VLC – Visible Light Communication

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***Abstract* — The objective of this project is to identify, test and construct a working prototype of a communication compliment that can be scaled to achieve the flexibility of wireless internet with the speed of buried fiber or cable. Our system uses lasers as transmitters and free space as the medium. Our goal is to make a device that easily interfaces with existing Ethernet Technology. In the interest of time and cost we've chosen to utilize the 10Base-T Ethernet standard.**

***Index Terms* — Laser diode, wireless transceiver, Ethernet, Photodiode.**

I. INTRODUCTION

As it stands fiber optic networks are the pinnacle of communication systems, they are unmatched in both speed and reliability. However, fiber systems fail in the aspect of being flexible in their use and implementation in certain situations, notably in metro networks. For instance, internet services supplied by fiber networks are exclusively buried underground and overhauling the city infrastructure for fiber has multitude of permits and regulatory compliances within the metropolitan networks. Another example would be data centers where thousands of servers are connected in a central hub. In both of these cases all the connections are restricted by a physical link meaning that each one must be pre-planned before application. Keeping in mind that our project is meant to be a complimentary technology; we are proposing a similar system where we use light as a carrier, just like in fiber optics, but alternatively use air as our medium instead of glass. We use laser diodes as our transmitters and photodiodes as our receivers all on the same printed circuit board. A simple direct modulation of the laser diode allows us to take advantage of the 10Base-T standard. To get an idea of implementation, imagine a commercial setting where new construction is in progress, let's consider that an existing building nearby has fiber internet service. Instead of burying fiber to each new building we would connect our device to the existing fiber network and wirelessly connect to surrounding buildings. An illustration of this is seen in figure 1.

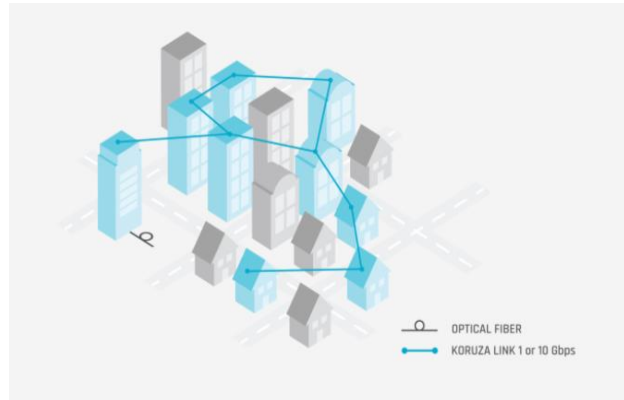


Figure 1. An illustration of a wireless optical network supplied by a single fiber source, courtesy of Koruza.

II. SYSTEM COMPONENTS

The term system is used to describe the device and its functionality. It consists of eight active components including integrated circuits, as well as numerous passive components. Below is a description of each component as categorized by its function or role.

A. Transmitter – The transmitter consists of two devices an op amp, and a laser diode.

For the transmitter, the laser diode serves as the signal source to be collected by the receiver. The current supply for the laser diode is a Maxim Integrated microchip, model MAX4390. The MAX439x family of op amps are low cost, high speed chips meant for communication systems. These chips can operate at speeds up 85 MHz before reaching half power, making them suitable for this design. This amplifier specifically can operate from a single positive supply voltage, simplifying the power supply circuit. The laser diode the chip is powering is a Jameco Valuepro 154145-VP. These small form laser diodes benefit from a low threshold current and small operating voltage of 5 V. The two 3" wire leads give us flexibility in mounting the device.

B. Receiver – The receiver consists of four components the photodiode, a transimpedance amplifier, a comparator and an op amp.

Possibly the most critical piece of the receiver, a photodiode sits opposite the transmitter. Since our laser

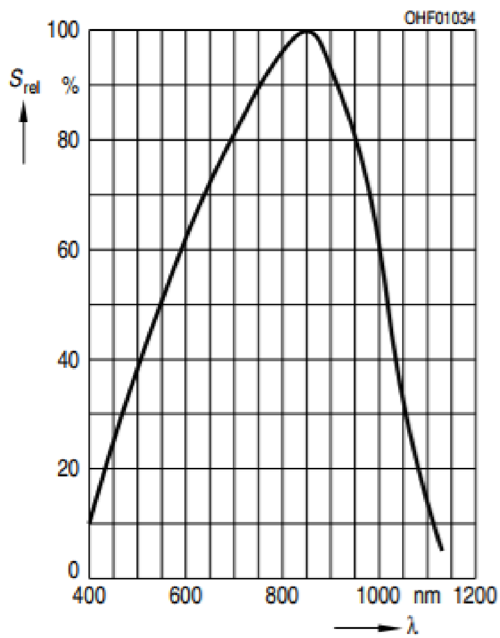


Figure 2. The spectral response of the SFH 203 photodiode

diode is emitting at a wavelength of 633 nm it is important that the photodiode be particularly sensitive in this region of spectrum. We found that an SFH 203 will do well, supporting a broad spectrum with a decent response to our laser's wavelength. Figure 2 illustrates this concept. The SFH 203 diode has very small dark current and an extremely fast response time of 5 ns. The photodiode output needs to be referenced back to voltage which is where a transimpedance amplifier comes into play. For this system, we are using a TI OPA695. Like the other amplifier used, the OPA695 operates from a single positive voltage supply and boasts a high bandwidth of 450 MHz at unity. Since the signal can potentially be hard to resolve or weak the system benefits from a comparator. The Linear Technology LT1713 comparator discretizes the signal into two levels, a complimentary ± value. It has a response time slightly slower than the photodiode at 7 ns, and can also work from a single positive voltage supply. One final amplifier follows the comparator to ensure a strong enough signal is received by whatever device is connected to the system. In this case another Maxim Integrated IC is used, particularly a MAX4392. Also, being from the 439x family, it shares characteristics and features with the previously mentioned MAX4390.

C. *Power Supply – The power supply consists of two parts, a voltage regulator and a voltage booster.*

The power supply plays a defining role in the overall system in that it regulates what kind of chips can and cannot be used. A 9V DC transformer plugs into the wall and provides the initial power to the system. A voltage regulator, the TI LM78M05CT, outputs a constant 5V DC to the rest of the system. Every chip using the power from the regulator must be able to run on single positive supply. The exception is the photodiode that receives its own voltage supply separate from the rest of the chips. The Micrel MIC2605 is a voltage booster capable of outputting up to 40V for the photodiode reverse bias.

III. TECHNOLOGY AND HARDWARE BACKGROUND

Ethernet - Ethernet technology was invented in the late 1970s and has been a crucial part of networking ever since. It was developed as a local area network technology meant to allow any devices connected by Ethernet to communicate with one another. It works on the Physical layer as well as the Data Link layer. Originally Ethernet made use of single coaxial cables, and then developed into twisted pair cable, and nowadays fiber optic cables. The most common medium for Ethernet is twisted pair cables that can be classified as category 3, 5, 5e, 6, 6a and most recently 8.1/8.2. These twisted pair cables consist of eight copper wires half meant for transmitting half meant for receiving. In 1980 IEEE decided to standardize Ethernet technology under the group 802.3 as it was becoming so wide-spread. In 1990 Ethernet moved to a twisted pair cabled medium under the name 10Base-T. 10Base-T networks have a speed of 10 Mbit/s operating at 10 MHz. It is important to understand that data transmitted on 10Base-T networks work on a base 2 system in that the signal takes only two values +1 V or -1 V, corresponding to bits of 1 and 0 respectively. It is also worth noting that 10Base-T systems only use 2 of the 4 pairs of cables one pair for transmitting one pair for receiving.

Laser Diodes - Laser diodes, as the name states are lasers based on diodes, and are commonly abbreviated LD. A laser diode has the same basic structure as an LED in the sense that it contains p-type and n-type semiconductors. However, LDs are made with an additional region between the p-n junction, this region is intrinsic in nature, having no dopants. Laser diodes have a threshold current which must be reached before lasing can occur. Before this threshold current, laser diodes emit spontaneous light just like an LED. When the threshold current is reached the optical gain is exceeding the optical losses for the cavity. The cavity of a laser diode is created by the edges of the semiconductor, usually polished and cleaved to create a highly reflective side (99%) and a completely reflective side. This cavity provides an oscillator for the emitted photons to travel back and forth. When photons are injecting and transporting through the cavity there is a chance that a photon can elicit an electron and hole recombination. The response is the emission of a photon duplicate to the one that elicited the recombination. When this process occurs and the amount of emitted light has become greater than the amount of absorbed light inside the cavity, lasing occurs.

Photodiodes - Photodiodes illuminated by light and without external bias can generate electric current, and we refer to this mode of operation as photovoltaic. The photoconductive mode is characterized by an external bias. When an external bias voltage is applied, photodiodes conduct current and the current to voltage graphs have a linear regime. When light is absent, only a smaller 'dark' current can flow under reversed bias. When under illumination, photons absorbed in the semiconductor create electrons and holes that can essentially move from the electric field across the photodiode. The amount of electron and hole pairs created and thus maximal electric current is proportional to light intensity.

Op Amp - An operational amplifier (commonly called an op-amp) is a is an integrated circuit that amplifies the difference between two input voltages and produces a single output. The op-amp is prevalent in analog electronics, and can be thought of as another electronic device. it is fundamentally a voltage amplifying device designed to be used with external feedback components such as resistors and capacitors between its output and input terminals. These feedback components determine the resulting function or "operation" of the amplifier and by the different feedback configurations whether resistive, capacitive or both, the amplifier can perform a variety of different operations.

Comparator - A comparator is essentially an op-amp operated in an open-loop configuration with either a high or low saturated output signal. As the name implies, a comparator compares two voltages to determine which is larger. The comparator is usually biased at voltages +VS and −VS, although other biases are possible. One major difference between a comparator and op-amp is that a comparator need not be frequency compensated. Frequency stability is not a consideration since the comparator is being driven into one of two states. Since a comparator does not contain a frequency compensation capacitor, it is not slew-rate-limited by the compensation capacitor as is the op-amp.

IV. Principle of Operation

When considering the system as a network it can be broken into three different parts, the input, transmission and collection, and output.

A. Input –

The input to the system is determined by the 10BASE-T Ethernet standard. The signal generated by an Ethernet enabled device under this scheme will change in value discretely between a +1 V and a -1 V at a rate of 10 MHz. Ethernet devices transmit positive and negative signals on independent transmission lines, meaning we can connect them "across" the laser diode. Specifically, the positive transmission line will connect to the positive lead of the laser diode and the negative line will connect to the negative lead of the laser diode. What this has done is associate the current across the laser diode with the value of the incoming signal. In principle a direct modulation occurs, as the input increases the laser diode glows brighter, as it decreases it glows dimmer, but doesn't turn off. Keep in mind the laser diode is biased with a constant current source so even in the absence of a signal it is always on. Figure 3 illustrates this concept in terms of signal.

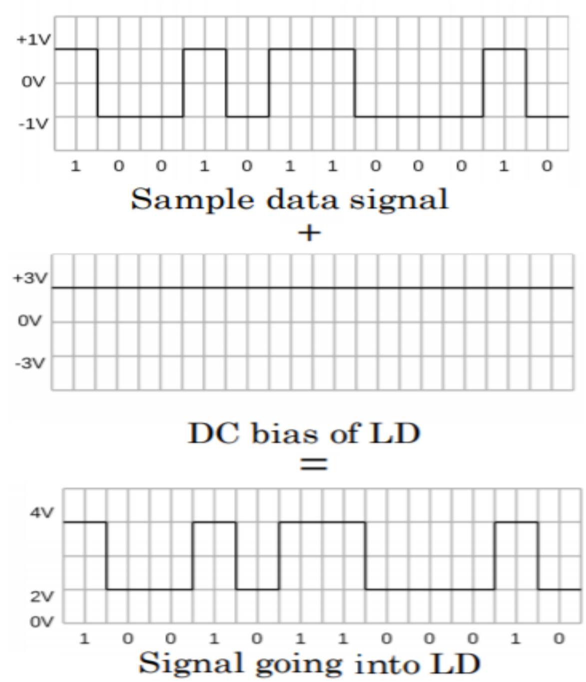


Figure 3. A hypothetical signal in terms of voltage, below the signal are corresponding binary values.

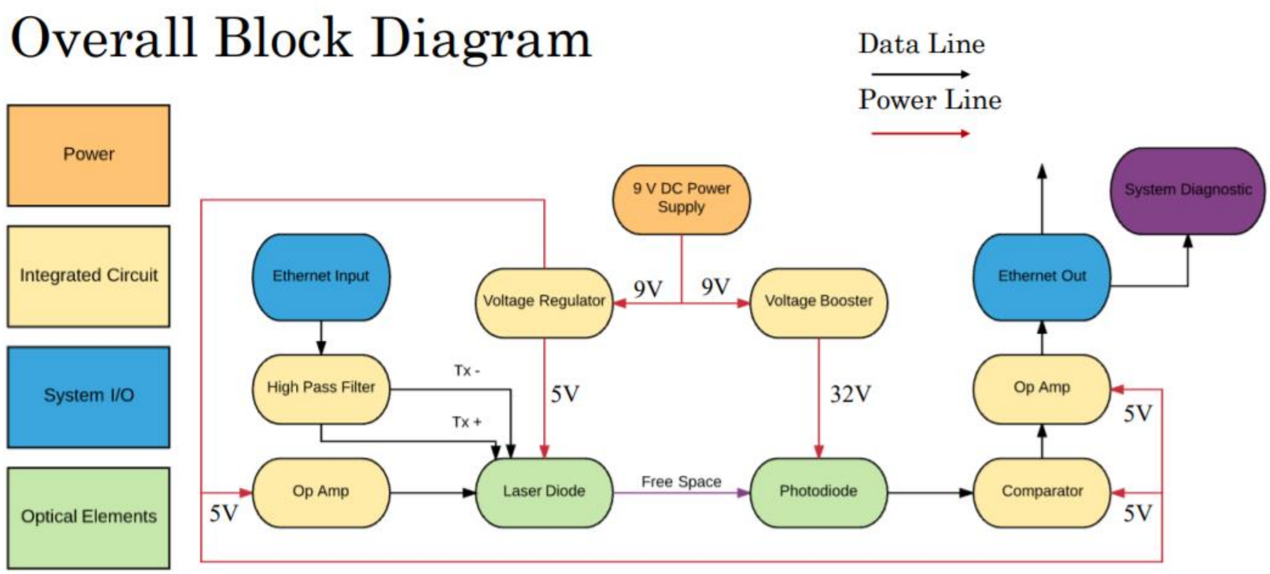


Figure 4. The overall block diagram showing the flow of information and power through the various components.

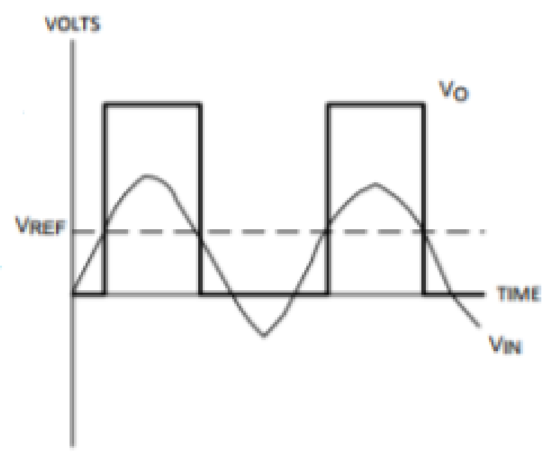
B. Transmission and Collection –

In normal Ethernet networks the data signal travels down a fiber optic, or copper transmission line. In our case our signal, once being passed through the VLC device, will transmit into free space. The laser beam must be directionalized toward another VLC device to hit the receiver. Absorbing the lasers signal of light, and producing an electrical one, the photodiode reverses the initial transition into the visible spectrum. From the photodiode, we get an output of current that is directly related to the intensity of the incident light onto its active region. Passing this output through a transimpedance amp will reference it back to voltage making it usable to another Ethernet device.

C. Output -

The voltage signal coming from the amp following the photodiode is still weak compared to the signal that we started with. To overcome this, we use a comparator to separate the values into either a positive voltage or a negative voltage. Figure 5 illustrates this concept. The last stage of the network output is to apply one final amplification to the signal. A dual output op amp passes this signal to the respective lines of an Ethernet device.

Figure 5. A reference signal and what the output would be after passing through a comparator.



V. ELECTRICAL SPECIFICS

The aim of this section is to provide details to the implementation of components mentioned in the previous section. For instance, the laser diode has multiple currents applied to it at any given time. The difficulty with modulation in this scenario is that we are trying to achieve an on-off-key modulation scheme without the laser diode turning off. As previously mentioned the laser is biased with a constant current source so it is always on. Following the manufacturers spec sheet, we can use passive components such as capacitors and resistors to set this level of current. The VLC device is setup such that a constant current of about 20mA is applied to the laser diode (the diode starts lasing around 10mA). Now, we know the voltage level coming from the transmission lines of our Ethernet connected device is ±1V. Then using a couple resistors, we can easily control the current that those two lines apply to the laser diode. The values are such that only 4mA of current is either being added, or subtracted from the laser diodes constant current. These results are shown in Table 1.

Data transmitted	Change in current	Current across LD	Status of LD
0	-4mA	16mA	Dimmed
1	+4mA	24mA	Brightened
Nothing	0	20mA	Constant

Table 1 – The details of the laser diode in various states

Opposite a laser diode is a photodiode, as shown in the overall block diagram it's biased with 32V which may seem like a lot. In practice, the more you bias a photodevice the quicker its response becomes. Conditionally the more you bias a photodevice the larger the dark current becomes. Dark current is inherent to all photodevices, due to random recombination of electrons and holes. When setting up the VLC system it was important to use a photodiode that had dark current that was much smaller than that of the signal. The SFH 203 has a dark current on the order of micro amps, making it almost inconsequential to our signal.

VI. Software

This project be based on 10BASE-T Ethernet and the utilization of the packet topology, using UTP (Unshielded Twisted Pair) cable as the physical medium to carry information via the VLC connection. The protocols used in this are the Transport Layer which are TCP (Transmission Control Protocol) and UDP (User Data Protocol). In our computer software we will use TCP/ICP but to begin with, what is a protocol? A protocol is a set of formal rules for their interaction in a computer network. The TCP/IP protocol is located at a lower level than the application layer and higher than Network layer following the TCP/IP stack model as seen in Figure 6.

The difference between UDP and TCP are also important to highlight. UDP is non-connection oriented, and hence it does not provide any kind of error

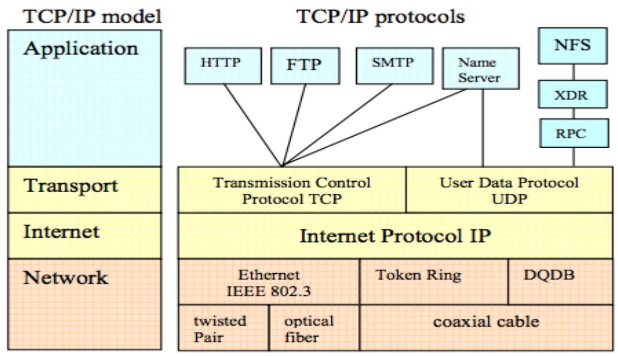


Figure 6. The block diagram analysis of the TCP/ICP Stack protocols

and flow control, rather it uses ways to detect errors. UDP is a very simple and there is no handshaking between UDP sender, and receiver. There is no preservation of the sequence of information provided by the application. This way, each UDP segment is handled independently of others and can blast away as fast as desired providing no congestion.

TCP is one of the main protocols of TCP/IP model where whereas the IP protocol deals only with packets, TCP enables two hosts to establish a connection and exchange streams of data. TCP guarantees delivery of data and also guarantees that packets will be delivered in the same order in which they we sent unlike UDP protocol.

A. The Ping Test

The Ping Testing GUI in figure 7 is essential because it will verify if the specific laser Ethernet transceiver will function, essentially if it responds, the data is flowing. By writing the user's name on top blank space, we would get the IPv6 address and the time it took to reach the machine. In addition, this test allows an application to determine whether a remote computer is accessible over the network. This is a crucial step to continue with the next phase of the software.

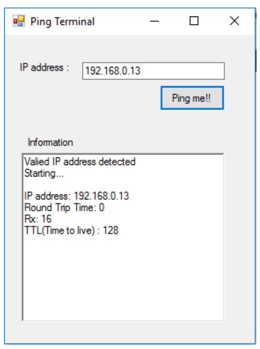


Figure 7. The Ping Terminal GUI.

B. The Client side

The initiation of the Client GUI is on one side of the data transmission, and this GUI will provide us with the estimated of what the information of the link communication when data is being transferred is. The functionality of this client is to upload the file that would be sent by selecting the 'Browse' button and then 'Start' button to make the transferring to the Server side.

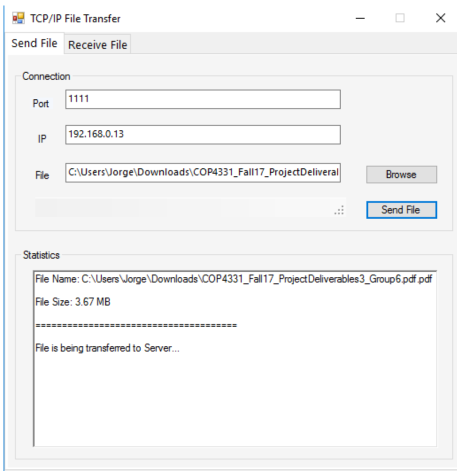


Figure 8. The Client Side GUI.

C. The Server Side

The TCP/IP Server GUI will function as the receiver from the Client. The functionality will be about the place to download data and save by the "Save To" button in the local machine. Simply by writing the Port number from where the Server will be listening to any connection.

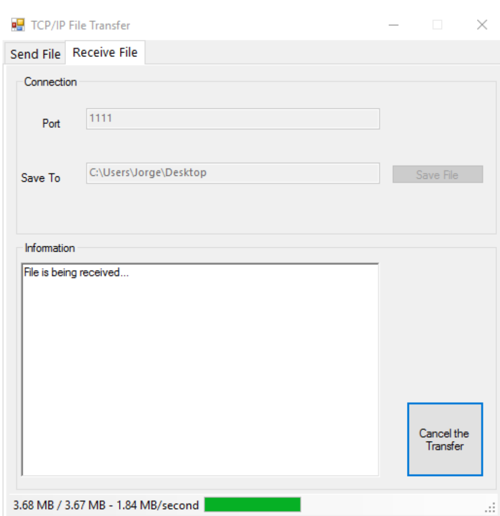


Figure 9. The Server Side GUI.

D. The Network Information Display

The main objective of this Network Information display is to analyze the measurement of link transmission for the different network interfaces a machine may have. The figure above shows the data of the network interface used to transmit data from one computer to the other. The development of this network display tool is dedicated to giving the user an application to verify the speed of the link communication complemented with other extra features.

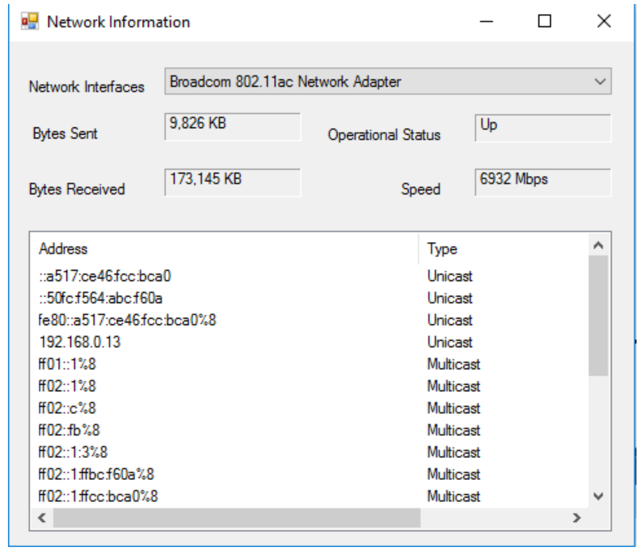


Figure 10. The Network Information GUI

The expectations of the software is that it will work over any network system even where Visual Light Communication mean is not involved. The validation in this application will abide by the specifications listed earlier in the project requirements such as the speed testing and data throughput.

VII. BOARD DESIGN

Each VLC device is fitted onto its own PCB, which stands for printed circuit board. PCBs have their advantages and drawbacks. On one hand PCBs are especially great for communication systems as they mitigate parasitic characteristics of the passive components. Contrarily because each component is soldered on, any defective elements are extremely difficult to remedy, as they cannot simply be removed. PCBs support through-hole as well as surface mount technologies. Each VLC device has predominantly surface mounted components with the exception of the photodiode and the laser diode. The total size of the PCB is about 2.5"x2.5".

Figure 11. The final laser Ethernet transceiver design.

VIII. Conclusion

The overall design of this project for the senior design class required a collaborative effort of discussion in weekly meetings, constant communication, and research and investigation into fields that we all had new insight into. We were challenged to be analytical, contemplative and critical in our decision making.

The research into optical wireless communication technology and relevant companies allowed for us to understand the overall profile of the scope of our design and impact that it could create in the market and in terms of where there were economic driving factors. The ability to assimilate the companies in the market as they stand in terms of a technology is a project management skill and ability to make decisions in how a particular technology if pursued can make a broad or little impact. Since time is money, a conceivable notion is to understand the competitors ahead of time to save someone “beating you to the punch.”

The design iterations taught us about being thorough and dedicated in execution. With constant effort, even without a grand scope of understanding allows an engineer to be able to be ready and able to understand when and why adjustments need to be made. Experiencing this first hand was a challenge and a rewarding experience.

Comparative part selection allowed for the group to gain a better insight on how to identify key characteristics of components, as well as how to understand tradeoffs in terms of design impact and economic gains. The method of using tables and visualizing the components is a forceful tool in the future when asked to do a system upgrade.

Understanding how standards are created and enforced was something not taught in regular courses. It was an interesting learning experience to see all of the institutions involved in the regulation of communication, electrical power, environmental impact, safety and health compliance, mechanical compliance and Computer network topology.

Creating a GUI with a purpose by identifying the goals and making one which is readily available no matter hardware upgrades is a challenging feat. The non-computer engineering members learned a lot about TCP/IP protocols and how byte structure and datagrams effect communication flow.

We should point out in a personal way, that the work realized has extended our knowledge in this important area which is communications. Considering the boom in the development of communications and future aspects in this area, it would be interesting on the development of more secure systems, either in the hardware equipment that use VLC or any other type of network communication.

The hardware construction was instrumental in cultivating job skills in prototyping, circuit design and PCB design and configuration. Not only is the hardware design the integration of the understanding of the strategic part selection, it is the execution of understanding what the different electrical manufactured structure can be used in a design. The way a structure of a component is designed is not how part of what is taught in classes as much as it is required for real prototyping.

Working in a team is in itself a skill which the group has felt was very rewarding and a learning process in communication. Overall the ability to work in a team is critical in today’s job climate and future growth as a society. Therefore, understanding how each person has their respective role in the design and implementation of technology was an excellent experience to undertake.

THE ENGINEERS

Benjamin Stuart is a photonic scientist and engineer who is actively engaged in communication research with fiber optics. He is looking to pursue a career in photonics with an emphasis on obtaining information from the natural world or in propagating information. He is also interested in bio-photonics which is related directly to this project where the transmitting laser with a high frequency can create novel imaging techniques. He was having been assigned as the project manager, responsible for the overall robustness, and continuity of the design in each aspect and interfacing with each group member in order to establish their goals and responsibilities.

Garrett Bennett, also a photonic scientist and engineer is looking to pursue a career in RF design of antennas and semiconductor design. He hopes to go to Master's school for this specialty. He is actively working for a radio and telephone communications company. Garrett was responsible for the prototype assembly and in making sure the optical system can handle the requirements. In addition, for the final design, he will construct the physical housing.

George Salinas is a computer engineer, he is interested in the technology of wireless communications networks and the interfacing of the incoming and outgoing signal of internet technology. He aspires to work on technologies to increase the throughput of communication technology. George was given the responsibility of researching communications technologies that could be implemented with the given optical wireless communication system.

Zhitao Chen is an electrical engineer. Zhitao is interested in electrical circuit design. Zhitao was in charge of designing the power supply to the VLC system, which included properly implementing of the LED and photodiode and their subsequent electrical processing components. Zhitao is given a duty to test the power supply. Also, he has a responsibility to design a PCB through KiCAD as well as manufacturing and ordering the PCB.

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