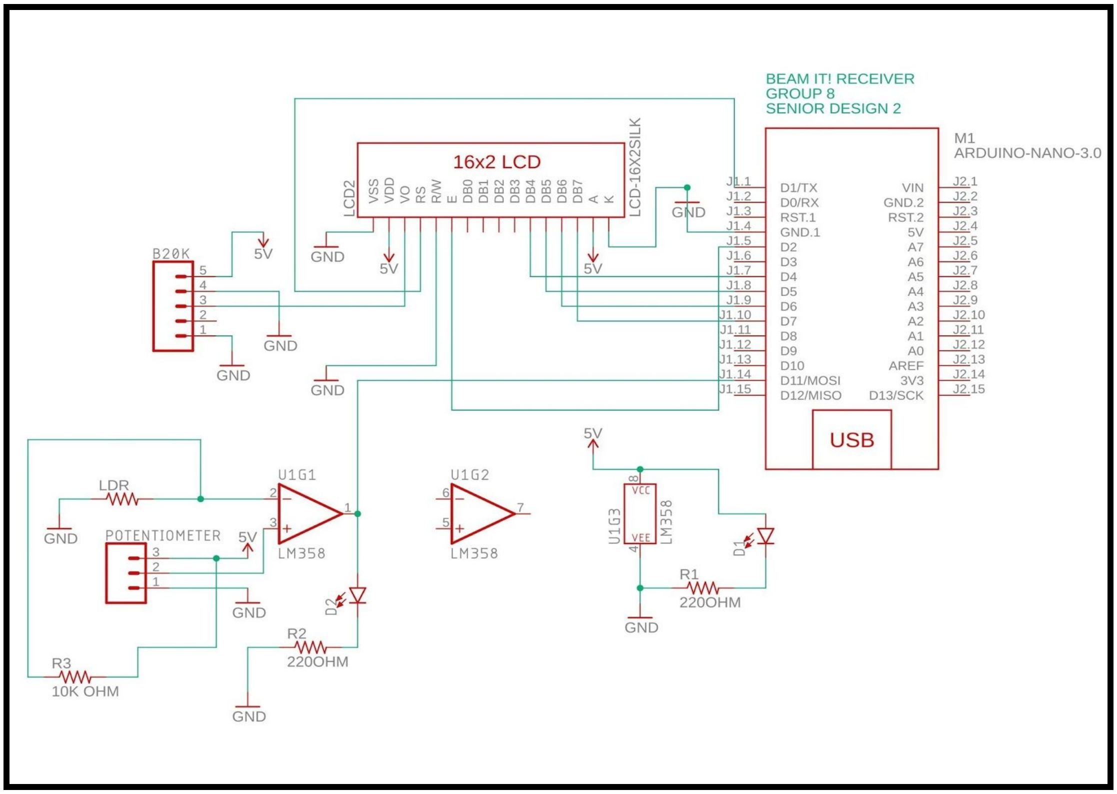


Figure 8: System Design of Beam It (Digital Receiver)

3.6 System Diagram

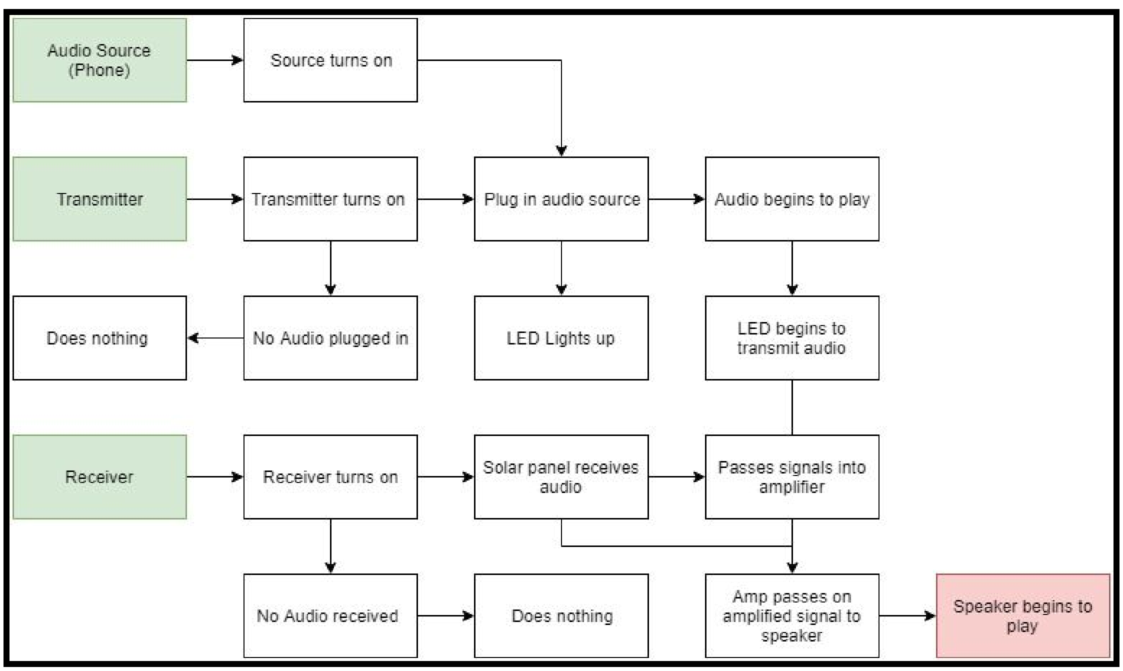


Figure 9: System Diagram of Beam It (Analog System)

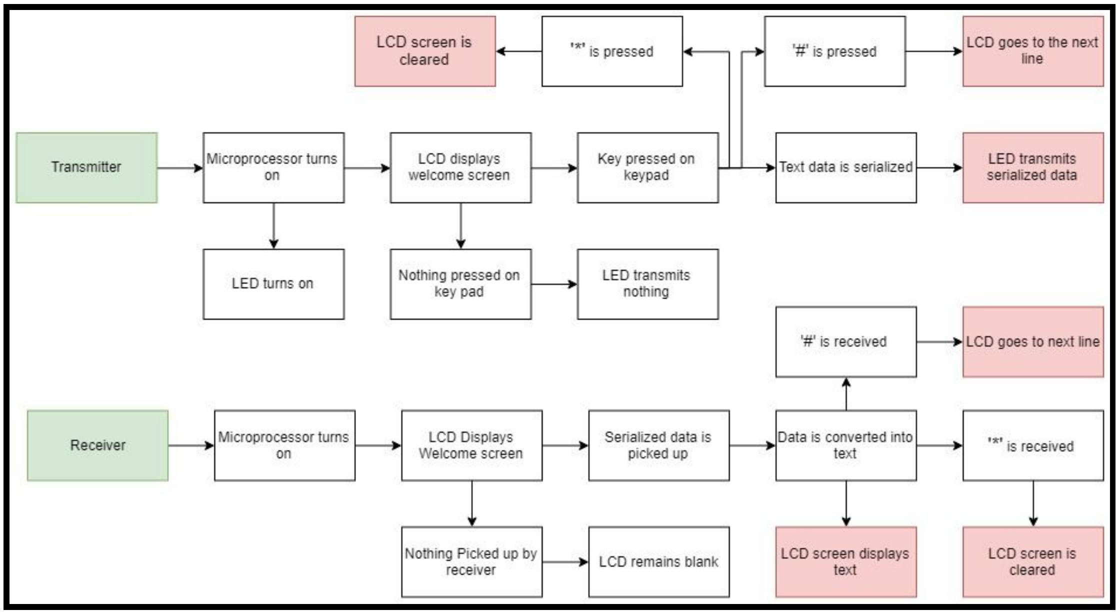


Figure 10: System Diagram of Beam It (Digital System)

3.7 How It Works & Deliverables

Using an aux cord and a power supply we will transmit audio data through a laser light module. We It will receive this data using a solar panel which will output the changes in light with the amount of voltage it produces. It will then amplify those signals using an audio amplifier and power supply. These amplifies signals will go to two speakers which will play the music.

For our second system we will be using an arduino nano to get text from a keypad and display it to the LCD. The possible values are 0-9 and A-D. The * symbol will clear the screen and the # will jump to the next line of the LCD. The text data will also be serialized and sent to the laser light. The receiver uses an arduino nano and an LCD screen capable of displaying the received values and the same functionalities as the transmitter LCD. For the receiver module we used a photoresistor, 10K potentiometer, a few resistors and LEDs, and an Op Amp. The potentiometer allows us to fine tune it so when light from the laser light hits the photoresistor, digital high is read from the receiver pin and when the light is off, digital low is read from the receiver pin.

As a result, this system should be able to transmit information over a range of 14 feet. Both fully functioning transmitters will work with the receivers to accomplish this.

4 IMPLEMENTATION DETAILS

4.1 System Specifications & Functionalities

Digital Specifications: Our approach was to use a microcontroller to serialize text data to be transmitted via laser module. To receive this data we used a module we designed our selves which consists of a photodiode, two 220K resistors, a 10k potentiometer, and and OP Amp.

Analog Specifications: Using a spliced aux cord connected to our phone we were able to send analog signals through our laser module and receive them using a solar panel an amplifier to play these signals through a speaker.

4.2 Overall System Design with Block Diagrams

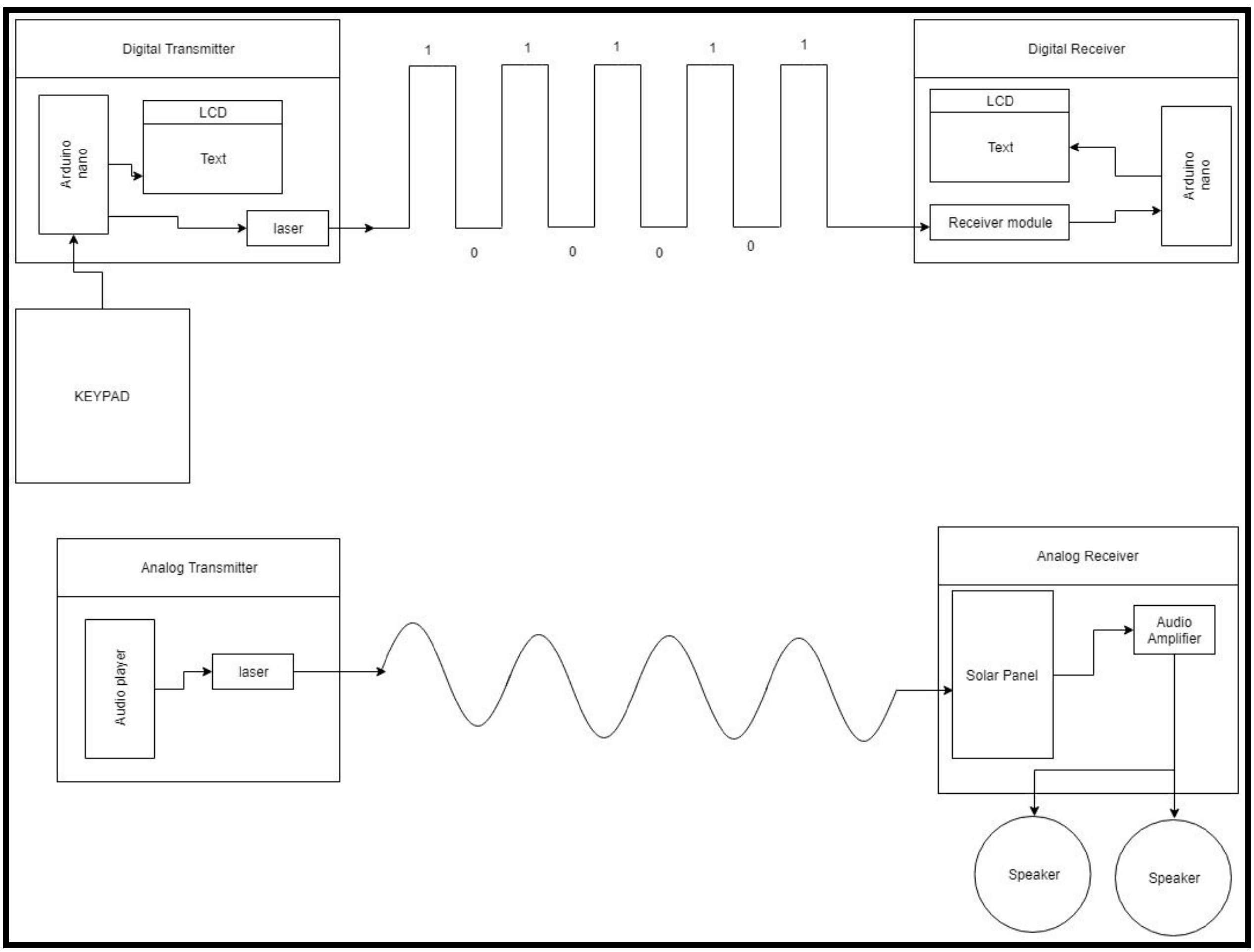


Figure 11 : Overall Block Diagram

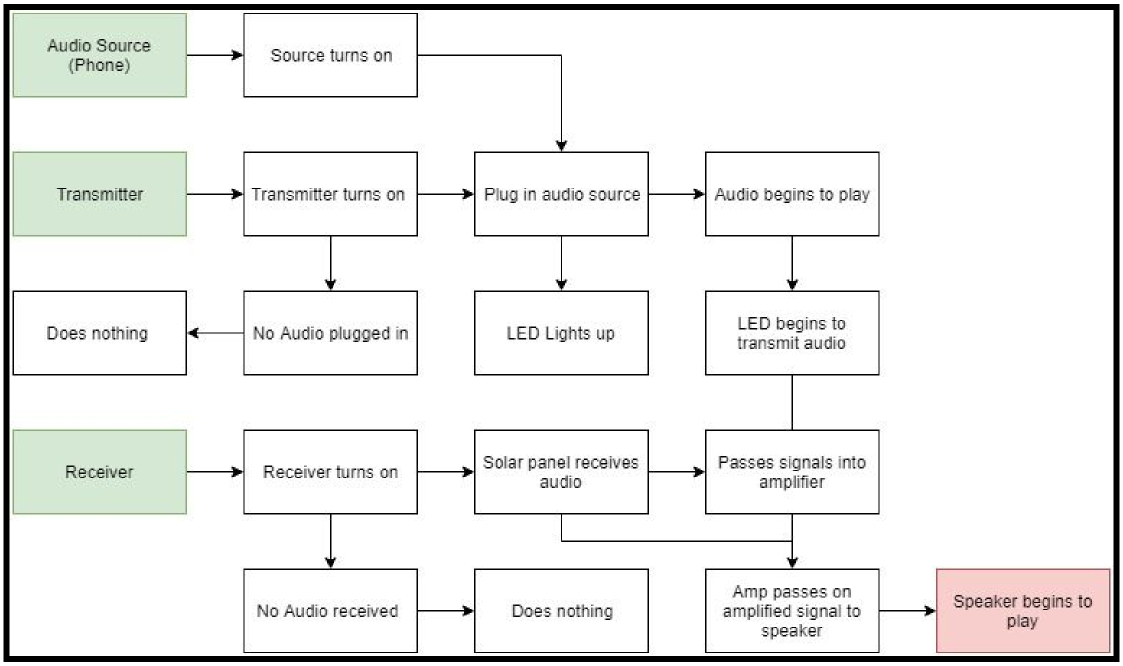


Figure 12: System Diagram of Beam It (Analog System)

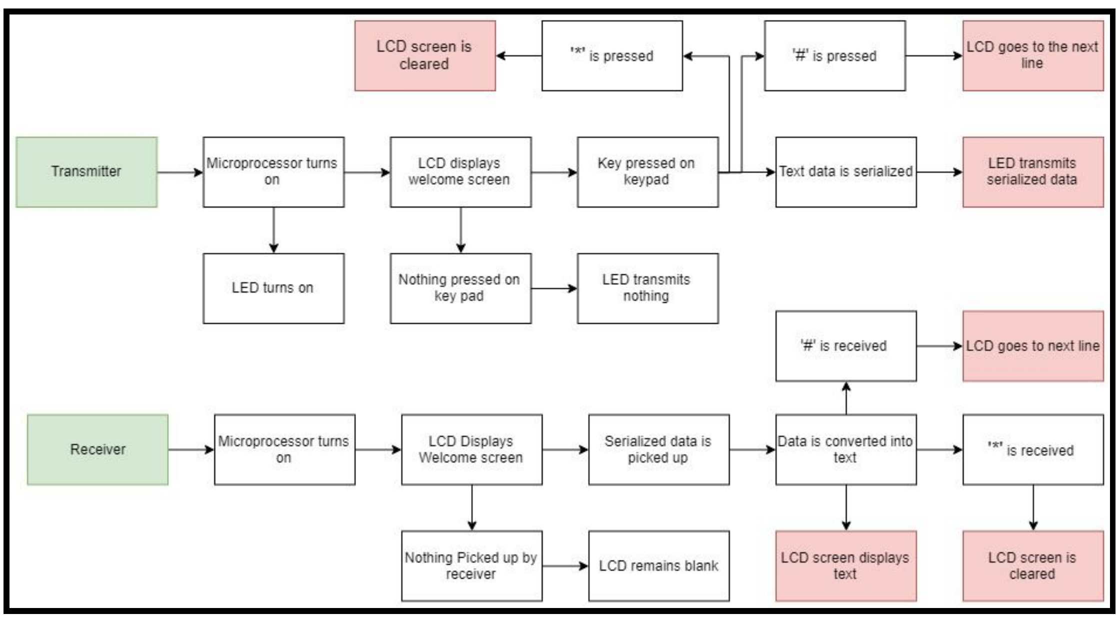


Figure 13: System Diagram of Beam It (Digital System)

4.3 Circuit Diagrams and Case Diagrams:

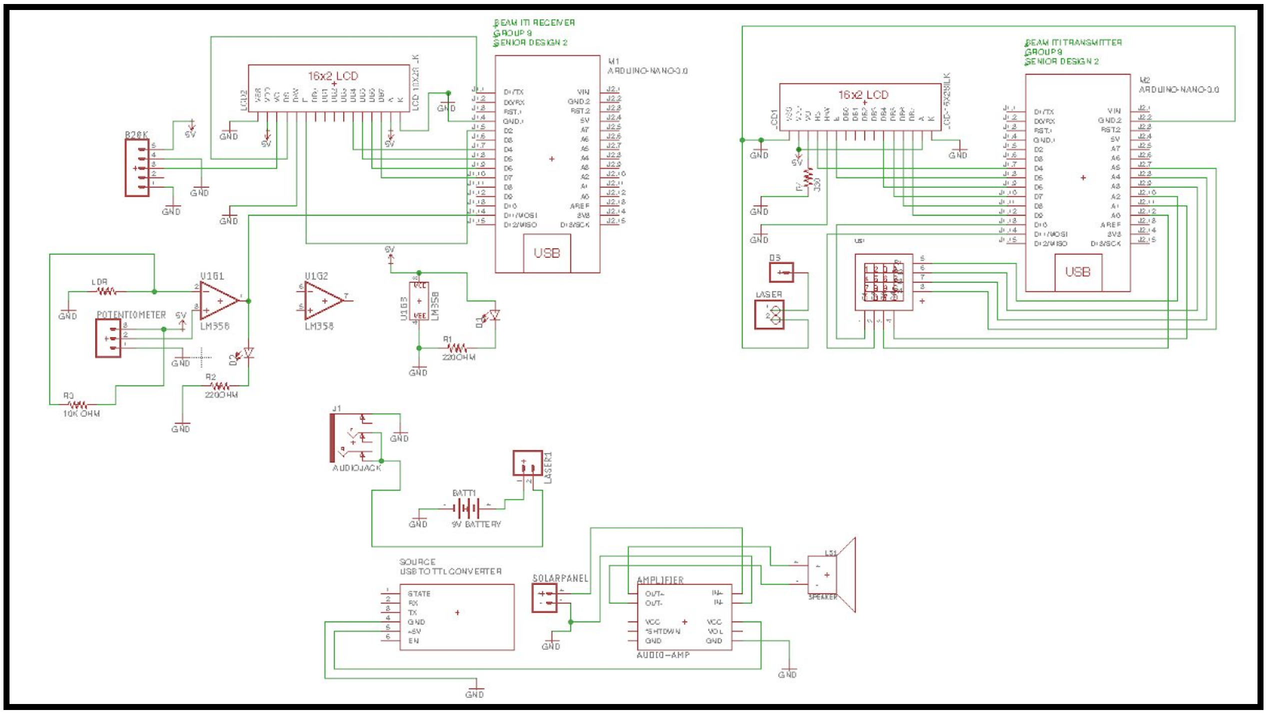


Figure 14: System Diagram of Beam It (Full System)

4.4 Testing & Calibration Results

One method we tested our system was through the functionality of the code. We used software to help us debug any issues with the microcontrollers or LCD screen. As a result, we were able to find our errors efficiently. Our testing code is listed as follows:

Transmitter Testing Code	**Receiver Testing Code**

#include <SoftwareSerial.h>
#include <LiquidCrystal.h>
#include <Keypad.h>
LiquidCrystal lcd(4,5,6,7,8,9);
 	
const byte ROWS = 4;
const byte COLS = 4;
 	
char hexaKeys[ROWS][COLS] = {
  {'1','2','3','A'},
  {'4','5','6','B'},
  {'7','8','9','C'},
  {'*','0','#','D'}
};
byte rowPins[ROWS] = {11,12,A0,A1};
byte colPins[COLS] = {A2,A3,A4,A5};
SoftwareSerial GSerial(2,3);
	#include <SoftwareSerial.h>
	#include <LiquidCrystal.h>
	
	LiquidCrystal lcd(4, 5, 6, 7, 8, 9);
	SoftwareSerial GSerial(11,12);
	char rec=0;
	
	void setup()
	{
	  Serial.begin(9600);
	  GSerial.begin(400);
	  lcd.begin(16, 2);
	  lcd.setCursor(0, 0);
	  lcd.print(" LiFi - Wireless");
	  lcd.setCursor(0, 1);
	  lcd.print(" Communication ");
	  delay(3000);

```
Keypad customKeypad = Keypad( makeKeymap(hexaKeys),
rowPins, colPins, ROWS, COLS);
char keycount=0;
char code[5];


void setup() {
 delay(1000);
 Serial.begin(9600);
 Serial.println("Keyboard Test:");
 GSerial.begin(400);
 lcd.begin(16, 2);
 // Print a message to the LCD.
 lcd.setCursor(0, 0);
 lcd.print(" LiFi - Wireless");
 lcd.setCursor(0, 1);
 lcd.print(" Communication  ");
 delay(3000);
 lcd.clear();
 lcd.setCursor(0, 0);
 lcd.print(" using Light    ");
 lcd.setCursor(0, 1);
 lcd.print(" TX TESTING ..  ");
 delay(3000);
 lcd.clear();
 lcd.setCursor(0, 0);
 lcd.print("  By Team BMES  ");
 lcd.setCursor(0,1);
 lcd.print("    bm-es.com   ");
 delay(3000);
 lcd.clear();
 GSerial.print('&');
}

void loop()
{
 char customKey = customKeypad.getKey();
 if(customKey && (customKey !='='))
 {
  if (customKey == '#')
  {
   GSerial.print('^');
   lcd.setCursor(0, 1);
   lcd.print("                ");
   lcd.setCursor(0, 1);
  }
  else if (customKey == '*')
  {
   GSerial.print('&');
   lcd.clear();
  }
  else
  {
   // otherwise, just print all normal characters
   Serial.print(customKey);
   GSerial.print(customKey);
   lcd.print(customKey);
  }
 }
}
```

```
 lcd.clear();
 lcd.setCursor(0, 0);
 lcd.print(" using Light    ");
 lcd.setCursor(0, 1);
 lcd.print(" RX TESTING ..  ");
 delay(3000);
 lcd.clear();
 lcd.setCursor(0, 0);
 lcd.print("  By Team BMES  ");
 lcd.setCursor(0,1);
 lcd.print("    bm-es.com   ");
 delay(3000);
 lcd.clear();
}

void loop()
{
 if(GSerial.available() != 0)
 {
  rec = GSerial.read();
  if(rec=='^')
  {
   lcd.setCursor(0, 1);
   lcd.print("                ");
   lcd.setCursor(0, 1);
  }
  else if(rec=='&')
  {
   lcd.clear();
  }

  else
  {
   Serial.print(rec);
   lcd.print(rec);
  }
 }
}
```

- Another method we were able to test our project was through the use of a multimeter and an oscilloscope. Due to multiple testing procedures, we are unable to include images or data.

4.5 Discussions on Lessons Learned

We had issues with our range when using LEDs. LEDs had a max range of a few inches. Adding multiple LEDs or using an extremely bright LED would only extend the range a few inches. To fix this we decided to switch to a laser light instead because it can travel long distances without a lot of degradation to the quality of light.

When it came to receiving digital data we found that a lot of components for detecting light were simply not sensitive enough to read the data. To solve this we tried many different sensors such as photoresistors, multiple types of photodiode, and a solar panel. We finally concluded that photoresistors were the most sensitive when detecting light for digital data and solar panels were better for analog data.

Another major problem is that as we get closer or farther from the transmitter the quality and strength of the light changes and therefore the quality of light the receiver is looking for changes as well. We would have to redesign the entire receiver module every time we wanted to change the distance. With the help of a 10K potentiometer we were able to design a receiver module so we can fine tune the quality of light we are looking for, just by changing the resistance of the potentiometer.

5 CONCLUSION

The Beam It! system was successful as it allowed us to send and receive text as well as audio. While the system was successful, we had internal issues with the PCB board design. Due to last minute failures with the printed board, we had to present our circuits on breadboards. One way to have avoided this would have been to thoroughly check the design of the boards making sure the traces were matched up correctly.

The concept of how to receive and transmit information through light is are always being developed and improved upon however there is still some room to grow till we are a reliable as other communications like WIFI. Despite this there is a lot of potential in both the concept and the implementation of this communications system. With the way technology is growing we will need another method to send data and LIFI seems like a distinguished and feasible solution.

6 BUDGET

Name of Item	Purchase Link	Quantity	Total Cost
ELEGOO for Arduino Nano V3.0, Nano Board CH340/ATmega328P Without USB Cable, Compatible with Arduino Nano V3.0 (Nano x 3 Without Cable)	https://www.amazon.com/ELEGOO-Arduino-ATmega328P-Without-Compatible/dp/B0713XK923/ref=sr_1_1_sspa?keywords=arduino+nano&qid=1564426774&s=gateway&sr=8-1-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUFQQkpBU1RFTzhBQ1gmZW5jcnlwdGVkSWQ9QTA4Mzc0ODkyMk5CRDlaODU5R0tSJmVuY3J5cHRlZEFkSWQ9QTA2NjkyODkxN1hJSjdRU1JQNlpVJndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ==	3	$12.86
Mini lasers	CEECS LAB	2	FREE
Resistors, photoresistors, & LED's	CEECS LAB	10	FREE
LCD Screens	CEECS LAB	2	FREE
Potentiometers & Wires	CEECS LAB	2	FREE
Audio Amplifiers	https://www.amazon.com/HiLetgo%C2%AE-PAM8403-Digital-Amplifier-2-5-5V/dp/B00LODGV64/ref=sr_1_20?keywords=audio+amplifier+arduino&qid=1564427131&s=electronics&sr=1-20	5	$5.39
Medium Solar Panel	CEECS LAB	1	FREE
Speakers	CEECS LAB	2	FREE
4x4 Keypad	CEECS LAB	1	FREE
PCB Boards	CEECS LAB	2	FREE

Total:	**$18.25**

Table 1: System Budget

7 PROJECT MANAGEMENT

7.1 Gantt Chart & Workload Distribution

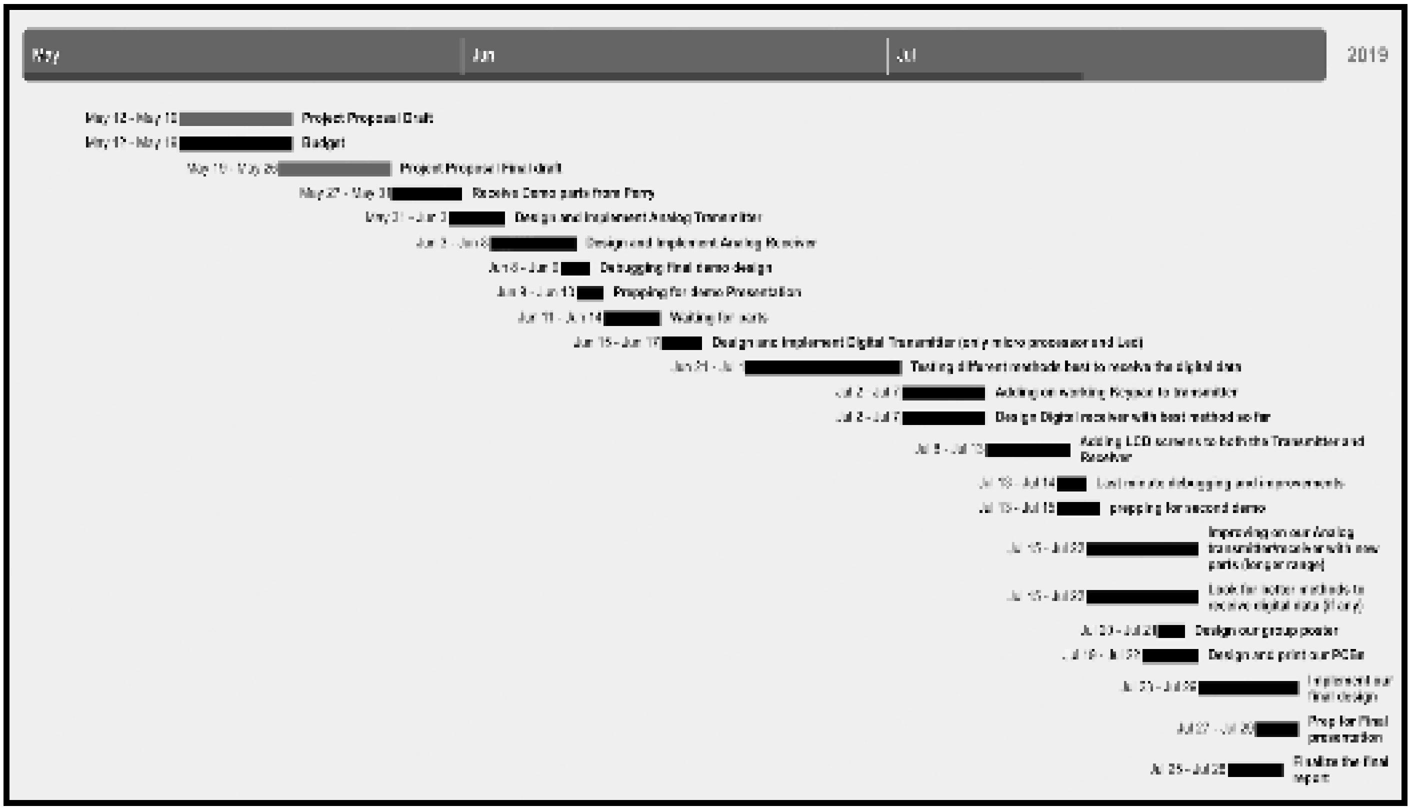
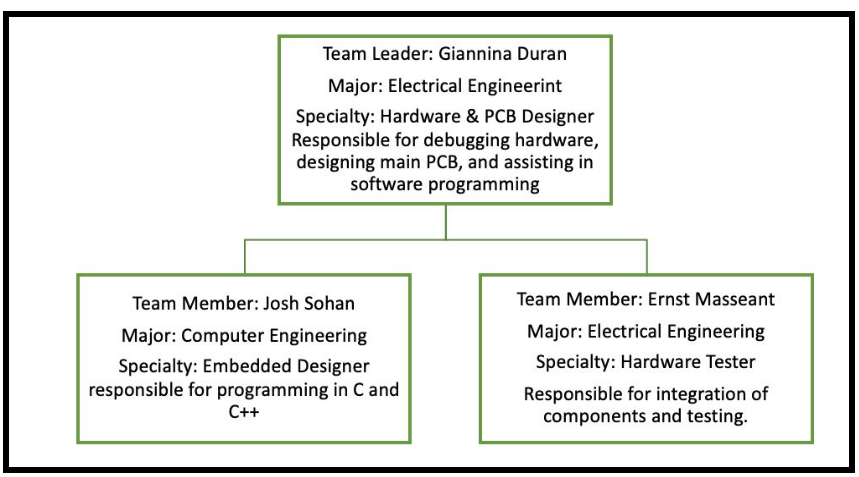


Figure 15: Gantt Chart of Beam It!

- 5/25/2019:
    - Complete final project proposal
- 6/1/2019:
    - Receive parts from Perry
    - Design analog circuit
- 6/8/2019:
    - Build and troubleshoot circuit
    - Present subsystem demo
- 6/15/2019
    - Look for methods of receiving digital data
    - Design digital transmitter circuit

- 6/22/2019:
  - Receiver parts from perry
  - Build digital transmitter circuit
- 6/29/2019:
  - Troubleshoot circuit
  - Code transmitter arduinos to for digital transmitter
  - Design digital receiver circuit
- 7/6/2019:
  - Build digital receiver circuit
  - Troubleshoot circuit
  - Code receiver
- 7/13/2019:
  - Debug receiver and transmitter
  - Present second subsystem demo
- 7/20/2019:
  - Improve designs for both the digital and transmitter module
  - Design PCB circuit
- 7/27/2019:
  - Implement the PCB circuits
  - Present final presentation
  - Submit final report and remaining assignments

7.2 Organizational Chart & Tasks



Name	Tasks
Giannina Duran **Team Leader** **Major: Electrical Engineering** **Contribution to Project: 45%**	• Design and implement circuit for digital transmitter • Design and implement circuit for digital receiver

	• Design and implement circuit for analog transmitter and receiver • Organize and keep the project on schedule • Schematic designs and PCB layouts • Solder all components on PCB units and debug any issues with electronic boards • Video editing, powerpoint presentation, and report editing. • Provide Hardware and software support • Contribute to final report and presentation • Weekly meeting and reports
Josh Sohan **Team Member** **Major: Computer Engineering** **Contribution to Project: 45%**	• Troubleshooting and finding bugs in Transmitter & Receiver code • Developing code for transmitter • Developing code for receiver • Debugging issues for circuit board • Testing of microprocessors and microcontrollers • Weekly meeting and reports • Video editing, powerpoint presentation, and report editing. • System Diagrams • Contribute to final report and presentation
Ernst Masseant **Team Member** **Major: Electrical Engineering** **Contribution to Project: 10%**	• Organized meeting times with professor • Provide detailed writings on each component • Picked up parts

Table 2: Contribution to Project

8 REFERENCES

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[5]https://pdfs.semanticscholar.org/1146/869b6752a1dedf499f064354f5c199c1d0fe.pdf

[6]https://patentimages.storage.googleapis.com/88/b9/d6/4b3aed821ccec1/US20160218807A1.pdf

[7]https://patents.google.com/patent/CN205336548U/en?oq=lifi

[8] S. Louvros, D. Fuschelberger, N. Sklavosm M. Hübner, D. Goehringer, and P. Kitsos, "VLC Technology for LTE Indoor Planning," *System-Level Design Methodologies for Telecommunication*. NY: Springer, 2014, pp. 23.

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9 APPENDICES

9.1 PCB Board Design

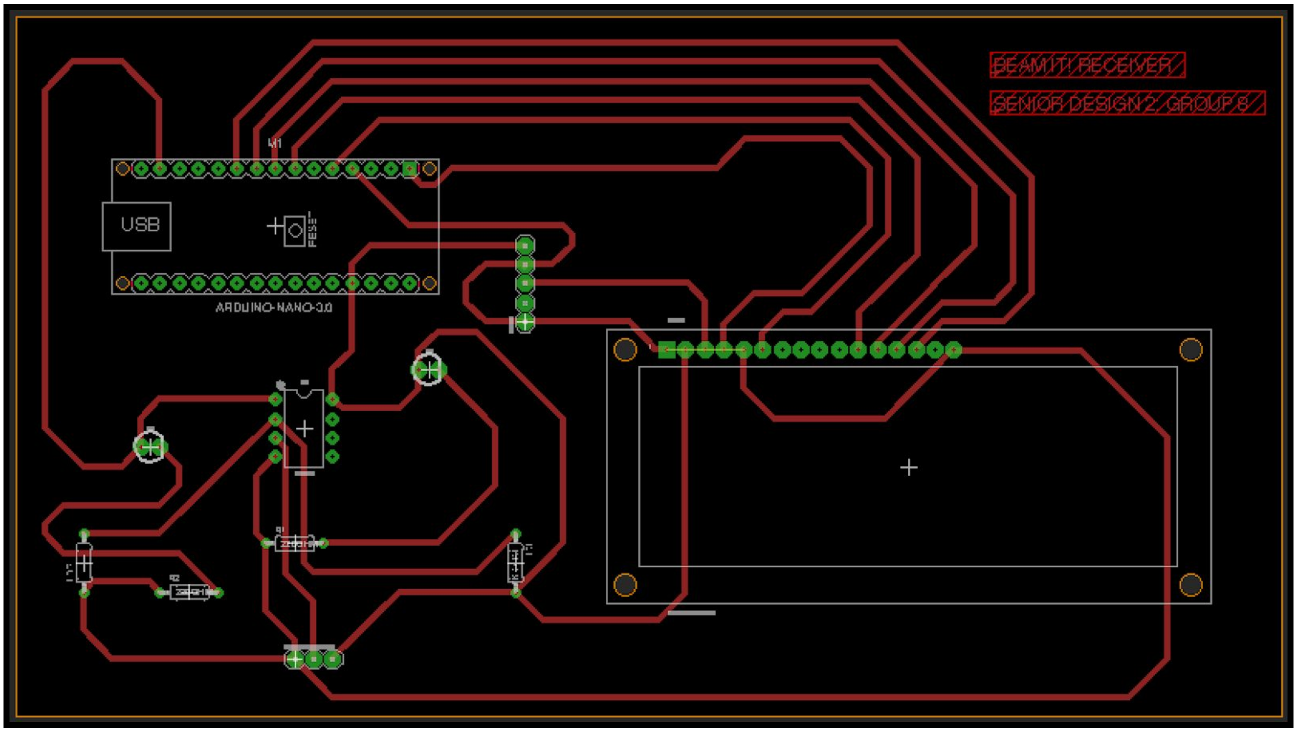

Figure 16: Beam It Receiver (Eagle PCB Design)

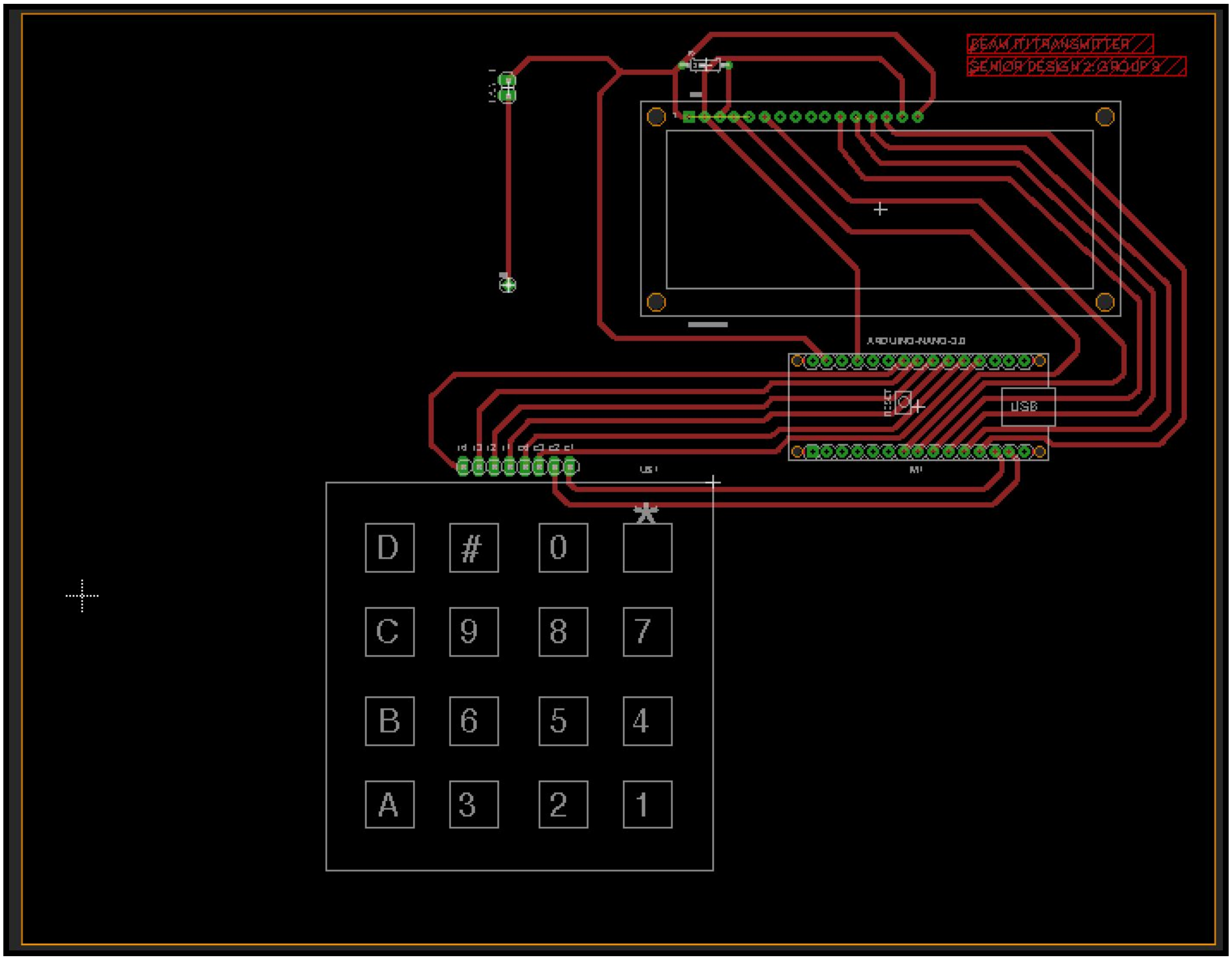

Figure 17: Beam It Transmitter (Eagle PCB Design)

9.2 Final System Prototype

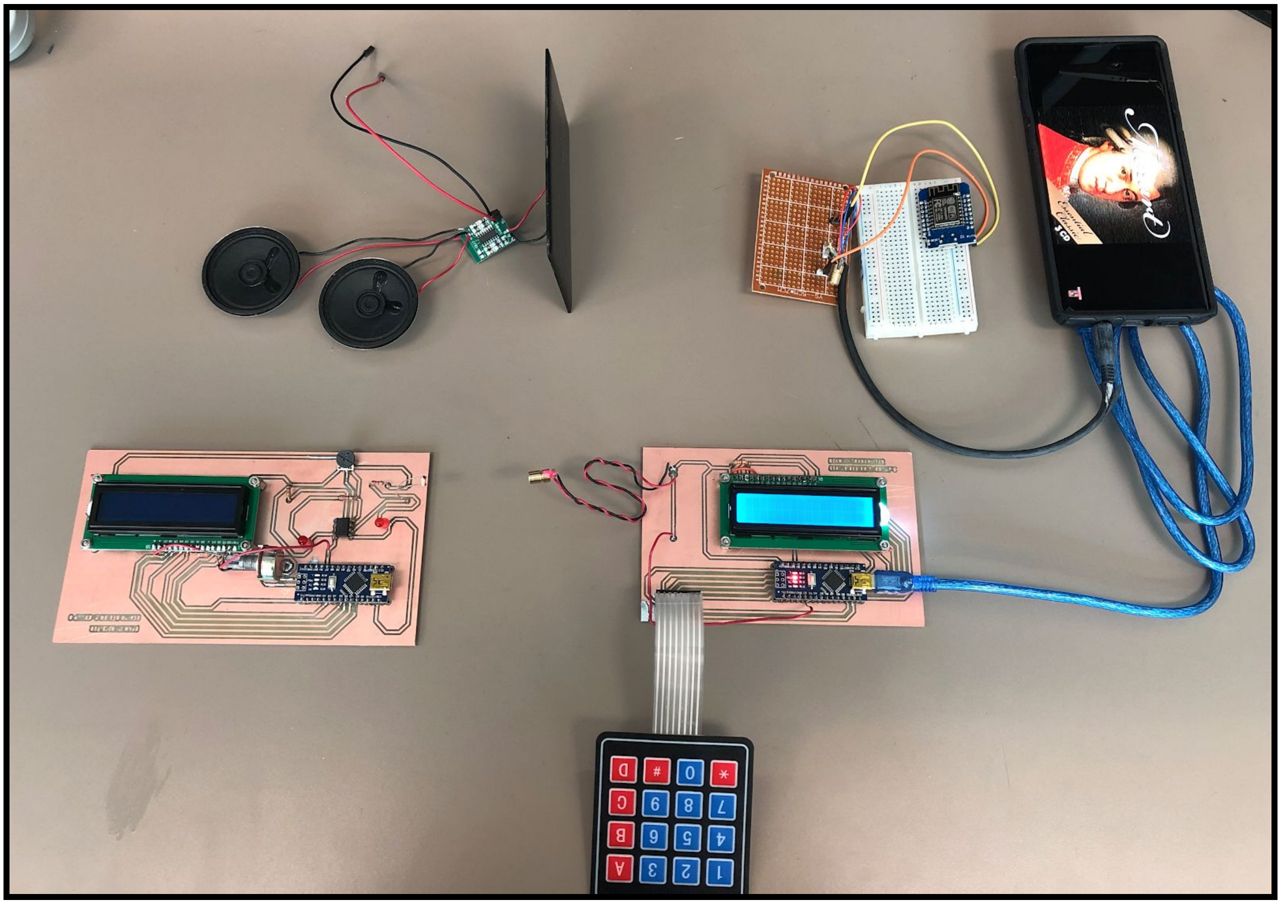

Figure 18: Beam It System Final Prototype