LASERef

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***Abstract*—LASERef is a system designed to mark first downs in the game of football faster and more accurate than the conventional way. LASERef is a break-beam detecting system that can determine if the football has crossed the first down plane on close calls. The system then relays this information to fans and refs via Twitter.**

I. INTRODUCTION

THE current first down marking system in the NFL is flawed. The method is slow, inefficient and prone to human error. The following report will demonstrate the design and build of the LASERef, a new and improved way of determining close-call first downs throughout a football game.

The Current System: Once the referee spots the ball on the field, they look to the sideline and attempt to determine whether or not the ball crosses the first down line, marked by 2 markers, one on each side of the field. In situations where the referee cannot make that decision with the football and marker being some distance away, the game is stopped and the markers are brought onto the field for a closer look. At that point, the referee determines whether or not the nose of the football has crossed the marker.

As of late there have been articles commenting on the implementation of lasers and potentially chips inside footballs to solve this controversial situation. Recently, Pro Football Talk published an article detailing the Houston Texans' frustration with a pair of first down calls in their Monday Night loss to the Oakland Raiders earlier this season [2].

Human judgement is something that any sport would love to eliminate. Human judgement brings in the possibility of mistakes and biases. Even with the marker being brought onto the field and placed right next to the nose of the football, there have been mass amounts of controversy on the referee's decision of whether or not the ball has crossed the first down plane.

This is a slow and cumbersome process. With a society obsessed with instant gratification and stimuli that allow for shortened attention spans, a faster method could provide a much more enjoyable viewing experience. As it currently stands sports are moving to reduce the average game time. For example, the MLB is experimenting with a variety of new rule changes that will decrease the average time of a MLB game including the 20-Second rule - allowing a pitcher only 20 seconds between pitches, the Batter's Box rule - prohibiting batters from taking both feet out of the batter's box between pitches, No Intentional Walks, 2:30 Inning Break Clock, 2:30 Pitching Change Break Clock, and Three "Time Out" Limit - allowing a team only 3 times per game to conference on the field [1].

And finally, this process poses as a potential unfair and undeserved advantage to a team. While these markers are being brought onto the field, the clock is stopped, allowing the teams to reconvene, get set-up and make a more well thought out decision on their next play call. A situation where this clock stoppage is especially detrimental to a team is during the "Hurry-up Offense". The goal of this offensive tactic is to play a face paced game, running play after play in an attempt to both catch the defense off-guard and to tire them out. Having an unnecessary clock stoppage during a "Hurry-up Offense" is an underserved and unfair advantage for the defense.

The LASERef is the solution to all these problems. With the use of lasers, after the referee has spotted the ball, the system can determine if the football has crossed the first down plane with the click of a button. Refer to Table 1 for the specifications of the LASERef.

The first down marking process in the game of football has been a problem for some time. No alternative measures have been implemented into gameplay. An interesting solution to this has been proposed in a system called "First Down Laser Systems"[4]. In this system, a green line is actually projected onto the field at all times throughout a game to signify the first down line.

Specification	Value
Weight	<5 lbs
Height	14.5 in
Length	6.5 in
Width	6.5 in
Battery Life	>5 hours
Alignment Time	4.225 sec
Receiving Distance	<90 yards

Table 1: Specifications of the LASERef

Specifications were chosen in an attempt at making the system small, lightweight and mobile. The system had to have a battery life that was long enough to endure a full football game and also make it through a potential overtime. The alignment time was measured by taking the average of a variety of attempts at lining up the laser with the receiver from 50 yards away. The receiving distance needed to, at a minimum, reach approximately 55 yards (50 yards across the playing field and at least another 5 yards extra because the markers will not be place directly on the start of the playing field).

A final issue that needs to be addressed is the ability for a fan or team to "hack" our system. This is prevented by a "light shield" that is implemented over the receiver to stop any outside laser or light from causing a faulty reading.

II. DESIGN

A. Overview

LASERef is a proposed solution to the current state of first down determination on close calls. The system is essentially a break-beam detector that determines if a first down was made, and then sends that information to fans and refs via Twitter. The system consists of a laser emitter, a photodiode receiver, and a Raspberry Pi computer.

The system is designed to transmit a laser beam from one side of the field to another to create a precise and quick line that marks the current first down location. On close calls after the referee places the football, the system will shoot the laser across the field. If the beam is not broken and the receiver collects light from the laser, then a first down is not made. However if the beam is broken and the football blocks the laser beam from reaching the receiver then a first down has successfully been achieved. A signal LED located on the receiver will illuminate letting the chain crew know if the beam has been broken, and hence a first down has been made. This information can then be immediately uploaded to Twitter using a button on the marker. This entire system is highlighted in Figure 1.

The entire system is designed to be an unobtrusive improvement to the game. The receiver is built into the already existing poles that are used to mark the first downs and the transmitter is planned to be installed on first down marking matts as well. The receiver and transmitter were also constructed so that the chain crews who manage the first down markers could easily move and do their jobs without new complications.

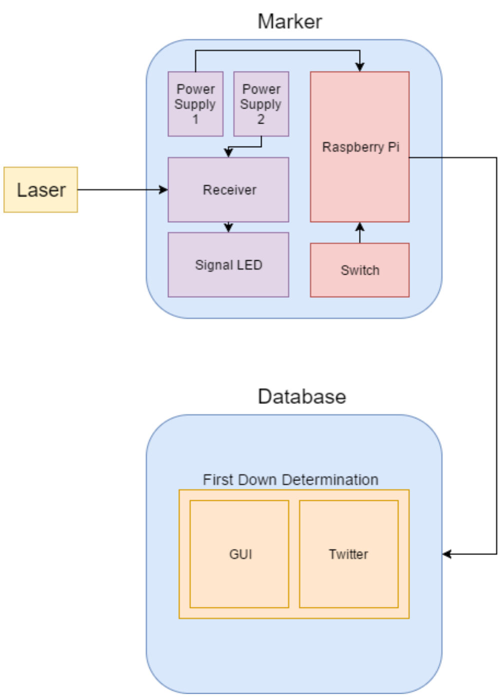

Figure 1. Block Diagram

B. Receiver

The receiver in the system was designed using a photodiode. The photodiode works by creating a higher current across itself when it is excited by incoming light. This increased current is then used to send other signals inside of the receiver.

However, building the receiver isn't as simple as a photodiode alone connected to a battery. The photodiode needs to be sensitive to the beam of light being shot across the field. The photodiode also needs housing to block any unwanted light from the outside that might excite the diode when it shouldn't be excited. The housing for this photodiode also needs a way to channel the light to the photodiode to make sure that it's getting enough light to produce enough current.

The laser that is used for the transmitter is a high power 5mW laser that emits a beam of light at 532 nm wavelength. This wavelength is important because it is a very big influence on the photodiode that is used in the system. As shown in Figure 2, a Vishay BPW21R Photodiode [5] is used.

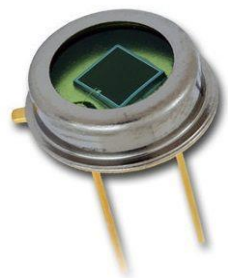

Figure 2: Vishay BPW21R Photodiode

This photodiode was chosen for two main reasons. The first is because it is able to operate effectively between -55°C and +125°C which means that it will be able to function in all temperature ranges that football is generally played in. The second and most important reason, is that it's peak sensitivity is to light at 565 nm wavelength. Figure 3 shows the spectrum of light that this photodiode is sensitive to.

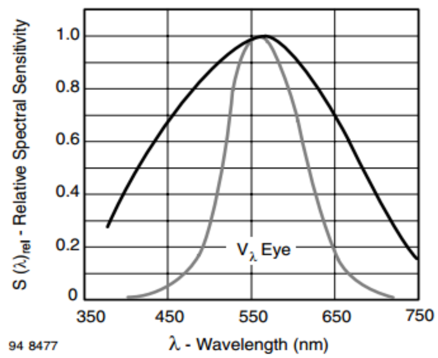

Figure 3: Relative Spectral Sensitivity vs. Wavelength taken from Vishay datasheet[5]

Considering that the transmitter laser in the system emits light at 532 nm, this means that the receiving photodiode is very sensitive to the laser transmitter and can easily be excited by the laser.

In addition to simply choosing an applicable photodiode to use to receive the light, the actual size of the diode itself needed to be taken into consideration. The photodiode is only 5mm in diameter. If the photodiode was used alone to receive the light from the transmitter, which is 50 yards across the field, the laser would have to hit a tiny circle that's only 19.6 square millimeters. Accomplishing that would be nearly impossible so the receiver is designed to direct light toward the photodiode and give a bigger area to hit. A reflective cone with a diameter of about one inch is used to surround the diode as shown in Figure 4. When light from the laser hits anywhere inside of the cone, the reflective material reflects the light all throughout the inside and excites the photodiode. This gives the laser a slightly bigger area to hit and makes it easier to excite the photodiode from across the football field. This design was chosen because it was an effective method of exciting the diode and it was simple to build.

Figure 4: Cone - Photodiode Receiver

C. Receiving Circuit

The receiver circuit makes use of a photodiode, comparator, rectifier, inverter and an LED. Refer to Appendix A1. In general, when the photodiode is excited by the laser, the LED is not illuminated. When the photodiode is not excited by the laser, the LED is illuminated.

When the photodiode comes in direct contact with the laser it generates a square wave with a peak to peak voltage of ~5.5V between 0V and 5.5V. This is a square wave due to the fact that our laser is shooting at a frequency of about 150 Hz which is unnoticeable to the human eye (This was discovered by shining a light at the photodiode and observing that the received signal was a flat voltage signal). This voltage can vary slightly due to the laser not directly striking the center of the photodiode or the laser reflecting off our reflective receiver and into the photodiode. Due to this, the square wave is first sent through a comparator (LM339) [6], comparing to a reference voltage of 500mV. This outputs a perfect square wave between 5V and 0V. The reason 500mV was chosen was to maximize the sensitivity of our system (Laser does not need to directly strike the center of the photodiode) but also to eliminate the possibility of ambient light from triggering the LED.

After the comparator, the square wave is sent through a rectifier. In this circuit the rectifier is simply a diode in series with a capacitor going to ground. The output of this is a 5V steady signal. How this rectifier works: The square wave is sent through a diode. A diode is a non-linear device that only allows current to flow through it in one direction. When the square wave is high (5V) the capacitor charges up to 5V. When the square wave is low (0V) the capacitor discharges it's 5V. This happens repeatedly and results in a steady 5V signal. Because a diode was used, the discharging cannot pass back through the diode and the output receives all 5V that is being discharged.

Finally this 5V signal is passed through an inverter (CD4049UBE) [7]. In this implementation, the LED is illuminated when the photodiode is not illuminated, so at 0V at the output of the rectifier the LED should receive 5V and at 5V at the output of the rectifier the LED should receive 0V.

Refer to Figure 5 for the output of the receiver circuit when the laser beam has been broken.

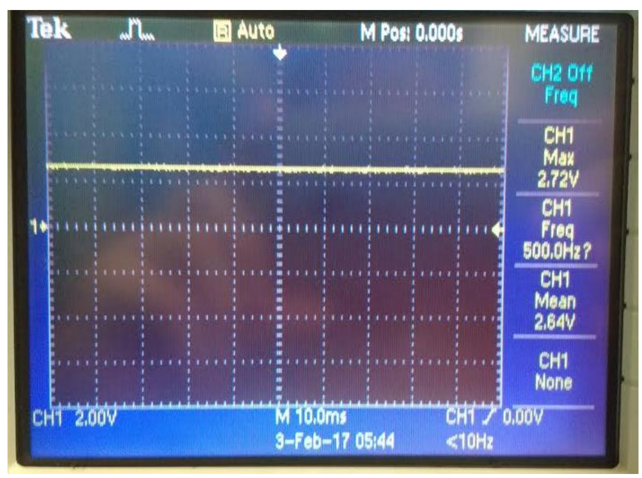

Figure 5: Output of Receiving Circuit When Beam is Broken

D. Box Design

The purpose of the Receiving Box block is to have a physical structure that can hold all the devices and circuitry needed for our first down determination system to work. A main objective for this block to have a structure that is sturdy while being unobtrusive to the game.

The Receiving Box contains a photodiode, a signal LED, the receiver circuit board, two power supplies, and a

Raspberry Pi. ¾” thick plywood was chosen as the material used to build the structure as plywood is sturdy, lightweight, and inexpensive. For easy mobility, the structure had to be connected to the first down markers.

The original design called for a 15.5” x 12” x 16” box with 2” wheels attached to the bottom of the box. This design had a large base as we wanted to make sure that marker would be able to stand upright by itself. The additions of the wheels allowed the chain crews to easy move this structure. However, once the list of devices that needed to go inside this structure was finalized, it was realized that this box structure was needlessly too large.

The redesigned structure shrunk down the box to a more modest size at 6.5” x 6.5” x 14.5” as referenced in Table 1. Wood glue was the primary material used to assemble the plywood pieces together. Instead of wheels to move the box, a clamp is attached to the top of the box where the metal pole of the marker can fit in and clamp in place. This allows the chain crew to easily move the box by just lifting the marker. In the end, reducing the base size of the structure did not affect its’ ability from keeping the marker from standing upright.

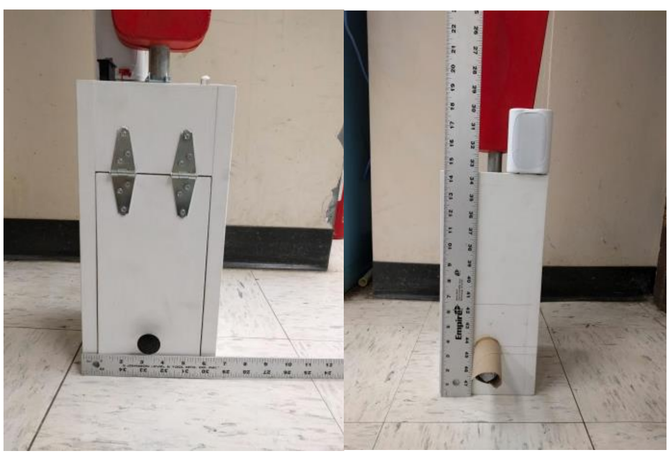

Figure 6: Receiving Box Design

Figure 6 shows photos of the receiving box design from the back and front, respectively. This box design was compact to the point that it fitted everything that needed to go inside the structure while there was spare room for any unplanned additions to the system. Foam tape was used to hold the devices inside in place. A 1” wide hole was cut in the front part of the structure to allow the photodiode receiver to stick out and pick up the transmitted laser. The center of the hole is 3.9” off the ground. Our first down detection system is currently designed to work for a junior size football, which has a radius of 3.9” [3]. A light shield, temporarily made out of paper towel tube, was added to the box to surround the receiver because it was discovered during an outdoor testing that sunlight could get in the reflective cone and trigger the receiving photodiode. The logic with the light shield is that it will prevent the sunlight from getting into the reflective cone while additionally preventing any fan in stadium with a laser of their own from using it to sabotage the system as the light shield will limit the photodiode to only picking up a laser from the sidelines.

Through the learning process of designing and building this prototype receiving box design, designing the transmitter box design, which will contain the laser, will be a simpler process.

E. Software

Initially, we decided to relay all of the information from the system to a graphical user interface (GUI). The GUI was developed using Java code in a program called Netbeans [8]. Netbeans is an applications that allows a drag and drop interface to build the program. The GUI in it’s final state launches a splash image with the LASERef team name and then enters the main interface. The application has one screen which shows the team name, if the ball was detected, and the current yard line. The GUI interface would load all of the text on the web page at the current time. The Pi creates a web server via it’s IP address and uploads relevant text (Ball detection and time) to the web page for the GUI to check. It would upload for example “Ball Located: Yes” or “Ball Located: No.” When the GUI loads the text it will display either “Yes” or “No” on the page depending on the text. The URL for the hosted web page is the Raspberry Pi’s IP Address plus “:8080”, where 8080 represents the port number. For this to work properly, both the Pi and the PC hosting the GUI need to be on the same wifi. Since the Raspberry Pi does not support Eduroam, we had to use UMASS. This method of creating a web server was not possible on UMASS wifi due to security reasons. The only remedy to this would be making a wifi hotspot with a router and bridging the connection. The router is able to connect to UMASS wifi and the Raspberry Pi latches onto that connection without directly connecting to UMASS. However, this was a such a minor issue, we felt it wasn’t the best way to utilize our time and we came to the decision to switch to Twitter to relay information. We may decide to establish the wifi hotspot and use the GUI later in our project if it proves to serves a better purpose than the Twitter.

The benefit of relaying all the information to Twitter was that anyone could access the information anywhere. This made it much easier to troubleshoot our project. In addition, during a game, anyone who would need the information could access it in real time without waiting for the referees to make the call. People, such as fans and coaches, can all open up the Twitter page and check to see in real time what the status of the system is.

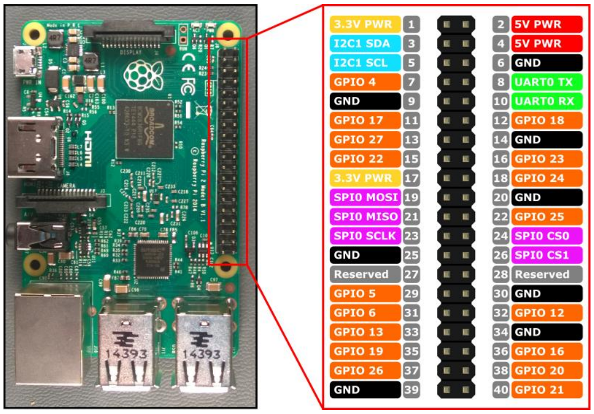

Figure 7: Raspberry Pi GPIO Pins

Relaying all of the information to Twitter was done entirely on the Raspberry Pi via a Python script that would run on startup. The Python script makes use of two different things: the Raspberry Pi GPIO pins and a Python package called Twython.

The GPIO pins are the metallic pins that are lined on the board. As seen in Figure 7, they contain input and output pins as well as ground and power. The python script in the Pi makes use of these input pins. Input pin 7 is connected to the flip switch on the board. When the switch is pressed, the input pin receives the signal. In the python we code, we can write a line of code that will perform an action when the pin receives this signal. This was initially tested with an LED on one of the output pins. When the input is received from the switch, the LED would turn on and when there is no signal to the pin, the LED would turn off. After testing with the LED, we knew that the pins were function properly and we could implement the Twitter.

As mentioned previously, the python script run on the Raspberry Pi makes use of Twython [9], which is a user-developed Python package that makes use of Twitter API to access core Twitter mechanics via Python script. The requirement for Twython is to register a "Twitter App." A Twitter App gives the user a series of serial keys which, when used properly, allow you to access the Twitter account without the need for logging in. The Twython package uses these keys to send Tweets via one line of Python code. By adding these lines of code into the Python script, we can send Tweets to Twitter when an input is received to the designated GPIO pin. The final script will, upon pressing the switch on the box on, send a Tweet saying "Connected" plus the current time. When the switch is turned off, and no signal is going through, the script sends a Tweet saying "Disconnected" plus the current time.

F. Future Alignment

Currently, the transmitter is lined up on the edge of the field and moved around until it can successfully hit the receiver. On average it takes about 4.2 seconds to align the transmitter with the receiver. However, there are some issues that still need to be addressed with this method. The most prominent one is making sure that the laser is actually shooting perpendicular across the field. If the laser isn't aligned perfectly with the edge of the field and is off by a small angle, it means that the beam is now skewed and not accurately marking the first down line.

To avoid this issue the transmitter will be equipped with a Raspberry Pi computer, gyroscopic sensors, and magnetometer sensors. Using the Raspberry Pi to interface these sensors, the transmitter will be designed to recognize angles and directions. The transmitter will be created so that it can be calibrated before a game to be perpendicular with the field. Once calibrated, the transmitter will be equipped with its own signal LEDs to inform the operator if it's perpendicular with the field or not based on the sensors' readings. The operator can then adjust the transmitter until it is at the correct angle.

G. Project Management

Initial MDR Deliverables
Demonstration that marker can detect the nose of the football up to 25 yards
Distance sensor can detect how far down the field the marker is placed
Bluetooth modules in football and marker to relay information to control software system

Table 2: MDR deliverables initially proposed at PDR

Our initial MDR deliverables can be seen in Table 2 above. However, since the scope of our project had dramatically changed since our Preliminary Design Review, when we came up with these deliverables, we had to refine what we wanted to accomplish.

Updated MDR Deliverables
Demonstration that the photodiode can detect the laser from 50 yards
Show that the football can successfully create a break in the laser beam
A Raspberry Pi in the marker that can relay first down information to Twitter

Table 3: Revised MDR deliverables

Our updated MDR deliverables are presented in Table 3 above. All of these goals were successfully accomplished in our project. We were able to demonstrate that the photodiode in our system could detect the laser from at least fifty yards away. We were also able to successfully demonstrate that the Raspberry Pi in the marker could relay the information to the Twitter.

Each member on the LASERef team has contributed important and significant aspects to the overall project and has a specific expertise. Joshua Setow designed the blueprints for the box which holds the marker and also worked on the website. Sam Auwerda researched the most efficient methods for reflecting and receiving a laser, as well as working on the website. Tim Freitas constructed the box and constructed the photodiode circuit. Joshua Gallant developed the Python script on the Raspberry Pi as well as the GUI application.

Although each team member had their own contributions to the project, everyone helped out to make sure that the goals that had been set were met. When it came to designing the receiver circuit and evaluating different receiver designs, everyone helped to build and test different aspects of the designs to make sure that they could function optimally and successfully. Whether this meant helping to troubleshoot circuit problems or helping construct different materials, the team was there to help when needed. Even for the software aspect, everyone inputted their ideas on how it should work and did what they could to make sure we had the right resources and materials. Although we divided the project up to be done by different people, it was really a group process to make it actually happen.

To complete the current aspects of the project, the team remains in constant contact with each other via text messages. We continually update each other on individual progress. In addition our team meets about once a week to update each other on current progress and work on the overall project (i.e. assembling the components, preparing for presentations, etc).

There are a few things that we will accomplish for our CDR. Our CDR deliverables can be seen in Table 4 below.

CDR Deliverables
More information to be relayed to Twitter
Design the other marker holding the laser
Alignment of the markers on the field

Table 4: Proposed CDR deliverables

In addition, in Appendix A2, a Gantt chart can be seen which details the current progress we have made so far, as well as how we plan on managing our time for the upcoming semester.

III. CONCLUSION

Currently, the designing and building process of LASERef is on track. For MDR, the group accomplished the MDR deliverables that were set. The objective of those deliverables was make sure that the basic premise of the laser beam detection part of LASERef could work over the width of a football field. As described in the Project Management section in more detail, the individual blocks all functioned together in an error free manner and that has proven the viability of this project.

For the next phase of the project, the goal to build and to improve on what has been currently built. The Gantt Chart in Appendix A2 shows our schedule for next semester. Josh G. will continue focusing on the database aspect of the project. He will be trying to relay the first down determination to a website instead of Twitter. Additionally, he will work on relaying more game stats from the Pi such as yard line or game time. Sam will be focusing on the alignment process of the two first down markets on the sidelines. Tim and Josh S. will be focusing on designing the transmitter marker, which will hold the laser, and building the PCB needed for the system. After those parts are completed, they will help on the alignment issue. After CDR, we will build our improved receiver box, which will include protective padding, and work on elements needed for final presentation such as a miniature football field.

There is an understanding that the alignment process will be a challenge for this project. However, we have come up with many different possible solutions, described in the Future Alignment section, that will improve on the manual alignment of the markets that our system currently requires. Assuming that all our set deliverables are accomplished on time, it is reasonable to expect that our finalized LASERef product to be ready and functioning by Demo Day in May.

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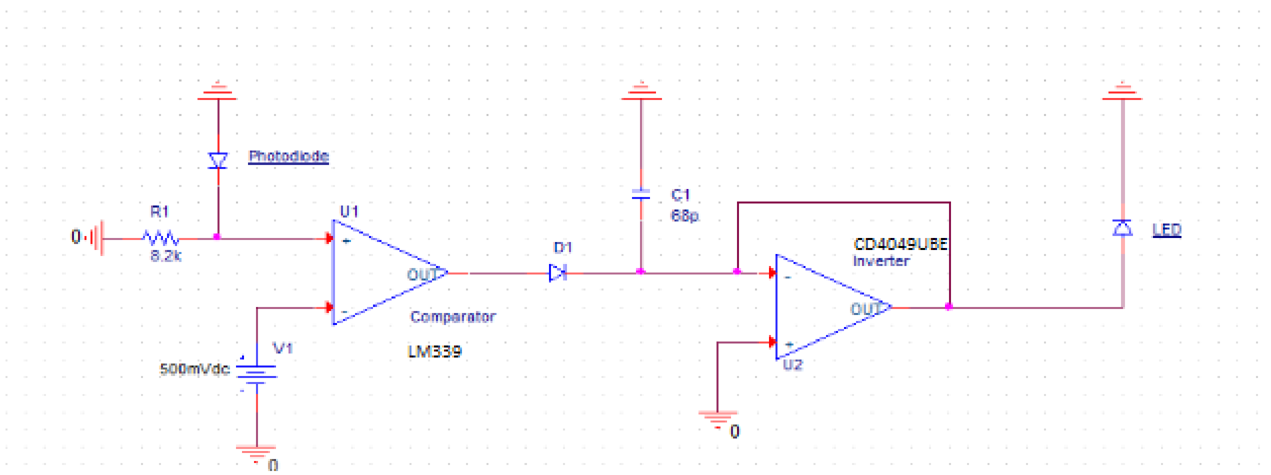
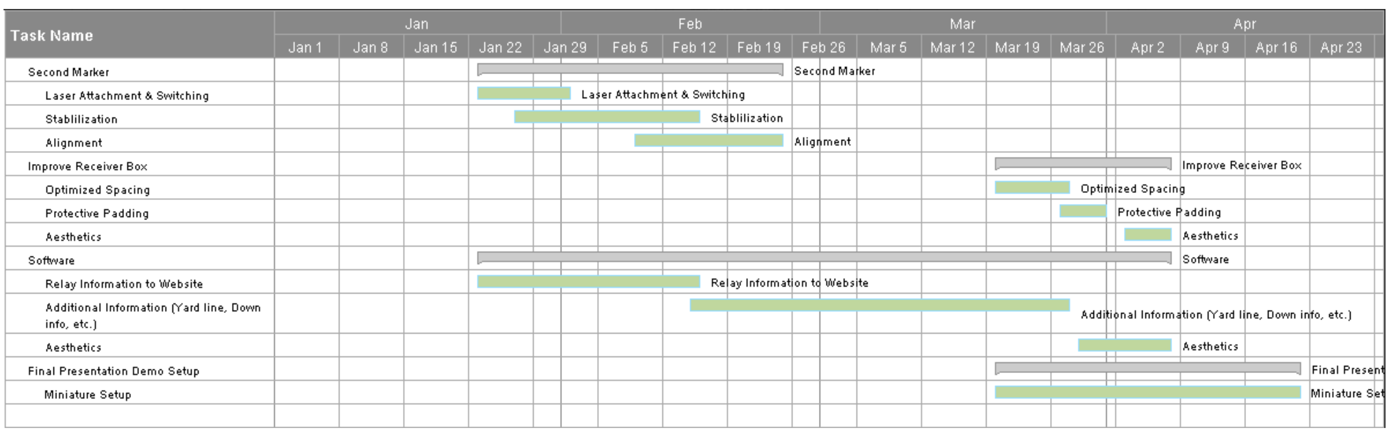
APPENDIX



Appendix A1: Photodiode receiver circuit



Appendix A2: Gantt chart for Spring semester