UCF Senior Design I

Department of Electrical Engineering and Computer Science
&
Center for Research and Education in Optics and Lasers
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Directed High Frequency, Open-air Communication

Group 29

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1.0 EXECUTIVE SUMMARY

In the modern era, where the pace of technical progress has been increasing exponentially, the electromagnetic (EM) spectrum that we depend on for communication is becoming increasingly crowded. AM/FM radio waves, microwaves, UHF and VHF, Wi-Fi, and Bluetooth, are signals that permeate the space we are familiar with in a uniform fashion when the signal broadcasts ideally.

This project proposes a means of communication via infrared laser beam. Additionally, the system should auto-align the sending and receiving instruments to keep a strong signal between the sending and receiving units. If such an analog communication link can be established and maintained, then there exists a means to efficiently transfer data.

The bandwidth of this channel provides a platform wide enough for multiple applications. Currently, specialized imaging sensors are used on drones for agriculture and firefighting while optics help satellites take detailed images of our atmosphere in a myriad of spectrums for use in meteorology. The method of application will vary depending on the requirements of specific applications.

The prototype solution seeks to provide a pair of micro-controlled optics and sensors that are specific to the bandwidth of infrared light that is accessible to users. The specific portion of the infrared spectrum to be used is, as of yet to be determined. The project additionally seeks to prioritize simplicity, wise use of mass and materials and to work reliably at whatever scale can be achieved.

The two core goals are as follows:

1. Establish a directed, high frequency, open-air communication link.
2. If time permits, integrate tracking to maintain line-of-sight for comm. link.

If the two above goals are met, the third goal will be to transmit meteorological data from a spectrometer that will collect data from the near infrared EM spectrum to test reliability of the link.

The information covered in this report will go over the overall process we went through in our project. First, the report will cover the main objectives the team wants the laser communication device to achieve. It will then go into the research we needed undergo to get the project to work. It will also cover the standards and limitations that the team will need to take into consideration when building the design. Afterwards, it will go into the specific design details that went into this project for each major. Additionally, it will describe the different types of testing that will need to occur to see how well individual components of the project work. Furthermore, it will describe how users should operate the device and list important warnings for the user's safety. Lastly, the report will cover the different administrative content of the device such as the budget analysis and the milestones that were set in developing it.

By providing the information listed in this report, the team will provide an overview of what to expect from the design. By taking this information into consideration, we believe we will have a steady plan for the overall construction of the design.

2.0 PROJECT DESCRIPTION

This section will provide the main goals and motivation behind the project. The reader will understand what reason was there for the need to develop an open air and high frequency communication device. The reader will understand what we hope to accomplish with our device and how the goals will measure against each other. Figure 2.0.1 provides a brief illustration to show an example of how the laser transceiver can be used.

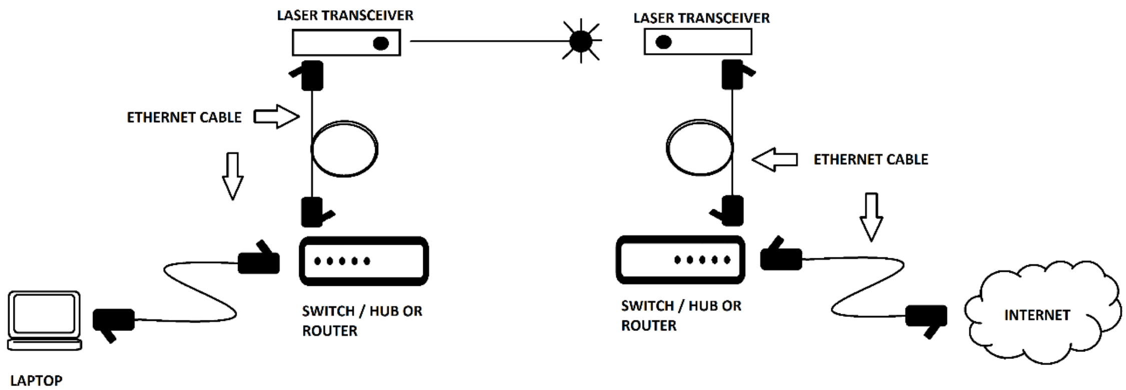


Figure 2.0.1

This of course, illustrates a static setup where the laser transceivers are forming a channel in place of an Ethernet cable between two switches on a local area network.

Because the secondary objective is to create the ability to maintain line-of-sight (LOS) between transceivers, this creates another usage scenario in which at least one of the transceivers is mobile as depicted in figure 2.0.2.

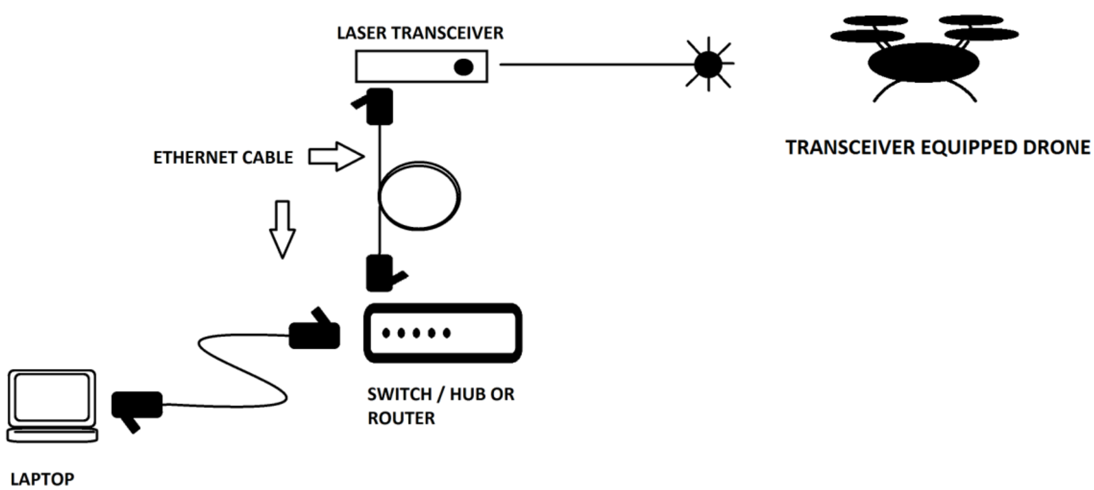


Figure 2.0.2

These two setups by no means illustrates all usage scenarios. There are a variety of network topologies that this transceiver aims to function with, which will be discussed later in section 3.

2.1 MOTIVATION

Traditional telecommunication that relies on laser light to transfer data has done so through fiber optic cables. These can be costly to manufacture, install and maintain. Currently there is no end consumer platform that provides a directional, wireless communication link that can compete with the bandwidth offered by available fiber optic solutions. Creating a pair of optical transceivers that communicate via infrared laser will allow untethered communication to form the basis of a variety of applications where high bandwidth and a real-time data feed is crucial.

There exist many scenarios in which this form of communication will be preferred when directed, free space communication matures. Ideally, this project will meet all of the engineering requirements of portability, power use and range so that it may be employed for applications in meteorology and avionics.

2.2 OBJECTIVES

Establishing a wireless infrared channel of communication is the primary objective of this project. The initial setup for prototyping purposes will establish this link between separate breadboards with at least 1 ft. distance between them. At this range optics to collimate stimulated emission from lasers will not be needed. At this stage, the primary focus will be setting up a commercially available microcontroller that is capable of recording input received from an IR sensor and plotting the output.

When it has been established that the link can transfer data reliably, efforts will focus on handling incoming data. Incoming raw data read from an infrared sensor should be able to be stored locally on some kind of solid-state storage device where it can potentially be read and transmitted at a later time. This raw data has no need to be application specific as it is only data regarding the modulated laser light that is received. This data must be demodulated first in order for higher level, application specific software and hardware to make use of after it is received.

A static setup will only provide so much utility. Such a setup can be acceptable for most telecommunication requirements, however the second feature requested is the ability to track the receiving unit and adjust the transmitting optics accordingly to stay on target.

Opening up the project to mobile applications necessarily imposes additional constraints upon the design of the project. Size and weight are primary factors when a transceiver is intended for mobility. Additionally, power consumption is also another concern as any mobile device implies that it must source the energy it uses from a battery. Meeting these demands on a prototype level should not be difficult, as the hardware needed for prototyping is small, lightweight and consumes little power. When the initial communication link is established a better idea of the physical platform required to house the optics and other hardware will be known. At the prototype level small servos should be capable of the torque necessary to adjust the alignment of the optics. These servos will be actuated via a microcontroller using a quadrant photodiode for feedback.

2.3 REQUIREMENT SPECIFICATIONS

The transceiver unit to be designed shall:

- have a maximum effective range of no less than 25 ft.
- be capable of transmitting data at a rate of at least 10 Mbps.
- be less than 10 lbs.
- not exceed 10 in^3 in size.
- use less than 100 W of power.
- utilize infrared light of 1550 nm.
- be printed on PCB not to exceed 8 in^2.
- operate up to 30 minutes on a single battery charge.
- support USB, RJ45 and serial interfaces.
- support the option of local storage of up to 32 GB of data.
- be weather resistant and operate in environments of up to 90% relative humidity and 95°F.

2.4 HOUSE OF QUALITY

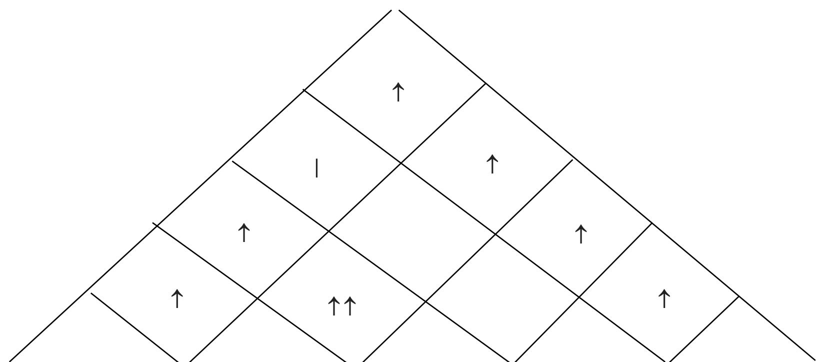
When building the product and meeting the requirements, we must determine what requirements work synergistically and those that impose trade-offs. As shown in Table 1, we measure each of these values with respect to each other. For our prototype we would like to use scaled values for our engineering requirements. For example, for the range of our light we would like to start with 1 ft. then expand to 15 ft. We may have the speed of the prototype start off at 1 mbps and will later increase to 10 mbps. Lastly, we could start off with an accuracy of 80%, and later increase that to 95%.

It will be important in Senior Design 2 that we meet these engineering requirements. So, it is important the House of Quality determines what values we are gaining and sacrificing by attempting to meet these requirements. As shown in the legend, each of the symbols represent where each requirement correlates to one another.

LEGEND

= no correlation
↑ = positive correlation
↑↑ = strong positive correlation
↓ = negative correlation
↓↓ = strong negative correlation
+ = high value
- = low value

Table 2.4.1 House of Quality Legend



		Speed	Accuracy	Range	Power	Cost
		+	+	+	-	-
Portability	+					↑
Power	-	↑	↓	↑	↑ ↑	↓
Installation	+					
Cost	-	↑	↓↓	↓	↓	↑ ↑
Tasks for Engineering Requirements		>=10 mbps	>80% ideal beam intensity	>= 15 ft. radius	=< 100 W	< $500 link hardware only

Table 2.4.2: House of Quality

2.5 USERS

Essentially, there will need to be at least two different types of users for the device to work properly. There will need to be a transmitting party, a group that will want to send data over, and a receiving party one group that will be receiving the data sent over. Although since the device is meant to implement bidirectionality, the role could be vice versa for the device. Additionally, as shown in Figure 2.0.2, the party would not need to be physically present to send data over, data can be sent to a device controlled by the receiving party such as a drone. Overall when distributing the device, there will need to be multiple parties involved.

3.0 RESEARCH

In order to develop a successful product, thorough research needs to be done into several of the main components we'll need for the project. Research will need to be done on existing products, its effect on the market, as well as any hardware and software components relevant to the project. In order to build the prototype as well as build the final device in Senior Design 2, it is important to know what currently exists out there and what other components we will need to know about.

3.1 Existing Products

There are currently several products that are similar to this technology, but none of them are exactly the same. It has been made clear to the team that our final product must not only work and function correctly but must also be unique and have never been done before, at least on the consumer level. While there are some concerns about say, 10 years in the future, there does not appear to be an issue at the time of this writing, which is good enough. Currently, there are two "products" that are similar to ours in this manner, one by NASA and one by a private company as a wi-fi alternative.

3.1.1 NASA Laser Communication

There are few, if any existing widespread consumer products that use this technology for long distance communication. However, NASA has been researching this technology since 1964 for airplane communications, where the pilot's (analog) voice would be converted into (digital) electric pulses and then into a light beam, with a receiver on the ground reversing this process (29, 30). This technology was able to be improved significantly over the last half-century, and it's use case has expanded substantially. "In 2013, a craft orbiting the moon launched by NASA sent data to an earth station through a pulsed laser beam at a rate of 622 Mb per second" (29, 30), which is more than ten times the speed of high-speed internet plans available at the time (42).

While our project may be more on a smaller scale, this example project definitely served as a good inspiration for the team.

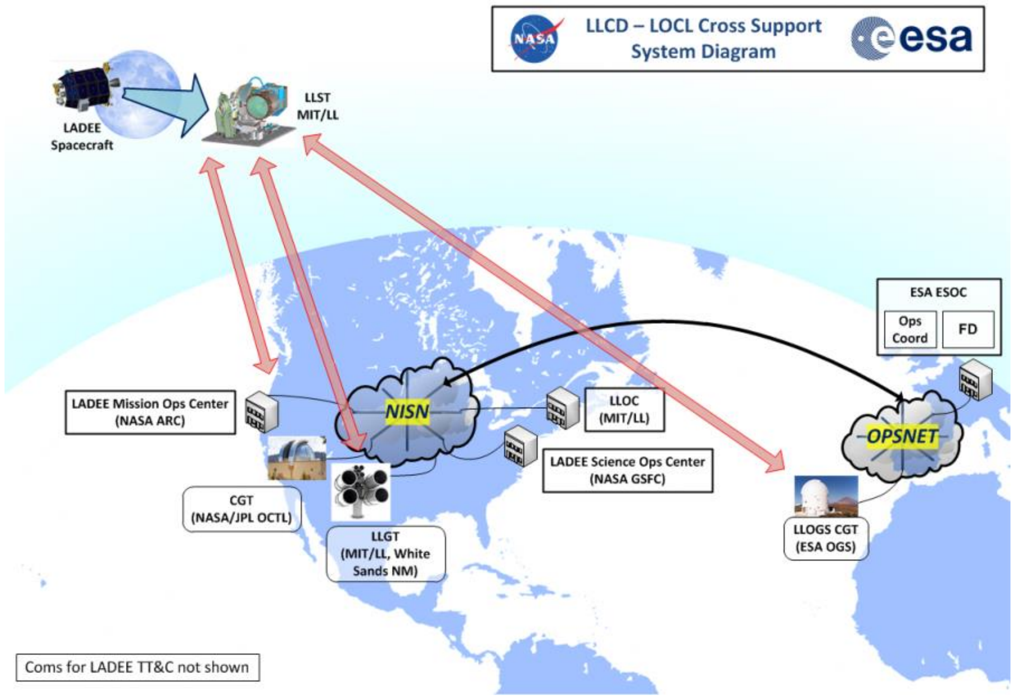


Figure 3.1.1.1: LLCD Cross Support System Diagram

The project, known as Lunar Laser Communication Demonstration (LLCD) was housed aboard the Lunar Atmosphere and Dust Environment Explorer satellite (LADEE), which was orbiting the moon at the time (29. 30). LLCD made post-flight calibrations, which decreased the difficulty in tracking and maintaining communication with the satellite, to the point where the error was less than an inch. Meanwhile on earth's surface was the NASA's Jet Propulsion Laboratory's Optical Communications Telescope Laboratory. The technology was also capable of communicating with multiple locations on earth, as it successfully transferred data to and from the European Space Agency's Optical Ground Station near Spain.

In addition, cryptographers and security experts utilize this technology as it is difficult to intercept and nearly-instantaneous communication. Meanwhile, some traders on wall street use this technology to improve their trade times, as a stock rapidly being bid on will rise in price quickly, and this technology would allow for bidders to place their bids when the stock is at a lower price.

3.1.2 Light Fidelity (Li-Fi)

As discussed in other sections of this report, the average consumer grade Wi-Fi connection in America is only 20 mega-bits per second, meaning that a full gigabyte of data (8000 mega-bits) takes a whopping 400 seconds, or 6 minutes and 40 seconds to download. Networking is quickly becoming a bottleneck, as everything from modern CPUs to RAM to storage runs at well beyond that speed. Since video games are gaining higher and higher resolution textures (as an example, Halo 5 is currently 100 GB, while Halo Reach from 2010 is less than 10 GB) and 4K is becoming more and more standard (4K is 4 times the size of 1080p), this will be a problem in the future.

Light Fidelity, or "Li-Fi", is pureLiFi's attempted solution to this problem. Li-Fi transmits data over visible light waves instead of radio waves. It works similar to infrared technology in today's TV's. "An an input command is given (e.g., "change channel" when you press a button) and that input is turned into binary code. That code is then transmitted over infrared light waves by your remote's sensor, and the light waves are received by your TV's infrared sensor, which decodes the light and performs the intended input action." PureLiFi produced a useful infograph which is included below.

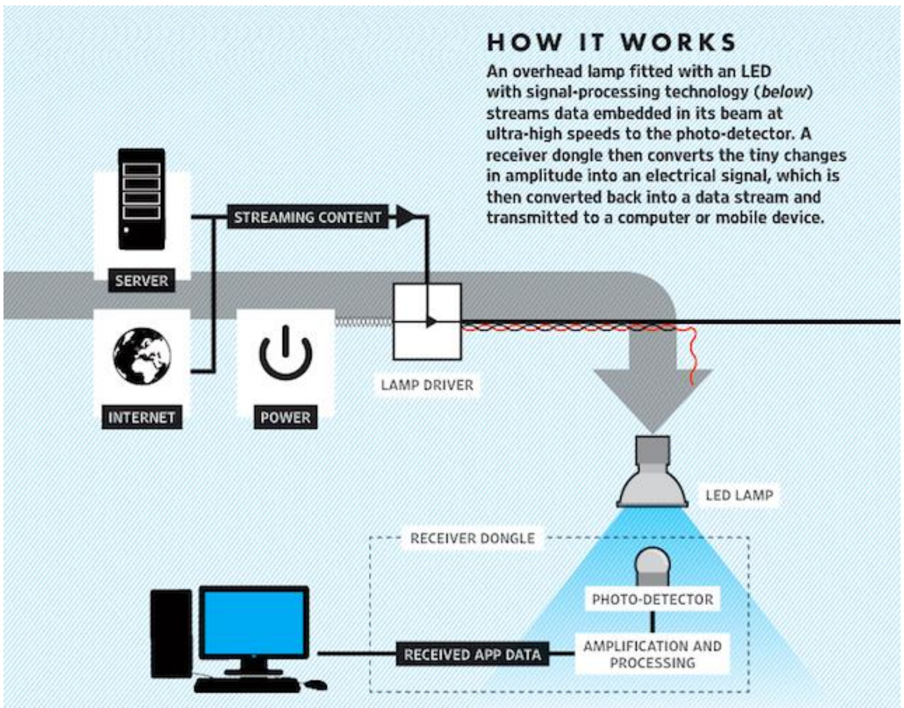


Figure 3.1.2.1: LiFi Diagram

The biggest advantage of Li-Fi is a dramatic increase in speed. As stated before, Wi-Fi currently uses radio waves, which run at a frequency range between 10^9 and 10^{10} Hz (64). The visible light spectrum has a frequency range of $10^{14.5}$ to 10^{15} Hz (64). A higher frequency means that more information can be encoded in the wave in less time. In addition, initial latency is also reduced dramatically due to how much shorter the cycles are. Finally, the radio spectrum is extremely crowded due to the number of devices that currently use Wi-Fi, and with the increasing popularity of smart watches, smart doorbells, thermostats, assistants, and speakers, this frequency band will only become more and more crowded.

Li-Fi's comparatively low adoption rate and increases in speed from a physics standpoint give it a dramatic speed advantage over the current Wi-Fi. A real-world test conducted by an Estonian company called Velmenni was able to transfer data between devices at 1 Gbps 50 times faster than Wi-Fi and faster than most wired internet connections on the planet (65, 66). What's more, the fastest recorded speed was 224 Gbps in lab tests (65, 66), which is unheard of. This technology being based on light means that it can be integrated into light bulbs that are already necessary indoors anyway.

It is also more energy efficient for receiving devices than Wi-Fi, which makes it perfect for portable battery powered devices such as smartphones, tablets, laptops, and smart watches. The line-of-sight requirement poses a small advantage in that it is more secure than Wi-Fi, as an intruder would have to physically near or very close to the home for a signal (65).

However, there are a few flaws with this technology. Given that it relies on purely visible light, it does not work through walls or when the lights are turned off, meaning households will need to keep the lights during the already bright and warm day for the speed advantage. This is obviously a problem at night as well if the lights are turned off before bed. In addition, this also means that adopters will need a light bulb with this technology in every room they hope to use it, and that the path between it and their devices is not obstructed by ceiling fans or furniture (larger rooms or those with multiple ceilings may even require multiple sources, which makes this system a bit of a patchwork one) (65, 66). Even during the day, bright outside lighting can interfere with the signal (as it is also visible light), which causes problems in homes oriented toward either the east or the west, as they will have roughly half a day of interference. Li-Fi will also require adopters to heavily alter their current lighting and wiring infrastructure in order to support it, which can be quite expensive as walls and ceilings will need to be accessed to do so (65, 66).

Given all of this, Li-Fi is best treated as a companion to your existing network setup (Wi-Fi) rather than a complete replacement. pureLiFi made another diagram featuring this below.

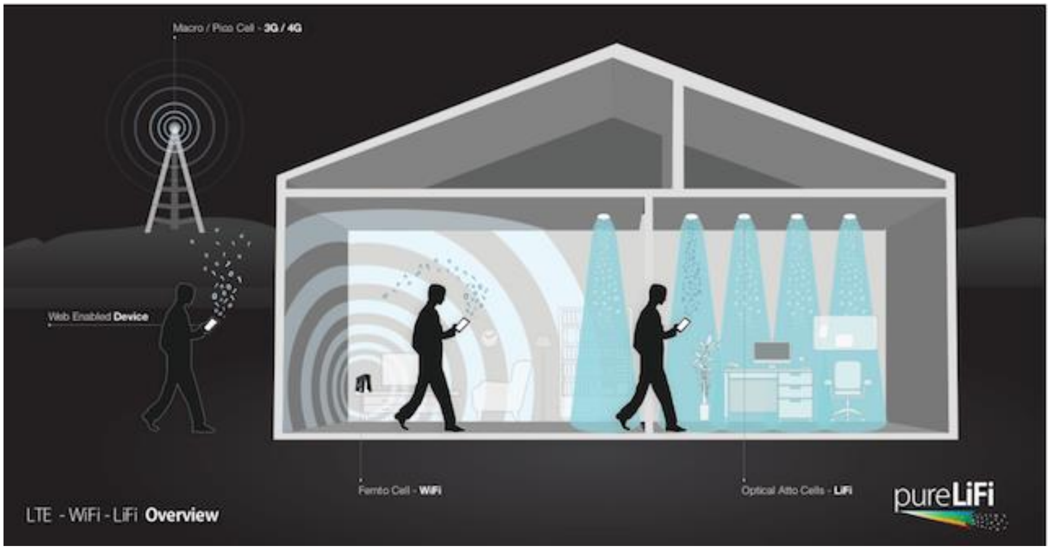


Figure 3.1.2.2: LiFi Overview

Like Li-Fi, our product is also targeted as a companion to existing setups, as it faces many of the same challenges that Li-Fi does, including issues with line of sight, interference, additional cost for adding new infrastructure, etc. However, unlike Li-Fi, our product can work over considerably longer distances (orbital ranges) as it relies on an extremely precisely aimed laser rather than a light bulb with a wide range. (65, 66)

3.1.3 RONJA

Reasonable Optical Near Joint Access, or RONJA, is a user controlled technology project of optical point-to-point data link.[84] This existing project is capable of sustaining 10 Mbps full duplex optical transmission. A few different models exist for the project, but all are capable of transmitting over a distance of 1 km. The divergence angle for each of these models however is roughly similar, featuring an approximate divergence half angle of 2 mrad to 3 mrad. RONJA uses visible light communication for two models, metropolis and tetrapolis, and infrared for the inferno model.
This type of open source approach regarding hardware and software is highly useful to our project at hand, as all systems meet the self-set minimum criteria of 10 Mbps. Additionally, several design choices regarding system packaging and mounting can be considered as all modules that are a part of RONJA have constructions steps available online. The modulation scheme employed for the laser channel in the inferno model uses binary phase-shift keying (BPSK).

3.2 Microcontroller

The microcontrollers are important components for the device we'll be building. The software of the microcontroller will allow the data to successfully transfer from one location to another as well as control the rate at which the data gets sent over. For this project there will be two microcontrollers, both of which will have the ability to transmit and receive data. This section goes on to list several of the conditions we look for when finding a microcontroller and what microcontrollers were brought into consideration.

3.2.1 Microcontroller considerations

For the microcontrollers of this project, there are a wide variety of microcontroller to choose from. While conducting are research for this project, it was necessary to narrow our microcontrollers based on a number of different factors such as CPU speed, Flash size, RAM size, and core size. This then will convey on a fraction of the microcontroller that are in the market as most of the microcontroller are used for various features. Only a limited amount of microcontroller contains all the features that is needed for this project.

3.2.1.1 CY8C54LP

This microcontroller was one of the first ones that was considered for the project. Since the device will be sending data over by laser, the microcontroller would need a high CPU speed. Since this microcontroller has a CPU speed of 67 MHz, we believe that will meet the speed requirement of the device. Additionally, we would want the microcontroller to be able to store the data the laser would need to send over and store it if the laser failed to send it over properly. That way, each and every single piece of data that is being capture will have a main home so that if the transfer is to be a failure, then the data can still be retrieve as it is store somewhere that can communicate between one to another. This can be a great feature, as nothing is perfect in this world and if the transmission fails the first time, it can try again and not retransmit the signal, just capture the data that fails.

One of the disadvantages of the microcontroller however is its pin count. The pin count for this microcontroller goes to 100 pins, which possibly may be difficult to solder properly. Additionally, the Cypress brand of microcontrollers will be new to the team, so unlike other microcontrollers out that the team is familiar with, we will need to be aware of new feature that are part of most Cypress microcontrollers as well as the IDE that Cypress microcontrollers use.

Specification	Value
Flash Size	256 kB
Ram Size	64 kB
CPU Speed	67 MHz
Core Size	32-bit

Table 3.2.1.1.1: CY8C54LP Specifications

3.2.1.2 ATSAME70

This microcontroller is manufactured by Microchip Technology. One of its most appealing features is its I/O pins. When constructing the device, we would like to limit the amount of pins the chip has because when soldering the chip on to the printed circuit, we want to make sure that it attaches correctly with little error as possible. The pin count for this particular microcontroller is 64 pins, while still a little high, we believe that it would be fairly mountable. Even with the smaller pin count, this microcontroller still comes with many additional unique features as well such as high speed, both ADC and DAC peripherals, and several additional connectivity ports. Several of these include USB, UART, and Ethernet. Even if all of these ports are not used, it would be great to have them if any of the requirements for the device change further on in development.

As mentioned with the Cypress microcontrollers, Microchip will also be new for the team to use in this project which could be a potential disadvantage in using this microcontroller. The IDE of this microcontroller, Atmel Studio 7, will be a new tool for the team to learn to use. However, since most micro-controllers use C code, the team will not have too many issues when it comes to using the software of the device. Another concern we may have is that the supply voltage goes up to 3.3 Volts. When deciding the hardware components of the device, we will need to be careful of how we work with the voltage of this microcontroller so there are no potential issues that will come.

Specification	Value
Flash Size	512 kB
Ram Size	256 kB
CPU Speed	300 MHz
Core Size	32-bit

Table 3.2.1.2.1: ATSAME70 Specifications

3.2.1.2 AT32U3C3

This microcontroller was also manufactured by Microchip Technology. One of the features appealing about this microcontroller is its high supply voltage range. This supply voltage range can go up to 5.5 Volts. So, if we have any hardware components that delivers around 5 Volts, the microcontroller can handle it. Additionally, it has a wide variety of connectivity and peripheral options similar to the ATSAME70 microcontroller, such as the ADCs, DACs, UART, and Ethernet connections. Also, similar to the MSP430 microcontrollers, this microcontroller also has a low power feature which will be beneficial to conversing energy for the device.

One of its disadvantages of the AT32U3C3 microcontroller is that its speed is 66MHZ which is less than the ATSAME70 speed. Additionally, several of its memory features are scaled down to that of the ATSAME70 microcontroller, where the Flash and RAM of this microcontroller are 256 kB and 64 kB. Also, similar to the ATSAME70, it will be a new brand of microcontroller to work on, so it will take time to understand the different features that come with the microcontroller.

Despite these disadvantages, the memory and speed specifications of this microcontroller are still good features that can meet the needs of the device. Also, it still has its advantages over the ATSAME70 microcontroller. This microcontroller chip will still be kept under consideration for the team to use.

Specification	Value
Flash Size	256 kB
Ram Size	64 kB
CPU Speed	66 MHz
Core Size	32-bit

Table 3.2.1.3.1: AT32U3C3 Specifications

3.2.1.3 TI MSP 430 options

This family of microcontrollers were in great consideration by our group. A majority of the team has the most experience with these particular types of microcontrollers and the IDE they were programmed on. Additionally, they are ultra-low power devices which will work well for conserving power for the overall project. Several of these microcontrollers have launchpad versions of them, which would serve well when constructing the prototype of the device.

3.2.1.3.1 MSP430G2553 Launchpad

This microcontroller was one of the initial boards that was considered for the prototype device. This microcontroller came in a launchpad kit which includes several components that makes it a great tool for prototyping purposes, such as an analog to digital converter, two push buttons, and a green and red LED. Having these components would work well for debugging the software of the device. This microcontroller also comes with 24 I/O pins where if we need to connect any other hardware component, we would be able to.

However, it does come with limited resources of communication and memory storage. For the final project, we would like for the device to transmit large amounts of data at a fast rate. As shown in Table 1, this microcontroller can only hold 16 kB of Flash memory and has a computer speed of only 16 MHz While this microcontroller won't be used in the final project, using this microcontroller for the prototype will assist us greatly in research purposes of what the final product needs.

Specification	Value
Flash Size	16 kB

Ram Size	0.5 kB
CPU Speed	16 MHz
Core Size	16-bit

Table 3.2.1.3.1.1: MSP430G2553 Specifications

3.2.1.3.2 MSP430F6659

This was second of one of MSP430 microcontrollers that were under consideration by the group. One of the features appealing about this micro-controller is that it's a low powered based microcontroller, similar to most MSP430. One of the teams marketing goals would be to make the device low power so it wouldn't drain the battery too much. Additionally, it does come with its own Analog to Digital and Digital to Analog peripherals, which is what is needed for the final product when transferring data over. This MSP430 microcontroller is also not a launchpad version though, meaning we can create our own PCB circuit board with this and add several components to it we believe the device will need.

However, it can be low power but the lower the power, the less features it will consist on, such as speed. This microcontroller has a CPU speed of 20 MHz, while it is not too slow, we believe we can go higher for the speed of the device. As we work on the final product, there may be certain new criteria that will develop, so it would be great to have a microcontroller that meets all those features. Additionally, this microcontroller does come in a 100-pin package. While we want the microcontroller to have many different features, we would like it to mount onto the PCB without any connection errors, and with a 100-pin package that may be a challenge. This will be great for manufacturing purposes as well for different interest groups.

Specification	Value
Flash Size	512 kB
Ram Size	64 kB
CPU Speed	20 MHz
Core Size	16-bit

Table 3.2.1.3.2.1: MSP430F66 Specifications

3.2.1.4 Arduino Mega

The Arduino Mega microcontroller is under consideration for the team as its one of the many development boards that could be used for prototyping, such as the various Texas Instrument Launchpads. Additionally, this board comes with many more features than the other Arduino microcontrollers

One of the boards most appealing features is its many I/O ports. This development board comes with about 54 digital pins, which 15 of them are able to produce a pulse modulated width output, which may be needed when sending an analog signal over to our laser diode. The software that compiles the Arduino mega, the Arduino IDE, is also a simple tool that comes with the Arduino Mega, more of the IDE features would be discussed later in the section. This particular microcontroller also is able to withstand an input voltage of 12 V, when prototyping this particular microcontroller, we would not want it to burn out, so by having a microcontroller that can handle larger voltages would be beneficial to the project. The Arduino mega does need to use Arduino specific functions to get it to function properly, but overall the microcontroller still uses a C bootloader.

The only disadvantage of the board is that while its features such as speed and CPU size can work well for the prototype, it may not be enough for the final product. When building the final device, ideally, we would like to speeds around 100 MHz, this microcontroller may be limited in providing those capabilities. Also, this board does take up a larger amount of space which could potentially have a negative impact on the size requirements for the project. Lastly, unless there are some input wires attached to the Arduino Mega that allows serial connection, the microcontroller can only connect to the user through a USB. For the final project we would like to be able to connect to multiple connection sources such as a UART port or an Ethernet port.

Even though the board may not be used in the final project, this particular microcontroller has quite a number of impressive features that make the team want to take it under consideration, or at the very least being able to find a microcontroller with qualities similar to that of the Arduino Mega.

Specification	Value
Flash Size	256 kB
Ram Size	8 kB
CPU Speed	16 MHz
Core Size	8-bit

Table 3.2.1.4.1: Arduino Mega Specifications

3.2.2 Microcontroller comparisons

The following section lists in further detail the additional features that some of the microcontrollers have. After looking at quite variety of microcontrollers we believe it would be best to narrow down the ones we considered. We will compare the top 3 microcontrollers that are under our consideration and list each of their features in the tables below. Several of these features include cost, packaging, speed and supply voltage.

	ATSAME70	AT32U3C3	CY8C54LP
Price per unit	$8.74	$9.28	$12.61
Package	64-LQFP	64-LQFP	100-TQFP

Number of I/O	44	45	72
Speed	300 MHz	66 MHz	67 MHz
Operating Voltage	3V ~ 5.5V	1.6V ~ 3.6V	1.71V ~ 5.5V
Resolution	A/D 5x12b, D/A 1x12b	A/D 11x12b, D/A 2x12b	A/D 1x20b, 2x12b D/A 4x8b

Table 3.2.2.1: Microcontroller Comparisons

3.2.2.1 Cost

When picking a microcontroller, it is important to take cost into consideration. As development begins for the device, it will be important to have the microcontroller we want to use with us as well as several back up microcontrollers if we run into any issues during development. So, it would be in the team's best interest to pick a microcontroller that isn't too costly so that we would be able to not have too much of a negative effect on the budget. For example, as shown in Table #, the CY8C54LP is the most expensive out of the 3 and while it has good features, it can also cost too much to order multiple amounts of the chip.

However, if the cost doesn't vary too much then either microcontrollers can be acceptable options. The AT32U3C3 costs more that the ATSAME70, but depending what other features ATSAME70 has, it can still be an acceptable microcontroller. Although when focusing on cost, the ATSAME70 would be the better option. Overall, cost can still be one of the many important factors to look at when deciding the final microcontroller for the project.

3.2.2.2 Packaging

An additional factor to look into when selecting a microcontroller is what type of packaging it has and how many I/O pins it has. Two of the microcontrollers both have a 64-LQFP (Low Profile Quad Flap Package) and one of them has a 100-TQFP (Thin Quad Flat Package). In both types of packages, our primary concern is the amount of pins each microcontroller has. In our design, we would prefer for it to have enough pins to allow additional hardware components such as buttons and LEDs. However, we don't want too many pins so that it would make it difficult to solder the device to the PCB. For example, CY8C54LP has a good number of I/O pins to allow additional hardware, but since it has 100 pins, it may be a challenge to add to the PCB design. Despite the differences in the packages, all 3 microcontrollers have some variation of the QFP package. While there are other packaging options out there which we prefer to stick to the QFP as it'll be easier to mount onto the PCB with its lead pins. When deciding a microcontroller, we'll need to know how many pins are available as well as the packaging type.

3.2.2.3 Speed

One other important factor to look at especially when selecting a microcontroller is speed. As mentioned earlier, we would like our device to transfer data at high speeds. Having a microcontroller with a high speed is an especially important criteria for having the project work well because we would want the laser to move at high speeds to successfully transfer data over. All 3 of the microcontrollers here each have speeds that would work really well for the project, but the one that has the high speed out of all the three is the ATSAME70 microcontroller, which has a high speed of 300 MHz. Although having high speed could possibly restrict having other features on the microcontroller, so when looking through the microcontrollers, we'll need to see if there are big feature restrictions from having a high-speed chip. Even so, speed will still be an important factor to consider when selecting a microcontroller.

3.2.2.4 Operating Voltage

Another factor that determines what to select in a microcontroller is its operating voltage. With our system we would want for it to operate at a low voltage while still being able to take higher voltage values. It would be nice for our system to be able to be powered by smaller voltage devices while also being able to be powered by devices that deliver higher voltages. For example, with the CY8C54LP microcontroller we have an operating range of 1.71V ~ 5.5V, this will allow the system to take higher and lower voltages. That example would be meeting the operating voltage requirement well. Overall knowing the amount of supply voltage, a microcontroller could have an important effect on our PCB.

3.2.2.5 Data Converters

One of the most important requirements we look for in a microcontroller is to make sure that it contains both an ADC and a DAC. Once we have both of those, we would like to know what is the resolution of both converters, meaning the number of bits they have as well the number of channels they both have. For example, as shown in Table #, the ATSAME70 chip has a 12-bit ADC with 5 channels and a 12-bit DAC with 1 channel. For this requirement, it would be preferable to pick the data converters with the highest bit number and most channels. This would be preferred so we can send and receive as much data as we can in one cycle. Between the three microcontrollers listed in the table above, the AT32U3C3 chip would be the better option for data converters, however all three could be acceptable for the final project.

3.3 Complex Single Board Computers

A single board computer is a full-fledged computer (an ARM processor, RAM, storage, and IO ports) that is on a small single board. They are different than microcontrollers in that they can run a full-fledged OS such as Linux and can be interacted with and be used to themselves to develop software (We don't need to plug them into another machine). A microcontroller on the other hand is merely a board that, once programed, executes a single program. They are used for a myriad of tasks, including small servers, software development, education, or even as a quasi-microcontroller themselves. If we need the power of a full time-sharing operating system like Linux, this may be the correct way to go. There are many examples of single-board computers, but the most popular one is the Raspberry Pi, which is discussed below.

3.3.1 Raspberry PI

Figure 3.3.1.1: Raspberry Pi 3 Model B+ (33)

The Raspberry Pi is a single-board computer the size of a credit card that was introduced in April 2012 (48). It featured multiple USB ports for connecting peripherals, an HDMI port for connecting to a TV or monitor, and a generous amount of general-purpose input/output (GPIO) pins that allowed it to connect with a host of devices, from cameras to temperature sensors. In addition, its price point was extremely low, at 35 Euros at most.

After great success, the developers launched successors with more USB ports, a quad core CPU, Bluetooth support, and additional RAM as well as an even smaller and cheaper version known as the Pi Zero. The specs of the current model (Raspberry Pi 3 Model B+) are in the table below (33, 31).

Raspberry Pi 3 Model B+ Specs	
SOC	Cortex-A53 64 bit @ 1.4 GHz
RAM	1GB LPDDR2 SDRAM
Wi-Fi	2.4 GHZ and 5 GHz IEEE 802.11.b/g/n/ac wireless LAN

Ethernet Speed	300 Mbps
Power over ethernet	Yes
Bluetooth Version	4.2
I/O	4 USB 2.0 ports, HDMI, Camera port, Display port (for small touchscreen display), microSD, 4-pole stereo output and composite video, 40 pin GPIO, 5V/2,5A DC power input

Table 3.3.1: Raspberry Pi Specifications

Given that the specs resemble a smart phone from a few years ago (the Cortex-A53 was used in several over Qualcomm's Snapdragon processors) as well as the ability to install Linux, the PI is certainly capable of a host of applications, and has been turned into a retro game console, media center, Netflix player, video surveillance, and numerous additional applications and personal projects.

It also features several programming languages installed (Python 2 and 3 for example). However, unlike the MSP 430's, there isn't a built in ADC, meaning that we'll need to purchase one separately for prototyping, and we may not necessarily need the power of a full OS for this project. More investigation is needed to determine if this is the best solution to creating our product.

3.4 Market Analysis

Market Analysis is one of the most critical points when doing a development of this magnitude comes into play. Due to the investor wanting to develop something that the whole market is interested. This means that the higher of the popularity of this development, the better off it will be. Remember, no one wants to invest in something that no one wants to buy due to the fact that if the product is being develop, then the whole point is to sell the equipment to the public. If the public does not want it or think that it is useless, then the resultant of this such product will be just a waste of money and resources. This then dive into the point of the market Analysis. Sometimes, it does not need something outrageous to be change to make a new project. Innovations happen most of the time by seeing the old product and analyzing it what to do to improve upon it. This is where engineers then noted that current market items are great but there can be a touch to make it innovative. Most of the innovation that are coming up will be computers. Back when the computers were being develop, they took a whole room to run one single Operating System.

This brought a notion that Throughout the development of the computer age, everything has been transferring thru cables from point a to b. Nothing was wireless as wire was an easy resource to obtain. If damage, just swap it and it should be good again. There was little to no code involve to this which was great as the more innovative contain a whole team of computer science and engineers to develop the knowledge of this equipment as code is what tells hardware what to do. This is why a standard, Universal Serial Bus (USB) will be easier and cheaper to develop at the time when it was invented.

Market analysis is defined as “a quantitative and qualitative assessment of a market. It looks into the size of the market both in volume and in value, the various customer segments and buying patterns, the competition, and the economic environment in terms of barriers to entry and regulation.”

The size of the market for this technology is enormous once it is perfected. Section 3.1 discussed the current products that implement this technology, of which there are none at the consumer level. However, it also discussed NASA’s project in 2013, where they were able to successfully achieve a transfer rate of 622 Megabits per second from a station located in California to a satellite orbiting the moon (29). That is more than 60 times the average internet speed in the United States at the time (46). If this technology could be implemented by Internet Service Providers (ISP’s), customers in the US would reap enormous benefits in internet speed (the current average speed in the US is around 20 Megabits per second) (46).

Additionally, this was done with a directed laser beam to a moving target, meaning that this technology is there for aiming this laser beam where the source and recipient are either stationary or moving in a predictable pattern such as an orbit. Thus, an ISP could mount satellites on the roofs of its customers and then beam the signal from a central location directly through open air. Alternatively, a telecommunications company could use laser communication between cell phone towers for faster communication. Currently, they are connected using either physical wires that run underground or through a wireless antenna signal if the ground connection is weak. Given that this technology is significantly faster than typical wireless signals and arguably faster than fiber optic wires, it could increase the speed of communication.

Unfortunately, this technology has many issues that make it unviable to implement in cellular devices (See section 4.2.10 for these). The short answer is that the laser beam must be precisely aimed at the receiver, which is simply impossible to do with an unpredictably moving device such as a cell phone. Thus, the target market for this technology is ISP’s and telecommunications carriers themselves rather than individual users.

There are several roadblocks to success in this area though, chief among them being regulation and competition with other ISP’s. Due to the extremely high startup cost of an ISP combined with the expenses of the various permits that need to be applied for, it is extremely difficult to break into this market, to the point where even Google has struggled dramatically with Google Fiber (41)

Due to the physical space needed for telecommunications and internet service (underground wires, cellular towers, and anything above ground on power lines), construction costs can increase by as much as 20 to 100 percent due to the necessary permits (40). In addition, many ISP's have been granted either local monopoly or duopoly by municipal governments, which means that some city laws would need to be changed for a newer company to get off the ground, even if this technology requires significantly less physical space.

Additionally, competition will be fierce in these areas, since even though outright price collusion between multiple companies is illegal, companies often have unofficial "don't rock the boat" policies, where they realize that rather than cutting into profits with constant sales and promotions to incentivize customers to switch, they can all overcharge and the customer will be forced to pay since they need internet. As of March 2014, 37% of Americans have only two wired broadband providers, 28% have just one, and 2% have none (46). It's no wonder the average speed in America is so slow (20mbps see (46)), as companies have little incentive to improve their service. In fact, many companies will be making their service worse by pushing for the fall of net neutrality, and 100 million Americans will be unable to choose a different company (47).

Due to the power of this technology and the expenses in rebuilding infrastructure, companies could even cut their prices to the point of losing money in the few areas where it launches in order to bury the technology so they don't have to improve their networks.

3.5 Relevant Technology

While constructing the device there are several other important pieces of technology that we use for the device. Each of these components have different capabilities and consists of multiple hardware and software components themselves. It is important to know how they work so that the device is the successful product.

3.5.1 Texas Instruments Spectrometer

Figure 3.5.1.1: TI Spectrometer

One important device that can be used in the project is a spectrometer provided by Texas Instruments, as shown in Figure 1. For the final project, we need to have an output device that contains data and have our transmitting device extract the data to send over to the receiving device. The spectrometer can scan a sample of a certain item such as food or pharmaceuticals and collect data on it. We can then connect the spectrometer with our device to be able to send the data over to the microcontroller. This spectrometer can connect to any device through USB or Bluetooth connectivity. This spectrometer costs over $1000 and will be provided to the group by Texas Instruments for the use of this project. This spectrometer could be one of many different types of data collecting devices that we could connect to our high frequency communication device. Further study on this device will be needed though to know how the spectrometer handles data. This will be important so the software of the device will be able to take all the needed information from the spectrometer

3.5.2 Storage

One additional piece of hardware that we will be having for the device is storage, which will be mounted on the PCB and be used to store additional data from the device during error states.

If there is an error in transferring, this will be used as a backup to store data so that it is not lost forever. There are several factors to consider when selecting a drive, chief among them being the choice between a hard disk drive (HDD), solid state device (SSD), an SD card, or integrated flash memory. To narrow the options, we first need to understand the physical size of the data that we are dealing with. If the data is quite large and a large backup is to be kept, integrated flash memory is not an option, as it is simply not large enough at a reasonable price to serve our needs. Henceforth, we will operate under that assumption.

Thus, the decision falls to choosing an HDD or an SSD, with each having their own pros and cons. HDDs utilize a physical magnetic disk to store information and a spinning head to access this data, while SSDs utilize NAND flash memory, much like flash drives (24). As a hard drive has moving parts, they are vulnerable to sudden impacts as well as general wear-and-tear over time. While it may seem that SSD's are superior in reliability, the technology they utilize to store information is not permanent, with each cell having a limited amount of read and write cycles, and given that the maximum storage is lower, means those cycles are used more often on average (24).

The second consideration between the two is the performance. Since SSD's use electrical cells rather than waiting for a disk head to seek, they are considerably faster with the average SSD having 4 times the read and write speeds (24, 25). Furthermore, SSD's with a PCIE interface are 15 to 25 times faster (24, 25).

The final consideration is the cost of the SSD, which are anywhere from twice to four times the price for the same amount of storage. At the time of this writing, a one terabyte SSD on Amazon is $162.99 (25) while a one terabyte HDD on amazon is $45.99 (26). A PCIE one terabyte SSD is an astronomical $294.79 (27). All 3 hard drives are pictured below.

Figure 3.5.2.1(a)(b)(c): `Top left: magnetic disk drive (25). Top right: SATA SSD (26). Bottom: M.2 PCIE SSD (27)

3.5.3 SD Cards: a viable alternative?

Keen readers will notice one form of storage that has not been discussed yet: SD cards. This is initially confusing, as SD cards are much smaller than all previously mentioned forms of storage besides built in NAND flash memory. In addition, SD cards have been increasing in speed over the last few years, with some of them even reaching similar transfer speeds of older SSD's. Since those SSD's were capable of running a full-fledge system back then, would it be theoretically possible to use an SD card for our purposes, as it's much simpler than a full computer?

Unfortunately, SD cards have several problems that end up being deal breakers. First of all, the price per transfer rate ratio is quite high, as most faster SD cards also provide additional storage, which increases the price. For example, a 64 GB 300 MB/s Sd card has a list price of nearly 200 dollars (it is on sale for $109.95 at the time of this writing). Meanwhile, a much faster 500 GB Samsung SSD has a list price equal to the SD card's sale price and is currently on sale for only $73 (71, 72).

There are also several other issues. The considerably larger footprint of SSD's has many advantages. SD cards are generally much warmer than SSD's due to limited heat dissipation because of their smaller footprint and the fact that they are near completely enclosed in an SD card reader when in use (70). SSD's also use their additional physical space and increased heat dissipation to house an army of intelligent circuits and caches that increase speed dramatically (70). The reasoning for this is that SSD's are divided up into a cluster of memory chips that each store a subset of the total data. Several additional chips and memory controllers dictate which of these memory chips incoming data will be stored on, which provides some advantages.

Since the average size of each memory chip is reduced and is roughly similar to the others, the average read operation is faster, as there is less data to parse through to search for the correct address. In addition, evenly distributing the "load" between the chips allows them to work more efficiently in parallel. Finally, these chips have a finite life span, so evenly dividing them up gives the greatest odds that one will not fail prematurely (this can be catastrophic for the drive and the memory within it). The caches are also quite useful, as the controller chips will use an algorithm to find the most recently/frequently used information and store it in the cache (73). Since the cache is both physically faster and smaller (less time to parse), it is much faster than the rest of the storage in the SSD, and since it is so small, the worst-case cache miss runtime is not much worse than the standard runtime of a caches SSD (73).

Due to the form factor of an SD card, there is no guarantee that these chips are present as they are power hungry (and will generate more heat) and relatively large compared to the SD card size, resulting in the storage space within being used unevenly and inefficiently, which is quite problematic.

The greatest evidence of the issues with SD cards is that no reputable company has ever used them to store core system files on for their devices. For example, nearly all mobile devices that require small form factor storage will generally place the operating system and crucial/frequently accessed software components on internal flash storage and will use SD/microSD storage for larger data files (easier to find) that are not accessed as often. Android devices don't even allow for most apps to store their core files on an SD card by default, and the workaround ("Adopting SD Storage") is prone to numerous issues that causes crashes and slowdowns if the SD card slow is not in a "stable location" (74, 76). iPhone have not featured SD card support from the beginning, and more and more Android phones are dropping the feature as well in favor of more internal flash storage as prices continue to fall (although this also allows them to charge more for extra storage) (75, 76).

In conclusion, an SD card will simply not be viable even for our purposes. Even if they were competitive in terms of performance to modern SSD's, their price point still renders them unattractive.

3.6 Developmental Tools

While working on the device, there are several different tools that can be used for the development of software and hardware when constructing the device. By having the right tools available to us, programming the software of the microcontroller will be much easier on the team.

3.6.1 Integrated Development Environment (IDE)

When ordering the microcontroller, it will list a recommended IDE that we can use for it. The IDE is a software application that has a built-in code editor and has several debugging features. When programming the software for the device, we will need to load that code into the device, connect the device to the computer, and use the IDE to debug it. Currently for IDEs there are three that will be most relevant to the team, Code Composer Studio, Arduino IDE, and Atmel Studio 7.

3.6.1.1 Code Composer Studio

When building the prototype with the MSP430 microcontrollers, we will use Code Composer Studio as that IDE. Code Composer was originally created by a company known as GO DSP in Canada, but was acquired by TI in 1997, upon which Studio was appended to its name (49). Eventually, it was merged with another IDE that TI was developing named Code Composer Essentials (designed for use with the MSP430 series of boards) (49). After a subsequent rewrite, this IDE is the go-to first party software creation tool for the MSP 430 series of chips and is used in a host of computer engineering classes (including our own), which make it vital to us. It also allows the user to code in both C and C++, two languages that both computer engineers on our team have extensive experience in. For the final project, a different IDE may be selected if CCS is not compatible with the microcontrollers used.

3.6.1.2 Arduino IDE

If an Arduino micro controller is used, the Arduino Ide will be extremely useful to serve our purposes, as it is freely available, easily installable on Windows, MacOS, and Linux, and open source. The Arduino IDE is written purely in Java and supports both C and C++, which several of the members of our group have a large amount of experience in. "It also supplies a software library from the "Wiring" project, which provides many common input and output procedures. (61)

"The wiring project is also open source, and is an electronics prototyping platform that is made up of a programming language, an IDE, and a single board microcontroller (such as an Arduino)" (62). It is a cross platform application written in Java that helps to introduce programming and sketching with electronics to artists and designers. It even features a code editor with features such as "syntax highlighting, brace matching, and automatic indentation capable of compiling and uploading programs to the board with a single click (62). For our purposes, The IDE includes a C and C++ library known as Wiring, which abstracts common input and output operations for us, A program only needs two functions in order to run, those being "setup()", which runs once at the programs initialization to define environment settings, and "loop()", which is true to its name as a function that is repeatedly called until the board is powered off or reset (62).

One of the limitations of Arduino IDE is that since it is more of a simpler IDE, it will be limited in several features such as debugging. While this IDE can be useful in prototyping, it may not be able to be used in the final product.

3.6.1.3 Atmel Studio 7

Atmel Studio 7 was taken under consideration because of its compatibility with microcontrollers manufactured by Microchip Technology, such as the ATSAME70 and the AT32U3C3. Similar to most Code Composer Studio, this IDE features a C/C++ compiler, a language most familiar to most of the team members. It also comes with many advanced debugging capabilities such as complex breakpoints and the ability to view into the peripherals of the microcontrollers. This will be beneficial to the team as we may need to see if each of the microcontroller pins are being properly connected to the PCB hardware. This IDE also is great to be used for low power designs. By using the Data Visualizer plug-in, the runtime power can be displayed from the IDE, which can help us ensure that the device runs on low power.

Additionally, this IDE is also compatible with microcontrollers that have AVR applications such as the Arduino. When conducting additional prototyping with Arduino development boards, we may use Atmel Studio 7 to test our code. This will also be of good practice to the team to be more familiar with all of Atmel Studio features as that may be the tool to do further testing for when the software testing the final project begins.

The only disadvantage that comes with this tool is that learning of all of its new features will take time for the team to master. This tool is used for more professional purposes, so it is larger in size and will have many features to learn about. Overall, this IDE can be a great benefit to the team. Given the advanced capabilities of all the microcontrollers under our consideration, this tool can allow the team to properly utilize all those features.

3.6.2 Soldering Iron

A soldering iron is an extremely useful piece of equipment that uses heat to melt a wire into liquid, where it adheres to circuits and electronics and then rehardens as it cools. Since the metals used are both highly conductive (both thermally and electrically), this is a perfect way to (semi)permanently attach two components of a circuit together to avoid faulty or noisy results from a weak connection. The processes are also reversible, where the solidified metal can be simply reheated, causing it to melt into liquid and releasing its grip on the components.

The Texas Instruments Innovation Lab at UCF has several soldering stations available for use, but they can also be purchased online or in stores in various outlets, with prices increasing if the user wishes for more temperature control or higher quality materials. At the time of this writing, a basic and highly rated soldering station can be found on Amazon. It is known as the “Weller WLC100 40-Watt Soldering Station” and is priced relatively inexpensively at $38.37 (15). Soldering wire by Mudder can be found on the same site for only $10.99 (16). Both are pictured below.

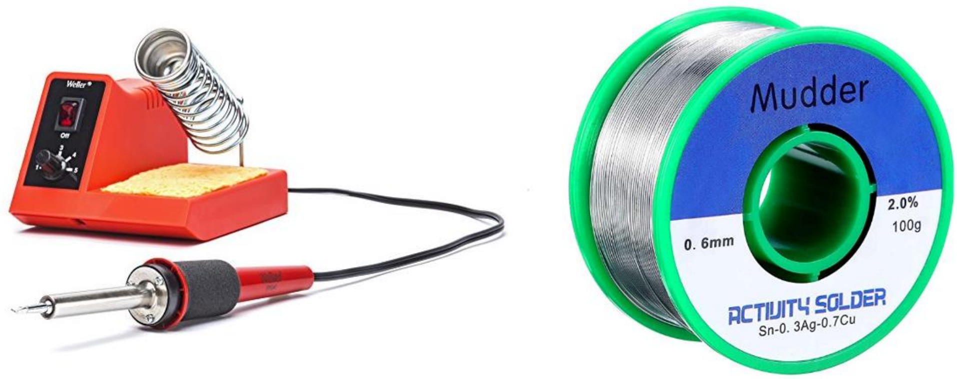


Figure 3.6.2.1(a)(b): Soldering tool and Soldering wire

3.6.3 Oscilloscopes

Oscilloscopes are used for inspecting waveforms at important points of the circuitry used within this project. They are also useful for inspecting the frequency components of signals as well. Having a visual of current and voltage within a circuit makes it possible to quickly inspect the continuity of a circuit and check demonstrable values with theoretical ones that are simulated.

3.6.4 Function generators

Function generators are being used throughout the prototyping and design phase of the project for quickly creating waveforms to test circuitry, and optical transmission. Having a function generator handy allows hardware design to progress without needing computer code to process and handle data. Direct digital synthesis (DDS) generators are used to generate arbitrary digital waveforms. These function generators will also be used to ensure transmission quality wherever there is a digital channel in our circuits.

3.6.5 Cymometer

A cymometer is also available for use to quickly identify unsorted electrical components. This is a highly useful tool to have when prototyping electronics within our lab environment. As well as identifying components, it also has the capability to display basic information on the components beyond passive RCL parts.

Figure 3.6.5.1: Cyclometer

Figure 3.6.5.1 shows the cymometer available. It is based off of the ATMEGA328 microcontroller. It offers the ability to test and list certain specifications for components by either using the surface contacts or DIP socket.

3.6.6 Multimeters

Multimeters are also an essential tool for any circuit prototyping. During development there will have to be constant checks on the circuit for expected values. This instrument will also still play a critical role after electronics are soldered to PCB for final testing. Models are available that offer a multitude of features like RCL characterization, continuity testing, AC and DC signals for voltage and current as well as true RMS readings.

3.7 Serial Communication Technologies

When constructing the device, it is important to take into consideration how data will be transmitted and received within the microcontroller, this is when we take a look into serial communication. Serial communication is where data is sent to devices one bit at a time. The integrated circuit that allows the serial communication to occur is the UART, while the different protocols of serial communication are SPI and I^2C. The serial method of communication may take longer to send data than parallel communication, which sends multiple amounts of data at a time, but serial communication is more reliable way to send data and can be cheaper to implement since it requires less pins.

3.7.1 SPI

The SPI (Serial Peripheral Interface) is a bus that allows communication between the microcontroller and the peripherals of the microcontrollers such as sensors and analog to digital converter modules. Within the embedded system there is a master device, the micro-controller, and multiple slave devices as shown in Figure 1. What's unique about this technology is its ability to generate clock signal when transmitting and receiving data. This clock signal allows data to be transferred at the same rate. Having this will work well for the device because when data is getting transferred over or received, the team will want everything to be sent over at a consistent rate.

One disadvantage that will come with using the SPI is that the slave devices will only have a single master device. Any information one slave device needs from the other will have to come from the master device. Also, if we do use multiple slave devices, more wires will be required to make sure data gets sent over to the devices properly.

Regardless of the disadvantages, it could still be beneficial to use the SPI protocol for our devices. So, when looking for micro-controllers, it will be great to see if the microcontrollers support SPI communication.

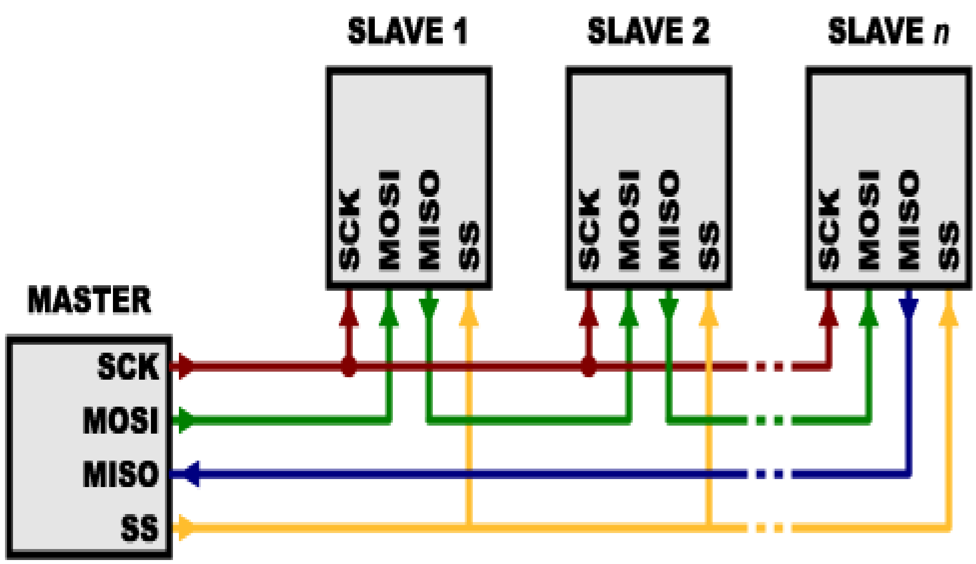


Figure 3.7.1.1: SPI Communication Permission Obtained Sparkfun

3.7.2 I²C

Similar to the SPI bus, I²C (Inter-Integrated Circuit) Protocol allows communication between master and slave devices and sends data at a synchronous rate. Unlike SPI, this protocol allows for multiple master devices to connect to the slave devices and only requires two wires to connect the master and slave devices, as shown in Figure 1. The two wires are represented as SDA, the data signal, and SCL, the clock signal. The slave devices that we will use may have different needs, so the I²C can help adapt to the devices needs.

One disadvantage of having to use this protocol is that it is a more complex than SPI or UART in terms of hardware. Also, I^2C uses pull-up resistors which will affect the clock speed of the device as well as take up PCB space. So even though I^2C can be used, it should be limited to save PCB space.

Overall, the high frequency communication device may be able to make use of this communication protocol. When selecting a micro-controller, we'll take into consideration that it can use this protocol.

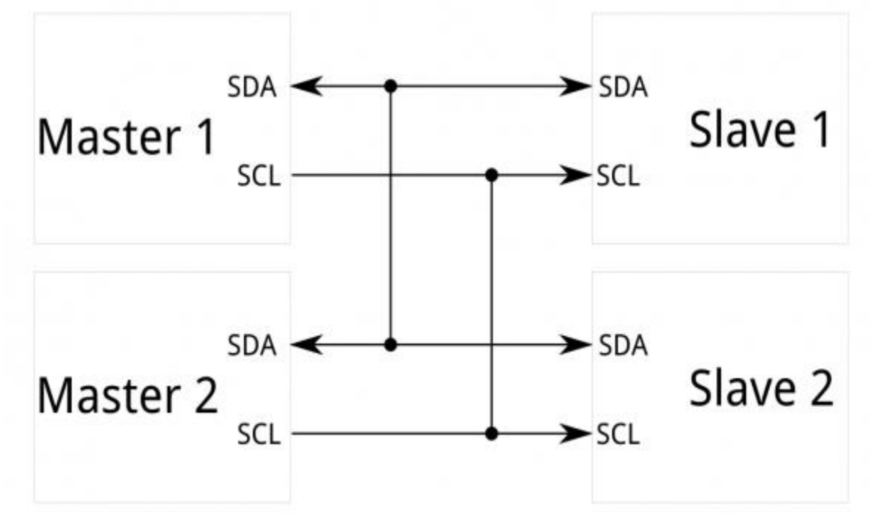


Figure 3.7.2.1: I^2C Protocol Permission Obtained Sparkfun

3.7.3 UART

A UART (Universal Asynchronous Receiver-Transmitter) is a piece of hardware that allows serial communication to occur. In Figure 1, the data bus and control pins use parallel communication, while the transmitter and receiver pins use serial communication. The serial communication it performs transfers data at an asynchronous rate meaning there is no determining how fast the data would get sent over at. UARTS send data over in the form of data packets. Each of the data packets has a start bit, a data frame, a parity bit, and a stop bit. Once the start bit is sent over, the UART will start to record the baud rate. The baud rate of the UART is the speed of the data transfer, measured in bits per second. Certain devices connected to a microcontroller can have UART connectivity, so it's a beneficial piece of hardware to have.

One disadvantage of the UART, that is different from SPI and I^2C, is that it doesn't support multiple master devices nor multiple slave devices. So, it will only focus on a single master device and a single slave device. Another disadvantage of the UART is that the baud rate of the transmitting and the receiving UARTs need to vary by only 10%.

Despite its disadvantages, it’s a good communication protocol to implement. One of the possibilities we may use to connect a PC to the microcontroller would be through USB to UART communication. The microcontroller itself will only have one USB module, so if we want to connect multiple output devices to the microcontroller, one way we may go about doing it is through a USB to UART connection.

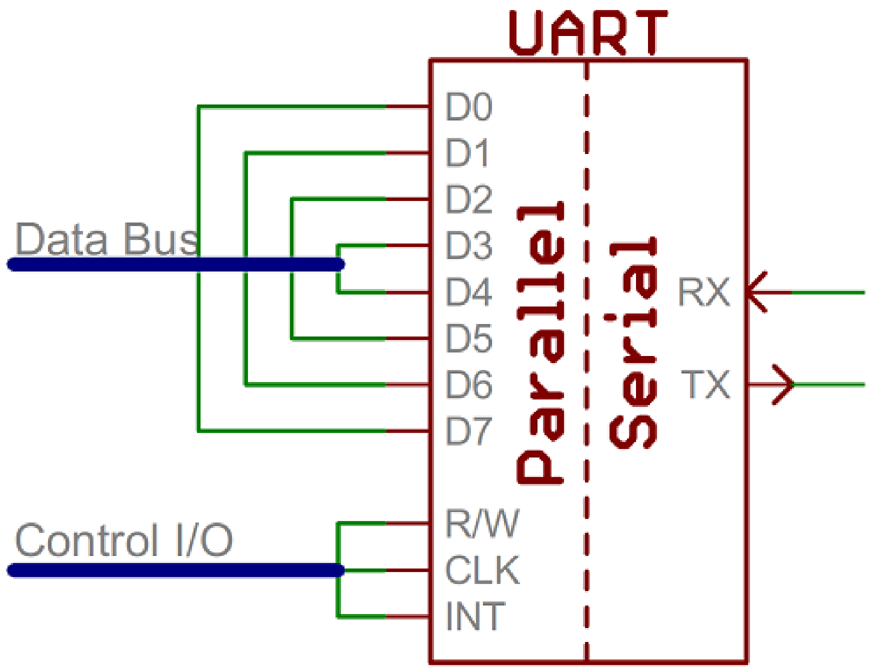


Figure 3.7.3.1: UART Permission Obtained Sparkfun

3.8 Photosensor selection

There are several different types of semiconductor materials that classify as being sensitive to incidental light. These devices have different benefits and drawbacks which must be considered when looking for a sensor for modulated laser communication. First, it must be sensitive to the incidental laser light that is being used to transmit information. Second, it must have a low enough capacitance so that the space-charge layer (SCL) can be depleted of carriers quickly enough to keep up pace with the modulation of incoming light. Third, noise level must also be considered as any information being received will not be useable if there is a poor SNR (signal-to-noise) ratio.

3.8.1 p-n junction photodiode

P-n junction photodiodes are the simplest photosensitive detector. The two sides composing the junction which are often group III-V semiconductor materials such as GaAs, InP, AlGaAs and other alloys which create an electric field throughout the junction. The electric field is created from ions that are held in place by the crystal structure of the diode. Incident light that is absorbed in the space charge layer where these crystal ions reside will generate electron-hole pairs (EHPs) that are swept to opposite sides of the diode which is usually reverse biased. These particle pairs are referred to as carriers, because they carry a charge, or lack thereof in the case of a hole. The absorption of photons and generation of carriers that are swept to opposing terminals by drifting in the electric field is what generates an electric signal in photodiodes. Drawbacks of the simple p-n junction include having a large depletion capacitance as well as a small SCL width. The large depletion capacitance limits the diode from being capable of high speed modulation due to the fact that charge carriers cannot be removed from the neutral SCL layer fast enough. The width of the netural region, which is at most a few microns in length limits the available bandwidth of incidental light that can be used as well as the electrical signal that can be read from any photogenerated current.

3.8.2 p-i-n photodiode

P-i-n photodiodes have no internal gain mechanism. This means that ideally, for every EHP generated, only one photon has been absorbed. The ratio of collected EHPs generated for every photon absorbed is referred to as quantum efficiency. P-i-n photodiodes can lightly dope the p-layer to tailor the SCL width to fabricate detectors that prioritize either bandwidth or response time.

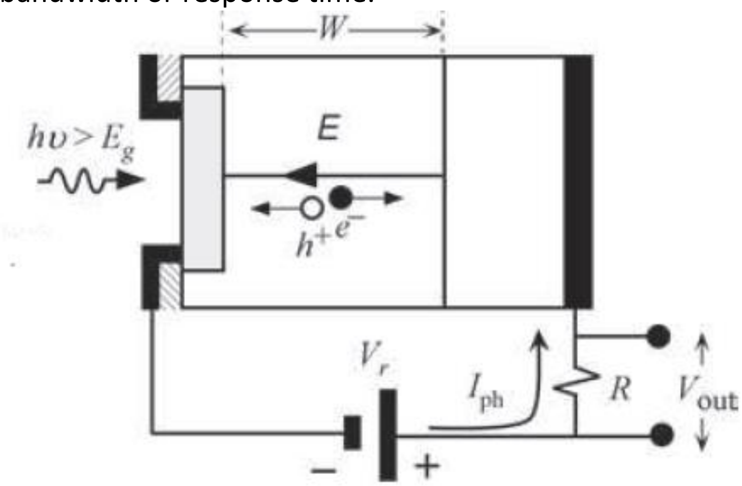


Figure 3.8.2.1 Simplified view of a p-i-n photodiode.

3.8.3 Avalanche Photodiode (APD)

Avalanche Photodiodes have one primary feature that make them very useful in many telecommunication applications. As the name implies, APDs have an internal gain mechanism which results from one photon being able to cause a series of electrons to be generated. Avalanche multiplication describes the event of one photon with enough energy to cause impact ionization within the semiconductor crystal lattice structure. The electron that was just ionized is then pushed within the drift of the electric field on its way to a terminal. It could make it all the way to the terminal contributing to useful current, but it can also gain enough energy and possibly cause another impact ionization. This process can repeat, and multiply leading to a sort of snowballing effect, hence the name and process of achieving gain. Looking at the diode as a whole, the structure wants to remain charge neutral so electrons drift and diffuse their way into eventually filling the holes left when impact ionization first occurred. The strong electric fields employed inside of APDs also implies that carriers drift with high velocity and thus APDs are also known for their high speed compared to other detectors.

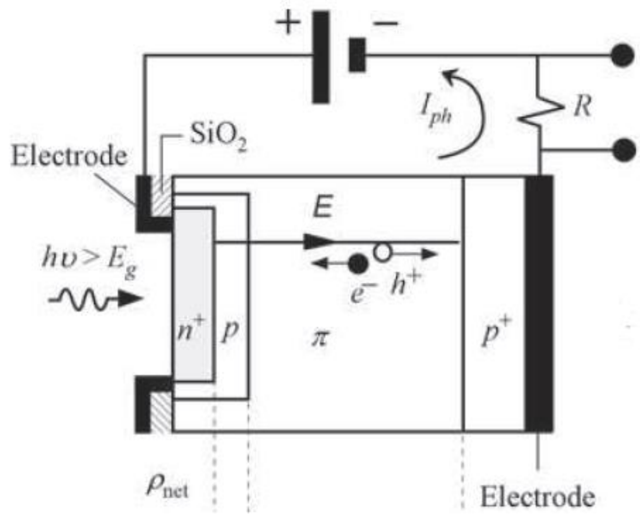


Figure 3.8.3.1 Simplified view of an APD.

3.8.4 Schottky junction photodetector

A Schottky junction photodetectors basic structure consists of a metal which is introduced to a semiconductor material forming a metallurgical junction. If a Schottky junction were to be employed as a detector it would be reverse biased in the receiving circuit. Incoming photons would lower the Schottky barrier enough in order for carriers to flow across the junction and provide current to the detecting circuit. The advantage of a detector in this configuration is that they can rectify current extremely fast. The type of contact used in a detector configuration is known as a blocking contact, or rectifying contact formed between the semiconductor crystal lattice structure and the metal. When in contact the fermi level is even throughout the device. The fermi level is an energy where there is a 50% probability of finding a majority carrier in an intrinsic material. When the detector is in equilibrium the blocking contacts prevent current from flowing in the backward direction, hence the name of a rectifying junction. Schottky junction advantages include low noise, good SNR and a very fast switching speed. The controlling voltage bias can increase or decrease the width of the SCL created and maintained by the use of blocking contacts and the built-in electric Schottky barrier created from ions in the semiconductor lattice structure. The tailorable width of the SCL is also what allows the bias to adjust the bandwidth and response time of the device. Across the barrier in the metal charges also accumulate, but are unable to surpass the electric potential barrier.

Having a large SCL width also means that there is a larger internal electric field in the device. The reason rectification and thus modulation can take place so quickly is that any electron-hole pairs that are generated will quickly be swept to their respective sides of the diode. Additionally, since there is little existing minority carrier injection from the metal into the semiconductor there is no requirement to wait for these carriers to diffuse back to their original side of the junction. Occasionally a carrier may receive enough thermal energy to surpass the junction barrier, but this occurrence is relatively low and this is what leads to a Schottky detectors low thermal noise.

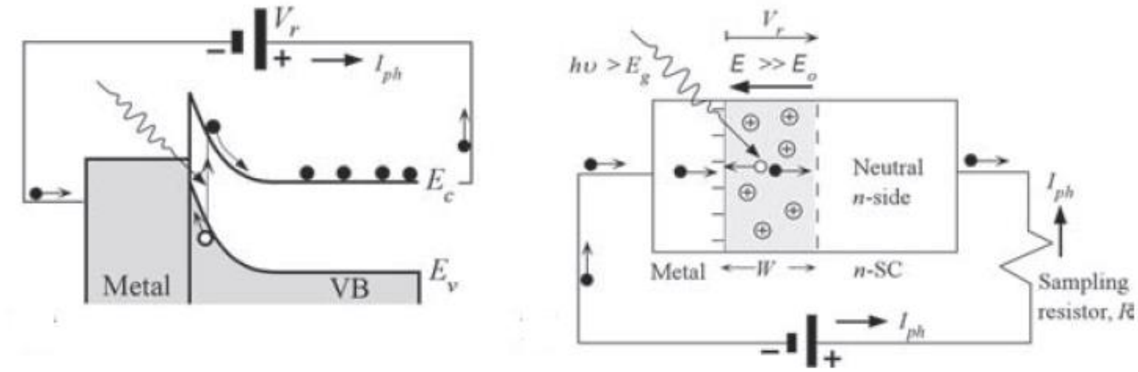


Figure 3.8.4.1 Band diagram (left) and simplified view of Schottky photodetector (right). These diagrams indicate incident light and EHP generation in the SCL.

3.8.5 Phototransistor

Phototransistors, like APDs, also exhibit gain. Much like a traditional transistor gain is produced in the base-collector regions where a space-charge layer exists due to the junction between them. The gain mechanism here, however, is due to EHP generation within the base-collector neutral region. The transistor wishes to retain its charge neutrality and when these EHPs are generated in the B-C region and separated they lower the potential barrier in the junction. This causes an increase in the emitter-base junction to retain charge neutrality. When the EHPs drift into a region in which it is a majority carrier, the imbalance created from its generation provides enough potential energy for carriers from the emitter region to surpass the potential barrier and recombine. The gain is created from the fact that only one of these carriers is needed to annihilate the EHP and the remaining carriers diffuse across the base to the collector which contributes to the useful current generated for the receiving circuit. One drawback of the phototransistor is that the gain results from the recombination lifetime exceeding that of the length of time required for the carriers to diffuse to the collector and emitter terminals. This means that the phototransistor will have a high response time arising from the need to deplete minority carriers from signal modulation which is not favorable in a detector that must sense high-frequency signals.

3.8.6 Sensor selection

Multiple vendors exist that can provide affordable options for sensors in this project scenario. The favored receiver as of the date of this writing is the FGA01 by ThorLabs. The primary reasons for selecting the FGA01 high speed photodiode is the fact that it has TO can style packaging which also supports a ball shaped lens. The specific reason that having receiver packaging with a lens is so beneficial is that it is much easier to focus light onto the 1.5 mm diameter lens than it would be .15 mm of the FGA015.

Figure 3.8.6.1 Photograph of the FGA01 featuring a ball lens to aid in collimation.

When choosing a sensor there are a few primary specifications that dictate what hardware will be chosen. First, the sensor must be sensitive enough to detect incident light from the laser beam at a long range. While a higher sensitivity in the receiver will let us achieve longer transmission distances, a lower incident beam power will force the receiver to amplify noise with the laser signal thereby reducing the signal-to-noise ratio (SNR). Sources of noise that are inherent with photodiode usage are dark current, shot noise and thermal noise. The receiver must also be reverse biased below threshold so that it will be sensitive enough to detect the IR laser beam directed towards it, but not too close as to signal noise as an incident wavefront of the beam. Second, the sensor must provide adequate bandwidth to transmit a signal of at least 10 MHz. Table 5.3.4 is a short comparison table that compares NEP, responsivity and rise and fall time. These three specifications are the primary factors being considered other than price when choosing a sensor for the project.

	NEP (W/Hz)	**responsivity (A/W)**	**Rise / fall time (s)**
FGA01	$4.5*10^{-15}$	1.003	$300*10^{-12}$ / $300*10^{-12}$
FGA015	$1.3*10^{-14}$	0.95	$300*10^{-12}$ / $300*10^{-12}$
FDG03	$2.6*10^{-12}$	0.85	$600*10^{-9}$ / $600*10^{-9}$

Table 3.8.6.1: Sensor Selection

The reason for considering these factors above all others is that it addresses our top priorities for the device. NEP dictates the minimum operating power for a 50% chance of a detector registering a 1 for an incoming bit or 0 for no signal. Responsivity dictates how efficient the sensor is at producing a useful electric current at the terminals for a given rate of incident photon flux. The rise and fall time of the detector determines the ultimate bandwidth of the sensor. The faster the sensor can respond to incident power, the quicker it can process data in a given period of time. This is important because the laser source will be modulated according to a certain clock cycle, transmitting information with the rise and fall of the clock signal. The reason for transmitting information in sync with a predetermined clock signal is to ensure that a sending and receiving unit will operate harmoniously. Software must be able to recognize incoming information and it processes information received by sending synchronize and acknowledgement packets of information, commonly referred to as (SYN/ACK). Knowing the sequence of bits for these packets is required, and it is the clock signal that defines the timeframe for the specific sequence of bits to be sent and received.

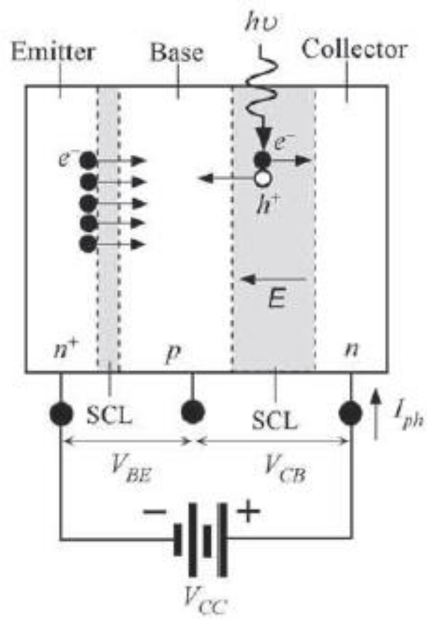


Figure 3.8.6.2 Simplified view of a phototransistor

3.9 Light source selection

Selection of a light source for high-frequency modulation warrants a detailed inspection of the variety of light sources currently available. This section will expand upon the most commonly known and accessible light sources and highlight the fundamentals of operation responsible for light emission. Each type of light source will also have their various advantages, disadvantages and key differences mentioned.

3.9.1 LED

The LED is the most well-known of all electrically stimulated man-made devices. Many different types of LEDs exist which can in some cases provide the same function as a laser diode.

LEDs are simple in structure and easy to fabricate for this reason. Just as a regular diode, the simplest type of LED also consists of a crystal junction with different levels of dopants on each side. The energy bandgap allows direct transitions of electrons from the conduction band down into the valence band. This direct transition preserves the momentum of the electron, so when the electron falls into the lower energy orbital of the valence band a photon is emitted with the same energy as the bandgap of the material the transition took place in. It should be noted that this stimulated emission of light is spontaneous, and not amplified. This means that LEDs emit many "colors" of light simultaneously, so the emissive linewidth of light is very broad in spectrum as indicated in figure 3.9.1. This allows two critical differences between LEDs and lasers to be contrasted. One, the emissive linewidth of a laser is narrower than that of an LED. Two, this narrow linewidth also means that if only one frequency of light is desired that there is no wasted power in radiated light emission.

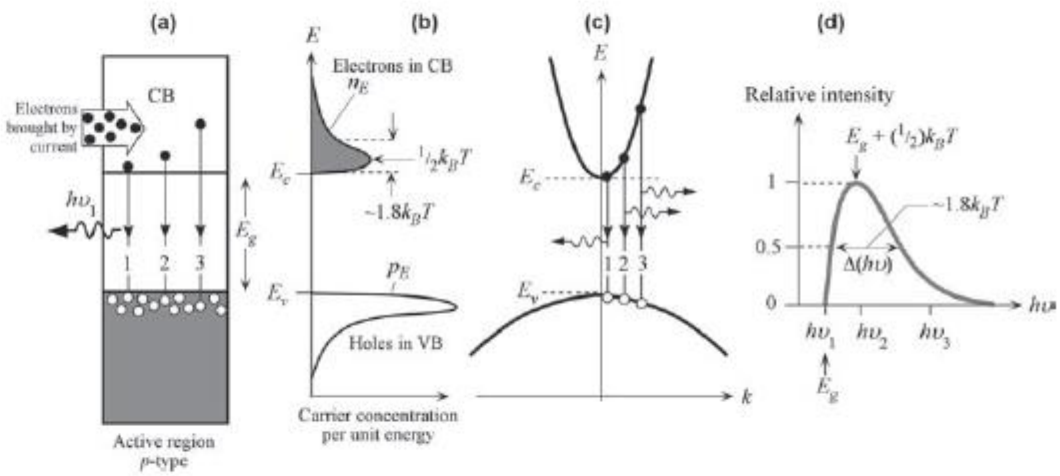


Figure 3.9.1.1 – a) shows that electrons can drop from different energies into the valence band indicating emitted light is not monochromatic. b) carrier distribution with respect to energy level c) energy-momentum graph d) power output spectrum which correlates carrier concentration with frequency of output light.

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A traditional LED based solely on a p-n junction is relatively inefficient, thus different structures have been tailored that harness the spontaneous emission phenomenon LEDs are known for. Interestingly, some of these structural and compositional changes to the material in LEDs can also be applied to laser diodes! A short list of such devices are as follows:

- Single quantum well LED
- Multiple quantum well LED
- Homojunction and heterojunction LEDs
- Phosphor LED
- Organic LED
- Quantum dot LED

- Superluminescent LEDs and resonant cavity LEDs

Obviously a thorough review of all LEDs available is outside the scope of this report. Luckily, because some of these variations to a typical p-n junction in an LED are also utilized in lasers they will be explained in the subsequent sections covering lasing source selection.

3.9.2 Fabry-Perot semiconductor laser diode

The Fabry-Perot laser diode is typically a solid-state semiconductor laser. The “mirrors” forming the resonant cavity are conveniently provided by the tendency of semiconductor crystal lattice structures to be cleaved along one of the crystal planes of the material. This means that mirrors for the active region in diodes can be made with remarkable precision very easily. A key part of the structure in a Fabry-Perot diode structure is an intrinsically doped layer between a p-region and n-region. This intrinsic region that is sandwiched between the p-n regions is also known as the: active region, optically active region, optical cavity, gain layer or gain region and sometimes waveguide. Typically, these are edge emitting lasers as illustrated in figure 3.9.2.1a, however some can emit vertically through the semiconductor layers, which will be explained in section 3.8.3. A potential drawback from edge emitting sources is the astigmatism of the beam profile as plotted in figure 3.9.2.1b. Typically, cylindrical lenses are employed to help correct for the discrepancy in the respective beam divergence angles. In applications where single-mode operation is desired, the height H in figure 3.9.2.1a can be reduced so that only the fundamental transverse electric mode (TEM_{00}) is supported by the cavity. By sizing the layer so that it approaches the free spectral range as indicated in 3.9.2.2b, the cavity is only able to support one standing mode, resulting in single-mode operation. The structure of the waveguide allows standing waves of light to resonate within the cavity as in figure 3.9.2.2b while the material in which gain is induced selects which modes are amplified. The result is a convolved output of the two functions and a possible output from the laser is represented in 3.9.2.2c.

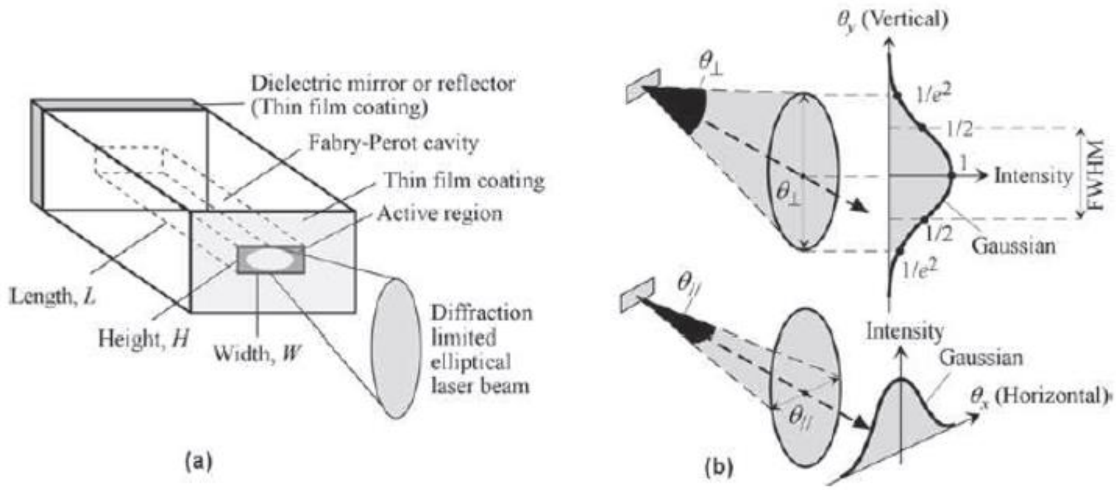

Figure 3.9.2.1 – Illustrations of simplified Fabry-Perot semiconductor laser and astigmatism from geometrically induced astigmatism. Optoelectronics and Photonics 2nd ed., S.O. Kasap

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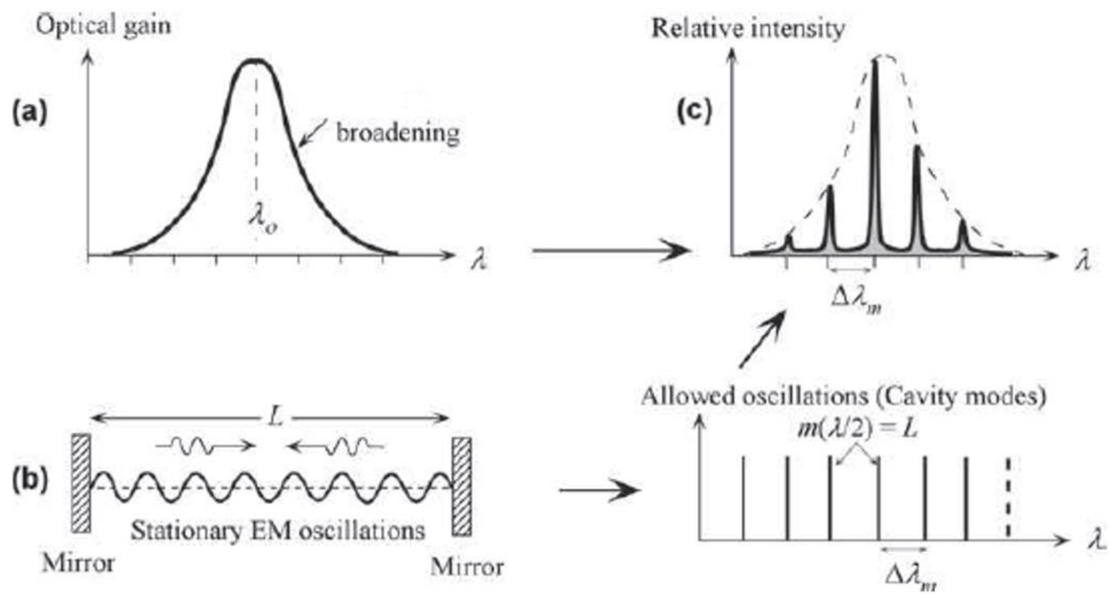


Figure 3.9.2.2 – Graphs showing gain curve of diode and supported modes within resonant cavity. Optoelectronics and Photonics 2nd ed., S.O. Kasap

One benefit that semiconductor lasers in general exhibit is that they are easily electrically pumped. Structure of a semi-conductive optoelectronic device alone could make it very complicated to determine if it was a laser or LED. The key to distinguishing the two seemingly similar devices is to understand the phenomena by which each generates and harnesses light. Simply put: lasers use amplified, stimulated, coherent light; and LEDs use light from spontaneous emissions that radiates in random directions. The stimulated emission from a laser arises from electrons in the gain medium rising to a higher energy orbital and then being forced back down by an incident photon as illustrated in figure 3.9.2.3a.

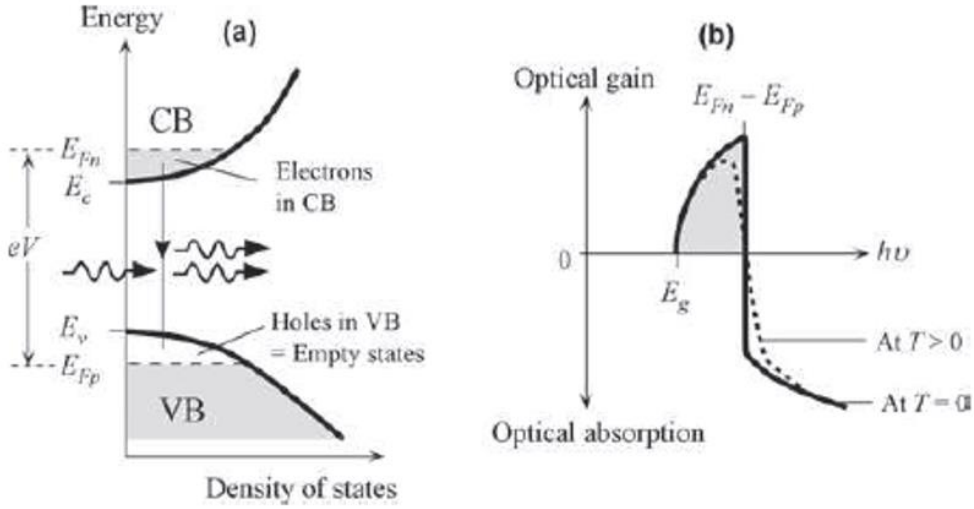


Figure 3.9.2.3 - Optoelectronics and Photonics 2nd ed., S.O. Kasap

The incident photon continues on, while the electron now in a lower energy orbital has emitted a photon of exactly the same direction and phase of the incidental photon. This process repeats itself leading to amplification and coherency of light through these photons that resonate and replicate throughout the gain medium. Of course it is possible to have other radiative processes amplify within the cavity which results in noise, or multi-mode operation of the laser. If photons exist within the gain medium of energy greater than the difference of the fermi levels of the diode as plotted in 3.9.2.3b, they are likely to be absorbed and contribute to population inversion. Of course population inversion effects the refractive index of the material, which also has the effect of gain guiding. The ability to easily electrically pump and generate gain guided within semiconductor material that can be cleaved and etched reliably to the nanometer scale allows laser diodes to reach increasingly small sizes making them perfect for any application prioritizing weight, size and power. Many modern lasers are some type of double-heterostructure crystal diode to provide carrier confinement as shown in figure 3.9.2.4, resulting in increased luminescent efficiency and wall-plug efficiency.

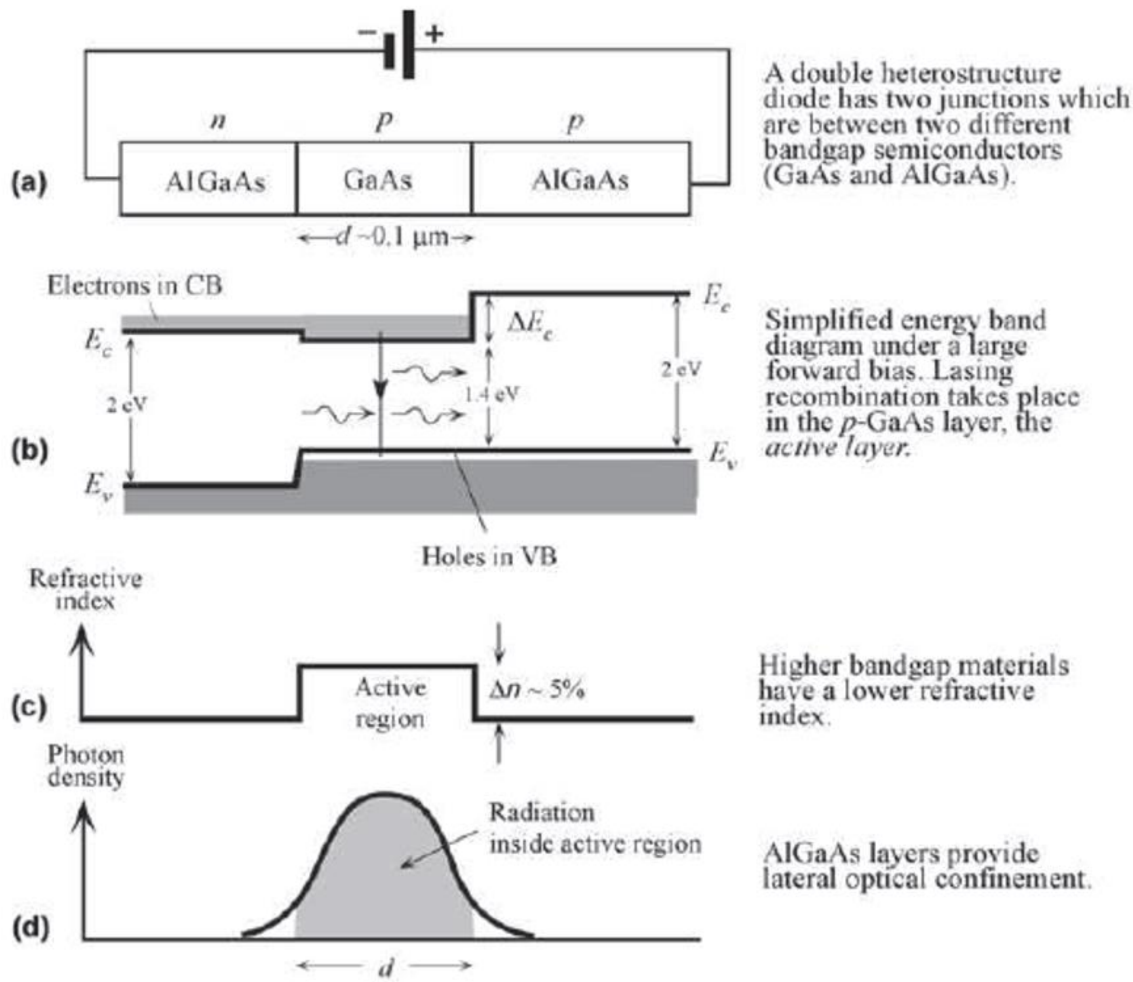


Figure 3.9.2.4 - Optoelectronics and Photonics 2nd ed., S.O. Kasap

3.9.3 VCSEL

Vertical cavity surface-emitting lasers, or VCSELs work in a fashion just like a Fabry-Pero resonant cavity. The difference in this device is that the material layers that form the "mirrors" for the light in the gain medium can be altered such that reflection and transmission is adjustable. Just as reflection and transmission can be altered at the boundary of the gain medium and confining layers they can also be tailored throughout the device. This is what allows engineers to guide light in one direction and not the other, thereby increasing power output in a controlled manner. Photons generated in the gain cavity that travel through other layers of semiconductor material can do so because the bandgap of the material is not narrow enough to absorb the photon. Inversely, one could say the photon has not enough energy to excite an electron across the bandgap into the conduction band. Figure 3.9.3 is a useful reference for many types of semiconductor types because it illustrates the use of alternating layers to achieve a variety of influences on the light field within. The ability to form layers on the order of nanometers has allowed semiconductor laser diodes to shrink even more. VCSEL construction and atomic plane accuracy of semiconductor material cleaves makes it easy to produce these devices for single mode operation. A longitudinal mode that resonates within a laser cavity determines the frequency, or wavelength that is emitted. This finesse is a double-edged sword because variations in temperature at this scale of size can lead to undesired behavior in the semiconductor and emitted light. The advantage of vertical emission however is that many beam forming options are available. There lie inherent advantages with VCELS ability to emit a beam profile sans astigmatism which is a potential issue with edge-emitting LEDs. Vertical emission also allows semiconductor fabricators to include different optical solutions for beam forming onto their chips.

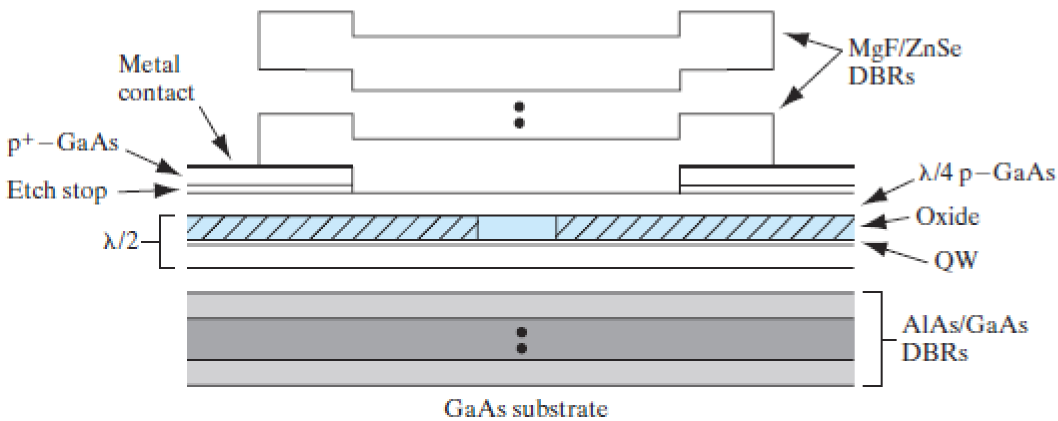


Figure 3.9.3.1 – A cross section example of a VCSEL illustrating a possible configuration of layers. The 'DBR' indicates a distributed Bragg reflector is being used.
Solid State Electronic Devices 7th Ed., Streetman, Banerjee

3.9.4 Quantum Cascade Laser (QCL)

A quantum cascade laser is similar to the VCSEL in that the structure of the QC laser also employs a stack of alternating semiconductor materials. It is through clever arrangement of these layers that a practice called band-engineering takes place. Unlike other semiconductor diodes the quantum cascade laser does not generate radiation primarily by EHP recombination or electronic transitions from electrons falling to a lower energy orbital in the valence band. A principle method involved in band-engineering is the creation of quantum wells via the layers of semiconductor material. The layers that comprise a QCL structure are heterojunctions, meaning they are not grown from the same crystal. Another remarkable property of the QCL is that the light emitted does not depend on the bandgap of the material, but instead layer thickness and element composition that defines the quantum wells throughout the structure and other inter-atomic forces at junction boundaries. These quantum wells and series of nanometer scale boundaries provide confinement to carriers and photons that increase device efficiency. As described in earlier sections, the same configurations can also be used in QCLs which provides incredible customization. Features such as having multiple lasers or frequency selective filters on one monolithic device enables a wide range of applications for one device. Figure 3.9.4 shows a typical path of one electron drifting through the length of a QCL. It is first injected and encounters a barrier and accumulates with other electrons creating a population inversion between states three and two in the diagram. When the electron reaches state three it tunnels through to the lower second energy state, releasing a photon while making the transition. The state the electron resides in on the second energy level is short-lived and it quickly transitions to a third lower state in order to preserve an acceptable number of vacancies in the density of states within the second energy level. This is only the first in a series of "steps" and each step can be configured differently to include different functions like filtering, reflecting, amplifying and more.

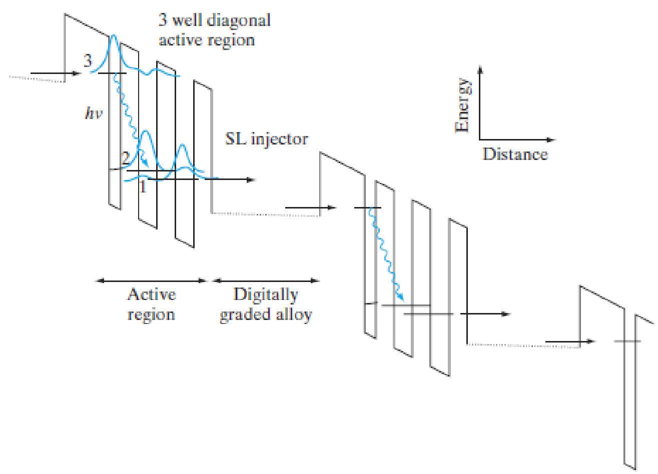


Figure 3.9.4.1 – An energy band diagram example for a QCL. The only energy band of interest is the conduction band as there are negligible transitions involving the valence band leading to radiation of light. Solid State Electronic Devices 7th Ed., Streetman, Banerjee

3.9.5 DFB and DBR lasers

Distributed feedback (DFB) and distributed Bragg reflector (DBR) lasers both use refractive index modulation to achieve their unique output. In the case of the Bragg reflector, a structural configuration resembling that of a Fabry-Perot etalon is used with one mirror being replaced by a Bragg reflector as illustrated in figure 3.9.5.1a. This reflector has periodic variations that has a cumulative effect on light-waves propagating within it.

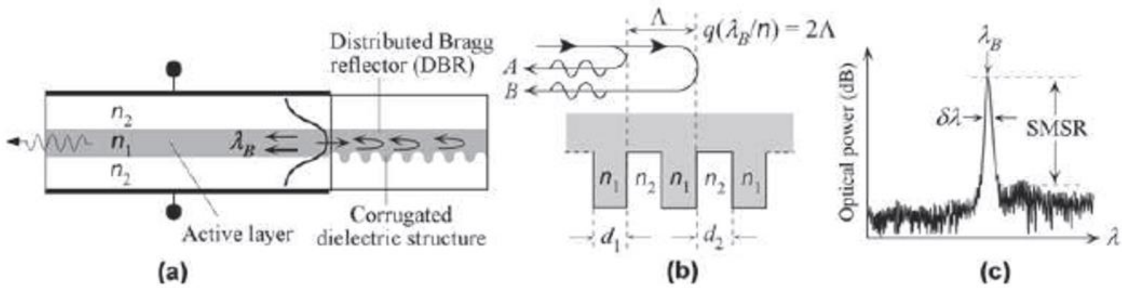


Figure 3.9.5.1 – a) simplified structure of DBR b) graph of periodic index modulation c) example output spectrum from DBR laser. Optoelectronics and Photonics 2nd ed., S.O. Kasap

The partial reflections induced by the refractive index modulation causes constructive interference centered around a wavelength determined by the periodicity of index modulation shown in 3.9.5.1b. This allows for a highly frequency selective laser that can enable single mode operation at a wavelength designated as the Bragg wavelength with an output resembling that of figure 3.9.5.1c.

The distributed feedback laser structure uses a corrugated variation on one side of the waveguide which also contributes a cumulative effect on the generated light in figure 3.9.5.2a. However a stark difference is that this index modulation takes place throughout the entire length of the cavity and thus partial reflectivity takes place in opposite directions along the same optical axis in 3.9.5.2b. This means that only fundamental modes supported by the physical width of the gain region constructive interference from the modulated index layer symmetric about the Bragg wavelength can exist as plotted in 3.9.5.2c. This could however, be useful if multiple narrow linewidths are desired for telecommunications.

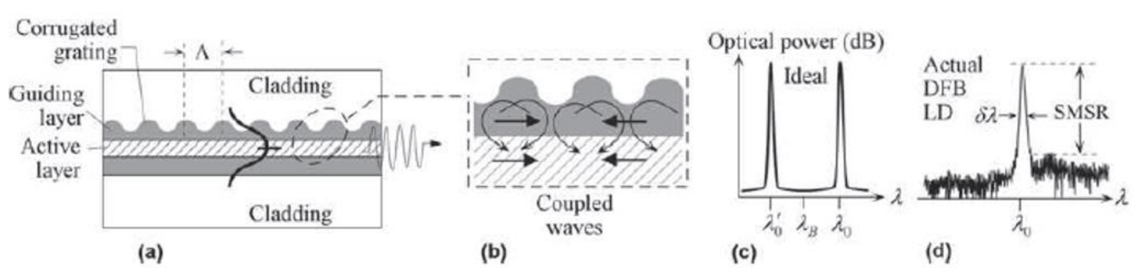


Figure 3.9.5.2 – a) simplified structure of DFB laser b) illustration of constructive interference between left and right traveling waves c) ideal optical power spectrum inside cavity d) example laser output. Optoelectronics and Photonics 2nd ed., S.O. Kasap

3.9.6 ECDL

External cavity laser diodes offer additional features that could be useful in our implementation of laser communication. A drawback of needing a narrow, specific wavelength is that such finesse has a large dependence on temperature. Temperature causes thermal expansion in emissive materials as well as affecting the rate at which population inversion is sustained. Change in cavity size and carrier transfer rates broaden the emissive linewidth and can also lead to frequency chirping and mode hopping. Frequency chirping can potentially be eliminated through continuous-wave (CW) operation and use of an external Pockel cell modulator. However, due to limitation of application specific packages, concerns with modularity, increased complexity, decreased ruggedness and lack of time available for research it is in the projects best interest to invest research into other types of lasing sources.

3.9.7 Gas lasers & Chemical lasers

Gas lasers and chemical lasers were not heavily considered for this project. Both types of lasers require complex driving circuitry and additionally lack the ruggedness and compact form factor required for mobile applications.

3.9.8 Laser diode selection

Current research into laser sources are currently leaning towards continuous-wave single mode operation sources. Thus far, all research into laser sources indicate that economic options exist for lasing in the near infrared region using distributed feedback lasers. One primary candidate for use as the laser diode is the L1550P5DFB by ThorLabs.

Figure 3.9.8.1 Laser diode of choice packaged in TO style can housing with lens.

Consuming only 5 mW of power make this laser a good choice for prioritizing battery use. Another benefit to this diodes low power consumption is the simplicity of thermal management required to operate it. One advantage that the TO package provides to users is its simplistic style. It is similar to a regular two-lead LED in shape so it is somewhat familiar in style with the exception of having four leads. These leads give the option to operate the diode as a laser to transmit, or a photodiode configuration to receive. The diode will be operated solely as a laser, so two of the leads may be neglected and this diode will be integrated into the transmitter circuit just like a regular LED.

	Output power (mW)	**Input power (mW)**	**rise/fall time(ns)**
ML925B11F-38	6	33	0.2
L1550P5DFB	5	22	0.1

ML925B45F	6	33	0.3

Figure 3.9.8

3.9.8 Considerations for optical components

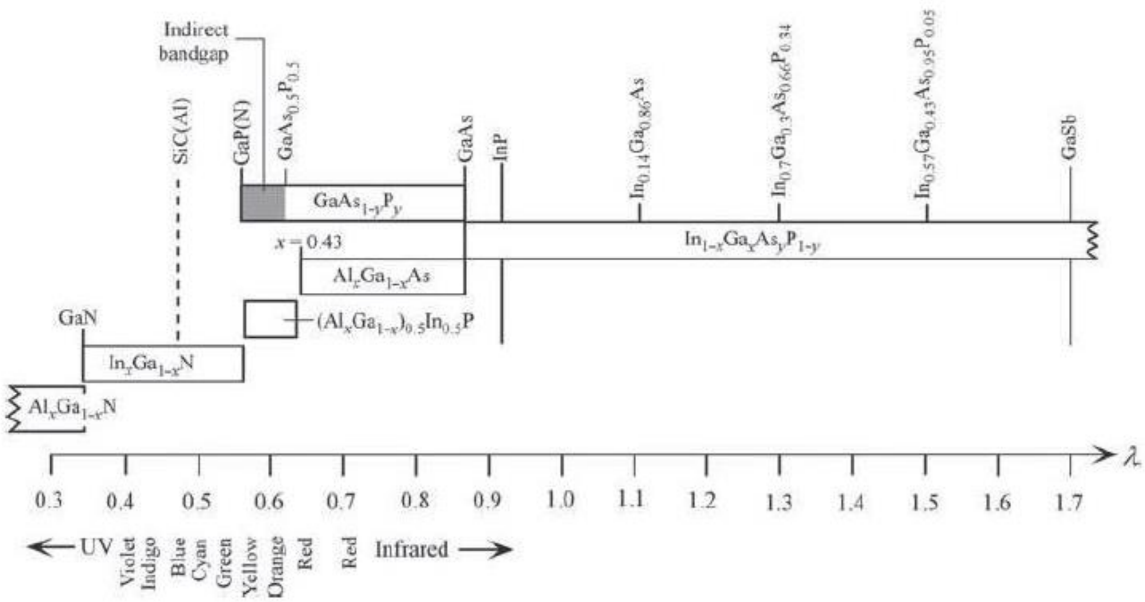


Figure 3.9.8.2 – Chart of material compositions with respect to their free space emission spectrum. Optoelectronics and Photonics 2nd ed., S.O. Kasap

The first question that must be answered is what materials are needed in the sources and detectors of the system. Semiconductor components are favored for their efficiency, small size and light weight. Figure 3.9.8.2 displays available material compositions for commercially available sources and sensors. Because 1550 nm is more eye-safe than lower wavelengths and the technology supporting this wavelength is already well established in the telecommunication industry, InGaAsP is the composition of choice.

Sources will be prioritized based on power consumption and thermal requirements. If high temperature heat dissipation is required this will inevitably increase the form factor and weight of the system. Coupling method with external optics is still under research. It is not yet known if the laser source of choice will be shipped with collimating optics or if a system must be designed for beam shaping. Whatever laser source is chosen must also be capable of direct modulation, thus an external driver will most likely need to be purchased separately or constructed. One current laser under consideration is the ML925B11F DFB laser. It is a low cost DFB laser that has a max power output rating of 6 mW at 1550 nm. It has a max rise and fall time of .4 ns.

Optical materials will preferably provide frequency selective windows, filtering out unused frequencies of light. Doped glass materials or thin-film coating of optics is usually employed to perform frequency filtering. Whatever is decided upon should be rugged enough to operate reliably and as desired in a wide range of environments. Operation should be possible in ambient temperatures ranging from 20°F to 110°F and be easily packaged within weather-resistant packaging to preserve electrical components.

Sensor response is also a concern. Sensors should be capable of high-frequency modulation and be capable of being modulated to 1 Mhz at minimum. Typical detectors for use in fiber-optic systems are PIN and APD devices. Avalanche photodiodes offer an internal gain mechanism, but require more time for the gain to build, thus slowing switching time down. PINs do not offer gain, but also do not require the high biasing that APDs need. The tradeoff here is that APDs could offer more utility at longer ranges because of their relatively higher sensitivity, but PIN diodes would demand less from battery reserves.

3.9.9 Simulation & Modeling

Simulation software is being pursued for modeling laser sources and optic components across time for a variety of factors like electrical current and power distribution and heat dissipation. Optic Studio will be used for modeling the optical system and any options available to simulate Gaussian beam propagation will be used to check against MATLAB results if there is adequate time while prototyping. If there is a big financial decision to make, simulations will be created to the best of our ability to aid in decision making.

3.10 Bluetooth Connectivity

While the team was considering different ways to have data sent to an individual communicating device, we were considering the use of Bluetooth modules to do so. Bluetooth is a wireless technology that uses radio waves to communicate between two devices. There are about 79 frequencies with Bluetooth and most of them are near 2.45 GHz, meaning there are different ways a user can connect to Bluetooth.

We were considering using these modules because several data collecting devices such as the Texas Instruments Spectrometer can send data over to our high communication device using Bluetooth connectivity. The communication devices wouldn't communicate with each other using these modules, only a data collecting device to one of these communication devices. Additionally, Bluetooth can only work over short distances so the two communication devices wouldn't be able to connect using Bluetooth. Using Bluetooth could be an alternative to wired communication such as USB. Having this could help us from having too much wired connections.

One of the disadvantages to using Bluetooth however is that it will be more difficult to ensure that a connection is set between the data storing device and the data communication device. This can be a disadvantage of most wireless technologies.

Communication could easily fail to send if the two devices are not within range to one another. Also, using Bluetooth connectivity can drain the battery of our device, and we will need to have enough power to operate the laser. Lastly, even though Bluetooth travels over short distances, it is not a very secure connection, so other users may be able to see that data if it were to be sent over to one of the transmitting devices.

Overall Bluetooth could be an interesting option to consider when connecting input devices to the final project. Depending on how the input device connects to the communication device, a wireless connection could be an interesting choice.

3.11 File System Types

While the project will need to have data be stored it is important to understand how that data will be stored, this is where we will look into several different file systems. When deciding on a way for data storage in our device, understanding what file system we have will show us the logical structure and which data is stored and knowing how to extract that data will be of great importance for the team. When connecting a particular storage drive to a Windows computer we will be given the option to choose how we want the files system to be formatted to that device. The primary file systems we will be looking into will be the FAT32, the NTFS, and the exFAT file systems. While there are other varieties of these file systems, we believe these should be the main focus for this project

3.11.1 FAT32

The FAT32 (File Allocation Table 32) is an older file system that comes with most USB drives. Mostly, almost anything with a USB port comes with the FAT32 file system. Having a file system with this type of compatibility can be greatly useful for this project. Also, this file system can be used with hard drives up to 2 TB, so if we were to use an external hard drive for storage, this would be the size limitation the hard drive would need to be, although that may be more than enough for this project. The FAT32 also has the ability to save a backup copy of the file allocation table which may make it less prone to losing data within the table.

One disadvantage that comes with using this particular file system is size. FAT32 gets its name from the fact that the rows of the table are differentiated by only 32 address bits, meaning that only 2^{32} bytes can be differentiated ("addressed") by the file system. This means that FAT32 can only locate files within a 4 GB range, which is a complete deal breaker for any volume of storage larger than 4 GB. This could make it a complete non-starter depending on the size of our data.

Overall the compatibility of this file system can work well for the project. If sending data over to our communication device only requires a simpler approach, we may use the FAT32 as our file system format for our storage device.

3.11.2 NTFS

The NTFS (New Technology File System) is one that works particularly well with Windows (most newer computers running Windows have their C drives configured to this system). This type of file system has no particular size limitations so that would work well for our project if we were to send over large data files. There are also several additional features that in NTFS that are not available in other file systems such as FAT32 or exFAT. One of these features include file permissions, which will allow the system to recover information if any errors occur within the system and make copies of the files. Having these security features could help me social constraints if users are concerned of anything happening to their data.

One particular disadvantage that comes with this file system is that its mostly compatible with Windows, it may not be compatible for other devices. It can work with some external drives but if it would work for our external drive is to be determined. Overall the security features of this file system are still quite impressive. If we can get it to be compatible for our storage device, then this particular file system type would also work well for the device.

3.11.3 exFAT

The exFAT (extended file allocation table) file is another file system quite similar to the FAT32 system, this file system is meant to work well with flash drives such as USB, or SD cards. Another name for exFAT is “FAT64”, which is named as such for a similar reason that FAT32 is named: the address bits that differentiate rows in the File Acquisition Table are 64 bits. This means that up to 2^{64} bytes, or 26 exa-bytes of data (storage of that size does not even exist yet). Also, the performance of the exFAT is much better than that of the FAT32 and sometimes the NTFS.

One limitation though is that while it may be more compatible than the NTFS, it is still not completely compatible with other devices. Additionally, this file system doesn’t come with the same security features as the NTFS, so the data that is uploaded to the system could be prone to corruption. Despite its disadvantages, the exFAT still is a potential useful file system to the team for its ability to work well with flash devices, which may not work as well with other file systems. If this file system is compatible with our device, then this may be the file system we could use.

3.12 Project Management Software

With each respective group member working on separate portions of the project, it is important that we are able to properly collaborate with each other using the right software. By having these software tools available to everyone in the group, the team can work together on different documents or programs of the project at different respective times or locations.

3.12.1 Beyond Compare

One collaboration software that would work well among the team, especially programmers is Beyond Compare. Beyond Compare is a downloadable software that allows the user to compare different files and folders. Beyond Compare can be used with multiple types of files such as word documents, images and coding files. This tool will display a side by side comparison of the two files line by line and will highlight different changes that occurred within the files. Additionally, it will also allow the team to merge the different lines across each and file and save those changes in. It can even ignore unimportant changes such as whitespace and character case. When working on the project documents and code files, there are so many different changes that can occur within the files, so this tool is beneficial to the team because they can much easily recognize what is the difference between the two files.

One limitation to this software however is that its not a free tool to use, users who want to use a permanent version it generally has to pay a fee for it. Additionally, it can't view images in text files, both of them would need to be viewed separately in different sessions. When working on project reports, this can be a small issue.

Despite the software's limitations, it is still a tool that is beneficial to the team. When comparing past and present files together, this tool greatly serves that purpose well. For anyone working on any coding project, we would highly recommend this software to them.

3.12.2 GitHub

Another project management software that has been used frequently among the team is GitHub. GitHub is an online project management tool created to help users be prepared for projects. One of its most useful features used by a majority of the team is uploading files to different branches. Once a team member uploads a new file to their branch, they can create a "pull request", where the rest of the team can decide if they want to "pull" their changes into the master/main branch of the project. This is quite a beneficial tool as it is easier for the members of the GitHub repository to continuously edit and make improvements throughout the same file without interference from each other.

As mentioned earlier Github is a project management site, one of its most useful features is its project management page. With Github we can create a project and organize each of our tasks separately to the different members of the team. This site comes with interactive GUI where users can make a to do list and assign themselves different tasks where they can record their progress on the list. By setting online notes for the team, it is easier for us to meet the required deadlines that is required for the project.

Only disadvantage about using GitHub is merging changes together. Usually when team members work on a file with the same name in GitHub they would upload at different times, however before the upload can be successfully loaded, the changes on the most recent file must have already been integrated into the file that is about to be uploaded. Otherwise a merge conflict would occur and it would be quite difficult to manage them.

Overall the team has found GitHub to be an excellent online site for project management. When Senior Design 2 begins, we expect to continue using GitHub for any additional documentation and coding files.

3.12.3 Slack

Established in 2013, Slack is an extremely handy program for any collaborative team in any environment, be it students or professionals for its many features. Slack allows users to combine together into “teams” to work on “projects” through a URL. Those users can communicate through a variety of messaging “channels” that they can create based on their topic. This allows for information on one such topic to be easily found and allows the team to have fun while not clogging up the professional channels with social-hour conversations. Finally, Slack integrates with a variety of programs to notify users when updates have been made or new files have been posted. Conveniently for us, Github is one of these programs. Every time one of the members of our team makes a commit to Github, all of us are given a notification, and we can easily read and discuss this commit all in the same app. Communication is important in any multi-person project, and we are grateful that Slack provides a convenient and intuitive environment to do so.

3.13 Major Part Decision

After careful research as shown in the sections above, the team has made decisions regarding some of the main components that will be used in the project. This section will illustrate what those components are and why those particular components are going to be used for this project.

3.13.1 Microcontroller Choice

The microcontroller the team decided would be best for the project at this point in development would be the ATSAME70 microcontroller. It comes with a high variety of features such as high 300 MHz speed, good connectivity options, such as USB and

Ethernet, a high memory of 512 KB, etc. We believe these features will be able to meet the requirements of the final project overall. This microcontroller chip has recently been acquired by the team, and will be ready for use once several other components are available such as the PCB. Until then, it will be kept in its packaging so that it will remain protected and unaffected by static or moisture. Overall, we feel that this microcontroller will be a great match for the project.

4.0 RELATED STANDARDS & DESIGN CONSTRAINTS

This section will mostly cover the related standards and constraints that were taken into consideration when working on this project. It is important to know what design limitations we may face when building the device. However, knowing these limitations will result in a product that will compatible to the needs of the user, as well as to the needs of the team.

4.1 RELATED STANDARDS

The device that is to be constructed will follow a set of set of standards relevant to electronics, coding, and photonics. While some of these standards can be voluntary for the team to follow, they can be of great benefit to users and are borrowed from several different organizations such as IEEE. This is because not only will this standard bring a new point to touch but more credibility as this a global standard that if follow, then whatever it is done, will be to a notable view under society that it will work not just only with this product, but every product that has the standards to make it compatible.

Another way to view the relative standards is what makes this product stand out. Remember, every product is good up to a point, but what makes everything appeal is the reputation which in this case be the standards. The more standards it has, the appealing to everyone is higher and will have a higher sell since everyone knowns that for instance a RoHS or IEEE standards have been apply then this means it will definitely work to peak performance, if not, then, even better than what should work. This would help not just performance, but market wise to when being sold in any place of the world since this standard are worldwide.

4.1.1 RoHS Standards

One set of standards that would be beneficial for the environment would be the standards for RoHS (Restrictions of Hazardous Substances). This set of standards require that certain electronic components must have the restricted amount of materials within them. These are the latest 2018 standards for RoHS compliance. The specific standards are set as listed in Table 1, which lists a substance and specifies the maximum amount we can have in the design. So, when looking for hardware components, it would be great to find components that follow these specific standards.

Fortunately for the team, RoHS compliant supplies are usually available for most of the time. Even the development board microcontrollers were RoHS material. We believe that building a device of this standard will be quite manageable for the team to accomplish.

Substance	**Restricted amount**
Lead (Pb)	< 1000 ppm
Mercury (Hg)	< 100 ppm
Cadmium (Cd)	< 100 ppm
Hexavalent Chromium (Cr VI)	< 1000 ppm
Polybrominated Biphenyls (PBB)	< 1000 ppm
Polybrominated Diphenyl Ethers (PBDE)	< 1000 ppm
Bis(2-Ethylhexyl) phthalate (DEHP)	< 1000 ppm
Benzyl butyl phthalate (BBP)	< 1000 ppm
Dibutyl phthalate (DBP)	< 1000 ppm
Diisobutyl phthalate (DIBP)	< 1000 ppm

Table 4.1.1.1: RoHS table

4.1.2 Coding Standards

When developing any software application, it is important for all code written to be readable such that it can be updated or maintained. Thus, general standards are necessary for coding to avoid confusion. As the project will most likely be done with the MSP 430 series of microcontrollers (See that section for more details), the code should follow either the C, C++, or Assembly coding standards.

The American National Standards Institute is a nonprofit organization that "empowers its members and constituents to strengthen the U.S. marketplace position in the global economy while helping to assure the safety and health of consumers and the protection of the environment." (35). ANSI has also produced a set of standards for the C coding language, which is very similar to C++. These standards that apply to this project are described on the following pages (36 for all).

No line of code should be longer than 79/80 characters. Any longer will make the code the look ugly and may require some users to scroll to see the full line.

Comments are acceptable, but care should be taken such that the code shouldn't be littered with them; too few is better than too many. Good places to put comments include at the very beginning of the application as a brief overview, inside data structures to define them, above functions to explain their purpose and return values, and any tricky steps where the code will be difficult to read without them. Comments should also be indented on the same level and have roughly the same size of the code below them.

For variable names, balance is the key. If the names are too short, their meaning is ambiguous to the reader of the code (although I, j, and k is fine for counters). However, if the name of a variable is too long, the code could lose its readability (an example being a long variable name at the top of a for loop). Ensure that variable name length is proportional to its scope. If a variable is temporary or will not be used very much in the future, reflect that in its name. Finally, ensure that the variable name correctly describes the purpose of the variable or how it was calculated.

Indentation and braces allow the reader to understand the "levels" of the code, as in if something is in a nested for loop that is within a function. Braces should only be used when necessary (the body of the loop or if statement is more than one line), and should otherwise be removed. Code should always be indented to match the "level" that the line is at, otherwise the code will very quickly become unreadable, and the recommended size of an indent is 4 spaces.

Functions are to be kept short and accomplishing a set task, to the point where the code of upper level functions should become increasing abstract with more and more function calls. This will ensure that the reader knows what the code should be doing by simply reading the main function, as the implementation is abstracted in the levels below it. Due to this, the main function can and should be declared at the top of the application after the introductory comments so the reader will not need to scroll through a bevy of functions.

Since the functions are short, variables can and should be declared at the top of them, so the reader can easily familiarize himself with their datatypes before reading the rest of the code. For this reason, "global" variables (variables declared above main that can be used by any function) should never be used, as their values are not encapsulated and can thus be altered by every function, which makes debugging extremely difficult. Short functions generally do not too many variables, so only one variable should be declared per line for easier readability with the datatype and variable name indented equally.

For operators (+, -, *, /, %, =, etc.), the reader should not be required to remember the full order of operations, so it is paramount to utilize parenthesis to separate them (total = (a * b) + c is preferred to total = a * b + c. This also keeps the code readable at first glance and lessens fatigue for the reader.

Proper organization should be followed depending on the file. File with the source code should follow the following organization: include system header files, include local header files, define type and constant definitions, global variables (there should be none), prototypes, and functions in that order. Header files, which are an easy way to define the prototypes of the functions as well as any constants should have the following organization: define type and constant definitions, external object definitions, and external function declarations. Nested include statements should never be used.

C also has a datatype known as a structure, which is a datatype that holds other datatypes (A "student" structure that holds a name string, a GPA int, and a student ID number int), and they have their own set of standards applied to them as well. Structures should always be type defined, which allows the coder to use a name of their choice rather than Struct XXXX in the code, which makes the code much more readable. Any pointers should have this specified in their name for maximum clarity as well.

C allows the coder to declare preprocessor commands, where the compiler swaps in a constant value to a set of locations before the code is ran. They are very useful for static (usually numeric) conditions of the systems that need to be changed readily, as they prevent the reader from having to edit several lines of code to debug the application. For example, if one were creating a board game application that uses an array as the board with a changing board size, a preprocessor constant would be useful since the reader doesn't have to manually change the code in the functions that get coordinates. Enums should be used instead of #defines, as they are more visible in debuggers.

Avoid declaring large arrays within functions, as they may cause many problems when placed on the call stack.

All of the above standards will have a significant impact on the design on our software.

4.1.3 Soldering Safety

Although soldering is quite useful for the development of electronics, it can also be quite dangerous for a variety of reasons, and special care needs to be taken to avoid injury. All of the information below is gathered from the University of Cambridge's Department of Engineering Health and Safety (59), and we believe that it is the best representation of the safest standards for the use of this equipment.

For the soldering iron itself, it is important to never touch the soldering iron itself, as it can reach a temperature of 400 degrees Celsius (752 degrees Fahrenheit), which can cause a second-degree burn near instantaneously when touched. Due to the thermal conductivity of wires, it is also extremely important to hold them with tweezers or clamps while heating them to avoid burns. Also, it is important to keep the cleaning sponge wet during use as a precaution. Never set down the soldering iron on the work bench, it is hot enough to burn wood instantly and may even result in a fire. Finally, turn the soldering iron off and unplug it when not in use to avoid electrical fires and burns.

Always wear eye protection, as the melted solder can "spit", and a substance at that temperature can be blinding with direct contact to the eyes. The most common case for this to happen is when de-soldering a wire that is undergoing tension, and the whiplash is strong enough to fling molten metal. Also important is the chemical composition of the solder; always spring for rosin-free and lead-free solders whenever possible, as they are both toxic chemicals. Lead can cause chronic health effects with prolonged exposure, including nausea, irritability, forgetfulness, constipation, high blood pressure, heart disease, kidney disease, and reduced fertility, and many of the earlier synthons can occur with even short exposures to lead (60). Lead exposure with be primarily through absorption through the skin, thus it is important to wear gloves if directly handling solder.

Rosin is also contained in solder flux and generates fumes when soldering. Exposure to it is also dangerous like lead, as it can cause “eye, throat and lung irritation, nose bleeds and headaches” with repeated exposure resulting in “respiratory and skin sensitization, causing and aggravating asthma.” Fumes should be extracted through an enclosed hood or tip extraction, and ideally both should vent to the outside. Tip extract units with filter boxes should also include both activated carbon and HEPA filters.” Bench top filter extract systems may be used for rosin-free soldering in well ventilated areas.” If the fume extraction is not working properly, DO NOT SOLDER.

As solder can be toxic, never throw waste solder directly in the trash, but keep it in a container with a lid on it when it’s not in use. Used solder sponges and rags should be bagged. Both should be disposed as hazardous waste with the nearest facility.

Soldering also uses a large amount of power, and thus it is important for users to cover the bases in electrical safety. This goes for any electrical product, but never use soldering irons with obvious damage to the cables (fraying or worn insulation), plugs, or bodies. The workstation must also be free of all cables to avoid exposing them to the hot soldering tip, which can melt them. Always use a grounded outlet and grounding prong if a short circuit is possible. Also, the soldering irons must be tested at least once a year. Finally, and this goes for any electrical device, but NEVER cut off the grounding prong of a device to attempt to plug it into a two-hole plug. That is a fantastic way to either destroy the device or cause an electrical fire in the case of a thunderstorm.

Due to the high power and temperature of the soldering iron, fire safety is also extremely important. Wear fire proof clothing and work on a fire resistance surface at all times, and always ensure that such clothing covers the arms and legs. On another note, wear clothing with natural (as opposed to synthetic) fibers such as cotton, as synthetic fibers will actually melt to the skin when heated enough. One member of our team was previously a fry cook and has had plastic gloves melt to his skin when heated by the grill and the grease from it. It is painful. Before soldering or working with any electronics, always take note of where the nearest fire extinguisher is and how to use it (note that there are different types of fire extinguishers for different types of fires.

4.1.4 Open Systems Interconnection model (OSI)

Although many physical communication channels that have been installed over the years may not change much, their function does not warrant the need to replace them. Copper cables still transmit much the same with old and new hardware alike, just like fiber-optic cables do as well. Free-space optical communication (FSO) is often deployed in “first” or “last-mile” network deployments. These FSO deployments may, or may not be temporary solutions. Regardless, the design of the product should keep in mind future changes in network protocols. For this reason, the OSI model is being referenced during development. The Open Systems Interconnection model (OSI model) is a conceptual model that characterizes and standardizes the communication functions of a telecommunication or computing system without regard to its underlying internal structure and technology. Its goal is the interoperability of diverse communication systems with standard protocols.[67] Although the model states it does not take into consideration underlying technology, this model is often compared and contrasted with the TCP/IP protocol suite. The majority of network communication packets that support most internet network traffic are IP based. Both Ethernet and USB have their own set of specifications for the engineering requirements of the physical layers that support the respective connection types.

4.1.5 Ethernet technologies

Ethernet is a collection of standards and protocols that are commonly employed in forming local area networks (LAN). Ethernet is defined under the IEEE 802.3 protocol rules. Ethernet rules under 802.3i that specify speeds for 10BASE-T using 8 position 8 contact (8P8C) connectors must operate at speeds of at least 10 Mbps. The notation of “10BASE-T” is as follows: 10 denotes the bitrate, BASE denotes that the connection uses baseband transmission, T denotes the transmission is to take place over twisted-pair cables. The affect this has on the project design forces us to ensure that our minimum bitrate is 10 Mbps. Because this ruleset makes specifications for twisted pair cables, it warrants discussion of the physical layer being utilized. The 8P8C nomenclature denotes 8 positions and 8 contacts. The termination specified for this Ethernet technology is specified under TIA/EIA-568. The style of termination concerned is commonly referred to as RJ45 where “RJ” denotes registered jack. Figure 4.1.5 below, depicts the pinout to be used on the RJ45 jack to be used in our system.

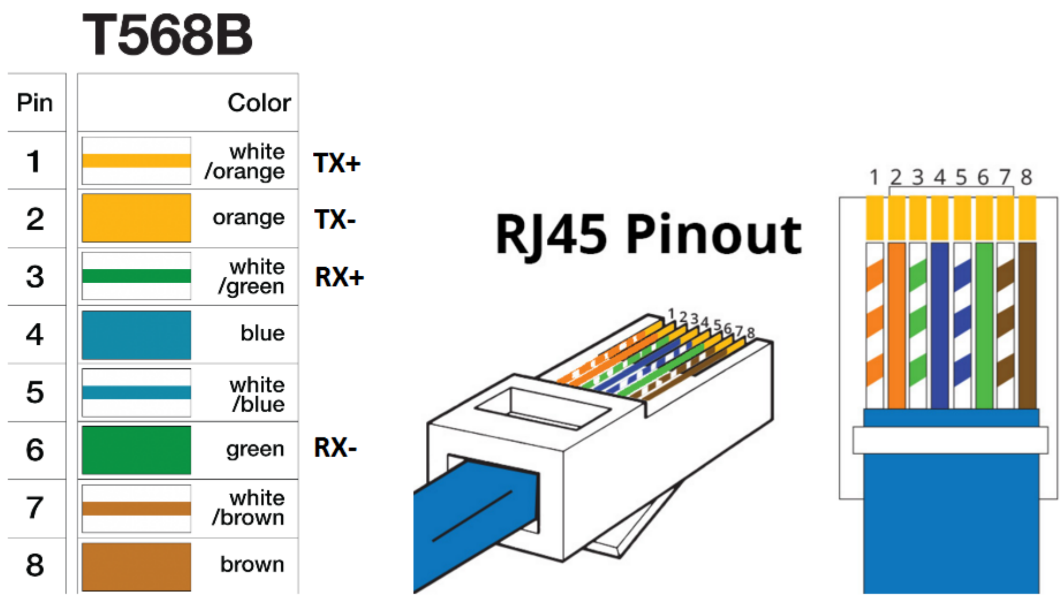


Figure 4.1.5.1 Depiction of TIA/EIA-568B pinout configuration.

This pinout configuration depicted above will exclusively be used whenever this type of cable is required within our system because it is the most commonly used pinout for this cable type. The twisted pair requirement is because twisting the data cables cancels out electromagnetic interference (EMI), thus reducing error rates in data transmission. An important thing to note about twisted pair cables is the TX+/TX- channels. These are bipolar signaling lines. The signals sent across this pair of wires range between +2.5 V on the TX+ line and -2.5 V on the TX- line. Signals are digital in nature according to the 802.3 requirements and the line coding used is a form of Manchester encoding called differential Manchester encoding. Figure 4.1.5.2 depicts an example of such an encoding scheme.

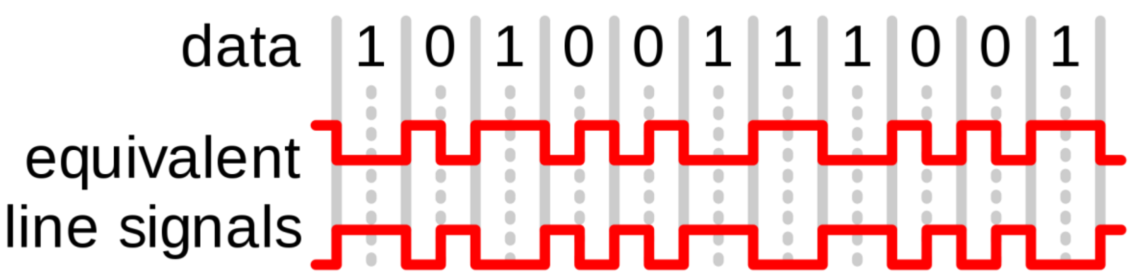


Figure 4.1.5.2 Differential Manchester encoding scheme example. Wikipedia, https://upload.wikimedia.org/wikipedia/commons/0/04/Differential_manchester_encoding_Workaround.svg, 10 December 2017

The combination of the twisted pair cables and differential encoding scheme helps to minimize crosstalk.

4.1.6 TCP/IP Protocol Suite and UDP

One of the ways we were deciding to make sure that data is sent properly between two different sources is to follow the Transmission Control Protocol/Internet Control Protocol (TCP/IP). This protocol will help ensure reliable data transmission between two sources. With the following transmission protocol our data will go through 5 layers, the physical layer, the data link layer will allow our data, the network layer, the transport layer, and the application layer. As shown in the figure is a general overview of the protocol. With the physical layer, it will specify how our bits of data will be transmitted as electrical signals. Since digital to analog conversion is important to send data over to our device, this layer will play an important role for our project. The data link layer focusses on being able to have our data moved from one source to another. This particular layer doesn't follow a specific protocol for how the link is formed. The network layer will ensure that the source host, the data source, will have a connection with the destination host, the transmitting device. There are many different routes involved when we connect our data to the transmitting device, so this layer will end up making sure that the best route is chosen when data is being sent to our device. Additionally, this layer will have our data form into different packets to send over. This particular layer is where the Internet Protocol is located. The transport layer will help provide reliability in our data connection. The Transmission Control Protocol is located in this layer. This layer will have Lastly, the application layer will be the programs that will create the connection requests between the two different hosts.

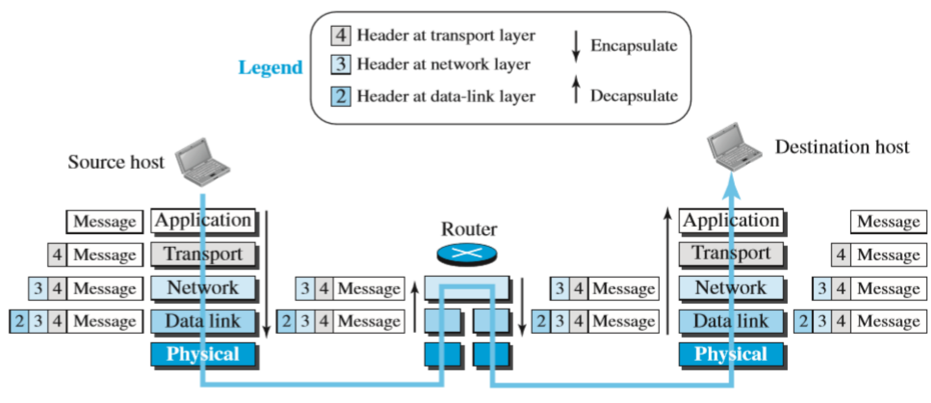


Figure 4.1.6.1: TCP/IP Diagram Textbook

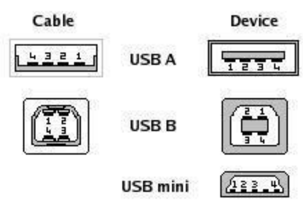
User Datagram Protocol (UDP) is another type of protocol that can be relevant to our project. Unlike TCP/IP, this protocol is a connectionless protocol that forms datagrams without having any previous information to the other datagrams. Regardless this is a much simpler approach to data transfer and can be beneficial when sending shorter messages over. However, a disadvantage to using these protocols over TCP/IP is that there is no error, or flow control. If there is a large amount of data that needs to be transferred over, this protocol could end up corrupting our data.

Overall, both of these protocols can be great guidelines to follow for sending data to the high frequency communication device.

4.1.7 Line Coding for 10BASE-T and USB 2.0

Line coding is a means by which digital data is transmitted down a channel. Both 802.3 ethernet specs and USB have physical spec requirements for the modulation method used in these standardized connections.

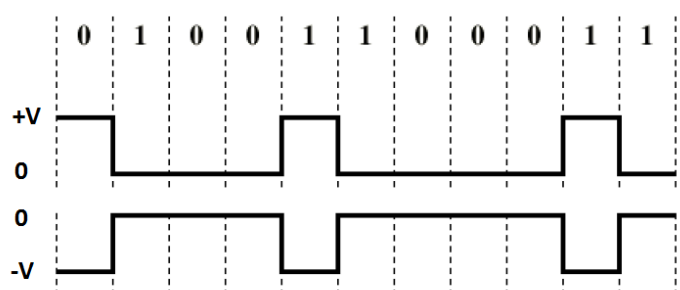
The USB standard employs non-return-to-zero inverted (NRZI) encoding. This modulation scheme employs a method by which a 1 is represented by a change of state in the bus. This means for USB, that either the +5 V rail or -5 V rail will change from the “on” state of a non-zero voltage to an “off” state of a 0 volt potential difference or vice-versa. On the contrary, a 0 is represented by no change in the state of the bus. This type of encoding can be either synchronous, or asynchronous in operation. The figure below, figure 4.1.7.1 shows a pinout of common USB terminations.



Pin	Signal	Color	Description
1	VCC	(red)	+5V
2	D-	(white)	Data -
3	D+	(green)	Data +
4	GND	(black)	Ground

Figure 4.1.7.1 USB pinout for common plug variations.[23]

Just like with 10BASE-T cables, this encoding uses a negative and positive lead to transmit data. USB or universal serial bus transmits data along the leads just mentioned serially just as the name implies. There are different standards that apply to each revision and iteration of USB hardware. These standards dictate bitrate and electrical specifications and cable type. Figure 4.1.7.2 shows an example of how a string of bits would be sent across a USB cable.



Differential NRZI

Figure 4.1.7.2

4.1.8 ANSI Z 136

The ANSI Z 136 governing laser safety was consulted regarding radiation safety. This guide provides information regarding classification of lasers as well as appropriate safety procedures for each class. Because our laser is 1550 nm and has a max light output of 6 mW it is a class I laser. The standards consulted do not typically mention lasing sources beyond 1400 nm.

The safety information contained within concerns eye, skin and non-beam hazards. Maximum permissible exposure (MPE) is specified for continuous-wave and pulsed lasers. Our lasing source is not included within the chart provided, but it can be extrapolated that our hardware does not pose significant risk to health or wellbeing of anyone in the vicinity of the device. Good form will be practiced, however to minimize the risk of injury not directly related to beam-hazards, including wearing proper attire in a lab environment and taking care to beware electrical hazards. In spite of the class I rating and low hazard potential, infrared radiation can still damage the eye. It is still advisable to never look into the aperture of a laser if it has the chance of being powered. Careful consideration should be taken not to align the transmission beam using any kind of magnifying optics such as binoculars. Although the laser is class I, the addition of magnifying optics enhances potential risk to the design group.

4.2 DESIGN CONSTRAINTS

While developing the device, there are several different design constraints to consider. These constraints can include time, economic, safety, environmental, social, ethical, and manufacturability. In fact, we should consider all of the constrains listed and not just one as this can be taken like a chain, each have a special function to do in the project that it is inevitable to just take one or certain ones into account.

4.2.1 TIME CONSTRAINTS

One constraint that will greatly affect the product is time. With both Senior Design I and Senior Design II is that there will be 8 whole months to complete the entire project. Everything that needs to be done in that time frame includes: research, designing, building, and testing that should be done in that time frame that is giving when merging both Senior Designs. Additionally, another constraint will be the time it will take to order the components of the device. The components will usually take a few weeks before they arrive here. However, there are ways for these components to arrive earlier but it is better to prepared when normal shipping is available if product is in another location in the world. Never the less, the preparation should always be to prepare for the worst rather than for the best as if everything is prepared for the worst scenario, there will be extra time for unexpected events. That being noted, the main problem at this point is to the delays of shipping and handling along with what would happen if the parts come defective. One of the main issues that will come along not just in this project but in all projects is the PCB design. Most of the time, the design that was made in the PCB might not work the whole way when connecting every single part together. That means that the PCB might have to be send back to manufacturing to rectify it and make it compatible with all the equipment that will be implemented. This then will provoke delays since shipping from current location to the manufacturing can be time consuming. However, if prepared for the worst, then there will still be a worry but not as much as if it was prepared like everything should work on the first try and receiving the parts right on time the first time around.

There will also need to be great care taken in the scheduling of meetings and development. As college students, we have other commitments besides this class, including other courses, research activities, family, friends, dependents, rest and relaxation, exercise, meals and jobs. If these activities are not scheduled around, it will be difficult for all 4 members of our group to meet, which means that the pace of our project will simply not be fast enough to finish in time and provoke of the project to not work or just not function the way it was intended. As time is one of the main priorities to claim for the completion of this project. There should be a schedule on when to do every single movement of the project along with the extra time that is needed for unexpected events which is the bad side when designing any project. As theory can work perfectly on paper but when applying in real life, it might move to something that can cause drastic outputs when dealing with each component live.

4.2.2 ECONOMIC CONSTRAINTS

Another limitation we have in the project is funding for components. UCF will not be providing funding for the major components we would be using, such as the PCB and the microcontrollers. All the major components will be bought directly by the team members, and as college students, we do not have access to an infinite source of currency. This may work to our advantage, as the goal is to create a product at a low price point to achieve success.

There are countless examples of incredibly good products that were discontinued because they were too expensive to produce, which reduces sales if margins are also not cut. This causes issues with the value of the product to the company and to it’s invested, leading to its discontinuation. There is also the issue of another company with the resources and connections to mass produce creating a similar product and undercut us on the price, resulting in the failure of our product. It has been shown time and time again that most people are unwilling to part with their hard-earned money to take a gamble on a product from a relatively unknown company in the product space, and a well-known company may not even need to undercut us on the price to outsell our product, as they are more trusted.

This is especially true in potentially dangerous areas such as photonics and electronics, which our project uses both of. An example of this is numerous customers buying chargers for their new iPhones directly from Apple, as the Note 7 debacle has reminded consumers that this is a potentially dangerous area, and they do not want to take chances to save a few dollars when charging their 800+ dollar phone.

Thus, it would be beneficial to limit the cost of individual components as much as possible while also preserving both quality and safety.

4.2.3 SAFETY CONSTRAINTS

When the user operates the device, we will need to make sure that the laser does not cause any harm to the user. It is important to remember that a laser is an extremely high frequency beam of light that may cause burning, harmful radiation if exposed to the skin, or blinding if shined directly into the eyes, so it is important to make sure that the laser that is being use for the device is safe for the user.

Also, to ensure that the user of the device is safe, the device will need to be safely housed so that if the device gets heated or the device gets wet, it won't cause any physical harm to the user.

4.2.4 ENVIRONMENTAL CONSTRAINTS

One of the marketing goals to be accomplished is to make sure the device is low power. It will be beneficial to the environment if the device doesn't consume too much power when it is not needed to. However, at this point, some of the equipment that are being implemented will be energy efficient also known as environmentally friendly. In the other hand, there will be other product that regardless of the large amount of research done from the start of its creation, it will be at the latest of its low amount power consumption even though it still causes harm to our environment. Remember, the more power that the equipment uses, the more resources. That being exposed to our knowledge, that's the main target in the implementation of the project. Since part of this project will be founded by UCF CREOL as this will be part of the research for the latest of all of the communication that have been done before by various large corporation, just not as efficient since this type of projects have been done with the oldest parts which will tend to be low cost but it will have a secondary effect. That secondary effect will be the large power consumption that will provoke. Luckily this High Frequency, open air communication will be partially founded by UCF CREOL which it will have access to another research of the environmentally friendly. That environmentally friendly will cause way more than the traditional parts, but in the long run it will be one of the most efficient devices, since it will use one of the latest equipment. As a prime goal of this project is to not just make the project going for the open-air communication, but to have it environmentally friendly, since it will have access base on the UCF funds.

Also, as mentioned previously, the device will meet the latest RoHS standards, so the product will be restricted in certain substances to benefit the environment. Although this have the RoHS standards, the whole project will be engineer to meet the most of the environmentally friendly side as that is one of its prime goals. Remember, it cannot surpass the RoHS standards that will fail those standards but can hit the limits. As the closer to the limits that it is at, the better since each and every creation in this modern era is to have it to the peak of its environmental side. As the point until now is to heal the ozone layers due to the large amount of damage everyone has cause at this point and if it's at its peak, then the ozone layer may not heal now but can start healing as the damage at this point is severe.

4.2.5 SOCIAL CONSTRAINTS

When finishing the device, we would need to make it easy for users to install and operate. After building the product we will need to make sure that it is designed so it can be mounted on other surfaces such as a drone or a vehicle. Since the device is small it shouldn't be too difficult to come up with the materials we need to make the device mountable, however the device does need to be able to mount on different types of surfaces, whether they are smoothed or flat. There are many products that were good ideas but were simply not practical to use or to assemble, and this must be avoided.

The mounting section should then be base on needs. The easier the better as the device is not big nor it is heavy to carry on anything. That means that wherever the device be mounted should be no problem. If there is problem, then that means that the device should not be there as it can cause a harm to the project as a whole.

4.2.6 POLITICAL CONSTRAINTS

Currently, there are not any known political constraints that would greatly affect the design of the project. The current way the product will be developed will lead to no political consequences.

However, in the future if this technology is licensed to a telecommunications company to communicate between towers, there absolutely could be political constraints that could come into effect. The telecommunications industry is heavily regulated and telecommunications companies are necessarily "cozy" with the government, especially in the current administration. A smaller company could license this technology and assist in honing it to achieve its potential, only to be blocked and/or regulated out of the market by larger ones or the government.

This doesn't sound entirely realistic, but some telecommunications companies have even gained municipal monopoly's through negotiating with local governments, while there is a limited amount of physical space for underground cables and cell phone towers, the financial benefits of a legalized monopoly or even a duopoly are enormous, as customers will be forced to pay whatever price is necessary lest they go without internet in the modern era (virtually impossible).

Even without a legalized monopoly, government regulations can be incredibly difficult (and expensive) for a smaller company to overcome. "Before building out new networks, Internet Service Providers (ISPs) must negotiate with publicly owned 'rights of way' so they can place their wires above and below public property." In addition, ISPs need to acquire contracts with public utilities to place all their above ground equipment on telephone and power lines. These fees can increase construction costs by 20 to 100 percent and can delay construction by years. Even giants such as Google struggled to enter this space.

All of this will have an impact on the viability of the product, as if it is not adopted by companies with a high market share and economic resources, it will not prosper due the difficulties in establishing a new company in this space.

4.2.7 ETHICAL CONSTRAINTS

This project requires research on existing examples and techniques, but it must become its own idea and take its own shape, lest we become rote copiers. Aside from causing major personal issues for all of us at the university level, copying is cheating, and it cannot be tolerated from an ethical standpoint. In addition, violating ethical rules goes directly against the Accreditation Board for Engineering and Technology. Even if ABET cannot personally affect us, it will reflect poorly on our university (The University of Central Florida). If the reputation of UCF slips, it will impact the value of the degrees of all students who have and will graduate from there and worsen their chances in the job market as well as throw the careers of all professors there into question. It will unfairly punish UCF's students and faculty for an offense that was simply not their own.

As mentioned earlier, it would be ethical if the device needs to follow the necessary safety constraints so that no harm comes to the user, even if it requires more research and work on our parts. If a person is injured by our product, it means that we have not addressed the safety constraints properly and throws our ethics into question, as it may appear that we had slapped the product together for the grade without a care for the impact it has on other people. It would also be extremely bad publicity for both us and the university and would damage the university's reputation and may even throw our fledgling careers as engineers and photonic technicians into jeopardy.

4.2.8 MANUFACTURABILTY CONSTRAINTS

When building the device, it needs to be considered how well can manufacturers recreate the device. We want to have the device simple enough so that manufacturers can build it with ease. Also, making the device simple will help from an economic perspective, where the device won't cost too much for the manufacturer to make or cost too much for the user to purchase. As if the device cost too much to make, then the price will be high for the consumer. If the price is too high for the consumer, then the sales will not be as expected as the higher price of good the set amount should be for reasonable for the price that should be paid for. If the price is high, then less people will be able to pay for it which means less money for the creator as not all will be able to consume the product. Additionally, we would want to make sure there are a reasonable number of components available for the device to be mass produced. As if here is a mass production, then of course, the prices will go down since there will be no reason why will it be the same cost since there will be less time to find a buyer and more time creating more parts. To achieve this, we shall strive to use as many "off the shelf" parts as possible, which avoid the manufacturer having to go through the expensive process of creating additional parts when building the product. This means to have as much product that can be found anywhere in the city rather than making a special order or a creation from scratch which is way costlier as the particular part will not be develop by bulk since bulk parts will cost less than just a couple of parts.

4.2.9 SUSTAINABILITY CONSTRAINTS

Currently, there are no sustainability constraints that the project has. The project will be able to last for as long as the hardware is still in good condition and the device has a good power source. Even though the project will be as mobile as possible meaning it will run on battery power due to it being as portable as possible. There should be no cabling to an outlet. It will just be an easy of just having the right amount of batteries powering the device. This will also reveal all of the efficiency that have been implemented by the latest of all Hardware.

Remember, the latest equipment should still have no sustainability constrains as this is use a better way to contribute to the exchange of information via laser and bring the photonics world into play rather than just the normal signals that have been in traditional equipment for years. This can even open more doors to any communication update. As wired communication is great but humans have entered to the wireless era. This means that the less wires, the better as it has been discovered that the less wires, the better as no more damage ports, cables, etc. the only thing that any of the devices have to do is to turn on the new feature and it will enable them to transfer whatever data that anyone wants. This means that there will not be a sustainability issue as this is based on improvement. Never the less, who would not want to improve the way you transfer information? No one will deny itself or will shy about a way to make it better for everyone.

As seen, the sustainability is pretty solid on it being a great improvement to society and will bring us to a futuristic world that someday every human being has to adapt to. Just like how everyone made the change from the older phone devices which were the old Nokia's or even the flip phone to now, smart devices. That those smart devices that each and every person has more power than even a typical PC that is on a household. That being mention, it will just need some time for everyone to get us to the transfer. Life will even be much easier as there is no cables to worry about.

4.2.10 LIMITATIONS OF THE TECHNOLOGY

While this technology is extremely useful, there are some key limitations that will need to be worked around (if possible) or they will reduce the utility of the project.

One such limitation is that it is not possible to use this technology for communication between devices that are moving unpredictably, as the laser must be precisely aimed to maintain communication with the target. This means that cell phones, laptops, and other mobile devices cannot use this technology in its current form. This is unfortunate because free-space optical communication is often employed in the "last mile" stretch in some network deployments.

This last mile stretch poses unique challenges in free-space optical communications. Although tether-less data transfer brings a unique advantage with potential mobile applications it also comes with tradeoffs. Inherent in free-space laser data transmission is the probability of reoccurring disruptions in the laser transmission beam. Unlike the broadcast technologies that this high-speed directed laser technology intends to compete with, a relatively clear line of sight is required for reliable, error free data transmission. Although the wavelength being used is infrared, it is still laser light that is being collimated into a beam with a relatively narrow field-of-view. Some people may be familiar with the phenomenon by which they can change the channel on their TV by aiming at a white surface and have the infrared signal "bounce" off and still transmit to the TV successfully. Although difficult and unreliable, it also is still possible to change the TV channel without having a line of sight that is 100% clear of obstructions. The two scenarios just described are possible because of the way light reflects and diffracts in response to a physical boundary. An analog to this would be the ability to receive FM radio signals from an unusually far distance because of changes in weather, allowing the atmosphere to reflect radio waves that would normally be lost to space. This is in stark contrast to the method by which this equipment is intended to operate. The infrared light to be utilized is 1550 nm in wavelength. Although a longer wavelength causes the light to disperse less than light of higher frequencies, it is expected to diffract to a greater degree. Diffraction describes the tendency for light to "bend" around physical obstructions, which explains how a TV channel can be switched without perfect line of sight.

Atmospheric conditions can also cause disruptions to the laser beam. Heavy fog will affect power intensity of the beam, but due to the relatively long wavelength of 1550 nm, weather will not hinder the signal as much as higher frequency IR wavelengths. Stability is also a concern, as a stationary unit that is not firmly anchored will have to withstand forces from wind. Performance in inclement weather is yet to be seen.

Because this project aims to serve as a networking device, one objective is to implement TCP/IP standards. These frameworks however, do not account for packet loss due to link failure or timeouts. Temporary link failure can almost be assured in uncontrolled environments, so the fact that network devices will continue to attempt to use a severed link will have to be considered.[83]

5.0 SYSTEM DESIGN DETAILS

The design of this equipment will be a collaboration of various side such as Electrical Engineering, Computer Engineering, and Photonics. Using all this discipline, we can design the directed High Frequency, Open-air Communication system. Never the less, each discipline will work independently to make each design the way it needed to as far as a solo component with attachable components to make assembly as smooth as possible.

5.1 Computer Engineering

The computer engineers will be primarily responsible for programming and implementing the microcontrollers and microcomputers that will be the “brains” of the prototype and the final product next spring. The computer engineers will also implement the analog to digital converters and the digital to analog converters that encode and decode the signal into a laser, with some help from the photonics field.

Looking forward to the communication of the equipment, we will have everything computerized from one to another device so that they can communicate each other open air between each other. Software wise will be essential as the software will take into place when deciding which language each of the components will use. Once the language is decided, the components that are being develop, will then be considered to then start the communication amongst each other. This means what variables will be used to start developing the software it needs to along with the best type of algorithms we will be supplying so that the work can be evenly distributed. To then, the software should work at its peak performance.

The computer engineering system design details will compose of the design process the team will undergo, the software requirements, as well as an overview of the software functionality. Having a set of specific guidelines for how the software will be implemented will be of great use to the team when developing the final software product for the overall design.

5.1.1 Software Design Process

Software development can be a long process that programmers need to go through. One of the methods of software that the team will start off with be based off the spiral model. This model will involve multiple cycles of developing software. This method will be best used for Senior design 1. Our team will first plan out what the objectives of the software, determine risks and alternatives, then we will write out the software. As we our prototyping the device, this is the process the team will go through to develop the software.

Once Senior Design 2 begins, the team will focus on a different method of software development. The software design progress that would work best for this team would be based on the agile model. This model focuses more on producing a working product rather than planning out the software. Given the time constraint we have, it is more effective to focus on getting the software working as soon as possible. This will allow flexibility for the team if there are any additional criteria that comes with creating our device that we weren't aware of.

5.1.2 Software Requirements

For our purposes, there are many requirements that are necessary for our software to run properly in in structing the hardware to accomplish its task. Firstly, the software must have as low of a runtime as possible, or more accurately stated, the lowest "big-O" runtime. Big O is a standard in software development for expressing the relationship between the size of the input dataset for a set of software and the change in runtime for the software (77). It is a heavy approximation as only the term with the highest impact/degree is specified (e.g "n^2" rather than "$n^2 + 2n + 1$"). However, most input sets are sufficiently large that all terms after the first will be considerably smaller, and this is also true in our case given that we are supplying and interpreting information from a spectrometer.

It is also important to minimize our runtime as we are using a laser, which is a form of light that runs at an extremely high frequency (thus the period of each cycle is smaller). If the runtime of our software explodes in response to an increasing input set (such as if there is a period where the data must be backed up a hard drive due to signal loss), it could cause corruption in the data, as it will not be correctly converted. The results of this are devastating on the functionality of our product, and thus avoiding this is a huge priority.

Another requirement of the software is that the code must be kept as clean as possible and must feature helpful comments where necessary to allow someone who has never seen it before or recently to piece together exactly what it is doing. This will also save a significant amount of time in the long run as it will be much easier to debug and revise our code if we can quickly understand what it is doing. Taking the time to clean up poorly written but perfectly functional code is always worth it.

Finally, the software must be as bug/error free as possible for obvious reasons. Since no software can ever be completely "bug-free", it is important that the software is tested rigorously in order to achieve as close to this as possible. See the testing section for more details as to how this can be accomplished.

5.1.3 Transmitter Software

When programming the microcontroller, we will include software that will need to be able to transmit data over properly. With the device, the software will first need to have the microcontroller to be able to read the input data from a certain output device, such as the Texas Instruments spectrometer. After we have that data, we will need have the data be converted into a format that can be sent over by laser, which is the analog format. The data would need to be sent through the device's Digital to Analog Converter in order to achieve this. It is also important to make sure the software gets sent over at a rate where the data doesn't get corrupted. To prevent this, we would need to set timers within our code that allow the data to get sent over at a consistent rate. To execute the software, we would like to possibly connect a button to the PCB and have the software run once the button is pushed. The transmitting software is will be about half of the software needed for the microcontroller. The other half will consist of the receiver software.

5.1.4 Receiver Software

In addition to adding code that can transmit the data, the microcontroller will need to have software added to it that will be able to handle all the receiving data. Once the laser sends the analog data over to the sensor, that data will be converted into digital data with the Analog to Digital Converter. The software will then need to be able to read that data over. The receiving software will also need to read the data at a controlled rate to ensure at the data won't get corrupted in any way. If all of the data has been decoded successfully than the software will cause an LED to light up to indicate that the transfer was successful. When the sensor contains new data sent over, the receiving software function will repeat itself.

5.2 Electrical Engineering

The electrical engineering prospective will the powering up the device to make sure everything is working and power properly. Once the device is power, the system will act to where it is needed and do such communication via a series of Signal communication between one to the other from the Digital to Analog way so that the signal can go further down as you can extend the signal Analog way but not digital. This is because a wave can travel for miles long while digital signal cannot do such a travel. This being said, the signal has to be use in digital for the systems but when it comes to sending the signal, it has to have the signal in analog. Along with the signals, the system has to have interfaces to connect from one device to the other in order to do such a design that can transmit a signal in high frequency.

5.2.1 Power

Powering up the hardware is essential in a way that this equipment needs some source to run. Never the less, it must be low power for the device so that everything can be easily transported if need be. This means having everything run using batteries and those batteries have to make everything function to what the specification tells it to do so. This will then call to power the PCB, microcontrollers, sensors, and spectrometer that will be used to analyze the signal and transitive the signal from point a to point b. As foresee, we can use 11.1 volt across to make sure we have enough power to supply for everything it is intended use. In between there will be voltage regulators to partition the right amount of voltage so that the system does not get overloaded. This will then bring the random voltage from the wire to a definite voltage which is required for the piece of equipment to function. For instance, 9 volts can pass by the wire that is providing the power and the board needs only 5 volts. If the 9 volts go in the board, the system will get overloaded and my not work or may just burn. This is where the voltage regulator will then step the voltage to the right amount so that the board would not get fry not overload the circuit. Never the less, the whole system will have a sum of 11.1 volts for everything to have its right power at the right time. Those components that need the power at the right time will be the microcontroller, sensors, laser, and the NIR spectrometer.

Each of the components that is implemented will need a voltage regulator unless the components are the precision time where it is needed. The main frame computer should absorb approximately 2 mA in which is needs a voltage of 3 to 5 volts. The sensors will absorb a current of 2 mA which is 2 volts. The laser will be one of the biggest power absorptions since it is the consistent light that will provide the transmission and the communication. Since that is the biggest power absorption, then it will induce us to make that the main power along with the NIR spectrometer. So, the Tx Laser and Optics will be around 2mA which is 2 Volts. In the other hand, the NIR spectrometer will induce 120 mA which is 2 volts. The lowest power will be the microcontrollers even though the main Microcontroller will be less than the processing microcontroller due to it having more processing power due to extra equipment that is has to incorporate.

In fact, all of the components mention above, will have the main power from a battery supply that will be led from that amount that the most power drain device so that it can be at least for the demo. However, if the power of the device can be lower, then most of the power will be step down to regulate all the power or just cut the power consumption which will be great as it will be eco-friendly by using less resources then what it will be in traditional equipment. As a resultant, the device use in this project will resemble the most efficient it can go up to this point of the century.

5.2.1.1 Power Jack

Besides having the normal port that will have so it can transfer data and communicate among all of the parts with a power source. Each and every single section will have a power jack xt80 port that will help to power the device when it is in standalone or it when it is in need to charge the batteries. This will help in many ways as implementation power is good, but there are many times when this system will not have a Universal Serial Bus (USB) port or The Universal Asynchronous Receiver-Transmitter (UART) available or even so there will only be a one-time implementation of code so this system can run for its lifetime. That being said, there should be a way to supply power without having a computer source.

One of the key features on implementing the power Jack xt80 is that anyone can get the power cord and plug it in to the wall rather then the computer source. This is because many times this will be use for a multipurpose that there will not be a computer around for some distance. This then can be another option to power the system as the power will last for some time in the battery. However, if implementing this power source, this will last for a lifetime as long as it has enough power to supply the needs. This can also mean that there will be no worries about the batteries running out.

Another key feature that by implementing this power Jack xt80, the system can run for finite time unless this power goes away. As the power grid is an amazing supply to give any system but it is not perfect. This imperfection can cause a lot of data lost. This can be tragedy, specially if it is for government systems that need to transfer data to a tower or even worst, a plane communication. For instance, an airport communication system or a military base that needs to talk from one area to another. If there is no communication, then there will be serious effect. That serious effect will be error when doing a data source by the military or for the plane communication a plane crash. This is a serious matter if the power goes out. Many people just think of the present but never of the future. However, if this jack is place when the power goes away, then this power can be redirected to the batteries which will run for some time until the power of the power jack xt80 get recuperated. This then brings three features rather than having it just with the battery. Those features is continuous power, backup power, and standalone power, which is perfect for any scene of event. This then will be place next to the implementation port so it can be easy to note when the user is not knowledgeable to the system.

As of this, the power Jack xt80 has many supplement ways to be used, this can be very intriguing as most of the time, people look on how to supply power to their device in more than one form. This then can bring that input of opinion to life. As the system can still get power by the USB or UART when using the computer or If there is a port that has the power socket with another end a USB, then it can be charge that way. However, to make it easier any user, the power Jack xt80 will be added since it is one of the most common ways to plug in a device. This then will implement a second effect to any device since most device come only with one port of charge. In this case, this product will bring two so anyone can supply power anywhere that there is a power jack. Even so, this will bring two other features which no device of this magnitude has. To have this system standalone with just batteries or an extra power when the power goes out. This comes very handy as no power has been able to just give power for finite time. This is because there will always be a damage transformer that will cause a blackout and the power has not been restore for a day or so. This will give the system a chance to obtain power when there is no direct power supply to the system. This can be also treated as an emergency power supply. Most systems would not posses this, but this one will so that the system can communicate all the information that the system wants to send and receive until the power goes back to normal.

5.2.2 Interface

The interfaces are essential for the whole circuit to run as smooth as possible as it makes all the connectivity amounts the parts. This means to have the converters, micro-controllers, and other components into place to then communicate amongst each other. Rather than just to have the components working independently without a communication.

This then brings what could it be put into place for the linkage. That linkage will be an interface that should make a smooth track to make every process as smooth as possible since we do not want any abruption to the signal and have a failure. As a fail communication amongst parts is a huge issue since one is tie with another work. If one works and does not send the signal then either the part should not work or the part should transmit erroneous output which is one the worst outputs that the components can do as that will bring chaos that will go from one device to another. Therefore, when designing this circuit, there should be a test point to make sure the signal is being send in order for the other parts to work. If it does not pass the test, then the signal should not continue as why will the circuit be a continues if everything will be erroneous

This is why each part and or component should have a start and ending test for the process. This test could be an interface that connects one cycle of work from each process to the other and this process will eliminate the project to stop working and having the most efficiency project that could be ever created amongst other projects if there is any.

5.2.3 Communication

The communication of this device is very critical. One section that engineers have to consider is the type of signal communication that is being used. As this is brought up, the knowledge of signal and analog commutation comes into place. Digital signal can travel for a short distance which will not have the same effects as the analog signal. In the Analog signal, we are expected a wave signal while the digital signal is a square wave. In most cases, that wave is a sine wave which propagates a distance that is unbeatable compare to the digital signal. This then will bring us to what distance we want the signal to travel. So, the transmitters will have the digital signal. The solution will be to use the converters to analog to create the analog signal to send thru mid-air. Capture the signal and convert the signal back to digital so that the equipment can then send the information to analyze it and give the output that it needs from the open-air communication.

Connecting this to the directed High Frequency, Open-air communication should then still apply the same way. However, the signals have to be one directional which means that the signal need to convert from analog to digital or from digital signal to analog signal since the parts only communicate one way and from what was mention above, the transmitting signal will be analog but all the analyzing will be digital. Then the signal will only be converted on the connection of the communication. Also, the steps should be the same when doing the conversion and making the signal back again to the original signal. In addition, due to the level of amount of intensity of work load. This project will be split into two sections. One section will then be with one microcontroller and the other section with the other microcontroller. The first section will have less components and the second part will have more due to the internal memory that have to be imply to make sure it has memory, just in case there is a failure when doing the process as seen in **figure 2: Project Diagram**. Also, it will have the NIR spectrometer so that it can read out the signal to then analyze what the signal is doing to then send the resultant data back.

For the first section, there will be a main frame computer that is digital base microcontroller. This microcontroller is not as intense as the second part as it will only receive the signal that it needs to transmit to and send it thru the optics to then make the communication. As noting the controller having a digital signal and the Tx Laser and optics being analog to make the signal go further than the normal digital signal that we use in traditional equipment in this century. The system will use a Digital to analog converter to convert the signal from digital signal to analog signal. To then make it ready for the Tx laser and optics work the right way. In the other hand we have to receive the signal with Rx optical and sensor which runs in the analog signal for transmission purposes. This then needs to be converted from the native signal which will be the analog signal right back to the digital signal that the mainframe computer which is a microcontroller that will be doing all that job.

As specified for the first section of the signal analyzing of the high frequency, open air communication device. The signals between the Rx optics and sensors and the Tx Laser and Optics are set to go since the signal from both of them are already analog. This then will not propagate any signal converter since it is in the same type of signal that it should be. However, with the components that the Rx Optics and sensor will be digital signal. Then, an analog signal to digital signal will be essential since we have a high-level microcontroller that will communicate amongst multiple parts that only communicates in digital signal. The only part where this section makes it different than the other first section is that this is the analyzing side. This being said, it will have internal storage and

NIR Spectrometer that will analyze the signal as it goes thru. The internal storage should have an in-house communication that will not promote any extra communication since it will live in the main microcontroller. While the NIR Spectrometer will have an inherent communication since it is Universal Serial Bus interface connection. This being said, the communication will be thru a wire to then implemented on the PCB to make the sufficient pin set for the microcontroller. Once all that is set to go, the microcontroller will then send the signal to the Tx laser and Optics. Just, like the incoming traffic of communication, the signal will be analog signal that is promoted and the microcontroller will be digital signal. That promotion will be a Digital to analog converter so that the Tx laser and Optical can then know that is being transmitted after the signal has been analyze.

Lastly, the linkage of all is the most critical part of all. Now that the first and second section have been developed, the interconnectivity inside the system will be digital signal since all of the components in this digital world. However, the transmission communication will be analog as explain above, it is the best way to communicate from one section to the other as per signal strength plays a huge role into this High Frequency, Open communication device and even though the main transmission of optics is the laser, they still tend to hold all the principals from the signal and analog communication.

5.2.4 Connectivity

The connectivity is essential as that is a way an Electrical Engineer can implement to make the interface of the connections so that either parts can communicate amongst each other or a common PC that can connect to the device so that Computer Engineers can implement the code in the higher language and compile to machine language. However, this will be essential for both boards. As the project is split in 2 boards, the first board will be. The first board will be the main board which is not as deep with connections as the analyzing board.

The first board connections will have one Universal Serial Bus (USB) which will be use to either connect to the board or charge the batteries so that when the system is in standalone, the batteries have enough power to make the system run without the computer power. This can be look at like a computer, cellphone or any other component that have a battery and a charging unit. As when it is not in use, the power has to dissipate somehow and if it has a place where electrons can be kept, then it will fill it right back up to how much it will be in maximum capacity. Once it is charge, then the computer will stop charging as a safety feature that all computers have.

The second board is a bit more inclusive on how everything is being done. As the Microcontroller has both Universal Serial Bus (USB) and the Universal Asynchronous Receiver-Transmitter (UART) connections. The first connection will be for the spectrometer connectivity and as a backup electrical connection as USB can produce electricity which can be used for the power but it is not like the direct power. Now when the Universal Asynchronous Receiver-Transmitter (UART) is taken account is due to the fact that the USB is already used by the spectrometer. Due to the spectrometer using the

USB, then there is no way to connect to the board unless we use other connection which in this case it will be the UART connection. This connection will fill what the USB will output, just another figure on how the pin out will be. As the UART is being use as a main connection to the board, then this will mean that this will give out of the information to the board along with charging the batteries when the system is on standalone. Just the first board, once the battery is fully charge, the system will stop giving power as there is no more space in the battery to put the electrons in.

All of this connection will then supplement to either communication to the boards or charging unite to the batteries. Never the less, the connections will be use in a fashion that will be for multiple usage such as a supplement of code, charge device, or even supplement of power. That is why, even if the port is use just like the spectrometer, it can be used for communication and power supply. Just the power needs to be available to give all of its essence product. As every connection that is being done by any media is an electrical connection, just its transiting of electricity, it will give a piece of data along with it which is the charge to keep the device going and the language that the computer or program is. This is the creation of machine language which no one wants to deal with but it is the only way that the computer has to communicate. That is why we have a compiler that will translate the higher-level language code to machine language. That higher level of language is somewhat of what any human can read, just it is dummy down commands of what a computer science or computer engineer has knowledge of.

5.2.5 Batteries

The batteries are an essential power source for the system as when it is not hook up to a computer or a power supply, this can be use to run the system. As the computer power is as good as long as it has power or it is connected, which is why it will have a power source which is the computer but in standalone, it will have a way to still remain on.

The hook up to these batteries is essential. As when it is not connected to a main power source, it will drain the batteries. However, the batteries will be hook up to the device for a lifetime. That means that if the high frequency, open air communication is not connected to the computer or a power source it will drain out the batteries to remain on. This is why there will be an on and off switch as when the system is not operating, then, the system will be off. This will then provoke a longevity of battery time and life. As the more times that the batteries get recharge, the less time the equipment will have those specific batteries as the life of the batteries wear out the longer the it is used. This is a mean on an extension of batteries life since the battery of life is essential in a way that no one wants to buy batteries every other time that they use the item as batteries are expensive and it will be very costly to keep swapping batteries just because there was not an on and off switch that could prevent a faster breakdown of the batteries. As all the parts in the battery are not meant to last forever and the more it charges and dissipate the charge. The more of the wear and tear of the batteries as shown in the picture below. It is not the structure that will go away but the chemical that is in will start to get weaker by the second as it has used all of its chemical power to retain the charge that is needed in order to sustain the charge.

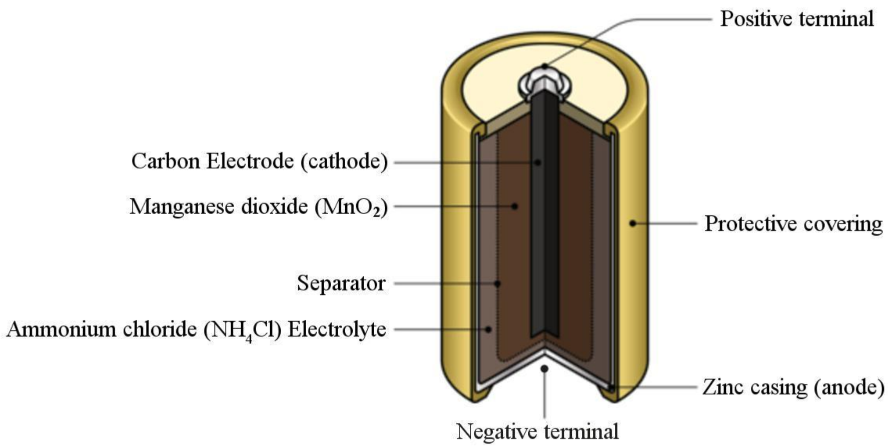


Figure 5.2.5.1s: Battery Structure

The project will also be accounted for 2 sets of batteries which are 11.1 volts as the more power the system constrain, the more power it will consume. This then sets another boundary that the system has to be environmentally friendly since it uses quiet a bit of resources to make such a design of batteries. Yes, it will still have the exterior connections but at the same time, the project should still sustain itself when operating standalone. If it cannot run standalone, then the project then becomes dependent which is not good since this needs to be use for multiple purposes in future usage if there was no power outlet near to power up the equipment.

5.2.6 Printed Circuit Board (PCB)

A printed Circuit Board is an essential piece of equipment that will be design during Senior Design II. However, in order to get the PCB in a good standing condition and think everything thru, the design has to be in a breadboard to see how to set and test everything before implementing it on the PCB. As when dealing with the breadboard, it will only take a few hours to debug rather than the PCB software since it is life rather than just a picture that can tell you a limited amount of functions. It can be simulated that the PCB is the final breadboard assembly that will take place rather then the actual breadboard since the breadboard can be disassemble compare to the PCB that is being design.

5.2.6.1 Designing PCB

The designing of the PCB will be a very essential piece which will lead to the final piece that will be executed in the middle of Senior design II in hopes of having it work the first time rather then reshipping to rectify. When designing the PCB, the most important part of designing is knowing the space it is being work on. To get knowledge of the space where is being work on, everything will be develop using the breadboard to test out all the equipment.

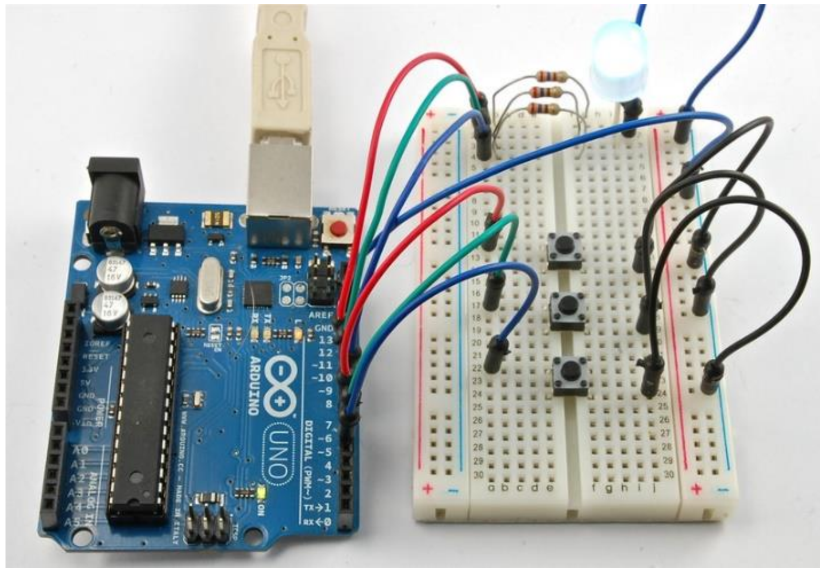


Figure 5.2.6.1.1 Developing Breadboard

Most of the development have been done using the developing boards rather then the actual microcontroller as it has almost identical like if it is being develop using the chip but it has all of the signal converters. Just this will give a base overview on the size of the board that will be develop for the main project and how it will function. Meaning that it will take all of the signal processing out of the electrical engineer and the only thing that the Electrical engineer has to worry about is the wiring the system along with the extra accessories. In addition, the electrical engineer has to then make it as easy to develop the PCB when it is being implemented. As shown in the example picture above, the chips are place in a specific place to get the signal pins to the right as that is how Arduino Uno works. This is just for testing purposes but when making the final project, the developing of the project will not be like how the developing board is design.

The development will only have what is needed for the project. Yes, the project will have the microcontroller, Analog to digital converter, Digital to Analog converters, connections, power units, and extra sections that will be implemented to make this project a success. As for the first board, it will be pretty basic as it will have everything that the developing board will offer, just connect it to the extra features that will have the photonics side where the laser and sensor will be. Along with the connection of the battery to make sure it can be in standalone mode along with a switch and a button. As the switch plays a very critical part of the design to make sure it is draining the battery when it is needed not when the system disconnects from the Universal Serial Bus (USB) source.

However, when the second board is being implemented, then the Universal Serial Bus (USB) type B will go with a main component and implement the Universal Asynchronous Receiver-Transmitter (UART) connections. That type of connection will then be implemented on the breadboard as an extension since the spectrometer is taking the USB connection and will be replace by the UART. Along with the extra attachment that the first board will have with is the laser, the sensors, and the extra storage if desired to have extra hard drive to store data if there is a failure. Never the less, if time permits, add lights at strategic points to make sure everything work fine. If the light does not turn on, then it will be easy to debug.

When doing both boards, there will be a significant notation on how theory works on the real world. Even the space required when developing both systems. As when describing the first breadboard, the system will be relatively small as there is not that much to attach and extra implementation that is needed. This being said, the system will be as big as the bread board as the extra implementation that will take place will take place what the extra feature the development board take. In the other hand, the second board is the one that will take the hit on space. As the second board will have the extra attachments that is not use on the first board. However, the construction of the board will be discuss later down where the area where everything be work on will take place on how to contain the space to make the system as small as it could be and the extra power attachment the PCB has to have in order for some heat dissipation that needs to take place in order for the circuit to have the exhaust that every circuit should have. This means that the circuit will need to have extra output voltage in 2 areas to put a fan in each side of the extrema to make sure that the PCB and other components are cool down rather than working in high temperature. As the higher the temperature, the less likely that the equipment will be working for the extend time that everyone would like this system to work. As known, the longer the product is alive, the better since every second that has as an extra life, the better as more money can be invested where it is needed.

5.2.6.2 Implementing PCB

When developing the PCB in the breadboard, it is easy to do, as it is being develop on what the principals of theory is all about. Everything should be working proper since all of the equipment is tested on breadboard. The implementation should not relate any debugging as of the debugging on how everything works should be done already. This means that the design should be just a copy and paste of what it is being work on when developing the board.

When dealing with the Printable Circuit board designing software, it will be actually a learning experience. As this type of software was never dealt with in the past, the only type of software that any Electrical and even computer Engineer have dealt with will be a circuit building (Multisim) that will have all the principals to that the breadboard has to deal with never the less, this will be a learning experience to get in the electrical Engineer as a background. As the main reason is being is due to the fact that as an electrical engineer purpose is to hold itself to designing all electrical components and schematics. The main principal of those schematics come from the Printed Circuit Board. Those schematics can be printed largely with a large format printed that can be 24 inches by 36 inches or even longer depending on the circuit that is being done. Never the less, every single circuit should go thru a circuit design software and even breadboard to then executing it in the circuit boards.

Remember, on the Printable Circuit boards, are just a cad base software that can tell you a maximum of data but the deal comes live which is where the base principals come into play. The main software that will bring the breadboard design into play will be either Easy CAD or Eagle CAD as those are Computer Aid Design software's that will then have a main frame to show every single feature. That the breadboard withholds as a base model but instead of the board having various socket that can be resign every single time and can be re-use. this software's will help Engineer a specific board that is right for the job that is being done at that precise time in the precise moment. Those boards will be for a one project use and cannot be reuse as each circuit is done for a purpose. That purpose cannot be redone as it is meant to tolerate whatever that one design is for.

As a first option, Eagle CAD will be the prime software that will be use to implement the breadboard design into a printable circuit board as it is widely use not just in the University but in multiple companies as it is a very sophisticated software since it has multi-purpose. That multi-purpose make you use the same software and run various points of view that cannot be done by many PCB designing software. For instance, you can have a PCB design, breadboard design, and create any part that is brought to mind. That being stated, not only will it bring another peace into mind to think that this CAD software may bring a lot of open creations into play but can help when designing a unique piece that may be needed for a special purpose.

As the secondary option it will be a manufacture software that they made it mostly for students. That software is Easy CAD which is the manufacturing site where you can set an account with them and they have everything pre-design software that is very useful. Not a sophisticated as Eagle CAD but can do as much as it is needed due to the fact that that it with pre-design parts that they contain in their library not like Eagle CAD where an Engineer can design any platform from scratch. There is no restriction to Eagle CAD rather Easy CAD brought many restrictions since its main purpose is to make it easy for students to start but not develop for a company that needs special parts. That being said, this is a secondary choice as the design of this printed circuit board is unique in a way that may need special parts.

As a whole, the software that will be used to implement the design may need to be Eagle CAD unless, Easy CAD can do extra functions that have not been explored. As there are many things that can be a lesson learn to all of the Electrical Engineers due to the fact that this is a new software that should not be an issue to learn, just like any software that have been in use. It will only take practice to master the beauty of the software as once the designer gets use to the software, everything should be pretty easy to develop and implement in the printed circuit board.

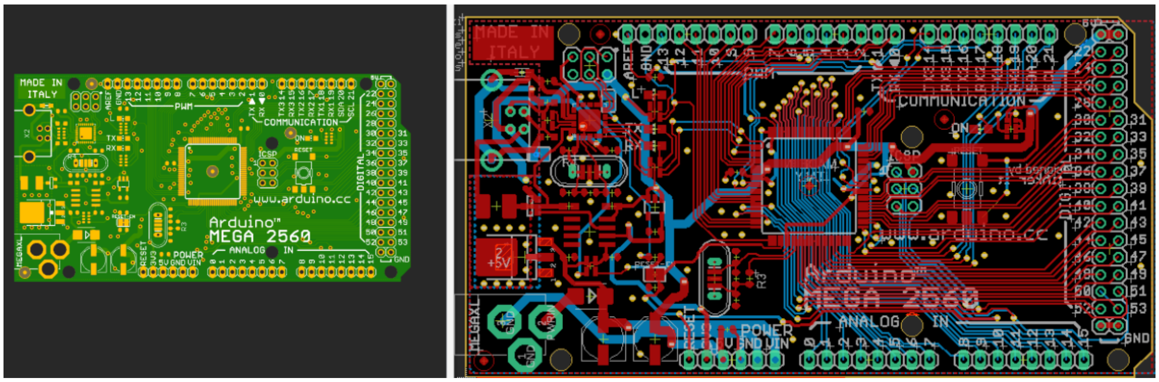


Figure 5.2.6.2.1: Arduino Mega Board

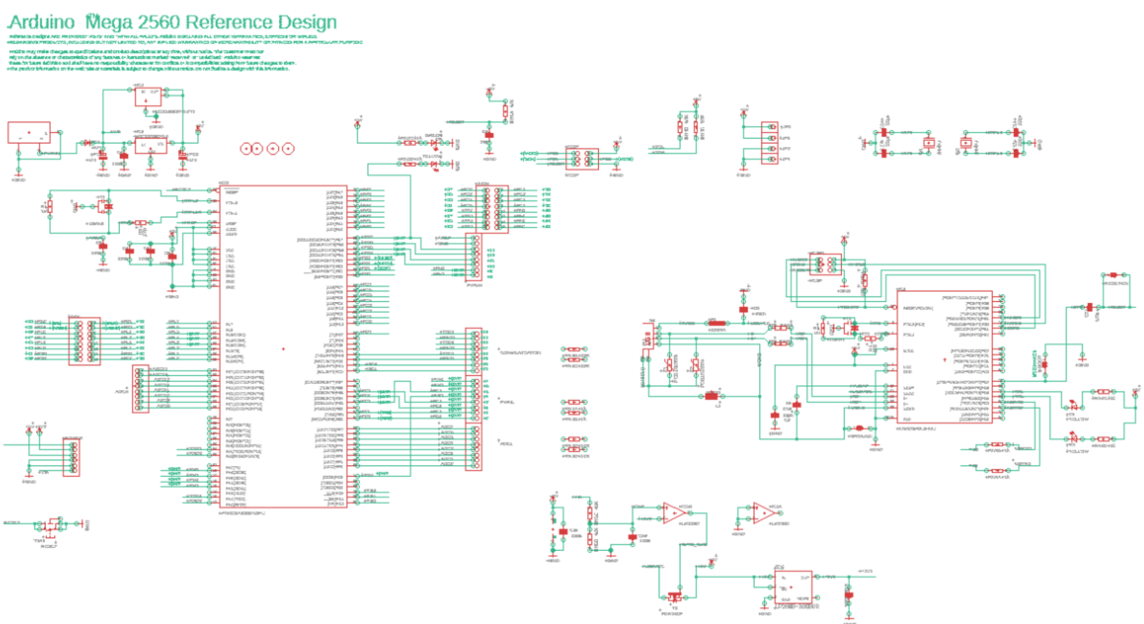


Figure 5.2.6.2.2: Arduino Mega Design

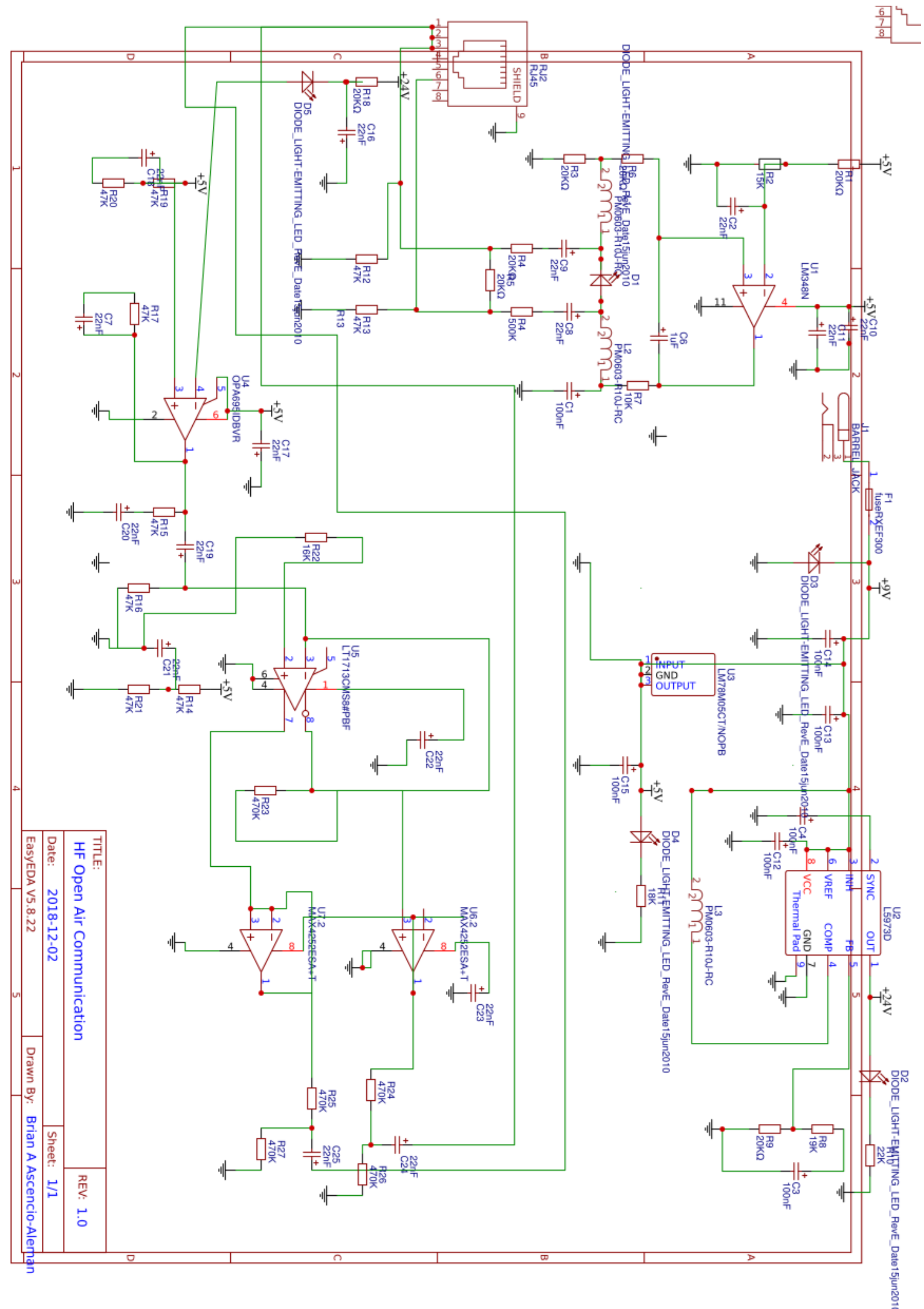
As shown in the above examples, the implementation from the breadboard to the Printable Circuit Board, it may take the same principals but the whole architecture is way different. As in the program that in the past classes, everything was develop using multisim which is a software that runs a built circuit that is used by theory. There are multiple circuits that have been built on that program but never to develop a specific board that will do a function. As in the CAD programs, there are options to do what multisim will let you do as it can be tested there and in the breadboard. While the CAD software, there be the same views but now it is a board design that will remove all of the extra pieces and put it for a specific task. As seen in the example, there are two views, board and schematics. The board will show how it will look when the board is manufacture and the schematics is the same view as if it was done by the multisim program that will notate what will each port used for not just the whole design that manufactures have but show the theoretical side that multisim reveals. As board wise, most of the time, no one sees what it being develop inside the chips, everyone just sees what is being done and connections. However, each chip has its meaning and built in circuit that no one can tell unless they actually study each side of the chips that is compress from normally size to microscopic view.

5.2.6.3 Manufacturing PCB

Manufacturing the Printed circuit board is a very critical part once the board being implemented. As software and theory wise can work but once everything comes together. Then the final product is being test, is an actual test. As the developing tools being use are great when everything is put as a whole but when building each section to make it specific, there might be complications. Normally, this boards will be seen multiple times before manufacturing due to the length of time it takes to get from one side to another. As Every semester, not only students send out printed circuit boards to companies to manufacture them, there are outside companies that have projects which is a huge conflict.

The main issues with the printed circuit board can be numerous of factors. Most of the factors may not be the designer, but the printing of the board. As computer are great when they work properly but may not be the case each time. As of a result, once the board is being done and ship to everyone, then, there might be issues that may need a second time to get rectified to make sure that the board is doing what it supposes to. As many times, the circuit that is being implemented may not work once it is printed out. If that is the case, then, there might need to be a rectified of the board that has to be re-printed to match what is needed. That may delay even more and can be costly due to it being a designer issue not a manufacture issue. Traditionally, shipping and handling could potentially take five to seven business days depending where the company is located. Not just shipping has to be taken into account but ratification and the companies process to then ship it back. As a result, when developing this type of boards, it is best to not just look at this boards with senior engineer students but experience people that have done this for years. If one is available, then it would be best to make sure they take a look at the board to design in the software that is being use. As noted not just in this design, it is better to check twice rather than wasting time sending it to manufacture. It be best for the manufacture to make the mistake but not the developer as if it is the manufacture mistake, then every single cost will be run by the company that is developing the board which will be great since they can even cover the rush process if the board needs to be done NOW.

5.2.6.4 Circuit Schematics



5.3 Photonics

The photonics involved in the production of the laser transceivers determines the type of light sources and sensors used to send and receive data. Although the choice of what lasing source and sensor to use may be somewhat trivial and straightforward, there are several constraints imposed upon the design process to be considered. Cost and availability play a role, as deadlines loom and time allotted for work can be somewhat short, having a system that can be comprised of readily available and commonly manufactured components is a very attractive feature to have in a project. There are more technical constraints to consider when it comes to interfacing the optoelectronics devices highlighted below. A few of which are driving circuitry, bandwidth bottlenecks in considered integrated circuits, power consumption, laser and sensor biasing, data modulation schemes and analog-to-digital conversion and so forth.

Because the channel provided by laser beam is the fastest part of the transmission chain of hardware it makes sense to reference this speed of transmission when selecting other signal processing components. The signal can only be processed as fast as the slowest link in the chain, so it does not make economical sense to pay for an extremely expensive component for marginal return in system performance. Modulation schemes must also be considered for the laser channel and sensor, as there are a few choices. Among these choices are frequency-shift keying (FSK), on-off keying (OOK), amplitude-shift keying, pulse-width modulation (PWM), pulse-density modulation (PDM), pulse-code modulation (PCM), pulse-amplitude modulation (PAM) and frequency-division multiplexing (FDM). At the prototyping stage, it is unlikely that any sort of TCP/IP socket programming can take place. Thus, existing network protocols won't be considered for the first demonstration of transceiver operation. Additionally, free-space optical communication does not have many regulations regarding 1550 nm transmission. This, fortunately aids flexibility in design by leaving the project team free to pursue solutions to technical challenges without having to consider regulatory impositions on design.

Existing standards are also used to form a frame of reference when choosing supporting hardware. Design of this system is very much centered around the optoelectronics chosen. Once the optoelectronics are chosen, the supporting electronics are then appropriately picked to fulfill needed roles. These roles consist of converting between signal types, signal amplification and noise reduction, clock generation and other waveform manipulation functions. Because the laser transceiver device can essentially be considered a relay, it is important to also consider how the end user will ultimately be interacting with the device. Most people do not think about the embedded specialized hardware running code inside a soda vending machine, but it is there. The user picks a drink, presses a button and a computer inside the vending machine processes the input and vends the appropriate drink, meanwhile the client is thinking only of the cost-return benefits of their exchange between a few dollars in their wallet and a tasty beverage. Much like the embedded hardware just discussed, and other networking hardware forming all network infrastructure, the laser transceiver will not be a device that the user will need to constantly be interacting with. Rather, the transceiver should be able to operate autonomously, providing a reliable connection while the user is free to carry out network based tasks through a variety of network protocols. Currently, it is planned that the transceiver will support Ethernet and USB connections and protocols. This necessarily implies that certain standards must be adhered to, as the transceiver helps form the physical layer of any network protocol that it supports in the future.

5.3.2 Laser driver circuit

The laser driver circuit should be capable of directly modulating the laser at a minimum frequency of 10 Mhz. A driving circuit is required to convert voltage modulation signals into a modulated current signal. Figure 5.3.2 shows two examples on how we can potentially modulate our laser diode. The left figure shows a digital, on-off modulation. The right figure shows a laser biased at threshold, while being modulated with a small analog signal.

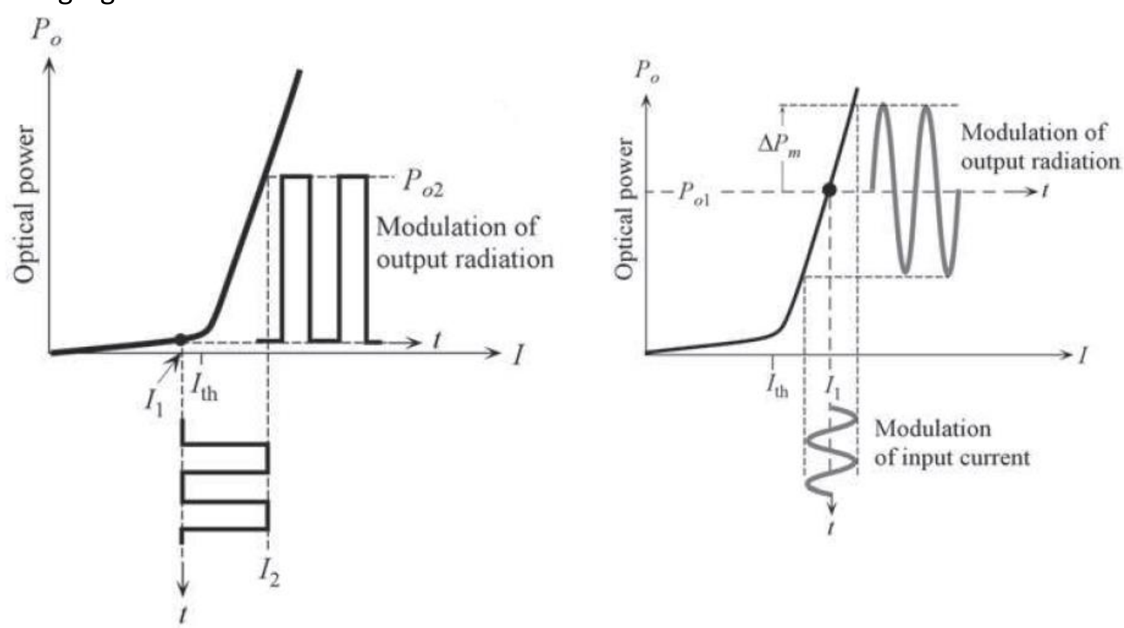


Figure 5.3.2 Laser modulation schemes.

In both cases, there is a delay between the input current, and the output flux from the diode. The current and light signals are out of phase.

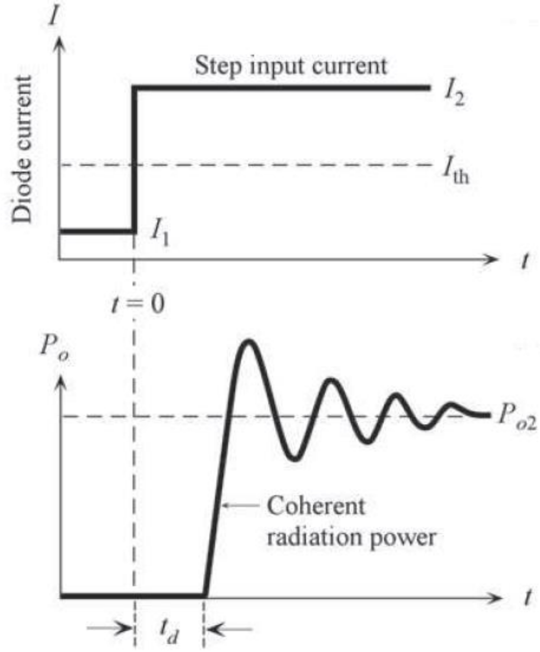


Figure 5.3.2.2 Graphs showing the delay between current and output photon flux.

5.3.3 Receiving amplifier circuit

The output signal from the photosensor will be a current signal, thus it requires conversion to a voltage signal. The circuit that supports the photosensor should also provide amplification. ThorLabs also suggests a circuit configuration for the sensor chosen which is displayed in figure 5.3.3.

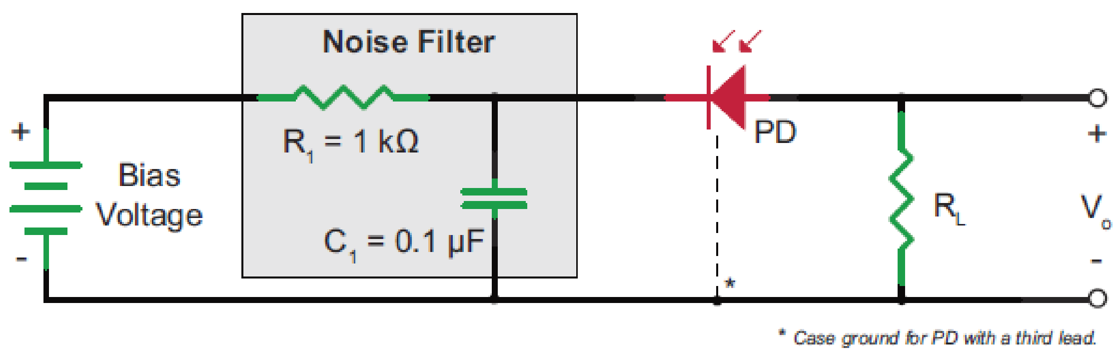


Figure 5.3.3 Suggested circuit configuration for FGA01, provided by ThorLabs.

This circuit configuration will be used, where V_o will be wired to a differential driver. The purpose of the differential driver is to convert the singular voltage output signal to a differential signal. A differential signal consists of two polar opposite voltage leads that both carry information. This is a typical pin configuration for Ethernet and serial jacks. It is not desirable to amplify noise that is intrinsic to the sensor, or light that is not the wavelength of interest.

5.3.5 Optics

Design for optics is currently in process. Collimating optics are being modeled in Zemax with their spot diagrams for the appropriate wavelength being compared to sensor sizes under consideration. To expedite this process, example optics that are available for purchase are being used as starting points for generated models. Current sensor models active area is around .3 mm to 3 mm in size. Prioritization of critical components would also put optics at the bottom of the list. If necessary, optics can be salvaged from currently available commercial laser pointer devices. One thing to keep in mind for optic coupling between the laser and outgoing collimation optics is that the NA of the collimation optics should be twice that of the ball lens of the laser.[59] Currently it is not anticipated that any sort of aberration correction will be needed in this design. This negates the need for a complex optical system on both the transmitting and receiving ends of transceiver modules.

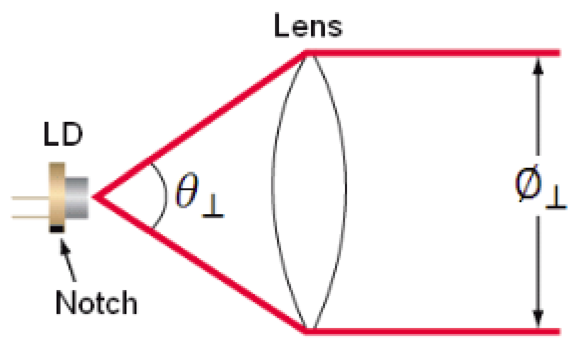


Figure 5.3.6 Illustration of LD light emission being collimated by a converging optical lens.

Because the laser diode of choice is an edge emitter there will be some astigmatism afflicting the laser beam. This means that light emitted from the diode will diverge at a different rate in the transverse and lateral directions with respect to the optical axis. Thus, for succeeding calculations the full-width half-maximum (FWHM) beam divergence for the largest divergent angle will be used. The reason for this is that radiative power contained in the beam theoretically remains the same, but the increase in wavefront area will lower incident power at the receiver. If safety calculations are performed, then the smaller divergent angle should be used so that incident power is not underestimated, leaving room for a safety buffer.

Ideally, the optical system should have some method of adjusting focus in response to the distance between transceivers. This will optimize the beam profile for whatever distance is required for the beam to traverse. At extremely close range, it may be ideal to widen the beam profile for two reasons:

1) To minimize demand on beam tracking servos and
2) To eliminate the possibility of damaging the receiving sensor with excessive optical power.
The sensor of choice lists 18 mW as the damage threshold. The laser of choice has a typical output power of 6 mW, so if time allows only the first reason listed should be of concern. Figure 5.3.5 shows a simple optical system consisting of two convex lenses. Although the exact lasing source is not yet known, most sources are edge emitting lasers with the largest beam divergence measuring roughly 15° for the full-width half-maximum beam diameter. The reason for including two lenses is to create a telecentric design so that the laser beam does not diverge from its intended path. Lens diameters were chosen simply by either assuming the size of the optics to be used, or by simplifying the system by also assuming that a size of 1.5 mm diameter optics will come preinstalled on the sensor of choice.

	Surf:Type		Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT	Standard		Infinity	1.000			0.026	0.000	0.026	0.0...	0.000
1	STOP	Standard		Infinity	0.200	BK7		0.270	0.000	0.303	0.0...	-
2		Standard		-1.500	4.800			0.303	0.000	0.303	0.0...	0.000
3		Standard		7.000	1.000	BK7		1.222	0.000	1.269	0.0...	-
4		Standard		-7.000	10.000			1.269	0.000	1.269	0.0...	0.000
5	IMAGE	Standard		Infinity	-			1.269	0.000	1.269	0.0...	0.000

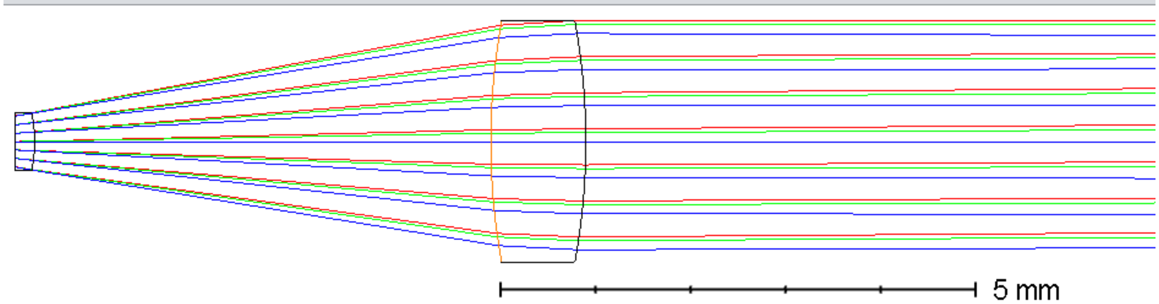


Figure 5.3.5 Current proposed optical system for transmitting and receiving optics.

5.3.6 Radiosity calculations & range

When selecting lasing sources we must check ahead of time to make sure that the output power meets our range requirements. Because collimation optics will form a beam as close to parallel as possible, some divergence will inevitably occur. However, extreme range is not required for our project, but it is desirable to extend the range as far as possible. Earth's atmosphere will cause power loss across the optical path length. Most receivers under consideration have a very low noise floor. This noise floor is defined as when the photogenerated current is equal to the noise inherent to the detector. This noise floor is typically orders of magnitudes smaller than the output power on any laser diode under consideration.

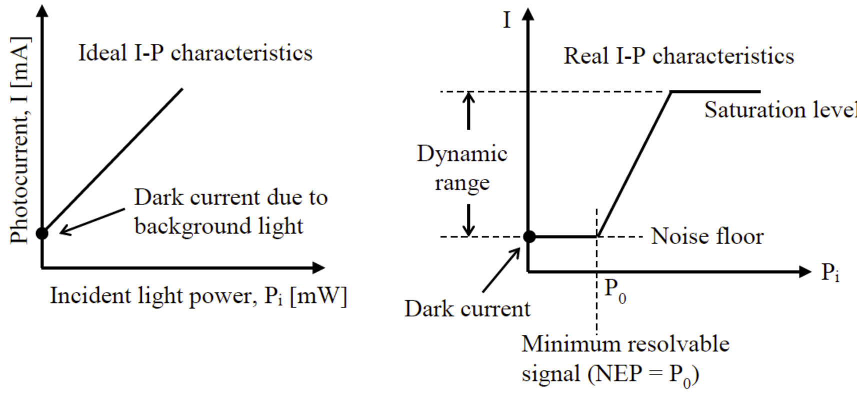


Figure 5.3.6

5.3.7 Mechanical housing

System packaging is also under research. Optoelectronic components that are currently being considered are all housed within TO style packaging. This simplifies design somewhat as there are existing modules easily sourced that can house such packaging. It is likely that whatever supports the diode package will be a conductive material of some kind to aid in heat dissipation away from the diode. The current foreseen design path will utilize 3-D modeling software that is capable of exporting an .stl file so that parts can be extruded for use. The TI lab offers a few options for printing. Typically, ABS plastic will be available to model with. ABS plastic is a good option because it is relatively cheap, lightweight and should offer enough printing resolution to work within our system tolerances. Below in figure 5.3.5 is a picture of three options provided by ThorLabs which are diode packaging options that include collimation optics.

Figure 5.3.8 Assortment of pre-available options for beam shaping. (Photo provided by ThorLabs website)

The LTN330-C (middle) is a particularly attractive option as there exists with the packaging the ability to adjust the displacement of the included lens along the optical axis. Although this built-in feature is useful, the cost of this housing is prohibitively expensive. High cost is an ever increasing motivator to utilize mechanical modeling solutions to facilitate the ability to tailor make housing according to the optical system needs.

Any structural design must also keep in mind the secondary objective of the project narrative. Line of sight must be maintained between transmitting and receiving units if at least one transceiver is actively moving. In addition to providing adequate thermal management options, the housing must not be bulky. It is known that the laser diode at minimum must be mobile and have the ability to traverse 180° in two orthogonal directions resulting in one hemisphere of free motion. Figure 5.3 shows a potential design for the mechanical housing. This housing features a hemispherical window to provide the laser diode with adequate line-of-sight. The sensor window is recessed so as not to obstruct beam transmission. Ideally, the transceiver should have the sensor window normal to the incident laser beam. The sensor window will ideally be a type of Fresnel lens, allowing the light to come to a tight focus without needing an excessive optical track length in the image space of the receiver. The hemispherical windows purpose is to protect the laser turret, while allowing it maximum range of motion. Because the diode and sensor are mounted separately, it could be possible to arrange the transceivers in a relay configuration. This design does have its drawbacks. Having a sensor window that is flush with the packaging reduces the ability to catch laser transmission that is not perfectly aligned. On the flip-side, this also has the potential to reduce unwanted interference. Because no team member has substantial experience with mechanical modeling, this portion of the design is being put off until a more concrete set of requirements can be produced for mounting the PCB and other electronics within the casing. Servos will be inside of the case, eliminating the possibility for having a large unit needing to be traversed to maintain line-of-sight. It is not yet known how much heat onboard electronics will generate. Primarily, it is expected that most heat will be generated from the laser diode. It is likely that this will need to be housed within a metal, cylindrical heatsink. If necessary, a cutout can be made in the case, where passive cooling heatsinks can be mounted on chips on the PCB and exposed to the external environment where airflow can flow and dissipate heat. If modifications must be made, RTV silicon gel may be used to form a gasket to ensure weather-resistant packaging.

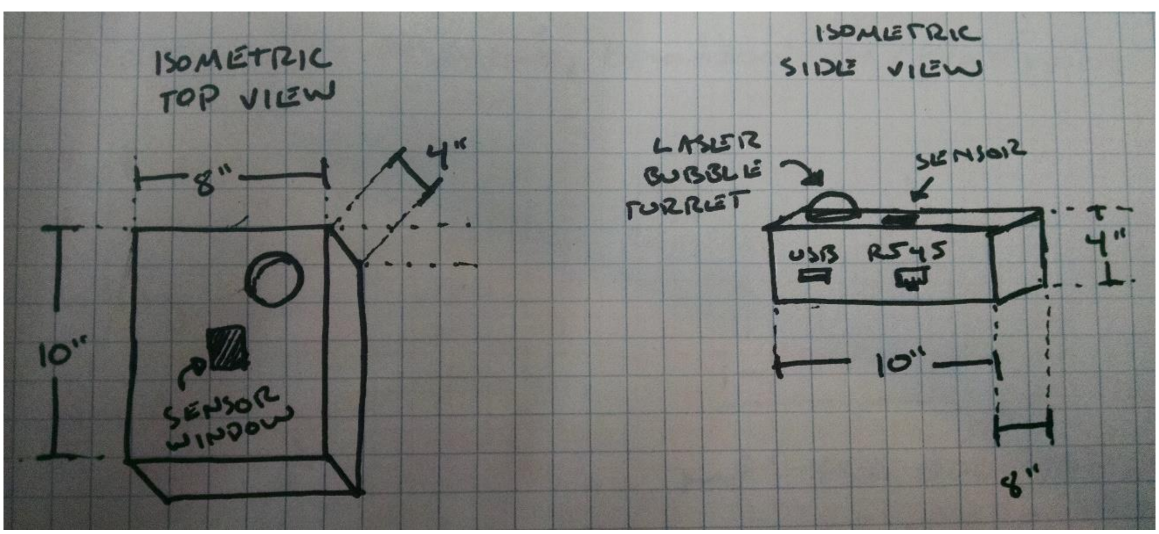


Figure 5.3 Concept art for mechanical housing.

5.4 PROJECT BLOCK DIAGRAMS

As shown in Figure 2, the project's main hardware components are listed below. The NIR Spectrometer records the pressure and temperature, and this data is communicated to the microcontroller, which in turn stores the data. When a connection is made, currently stored data is converted to analog and transmitted via high frequency communication to the mainframe computer, where it is received, converted into digital data, and stored. To communicate with the receiver, the mainframe computer encodes data into high frequency communication and transmits it, where it is then decoded and stored by the receiver's on-board microcontroller.

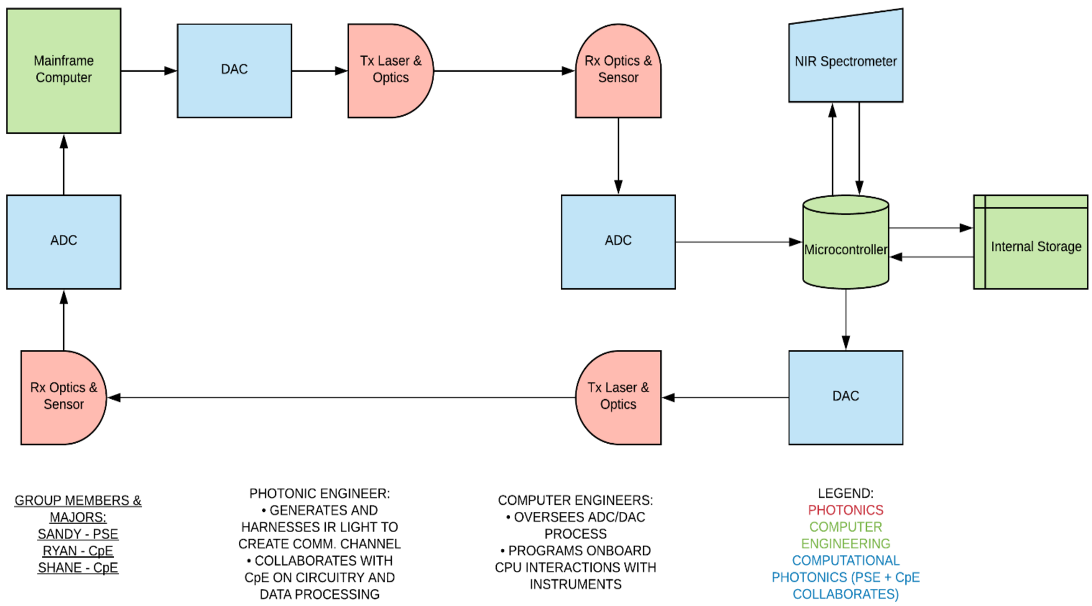


Figure 5.4.1: Project Block Diagram

In Figure 3, it's shown how the software will operate within the system. The software of the transmitter and receiver is separated by the red lines, which communicate between the two parts of the system. The microcontroller will ensure that all of these commands are followed and the laser gets transmitted through the following components in the system. If the data has been found, then we would send it to the digital to analog converter. Then, we would need to would need to wait until the DAC encrypts the data so it can be sent over to the receiver via laser. Once the data has been sent over successfully it would go through an analog to digital converter so that the data can be decrypted into its original format. If the data has done this successfully, then an LED will turn on to indicate that the code has ran successfully and the display will update.

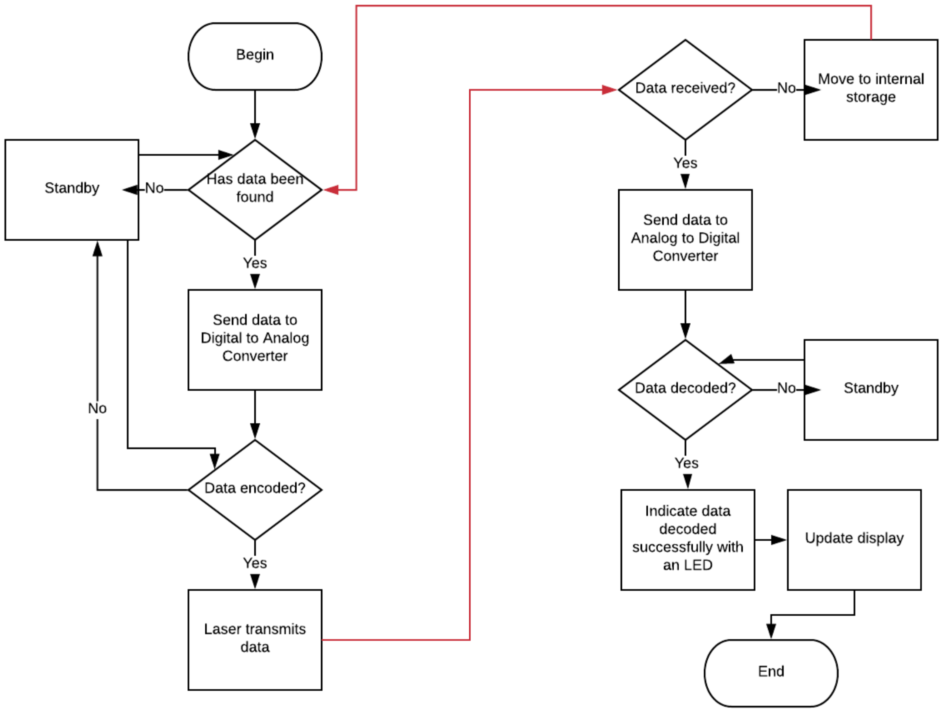


Figure 5.4.2: Software flowchart

6.0 INTEGRATION & TESTING

One of the most important steps that comes next is testing the device. It is important to see if each of the individual parts of the device work separately before they can work as a whole. Several of the tests will need to be done on the hardware and software components. This will need to be done before we can have each of components integrate with one another. It may be difficult to remove certain hardware components once they are integrated with the PCB board, so its important to make sure our components work properly. Once all the individual components of the device work reasonably well, we can integrate all of our changes together into the main device. Then, more testing will come after that to see how well everything interact with each other.

6.1 INTEGRATION (construction)

During the development of this high frequency, open air communication, there will be a lot of brainstorming which is going to take during the Senior Design I. While constructing the senior design I main backbone of the knowledge base of what the whole product is all about and what is expected throughout. There will be the construction for the integration of the circuit such as the development of the parts and PCB that will connect all the parts and make sure of all of the step up and down of the process. Never, the less, this step is critical point of the project due to the fact that this is where all of the parts connect from all to another. If the parts do not connect properly, then this this is the part where the debugging will take place. There will be multiple times where the PCB might need to be adjusted and this will take time. However, this is the main reason why in Senior Design I, this schematic is done and rectified before the blueprints is send to manufacturing. This means that this will be look over multiple times and if necessary this PCB will be view by experience engineers to make sure this board be done right the first time that way there will be no resending back the equipment as it was check multiple times.

As seen in previous project and even until today, most of the projects have been view by multiple engineers to make sure that each and every part is done correctly the first time around. Remember, the deadline constrains are very critical when dealing with this. Integrating each and every part is can be simple if rectified that way engineers are not wasting time when doing the integration of each and every part. Remember, it is very essential to view it multiple times rather then send everything while integrating the equipment sending each thing back and forth due to not checking as there will be extra cost relating each shipment. This why integration of the equipment becomes ways easier when checking work. Specially if each work is checked by experience engineers that can predict the best of all equipment.

6.2 TESTING

While constructing the device, there are different testing procedures we'll need to implement to ensure that each individual component of the device is working properly. This section will include the testing for individual hardware components such as the microcontrollers, and the sensors, and specific sections of the software, such as receiving data from the device and sending it over to the ADC and DAC. In addition, the project has to be tested on the power consumption when it is on the main power or when it is in standalone. As it should remain with the same power consumption. Also, each and every port has to be tested to make sure it is not just hardware nor software failure.

6.2.1 Hardware Testing

One of the first areas we can start off our testing in is the testing of hardware. Even though some of the hardware components need to be used with software or other hardware before they can be tested, some of the hardware components can be tested separately. Some of the main hardware components we will need to focus on testing will be the micro-controller and the sensors of the device.

As a whole, all of the components that will be implemented, should be in perfect standing conditions as the manufactures that any equipment provides have been tested by prestigious companies that all they do is break each component where it will fail and test each side where there are points that no one thinks that it will fail. For instance, the prime fail of the component is temperature as in different temperatures, parts have different failing points. Most parts are tested from the extreme cold such as -52C, room temperature, and extreme heat up to 152C. Most people think that just because the part will work in one temperature, it should work any temperatures which is a wrong assumption. Those assumption can be shown when being tested in the testing facilities.

The testing facilities are very intriguing how they work. They have various PCB's where they will put all of this component to the test. They have a destructive test, where they will take the component and put it in a vibration unit where their component be tested when it gets a huge impact when doing its job along with a circuit test in different temperature. The components will be pass thru numerous of other test in order to assure that each component is good to go when it is out in the field. Never the less, they thru other test that may impact the circuit to work properly. Although these facility goes thru all of this test, there is one huge enemy that it is inevitable when dealing with this type of equipment that in these facilities have had issues which every measure is taken into account. That enemy in which is spoken by every single facility is the Electro-Static Discharge (ESD) which lives in the layers of every equipment. Every single human would not be able to note what this ESD is as is microscopic damage that can only be noted with microscopes and specialized equipment. As taken into account, those testing would not be able to be done in the current labs that most Engineer student goes to as those labs required special care of the equipment. That extra care will be done a specialized lab that do extra care for the equipment. That extra care would be Specialized lab coats, finger cots, wrist strap that will be attach to sensors, specialized matts, and other ESD equipment.

As for an Engineering Student, each testing of the hardware will be done as a base model to make sure the equipment outputs what it should output as the project is only for a single use or just for a demonstration needs to work for a few minutes or a semester long to prove the learning objectives where it will not only show universities that the objectives was meet where students prove themselves having the knowledge when they go out in the field but showing that now, all the students whom successfully showcase their project be able to do whatever they know to the real world. However, there are facilities that work for the real world where they test each component to the bare bones to make sure it is good for a lifetime usage as no one wants to go on an equipment that people trust that it will be safe but at the end of the day, it is a trash equipment where it only works part of the time which is not good since everyone wants something that works all the time. As of that, all of the parts that are sold anywhere in this world, should pass by this type of places to make sure equipment is not ESD damage nor will it fail anytime that a new extremum hit. As this extremum have to put added as a part of the reliability of each company for each hardware being built since it can be tested piece by piece not as a whole.

6.2.1.1 Microcontroller Testing

One of the most important hardware components that needs to work in the device is the microcontroller. One of the first steps that will need to be done with the microcontroller is to check the peripherals of the chip, such as the USB and RAM. With the connectivity peripherals, such as the USB, one of main ways we plan to test this is to upload any C program into the device and if it installs successfully, then the connectivity works well. As we continuously develop our software, we will want to continuously upload new code to the microcontroller, so making sure the connectivity peripherals works well is an important requirement to focus on.

The next step is checking the I/O pins. The microcontroller can come with a high number of I/O pins in its packaging and each of those pins can be necessary to the overall device. To make sure that none of the pins are damaged or misconnected, one of the ways to test it is to write software that can toggle the devices LED with each of the pins. If the LED doesn’t toggle then one of the pins may be damaged. Otherwise, the pins ae working and when building the PCB, we can connect other hardware devices to the I/O pins as well.

6.2.1.2 Sensor Testing

Receiver error will be something that must be accounted for. When a pulse is received via analog free space channel it will undergo amplification and conversion to a digital bit. A comparator must decide between a signal coming from either the sensor or amplifier which will have a reference voltage. Any signal exceeding this threshold will count as a 1 for “ON”, or pulse received. Having an amplifier before the comparator stage will also amplify any noise, so a filter circuit may be utilized to block incoming frequencies below the range we are interested in.

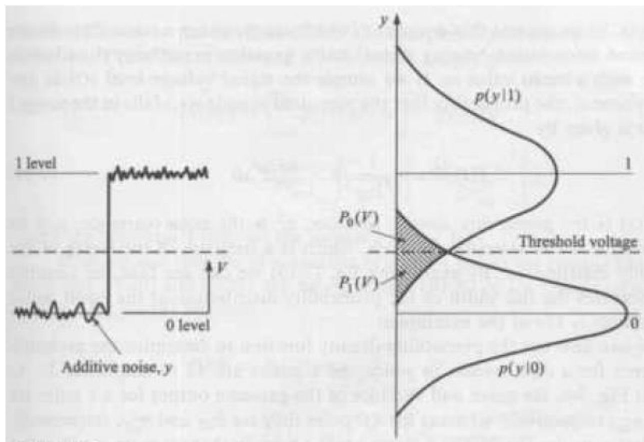


Figure 6.2.1.2 Shows the probability distribution of receiving a 1 or 0.

If the threshold voltage is v_{th} then the probability of error is:
$P_e = a * P_1(v_{th}) + b * P_O(v_{th})$ where a = b = .5 if there is an equal chance of receiving a 1 or 0.[59] The distribution that occurs where events that occur over time happen independent of one another would be referred to as a Poisson distribution. The sensor will function under two basic conditions. The first condition is when the laser beam is incident on the sensor. The second condition would not involve any incident power from the laser transmitter. To see how this would translate for a comparator that must decide if incident power is high enough to register as a bit, table 6.2.1.2 below is provided:

	Detection	No Detection
Photon presence	1	Error
Photon absence	Error	0

Table 6.2.1.2.1

In order to get a reading for the bit-error-rate (BER), it is proposed to support an Ethernet jack within the system. An Ethernet signal is a differential signal, meaning that two leads are responsible for sending data. Electronics should support an Ethernet jack that can be hardwired to the transmitter circuit allowing for conversion from the differential signal, to a single signal that is prepared for modulation via laser light. If this can be accomplished then getting a BER whenever the sensor is powered will be trivial.

6.2.2 Software Testing

The next area where testing can begin is in our software. The overall device will be having all of its software functions running sequentially. Once a button is pressed to activate our device, all the software functions will run together at different times. However, we can still test the different software capabilities in different sections at a time. Additionally, even without currently having the hardware parts, the software can still be written as long as we have the necessary datasheet for the microcontroller. One of the biggest challenges that come with software testing is that if a test fails, is determining that the reason why it failed was due to a hardware issue or a software issue. So, it is important to make sure that the hardware is working properly so that any issue that may come in software testing will be a software issue.

6.2.2.1 Interaction with Data

In order to ensure that the software is working properly, there are several things that need to be tested. First, the software needs to be able to receive input data from an output device, such as the TI spectrometer. This is an important step, we want the person operating the device to be able to be able to connect their output device to our device and be able to send data over to it. Then, we would need to see if the data can be moved over to internal storage. Furthermore, we would need to see if it can send data over to the Digital to Analog Converter. In order for the data to be sent over by laser, it is important that the data be packaged properly so that it can be sent over to the transmitter. Lastly, we would need to see if data can be sent over from the sensor to the Analog to Digital Converter, and then back over to the microcontroller. Several of these communications between output devices may rely on the serial communication protocols such as the SPI (Serial Peripheral Interface) and the I^2C (Inter-Integrated Circuit).

6.2.2.2 Interaction with Hardware

Once we see understand how the software works in handling data, it is important to know how the software interacts with the physical components of the device. One of the important physical components of the device is the LEDs of the microcontrollers. We'll be using the LEDs as an indicator to determine whether the data has been successfully transferred over or not. Also, as mentioned earlier, we will need to use the software to interact with the LED to check all of the microcontroller pin connections to see if they are working properly. Another important component that will need to interact with the software is the buttons of the device. The buttons on the device will be used to execute the software and keep it running. This component is especially important, since it's the main way the user can operate the device. The last main component the software needs to interact with is the external storage. As mentioned earlier, our group plans on having an additional storage area for the device. The software will need to be able to send data to this hardware component if the device fails to send data through the transmitter.

Overall, in order for the device to work properly, there needs to be good interaction between the software and hardware.

6.2.2.3 Interaction with Timers

Each of the microcontrollers will each have its own timer capabilities. It will be important when developing the device that we have good control over these capabilities so we can control the rate at which data is sent without any corruptions in data. Several example of timers within a microcontroller can include the watchdog timer (WDT) and the Real-time Timer (RTT). Throughout the code, we may will include different interrupts within the software to allow our data to be sent at a consistent rate. Depending on what rate we want the software to be sent at, the delay of our timers may vary in time.

6.2.3 Testing Environment

The Texas Instruments Innovation Lab and the Senior Design lab in the Engineering 2 Building at UCF will be used for testing and for some development of the project. Given the equipment set both features, they will be extremely useful for testing and refining our project during Senior Design 2.

The TI Innovation lab is a state-of-the-art laboratory with many tools that will be useful to our group on creating this project, including but not limited to an oscilloscope, function generator, power supply, digital multimeter, and 3 large wooden tables for space. A laser cutter is also present if there is a need for precise cuts of wood, acrylic, paper, glass, and cardboard. There're also several 3D printers available, a cabinet of TI microprocessor boards (including the same launch pad that we are prototyping with), solder stations and soldering irons, a microscope, and various basic tools such as screw drivers, wires, hammers, tape, etc (44).

The senior design lab (pictured below) is like the TI innovation lab but with the focus shifted farther to circuit creation. It features additional oscilloscopes, multimeters, and function generators in addition to a wide variety of breadboards, resistors, inductors, and capacitors (45). It also has several shady areas underneath the desks to offer third class accommodations in the event that we procrastinate too much. The lab also offers multiple lockers to store our project in, if we need to leave in the lab for a particular reason.

While our testing environment could be in multiple locations, this lab will be our primary focus for the semester.

Figure 6.2.3.1: UCF Senior Design Lab

6.2.4 Power Testing

One of the most important items that each and every project should consider be the power testing. As known for any project, each and every project requires power of some sort to make sure everything works the right way. If there is no power, then the parts being imply to the project would not work the proper way that it should. As each component that is being imply to the project has to have a certain threshold that must be meet. If not meet, then there will be certain issues when dealing with the matter.

For each and every single component, there is a certain threshold that must be meet. Never the less, there is a certain number that would make the system work ideal, but as an overall factor, it will have a variation that the system would work with as the power can be received by any place that it is connected in that certain voltage where it indicates. However, theory is one way, but real life is another. In this sense, that variation that is being calculated as an ideal source such as 5.0 volts with a current of 2.0 mA and when being connected to the real-world power, it is roughly 4.98volts 1.94mA. It might seem that it is not too bad, since it’s 2% voltage and 6% current but every single voltage count. This recessive voltage and current can prevent the equipment from not turning on or not functioning properly as it requires a certain amount and the power it needs, it is not given which means that it will be weak. In the other hand it can be an excessive power where the equipment can get damage if it has the excessive power where it will overwork the system.

Now, when developing the test, each test will consist in an input and output power. This means that the test of how power it is receiving in one end and outputting. The transfer from one side to another should not dissipate at all as it is just electricity that is passing thru a wired which for every case it will be a copper line unless it is passing thru an equipment or part. This being noted, the power will be tested at the beginning of the circuit where it is obtained and at every point where it is being receive which for the power, it will be the output. This may be odd as it is the input of the device, but at the same time, it be an output of the power as it is the location where it will end up giving the power. If the power keeps transmitting to another, then it will account for the amount of power the first device absorbed.

Overall, the main testing device will be a multimeter that test power, voltage, current, etc. this piece of equipment will then give the information that is needed in order to address the power that this is obtaining in a specific point as it has to be for sure to get the correct amount of power to not let the above issues happen when having the power imply to the circuit. Never the less, the main concern when dealing with this project be the power that it will consume for every single point. This will not take account when the system has no batteries or low power batteries unless the project consumes more than the input amount then the excessive power will either be for the battery or dissipate to ground.

6.2.4.1 Standalone Testing

Standalone testing is a very critical point that most people do not think of. Most of the time, this testing will be completed in the Senior Design lab where there are test equipment such as a multimeter and other parts to test to make sure everything is continuous. That continuity may not just be just when power is directly inputted when supplementing the power either thru the Universal Series Bus (USB) or the Universal Asynchronous Receiving-Transmitter (UART) but the power Jack xt80 and even the batteries since those are the main power streams where power is being obtain when standalone.

When being standalone, the power will be receiving by the input power source. That main power source is where the system gets the information, where that information is being obtain but when standalone, the system will receive power via the Power Jack xt80 which is a tremendous help as it has various source to import power. This test will check the power to make sure the system has enough power to run the cycle without the battery source. Then the batteries will be implemented to make sure that the system charges the batteries without having it turn on. Secondly, the system will be turn on and check for the system to turn on and if there is extra power, to check the amount of power dissipated to the batteries. Never the less, check the system when it is without power to see if the system will sustain with just the battery charge. This test is to make sure that the system runs with just the batteries and if the main power goes out, that there is some source of power for emergencies.

Therefore, standalone testing is very critical. Many do not take in account for this test as if it works with direct power, then for sure it should work with the standalone. That knowledge sometimes works, but sometimes it does not which engineers have to be knowledgeable of the system issues from different point of view. As there are special labs that test more in dept but never the less, the more test the better as that is the main purpose on testing the equipment. To not have any failures when designing the equipment and furthermore in the future. Nothing design will live in the lab, but it will live in different place. This is why this system not only has to be tested in the lab environment where everything is good, but when the system is working by itself. That is one of many safety precautions that everyone has to take in order to not have any issues. As no one wants to go in a plane that is using this system and the pilot lost the communication with the tower since they just implemented this type of device and it stop working due to lost of power or it being on standalone where the power went down and there is no power supply which means in not just one person dead but hundreds, even thousands.

6.2.4.2 Battery Testing

Battery testing a critical point as the batteries have to be in good standing conditions to make sure that if the project is in standalone where there is no power coming to the system, then the batteries will then give up their charge to make the system work for x time until the batteries drain. The power will shut off in a safe manner and still have a recessive power in the batteries to preserve the last transfer files so that there will be no data lost. This means that the battery will be taken in a sense like a capacitor relating to obtain and giving power.

However, a capacitor is made for many reasons while the battery is made for a certain reason which is to store power and give up power. In this sense, each and every battery will do what it needs to but there are other factors that need to be taken into account. This factor will be the amount of voltage, current, power it will output. Also, depending on the type of battery, one of the prime factors that should be taken account be the durability of the chemicals that they put to the battery. Not all chemicals are good and will provide a shorter battery life then others as which is why if you buy a cheap battery, then the it will last for a tremendous short time while if you buy a well-built battery, then it will last to the maximum since the material used are on the quality of chemicals, they put to it. There be times where companies will dilute the chemicals that is being implemented to drop the price. Even age is a huge matter as the older the chemical the less effect due to the chemical decomposing.

As of the above reasons, the batteries have to be tested to make sure it is giving the right amount of voltage, current, and power. The multimeter will do the trick to make sure the battery is in a good standing order. In the part of the chemicals and structure of the battery, everything has to be read throughout to make sure it is a good quality of battery. There is special equipment to know the life of the battery and verify that the battery is in good standing conditions but they are not to the reach in any engineering laboratory. In the sense of well built, the only part standing to any engineer be warranty and reputation of the source.

6.2.4.3 Charging Testing

The charging side of this project is very tricky when dealing as it has to not only deal with the power it is receiving but the power it is being dissipated. This means the areas where the power be allocated and making sure that the power is not lost rather than giving the power to where it is needed. In many cases, this can be view when running the system or with a multimeter. This piece of equipment comes very handy when dealing with power, as is the main tool that gives the truth of what is happening in the circuit.

As of the above reasons the first test will be the power that the system is absorbing and how much power it has extra to dissipate. Furthermore, the test will be tested in low, medium, and high-performance mode as the higher the performance, the more power it will absorbed. As a result, the less power it will have to dissipate which will result in less power when charging. However, there will be some cavity to each dilemma which will be in test when putting the system to each and every test mode. This will then give how much power it will absorbed and the different levels that the charging capability be giving.

One huge side that must be taking into account will be the amount of power consume and the recessive power that will be used for charging capability will be so that it won't interfere with the main power. That being a huge insight, the charging section should only use the recessive power or when the system is not in use. As if the system is in use, then the power should only be concentrated on the system to make sure that the system works how it should.
Another section that it must be account be when the batteries are full of charge, then that is the point where the system has to dissipate the power into where it normally dissipates it which is ground for all stands or in today's world, the system should just stop receiving power to not waste any power that is being given since the system is not wasting any power and there is no source that needs it. Then the power should just stop flowing until it is needed. This test can be done by using the multimeter and the hardware itself. As the system can be shut down and see how much power it is being drawn by the system itself and battery when full, turn on system and full charge battery, system off and no charge on battery, or when both when system needs power and battery is without charge. This test is critical since the test needs to be done in a multi directional way so that the charging side has the leftover shares and not take over the power that for some cases, it is very common if the circuit is not develop the right way.

6.2.4.4 Signal Testing

When it comes to communication, this test is very critical as the signal has to be send and receive in various fashions. That being noted, the test will be done using the oscilloscope using two probes. One of the inputs and the other section for the output as it has to note what is coming to the system and what is going out since the signal will be need to be transfer from analog to digital or from digital to analog base on needs of the project.

Since the test will be done using the oscilloscope and the oscilloscope that is being provided by the university has four input signals where an engineer can view what is going on at a specific point in the circuit. One of the probes will be in the input signal the other probe be in the output where the signal is being transfer. For the analog to digital converter the input signal should be a sinusoidal as the signal of analog will be sine wave so that it can propagate the signal at a long distance. The output signal should be a digital which is a square wave where the sine wave be at its peak which means a one, middle of the wave be a zero and lowest point be a negative one. These outputs will be seen in the oscilloscope where it be noted as each figure be different.

When it comes to the digital to analog then this will be different but same bases apply as the digital wave will still be a square wave and analog be a sine wave. The only difference between analog to digital and the digital to analog is that the signals be in opposite order which will be shown during test if the converters are working the proper way. If not, then the converters are faulty and must be swap to make sure that the equipment gets the right signal and not get a false signal that could happen if not tested each equipment individually.

As this signal can be tricky and if not tested individually, then the whole project will give out false reading and not work to how it was design to. It may just not even work at all since the equipment was only design for the specific signal that was describe for. As of this issue, this is why there are the signal converters and testing this equipment are crucial as many engineers have design the whole equipment perfectly fine until they hit a bad converter a one simple converter will ruin the project efficiency and effectivity.

6.2.5 Transmitter Testing

This particular testing will mainly focus on the transmitter side of the final project. This will combine all of the testing of Computer Engineering, Photonics, and Electrical Engineering into a single aspect of the project. Before we interact our transmitter with the receiver, we would like to transmit our test data to a neutral receiving device. This way, we would know that if there is any issue transmitting data, it would be on the transmitter side.

6.2.5.1 Digital Transmit Software Testing

Transmit Software testing is an early opportunity to reduce software risk. In this configuration the “transmitting computer” will send “digital data” via an on-board serial interface UART (ex. RS-232) while a separate computer will receive via its own serial interface and display the data to the console (i.e. a HyperTerminal). Once were familiar with extracting data, this testing shouldn't be a problem.

Figure 6.2.5.1.1: Digital Transmit Diagram

6.2.5.2 Analog Transmit Testing

Analog Transmit testing is an early opportunity to reduce hardware/software integration risk. In this configuration the "transmitting computer" will send "digital data" to the on-board DAC. The DAC will output an analog signal which will be observed using test equipment (i.e. an oscilloscope). Once an analog signal is displayed, the analog transmit testing has been a success.

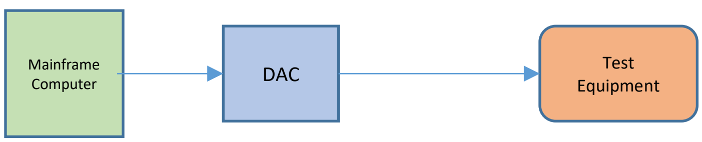


Figure 6.2.5.2.1: Analog Transmit Diagram

6.2.5.3 Laser Transmit Testing

Laser transmit testing is an early opportunity to reduce microcontroller/laser integration risk. In this configuration the "transmitting computer" will send "digital data" to the on-board DAC. The DAC will provide an analog signal to the Laser. The laser energy will be collected via test equipment (i.e. a spectrometer). Once we see a similar analog signal to the one from the Analog Transmit testing phase, the transmitting testing will be complete for the time being.

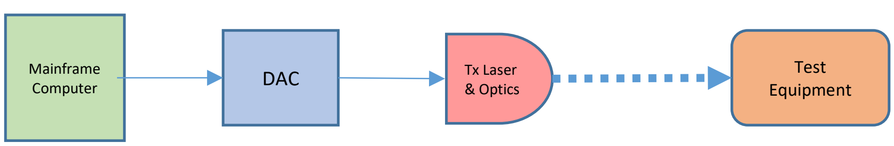


Figure 6.2.5.3.1: Laser Transmit Diagram

6.2.6 Receiver Testing

This particular testing will only focus on the transmitter side of the final project. Similar to the transmitter testing, it will also focus on each of our combined majors in this aspect of the project. Additionally, the receiving device will have a neutral transmitting device transmitting data to it. This way we know the results of the receiver are unaffected by the transmitter. To save time, this testing can also be done without completing the transmitting testing first.

6.2.6.1 Digital Receive Software Testing

Receive Software testing is an early opportunity to reduce software risk. In this configuration a separate computer will transmit "digital data" via an on-board serial interface UART (ex. HyperTerminal) while the "receiving computer" will receive "digital data" via its own serial interface and store the results to internal storage.

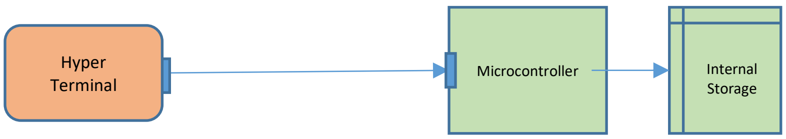


Figure 6.2.6.1.1: Digital Receive Diagram

6.2.6.2 Analog Receive Software Testing

Analog Receive testing is an early opportunity to reduce hardware/software integration risk. In this configuration, an analog source (i.e. signal generator) will be used to stimulate the ADC on the receiving computer. The ADC will convert analog signal to digital data and send it to the microcontroller. The microcontroller will receive the digital data and store the results to internal storage. Once valid data is shown within the device, then this particular testing phase will be considered complete.

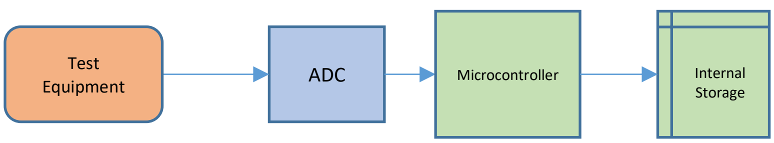


Figure 6.2.6.2.1: Analog Receive Diagram

6.2.6.3 Laser Receive Testing

Laser receive testing is an early opportunity to reduce microcontroller/laser integration risk. In this configuration, a known laser source will be used to transmit laser pulses. This laser energy will be received via the "receive optics" and converted to an analog signal. The analog signal will be converted to digital and stored by the microcontroller to internal storage. Once the data received is the same from that of the Analog Receive testing, the receiver testing will be complete.

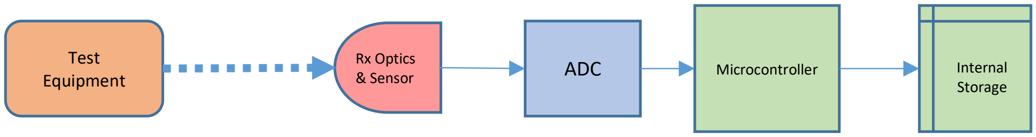


Figure 6.2.6.3.1: Laser Receive Diagram

6.2.7 End-to-End Testing

This testing will occur only once we have completed both the transmitter and the receiver testing. This testing will focus on making sure each of the devices will be able to communicate to each other through digital, analog and laser-based means. When all these requirements are complete, testing will reach the end of its cycle.

6.2.7.1 End-to-End Digital Testing

End-to-end digital testing, or software only testing, is an early opportunity to reduce software risk. In this configuration the “transmitting computer” will send “digital data” via an on-board serial interface UART (ex. RS-232) while the “receiving computer” will receive “digital data” via its own on-board UART separately. This will be one of the basic ways of checking if the two computers can communicate with each other properly,

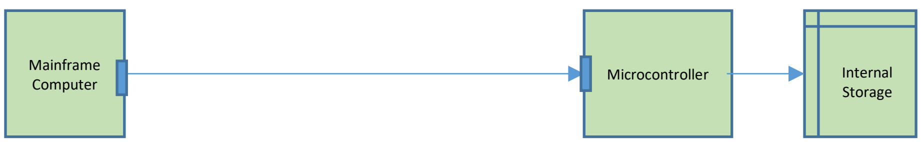


Figure 6.2.7.1.1: End-to-End Digital Diagram

6.2.7.2 End-to-End Analog Testing

End-to-end analog testing is a precursor to laser testing. In this configuration the “transmitting computer” will send “digital data” to the on-board DAC. The DAC will output an analog signal to the ADC on the receiving computer. The ADC will convert analog signal to digital data and send it to the microcontroller. The microcontroller will receive the digital data and store the results to internal storage. After this testing phase is complete, the two computers will be able to send analog signals back and forth to each other.

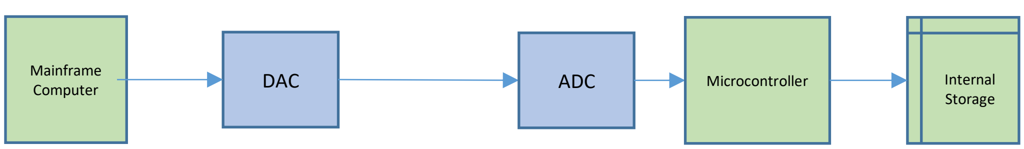


Figure 6.2.7.2.1: End-to-End Analog Diagram

6.2.7.3 End-to-End Laser Testing

End-to-End laser testing represents the culmination of all of the previous integration step albeit in one direction only. In this configuration the "transmitting computer" will send "digital data" to the on-board DAC. The DAC will provide an analog signal to the laser for transmission. This laser energy will be received via the "receive optics" and converted to an analog signal. The analog signal will be converted to digital and stored by the microcontroller to internal storage. After this phase is complete, data will be able to transfer from one computer to another by laser.

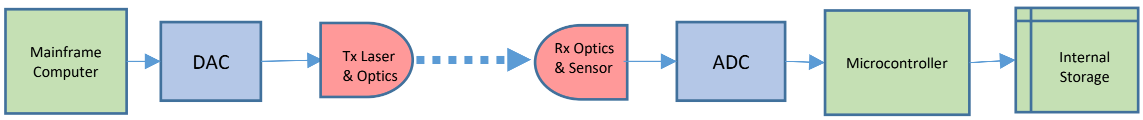


Figure 6.2.7.3.1: End-to-End Laser Diagram

6.2.7.4 End-to-End Bidirectionality

Once our transmitter and receiver are able to communicate with each other, we would then want to include transmitters features into the receiver and vice versa. This way, we can ensure our device has bidirectionality to allow it communicate back and forth with each other. This will require the transmitter and receiver to have the same software, electrical, and photonic components. After this point our overall testing would be complete and from here is where we determine what additional features, we would want our design to have.

6.2.8 Assembling Project

Most people do not take into account the amount of work and fragile the assembly of the project is until they are constructing the whole project and trying to put each piece together. Each and every piece will need to be put in the correct order in order for the project to communicate effectively. As even misplacing any component might lead to failure to an extend that it might shorten out the life of the piece of equipment or not work at all base on the location of the piece of equipment. This comes even more crucial as there are two different structure that will be come into play where they have to work together to make the project a success.

The first structure will be the smallest structure as it has the least number of components. The PCB will live in either wall left or right depending in the location that the person who is assembling this equipment decides. As it is the simplest of the two structures, then the location has freedom to be place where it fits the best. The microcontroller and signal converter will live in the PCB as it does not need to have any exposure to the exterior world. While the USB type B will be in the side with nothing in it of the assembly due to it needs to be away from where it will have the interaction with the signal so that there is no interference. The sensor will traditionally be in the lowest part of the assembly to note where the incoming signal be. The outgoing signal should be in the top to view of what is happening at the beginning from to bottom. Never the less, the ventilation should be place in the adjacent of the USB port so that it can have enough space to dissipate the heat and not damage anything that could potentially get damage if not put in the proper location.

The second structure should be assembled in a much more precise location. As this structure will have more components then the first one. Just, the large number of components will be more internally then externally as the only parts that should be external should be sensors and laser due to the fact that it needs to be out in the open to send out the signal that will be transfer thru open air. This being mention, the PCB will be on the right bottom side of the structure. That way, the system can have space for the spectrometer to me almost to the top side due to it being bulky compare to the other components. The extra memory should in the left almost bottom side of the structure. This is because it has to have space for the laser to have its home. As in the first structure, the microcontroller and signal converters will be on the PCB making sure it has direct connection to the system. In addition, the UART port will be in the side with the section that has nothing but the port and the switch so it won't interfere with anything and can be safe if it needs a direct power source from a computer or even when transferring data. The fans will be then place in the side adjacent to make to that the heat will not damage anything that is heat sensitive.

Lastly, assembly may be noted for everyone not too important and never care where everything goes but where everyone hits to put everything in order is when the assembly hits. This is which is why this side have to be thought out. Never the less, the engineers should only worry about making the project work. Just for this instance, this has to be taken account since the project development and assembly will be part of the whole process. As in the industries, engineers never think of the assembly and what could be easier for technicians to work on the item so that it can be easier for them which is a huge issue in today's product.

6.3 Prototyping

To learn further more on how the final product could function, we need to undergo the necessary prototyping required to build a successful product. By having a prototype available we can have a general idea of what to expect when we build the final product such as what we can integrate into the product as well as the limitations we will face. This section will cover the constraints that the team had in prototyping as well as the results of our current prototype.

6.3.1 Prototyping constraints

While learning from the prototype can be useful, there is only so much we can do with it that can help the team for the project. For the first prototype, we decided on using an Arduino Mega as well as an Arduino Uno for the transmitter and receiver units. While they both have useful features available to use for the team such as serial communication and speed, they can also be limited in those features as well. The Arduino is an 8-bit microcontroller, so it will be using simpler software, while that may be acceptable for the prototype, we will need to expand upon that software greatly when we are constructing the final product. Both Arduinos also only come with a 10-bit ADC resolution meaning we will get about 1024 output codes for the analog voltage, when we work on the final product it would be beneficial that we get a higher resolution to help ensure the transfer data remains uncorrupted. Additionally, the development tools that the software is programmed on can limit the prototype. As mentioned earlier, the IDE of the Arduino can be limited as well in debugging features.

Time will also be an important constraint that will affect the prototyping phase of our project. While it will be important to have a working prototype for the project, improving on the code for that prototype will need to be done quickly as there will need to be more learning done for the code of the newer microcontroller that will be selected in senior design 2. Even though these constraints will affect the prototype, we will still be able to develop a prototype that can meet some of the basic features of the project.

Time constraints have also imposed hardware limitations on the first prototype revision. Because the specific parts chosen will arrive after the end of semester demo period, hardware substitutions will have to be made. Until the laser diode and sensors of choice can arrive in the mail a visible laser diode and visible light photoresistor are being substituted. The reason for a visible diode is for ease of testing, so that it is certain when the diode is operating. Obviously, the supporting electrical circuitry will have to account for this change when the final parts arrive. The laser and sensor must be biased properly in order to maximize bit transfer rate and error free operation. Additionally, for prototyping, the optoelectronics are being directly controlled by serial pins on a TI Launchpad, or Arduino. This is in contrast to the final product, in which the hardware will be controlled by surface mounted soldered embedded MCUs.

These constraints pose a unique challenge for the end of the semester demo. In order to show satisfactory progress is being made in the design of this product, the demonstration should show some kind of information being transferred via laser. Currently there are several modulation methods under consideration for the laser channel. Because of time constraints it is most likely that the method offering the quickest implementation will be used in the proof-of-concept prototype.

6.3.2 Prototyping results

Initial prototyping consisted of implementing our temporary hardware onto a breadboard side by side with a prototyping TI MSP430G2 microcontroller allowing for rapid prototyping results. Code for sensor calibration is implemented to ensure proper voltage readings to the MCU. Waveforms across the laser diode and sensor were also inspected. As shown in the figure below, the temporary hardware for code testing is operating at 3kHz on the oscilloscope.

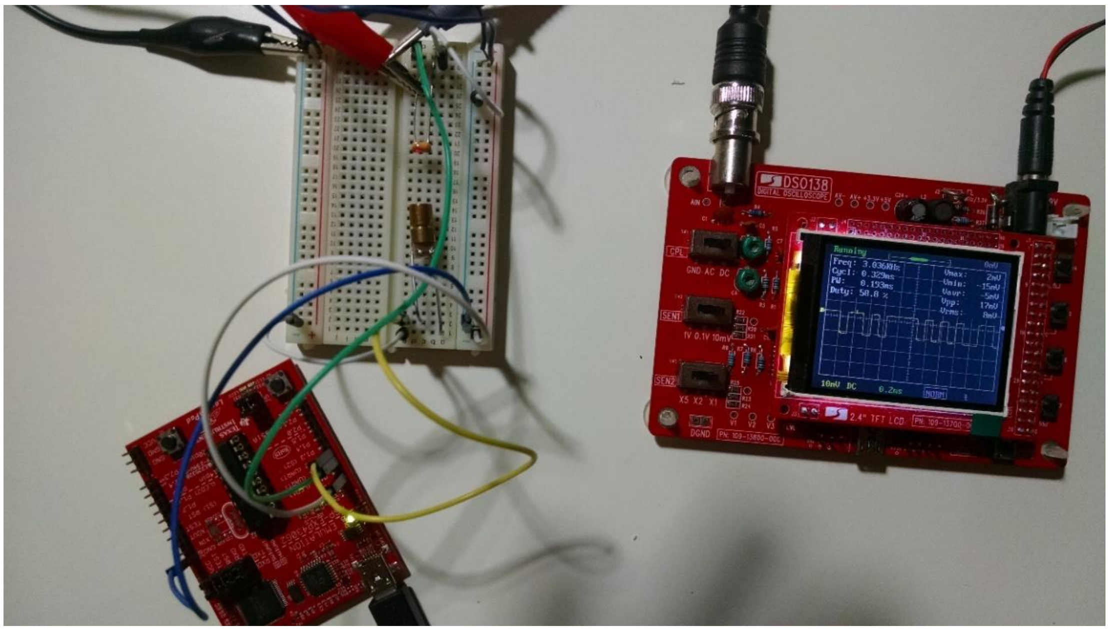


Figure 6.3.2.1

The photoresistor pin is set as an input and the laser diode is scanning between various pulse widths. The output on the photoresistor directly correlates to how long the pulses are. The longer the pulse, the lower the resistance the photoresistor has. The laser diode and photoresistor both have nice, square waveforms across them. Because of the simplicity of this setup, laser modulation and optoelectronic biasing can be tuned easily. When the final hardware arrives, these bias settings will have to be reconfigured.

6.3.3 Prototyping conclusion

Overall, when the final project begins, we need to take what we learned from the prototyping and be able to directly apply it to our final product. There were several engineering challenges that we learned of from the prototype that will affect us in Senior Design 2, such as being able to integrate the hardware with the software properly or being able to prevent data corruption as a pulse width gets sent from our laser to the receiver. However, we have been able to learn further more from these challenges and by possibly doing further prototyping in the time we have off will allow us to find even more challenges as well as solutions to those challenges. When conducting further research with are final hardware, we will need to revise are circuit greatly, however the results on the prototype were a good starting point for us to begin further research in our final design.

7.0 DEVICE OPERATION

This section goes what important things the user will need to know when they acquire the device, such as what safety feature they need to be aware of and how to operate the device. When the device is complete, we want it to be both user friendly and simple to install and operate.

7.1 SAFETY INFORMATION

While operating the device, the user should be aware of several different things to make sure they are safe. Make sure the device remains sealed. If the device ends up being unsealed, the circuitry of the device will be left exposed and if it gets wet, it could cause damage to the device while also exposing the user to risk of possible electrocution.

Care should also be taken to never look directly into the aperture of the laser diode if there is a possibility of it emitting. Because 1550 nm beams are infrared the blink-aversion response that normally protects eyes from visible light is not triggered. Although 1550 nm is more eye safe than shorter wavelengths, it can still cause damage to the eyes if incident power is high enough or if exposed for a significant length of time. The laser institute of America has a laser safety guide in print that was referenced for pertinent safety information. The current laser diode under consideration has a max output power of 6 mW at 1550 nm wavelength. Table III on page 46 designates a laser type of InGaAsP that emits in the far infrared region in continuous-wave operation as a class 1 laser. [50] Because the source falls under this classification it also implies that this is considered an “eye-safe” laser, however safety procedures applying to higher power lasers will still be practiced. The rubric this safety classification follows is provided by ANSI Z 136 standards.

A greater risk is posed by the possibility of electrocution inside the lab environment while prototyping. The laser diode can employ a current in excess of 20 mA, which is roughly the amount of current required to paralyze respiratory muscles. An average person can usually ungrasp up to a point of electrical current of 16 mA. Beyond this threshold an induced electrical current can override commands from the central nervous system and render a person incapable of releasing their grasp. Because the final product will be enclosed in weather-tight packaging the risk of electrocution is not a concern in field operations.

7.2 GENERAL USE

The laser transceiver, which is comprised of the laser, sensor and supporting electronics, is to be housed in an ABS 3-D printed polymer housing. The transceiving units should be largely symmetrical in design and function with respect to hardware. The microcontrollers that power the optoelectronics and supporting circuitry will have the option of running code to serve as a base station, or mobile unit. This will allow to prioritize data transfer between the transceivers. The difference between the two modes of operation is that the base station will be more computationally demanding, as it will be the unit that analyzes data from the mobile unit. Data computation will take place after being received at the base station. A typical function for an operational link between two transceivers where one is assigned to function as a base station, and the other is assigned to work as a mobile unit is outlined in figure 2.0.2.

In any case, there will be steps in common with whatever mode of operation the transceiver is used in. Steps to operation are outlined below:

1. Unpack the transceivers.
2. If the transceiver do not have batteries installed, provide power to the unit by plugging it into an appropriate power supply.
3. Connect the transceivers via the RJ 45 port to a network device such as a computer or another switch or router.
4. If the connection is static, or the transceiver does not support a mobile laser turret, manually align the optical beam by eye, without the aid of magnifying optics.
5. Test the connection by pinging a known network address on the other side of the laser channel.

8.0 ADMINISTRATIVE CONTENT

This section covers what the budget of the overall project will be as well as the set milestones that the team will accomplish

.

8.1 BUDGET ANALYSIS

The chart below lists some commercially obtainable hardware and other project components that can be used to increase the feature set of the project. The project budget will be continually updated according to need, mostly concerning budget, time and availability constraints of sourced hardware. When mature, the project budget will present an accurate cost analysis when the course of project development reaches completion.

Project Budget		
Component	**Quantity**	**Price**
Microcontroller	2	$20
PCB manufacture	4	TBD
Optoelectronic sensors	2	TBD
Battery	2	TBD
Laser diodes	4	TBD
Cables & Accessories		$50
Analog to Digital Converter	2	TBD
Digital to Analog Converter	2	TBD
Spectrometer	1	$1000
Benchtop DC Power Supply	1	$85
Optical components		TBD
Electrical components		TBD
Optics gimble	2	TBD
Total Price:		> $1,175

Table 8.1.1: Budget Table

It is important to note the $1000 spectrometer. While initially this may seem to drive up the cost of the project into unaffordable territory, this is actually not the purpose or the result. This project is merely a demonstration of a concept, transmitting information through high frequency communication. In this project specifically, the information itself is meteorological data and is being gathered from the spectrometer.

8.2 MILESTONES

As shown in Table 3, is our planned schedule for our overall process of what tasks we need to complete and how long it will take to complete them. The only tasks that are still to be decided are the tasks in Senior Design 2. Once we complete of final draft for senior design 1, we can plan out our new milestones for Senior Design 2.

Task	Time needed	Dates
Senior Design 1		
Develop Project Idea	2 weeks	8/20-9/2
Submit Proposal	1 week	9/7-9/14
Review Existing Projects	2 weeks	9/2-9/14
Update Proposal	1 week	9/20-9/28
First Draft	7 weeks	9/14-11/2
Final Draft	12 weeks	9/14-12/3
Prototyping	4 weeks	9/28-10/26
Research PCB	4 weeks	9/28-10/26
Research Microcontrollers	4 weeks	9/28-10/26
Research SolidWorks	4 weeks	9/28-10/26
Research Signals & Systems modulation	4 weeks	9/28-10/26
Research Sensors	4 weeks	10/26-11/23
Research Lasers	4 weeks	10/26-11/23
Research Optics	4 weeks	10/26-11/23
Research Light Sources	4 weeks	10/26-11/23
Order Parts	3 weeks	12/3-12/24
Build Prototype	TBD	TBD

Table 8.2.1: Milestone Table Senior Design 2

Senior Design 2		
Test Prototype	TBD	TBD
Finalize Report	TBD	TBD
Finalize Presentation	TBD	TBD
Finalize Project	TBD	TBD

Table 8.2.2: Milestone Table Senior Design 2

8.3 Division of labor

Division of labor is assigned according to expertise of each individual member. Any member possessing a CpE background shares some responsibility between all related tasks. As mechanical housing is a necessary requirement for the project and also integral to many optics projects it will be the responsibility of the photonic engineering member to undertake this responsibility. Electrical circuitry will primarily be the responsibility of the dual major member who has both knowledge of CpE and EE principles.

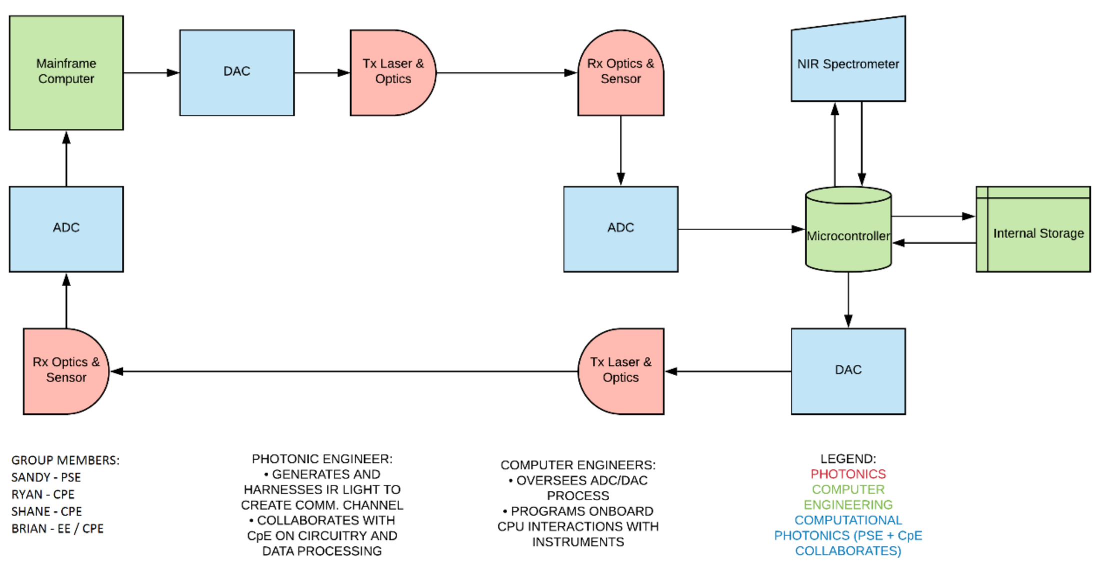


Figure 8.3.1 – A color coded guide to responsibilities shared among members for the project.

9.0 PROJECT SUMMARY & CONCLUSION

With a balanced team of a photonics student, 2 computer engineering students, and an electrical engineering student, we believe this project would be an achievable goal and a great way to demonstrate all the skills that were acquired from our respective courses. This project requires several different skills to successfully build the build the device that we have gained throughout our UCF courses, such as programming devices, building circuits, directing light sources, etc. There is also a good amount of available resources for the group to use such as the testing labs as well as the software resources available to us at UCF.

Given that a majority of the team has a good amount of software experience, we believe the software design of the program won't be too much of a challenge. The team will most likely need to use a familiar software such as C or Java. However, that will all depend on the microcontroller the device will be using too.

Additionally, our group was quite fascinated with the idea of direct communication between objects and metrology before this specific idea came up. With this specific product, it will work well in both fields as well as be applied in other different areas as well. The device will be useful in both transferring information over to a receiver as well as making sure there isn't any wasted space when communicating. Also, we found it interesting that a spectrometer can be used to obtain metrological data and would believe that could be great data to send over through the laser communication device.

The engineering of the device will prove to have some challenges as there are new skills we need to develop as well to properly build the laser communication device. Creating a PCB from scratch and directing the line of sight of a laser will be new to some of us. Additionally, we may develop new criteria for the specific components that are used. As we continue to improve our design over time, there may be new issues that will occur or our design may need additional features. However, we feel given our levels of experience that we can overcome these hurdles and have our device meet these requirements.

It also may be a challenge to try to adhere to the particular design and constraints of a challenge. It could limit the particular components that are selected for the device. The standards also may require more of the software design of the communication device. However, it will be best to stick to these constraints so that the device may be compatible with multiple interest groups. Also, with the needed research, the team we'll be able to select the needed components to meet the constraints.

Overall, this device will be a great way to send and receive data between two points. Some of the physical mechanics of the device will be a challenge, but in the end, it has the potential to be a great product that could be of good benefit to users. Based on the information that is presented in the report, we believe this will provide a good overview of how the device will turn out to be.

10.0 APPENDICES

This section lists the all the cited sources used in this report paper. It also lists permissions that were needed for the use of the figures in the paper.

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10.2 Permissions

OCT 31, 2018 | 11:46AM MDT
Shay W replied:

Hello!

That is no problem at all Ryan! As long as you give us credit where credit is due that is no problem at all.

If you need anything else please let me know. Have a great day!

Best Regards,

Shay Woods

OCT 31, 2018 | 11:16AM MDT
Original message
Ryan wrote:

Hello,

my name is Ryan Heitz. I am a computer engineering student at the University of Central Florida. I am writing to request permission to reference figures and information from your website as part of a senior design paper I am writing.

If you have any questions please let me know.

Thank you.

Ryan Heitz