Environment Aware Bike Light

Final Report

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Abstract

This report details the Team 31's design of Environmental Aware Bike Light and the findings of Team 31 during the process of the design and building the product. The motivation and high level requirements are listed. The block diagram and the design choices are explained. Cost and code of ethics follows and the verification of our system closes this report.

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1 Introduction

1.1 Objective

To be safe riding at night, bikers use bike lights to illuminate dark streets.

The number of cyclists has been steadily increasing in major US cities such as New York, Chicago, Portland and San Francisco [1]. This means there is a greater requirement for safe, secure and well functioning bike lights in the market. The problem with bike lights in the market is that they do not offer enough environment awareness in order to influence their brightness. Adverse weather conditions, such as fog, pose problems in terms of visibility for the biker and can play a part in a lot of dangerous situations.

Our project aims to give an environment aware bike light to the biker, so that the biker does not need to keep adjusting his or her light while riding the bike. We would add LIDAR functionality to detect fog and turn on the bike light as well as a floodlight in order to allow others to clearly see the biker in the fog. This would provide a lot of flexibility in brightness for the bike riders while also ensuring their safety without loss of convenience.

To detect fog, we'll implement Differential Absorption Lidar, DIAL. Lidar stands for Light Detection and Ranging. Light is transmitted and reflected back in lidar systems and by measuring the difference of power or delay between the original signal and reflected signal, one can figure out desired information such as distance. In DIAL, there are two lasers at two differing wavelengths: one at absorption wavelength and one slightly off the absorption wavelength. The difference in amplitude is correlated with the concentration of aerosol, which in our case is water vapor and high enough difference would signify existence of fog.

1.2 Background

While there has been an increase in the number of bicycles sold and ridden across the US, there has also been a rise in accidents related to cyclists. [2] We believe that our idea can benefit the cyclist by increasing their safety as well as reducing the amount of power being used by the bike light. With more and more people switching to bikes as a viable mode of transportation, an environmentally aware bike light would become crucial for their use. We also believe our idea is unique and novel, as the only other self adjusting bike light we saw for sale in the market, was one which was dependant upon the velocity of the bike itself. [3] Therefore, we can see a great potential for such a product in the cycling market.

1.3 High Level Requirements

- The bike light should be detect fog via an empirically determined threshold based on our differential absorption lidar system.
- The battery should power all modules in a sustainable manner.
- The bike light should be safe for the humans in the vicinity of the bike light and the laser used should be safe for human eyes operating under the maximum permissible exposure for 808nm and 850nm.

2. Design

2.1 Block Diagram

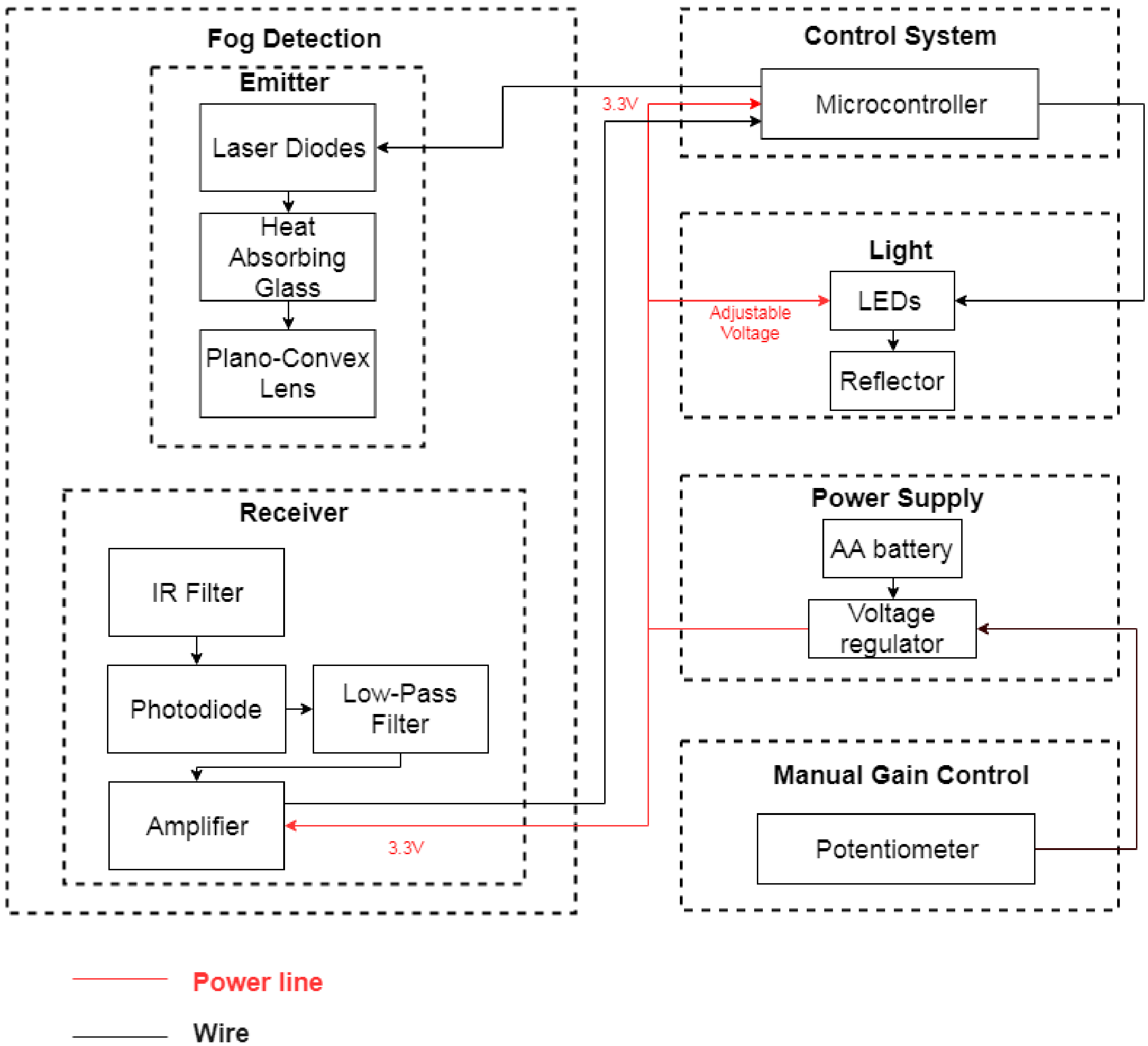

Figure 1. Block diagram of the whole system

Physical Design

The enclosure of our design is a plastic box as shown in Figure 2. This plastic box consists of 2 layers. The bottom layer is for main PCB, potentiometer, and breakout board for LEDs. The top layer is divided into 5 blocks for battery holder, USB breakout board, laser emitters and receiver. The direction of LED lights and the direction of laser emitters are orthogonal to each other to reduce interference. The laser emitters and receiver are placed in the same direction for less noises. The length of the laser emitters block is greater than the focal length of plano-convex lens which is 10mm.

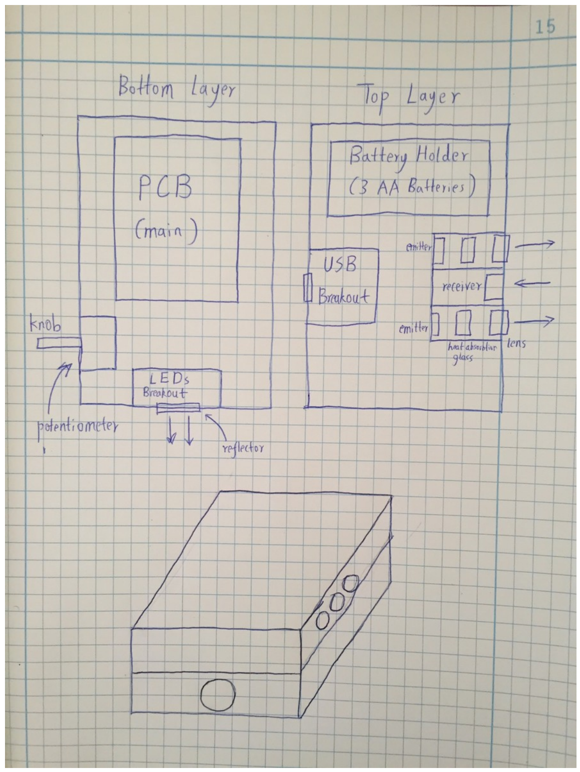

Figure 2. Physical Design of Product

2.2 Component Analysis

2.2.1 Power Supply and Manual Gain Control

The energy for the device comes from three standard AA batteries. This means that the input voltage of the device is expected to be 4.5V DC voltage. However, the battery lose its voltage as it is used up. So, we use a voltage regulator (TL1963A-33DCYR) to produce a constant output voltage for fog detection system and control system.

TL1963A-33DCYR is a low dropout regulator with 3.3V output. It can supply 1.5A output current with a dropout voltage of 340mV, which means as long as the input voltage is greater than (3.3V+340mV), the output voltage is constant 3.3V.

Our original idea is to let control system power the LED lights. The problem is that, based on the data sheet, the forward current of our LED light is 700mA when 2.85V forward voltage is applied (Figure 3). But the ATMega328p chip which is used in the control system can not produce such a high current. Thus, we chose another voltage regulator (TL1963ADCQT) to provide power for LED lights.

TL1963ADCQT is a voltage regulator with adjustable output voltage from 1.21V to 20V. This regulator can supply 1.5A output current and the output voltage depends on the following equation:

$$V_{OUT} = 1.21V\left(1+\frac{R2}{R1}\right) + I_{ADJ} \times R2 \tag{1}$$

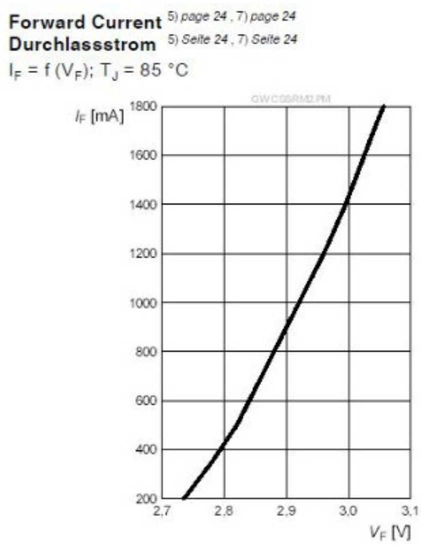

Figure 3. LED Forward Current vs. Forward Voltage [11]

The ADJ current is 3uA at 25 Celsius. With the regulator's 1.5A output current capacity, we don't need control system to provide power. Furthermore, user can change the ratio of R2 and R1 to adjust brightness of LED lights (manual gain control). In this case, we chose a 3.9k ohms resistor as R1, a 4.3k ohms resistor in series with a potentiometer (3~940 ohms) as R2. Based on the equation provided above, the maximum output voltage is 2.85V when the potentiometer resistance is set to 940 ohms. the minimum output voltage is 2.56V when the potentiometer resistance is set to 3 ohms. The schematic is presented in Figure 4.

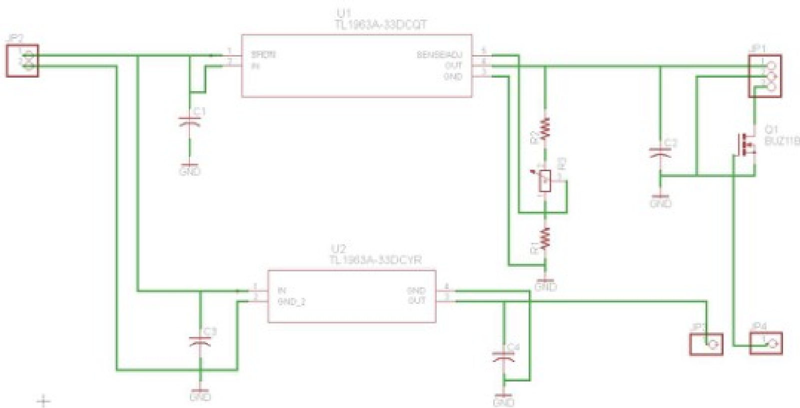

Figure 4. Schematic for power supply

2.2.2 LEDs

LEDs are on a breakout PCB (Figure 6). Both of them are GW CSSRM2.PM-N3N5-XX53-1. We chose this type of LED because it has typical forward voltage of 2.8V and luminous efficacy of 160lm/W. The cathode of LED1 is directly connected to the ground, since LED1 should be turned on in both regular mode and fog mode. The cathode of LED2 is connected to the drain pin of a NMOS (IRLB8721PBF) (Figure 5). The threshold voltage of IRLB8721PBF is 2.35V at maximum.The gate pin is connected to control system. When a fog is detected, control system will apply 3.3V voltage on the gate pin to turn on LED2.

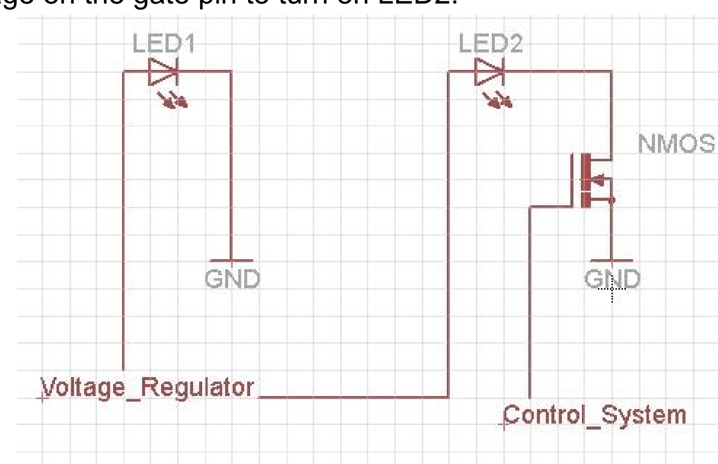

Figure 5. Schematic for LEDs

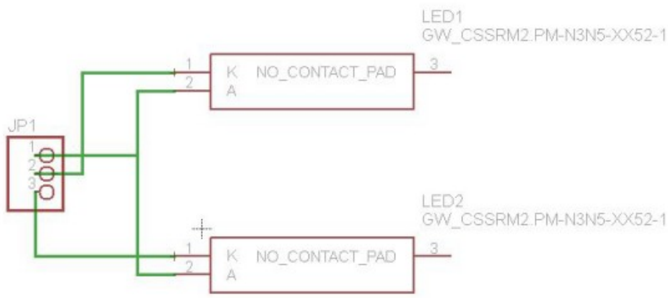

Figure 6. Schematic for LED breakout board

The results and verifications of the power system are explained below.

Two breakout PCBs were used for testing. The layouts are shown in figures below.

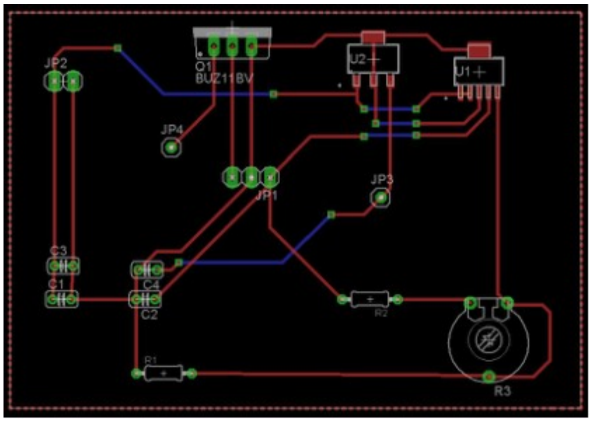

Figure 7. Breakout PCB layout for power supply

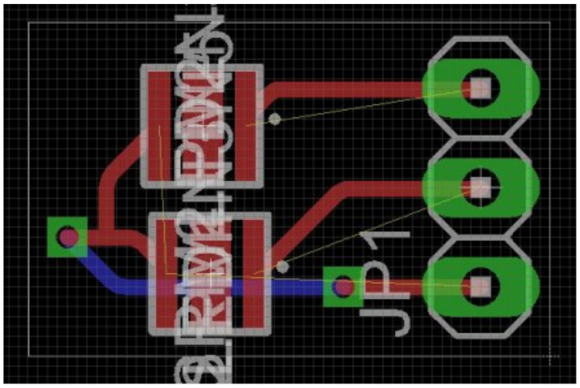

Figure 8. Breakout PCB layout for LEDs

AA Batteries

Three AA batteries were connected in series. The expected output voltage is 4.5V.

	Output Voltage
#1	5.42V

Table 1. Battery Test

As shown in Table 1, the voltage is higher than what we expected. However, since we use voltage regulators, 5.42V voltage is not a problem.

3.3V Constant Voltage Regulator

Since the regulator produces 3.3V constant output voltage, we expected to get 3.3V voltage from the output pin by using 4.5V and 5.5V input voltage.

Input Voltage	Output
4.51V	3.30V
5.50V	3.30V

Table 2. 3.3V Constant Voltage Regulator Test

As shown in Table 2, the result is what we expected.

Adjustable Voltage Regulator

Input Voltage	R1	R2	Output Voltage
4.51V	4kΩ	4kΩ + 1.5kΩ	2.90V
5.50V	3.9kΩ	4.3kΩ + 3Ω	2.56V
5.50V	3.9kΩ	4.3kΩ + 940Ω	2.85V

Table 3. Adjustable Voltage Regulator Test

Based on equation (1), the result is what we expected.

LEDs

By applying different forward voltage to LED, we got the following data.

Forward Voltage	LED state
2.90V	On
2.80V	On
2.70V	On
2.60V	On
2.50V	On (dim)
2.40V	Off

Table 4. LED Test

With increasing forward voltage, The brightness of LED increases.

The best range of forward voltage is 2.60V to 2.90V. This range is close to the output range of adjustable voltage regulator which is 2.56V to 2.85V.

2.2.3 Control System

The control system consists of a ATMega328p microcontroller. This microcontroller receives a photodiode input and depending on the values received by the photodiode this would either turn on the fog LEDs or not.

The value to turn the fog light on would be determined by how much backscattering difference we get from the two photodiodes, which is determined by the lidar equation [4] as follows

$$N_S(\lambda, z) = \left(\frac{P_L(\lambda)\Delta t}{hc/\lambda}\right)\left(\beta(\lambda, z)\Delta z\right)\left(\frac{A}{z^2}\right)\left(\eta(\lambda)T^2(\lambda, z)G(z)\right) + N_B\Delta t. \tag{2}$$

where

- $N_S(\lambda, z)$ = expected photon counts at detected wavelength λ in the range interval (z - Δz/2, z + Δz/2)
- λ = detected photon wavelength (m)
- $P_L\lambda_L$ = laser output power at laser wavelength λ_L(W)
- λ_L = Laser radiation wavelength (m)
- Δt = integration time (s)
- h = Planck's Constant (6.626 x 10^{-34} J/s)
- c = speed of light (2.999 x 10^8 m/s)
- $\beta(\lambda, \lambda_L, z)$ = volume backscatter coefficient at range z under laser radiation at wavelength λ_L for the scattered photons falling into the wavelength λ ($m^{-1}sr^{-1}$)
- Δz = thickness of the bin range or interval (m)
- A = receiving telescope aperture area (m^2)
- z = range from the scatter to the lidar receiver
- $T(\lambda_L, z)$ = one-way transmittance of the atmosphere for the wavelength λ_L from the lidar transmitter to the range z
- $T(\lambda, z)$ = one-way transmittance of the atmosphere for the wavelength λ from the lidar transmitter to the range z
- $\eta(\lambda, \lambda_L)$ = lidar optical efficiency for the transmitted wavelength at λ_L λ and received wavelength at λ
- $G(z)$ = geometrical probability of radiation at range z reaching the detector, based on the geometrical considerations
- N_B = expected photon counts per range bin due to unit time due to background noise and detector dark counts.

The microcontroller is attached to multiple LEDS in order to make a flood light effect and allow for better light to shine through in fog. It is also connected to the potentiometer block in order to allow voltage control and gain for manual handling of the lights.

The microcontroller was used with a USB to Serial Bridge chipset, in our case the FT232R which would directly interface with the AVR’s UART. The clock for the microcontroller ran through a 16MHz crystal. The microcontroller along with the clock and FT232 are shown in Figure 9.

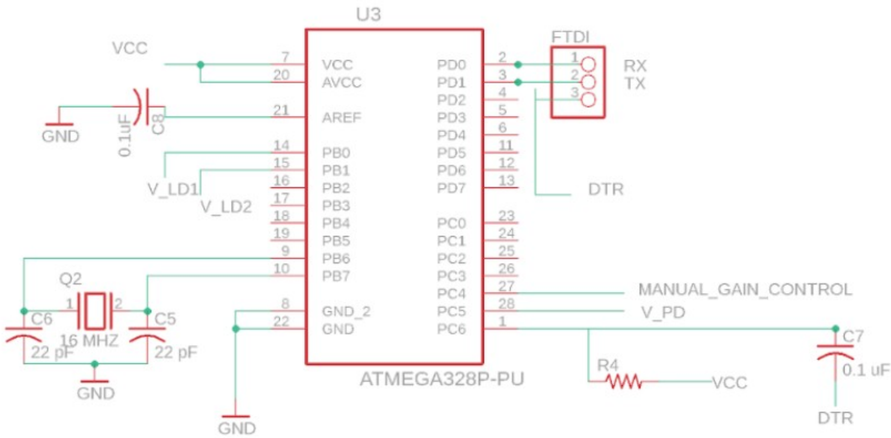

Figure 9. Circuit Schematic for Microcontroller

Upon testing, we were able to verify most of the tests including controlling multiple LEDs, reading values from photodiodes, and turning on the laser diodes in an alternating fashion. Unfortunately the laser diodes were not strong enough to cause detectable backscattering, which led to the microcontroller being unable to read any values from the backscatter.

2.2.6 Fog Detection

For our fog detection system, we built a small Differential Absorption Lidar. The lidar consisted of two transmitter and a receiver

2.2.6.a Transmitters

We have researched the absorption bands for water vapors. We have looked into High Resolution Transmission (HITRAN) data for the absorption band research.

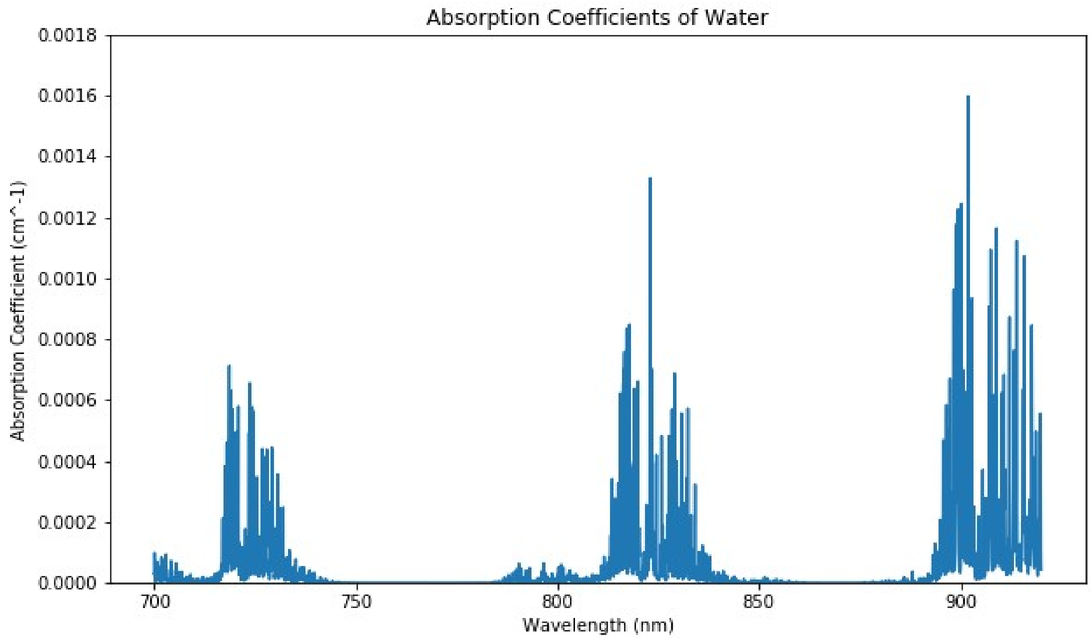

Figure 10. Absorption coefficients of water [9]

Potential absorption band to use were 820 nm, 940 nm and 1360 nm based on Figure 10. However, we weren't able to find laser diodes that were able to shoot at that wavelengths. Therefore, we have decided to use 808nm and 850nm laser diodes for our on-axis and off-axis diodes.

Lasers are divergent and in order to limit the range of backscattering, we had to collimate the lasers. We had couple options for collimation. Plano-convex, biconvex, and aspheric lenses would've satisfied the requirements. We went with plano-convex lenses because they were the cheapest These diodes was placed at the focal length beyond the lens.

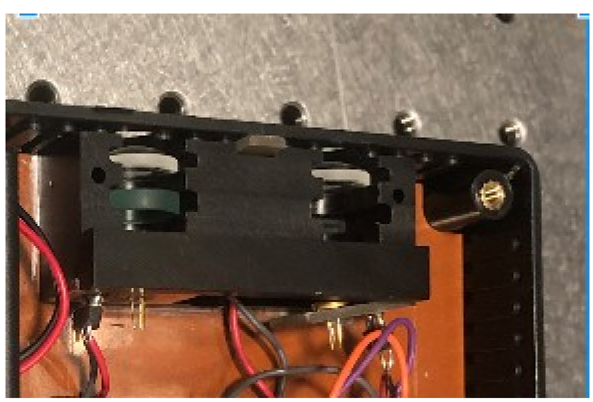

Figure 11. Lasers and Heat Absorbing Glass

We were able to find laser diodes that are 5mW in output. These without attenuation weren't eyesafe.

To make it eyesafe, we put bandpass filters to lower the power. We have looked into a few filters. We have settled with KG-3 heat absorbing glass. Using neutral density filter would've minimized the power difference equally throughout whole bandwidth, but the prices were very high for our project.

There are variants of the heat absorbing glass, but only one was able to provide enough attenuation without killing the laser output, the KG-3. The transmission curve is shown in Figure 12.

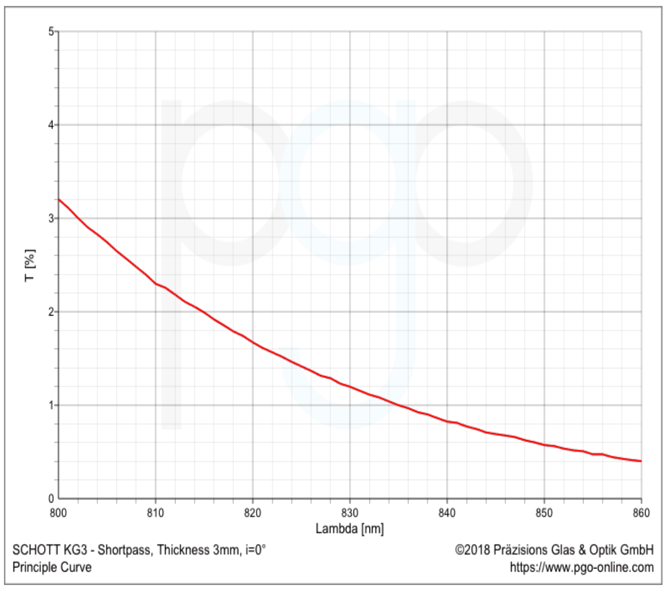

Figure 12. Transmission Curve of KG-3 [5]

We also designed a laser driver for each of the lasers so that they wouldn't overdraw the current and be damaged using a BJT. The schematic can be seen in Figure 13.

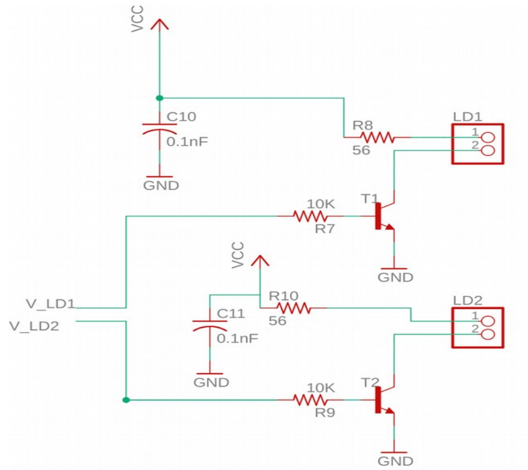

Figure 13. Circuit schematic for Laser Diodes

2.2.6.b Receiver

We had to filter out visible light range. The visible light range would affect the values we would be measuring and we are only interested in intensity of light rays in 808mm and 850mm.

VEMD5060X01 is the model that we'll be going to be using. This has light current at 26uA. Other photodiodes have light current averages at 5~10uA.

The signal is very low at this level. The amplification would be needed at this stage. Thus, an amplifier was used as seen in Figure 14.

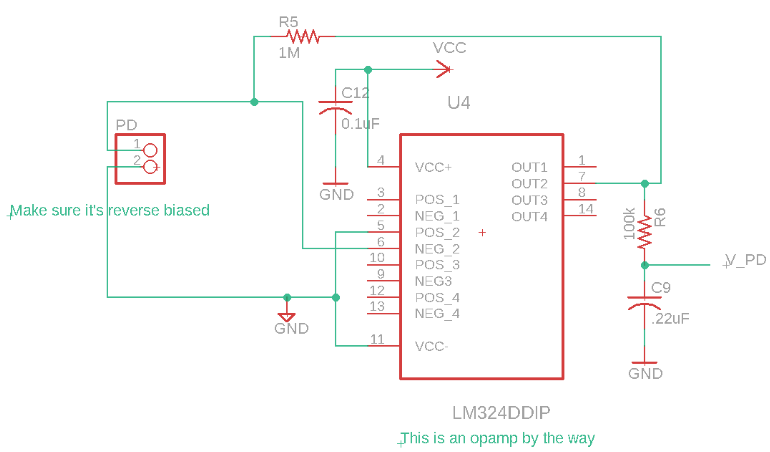

Figure 14. Circuit Schematic for Amplifier and Filter

The operational amplifier circuit amplified to the point where the peak of the photodiode signal would provide approximately 3V.

3. Cost and Schedule

Labor :
Assuming the labor cost is $35/ hour per person, we have calculated the total hours required to do the tasks:

Task	Hours of work needed
Design PCB and enclosure	15
Make revisions to circuit	20
Testing each part on breadboard	15
Code microcontroller to control LEDs and Laser Diodes	25
Soldering and making enclosure for circuit	12
Testing of laser at different wavelengths to gather empirical data	35
Presentation, final report and demo preparation	20
Miscellaneous	10
Total	**152**

Table 5. Labor hours

Total hours = 152
Total labor cost = Total hours * $35 * 3 = $15960

3.1 Cost

Parts	Model	Quantity	Price	Total
Energizer Ultimate Lithium Batteries (6-pack)	-	1	7.99	7.99
3.3V voltage regulator	TL1963A-33DCYR	1	2.85	2.85
Adjustable voltage regulator	TL1963ADCQT	1	3.15	3.15
LEDs	GW CSSRM2.PM-N3N5-XX53-1	2	2.54	5.08
Reflector	C12469_LISA2-R-PIN	1	2.39	2.39
NMOS	IRLB8721PBF	1	0.85	0.85

Microcontroller	ATMega328p	1	2.14	2.14
SparkFun FTDI basic breakout 3.3 V	-	1	14.95	14.95
SparkFun 16MHz Crystal Oscillator	COM-00536	1	0.95	0.95
808nm Laser Diode	D808-5I	1	31.61	31.61
850nm Laser Diode	D850-5I	1	36.12	36.12
KG-3 Heat Absorbing Glass	49-087	1	22.50	22.50
Aspheric Lens	36-165	1	19.50	19.50
IR Filter	43-948	1	10.00	10.00
Biconvex Lens	LB1761	1	25.90	25.90
Photodiode	VEMD5060X01	1	1.87	1.87
Total	**-**	**-**	**-**	**187.85**

Table 6. Cost Table

Total Cost = Labor Cost + Parts Cost = $15960 + 187.85 = $16,147.85

3.2 Schedule

Weeks	Hosang	Sid	Guan
Week 1 : 10/8 - 10/14 (Design Review)	Order laser diodes, photodiodes, optics Design PCB	Order microcontroller and UART	Order batteries, regulators, LEDs, reflector, NMOS
Week 2 : 10/15 - 10/21 (Teamwork Eval, Soldering)	Enclose the parts, Prototype circuit on breadboard	Prototype circuit on breadboard	Test each part on breadboard
Week 3 : 10/22 - 10/28 (1st round of PCBway)	Set Threshold in the prototype	Code and verify LED applications along with manual gain control	Contact with machine shop for the physical design
Week 4 : 10/29 - 11/4	Assemble our system using the enclosure	Write program to alternate laser diodes and calculate threshold for detecting fog	Revise the circuit Revise the physical design (if needed)
Week 5 : 11/5 - 11/11 (Progress Report, Final round of PCBway)	Set threshold in our final enclosure	Submit individual progress report, work on integration of different modules	PCB check and soldering

Week 6 : 11/12 - 11/18	Further testing and Begin integration	Work on improving laser functionality and getting finer data points	Circuit testing and integration
Week 7 : 11/19 - 11/25	Thanksgiving Break		
Week 8 : 11/26 - 12/2 (Mock Demo)	Mock Demo and Further Integration	Work on integration with other parts	Mock demo preparation and circuit integration
Week 9 : 12/3 - 12/9 (Demo, Mock Presentation)	Last minute realignment of optical system	Write final analysis and testing final procedures	Further circuit testing and debugging
Week 10 : 12/10 - 12/16 (Presentation, Final Paper)	Work on final paper and presentation requirements		

Table 7. Weekly Schedule

4. Conclusion

4.1 Successes

We met most of the requirements. We were able to power the system with 3 AA batteries. We were successfully able to drive the laser diodes, which also meant that we were able to control the diodes by microcontroller. The photodiodes were outputting current when light was shined through. The communication between the computer and our circuit worked properly since we were able to monitor output and flash programs.

4.2 Failures

The biggest part of the project which was to detect fog using DIAL didn't work. We have two reasons that are intertwined that attributes to our failure. One is that the laser wasn't strong enough. Other was that the photodiode wasn't sensitive enough. Therefore, we couldn't record any backscattering.

4.3 Future Work

If we were to keep the DIAL approach, we would have to look for more sensitive photodiode or alternative light sensing technology. We had taken off the heat absorbing glass and amplified the output further. We were able to record some backscattering after that, but we were only able to measure 0.04V worth of backscattering even with further amplification and that was already not eyesafe since the attenuation was gone.

Alternative way would be using non-DIAL approach. We would have to research further on this, but there may be a better way than implementing DIAL to detect fog.

4.4 Ethics and Safety

The major safety concern in our project would be the use of a laser. The use of a moderate or high powered laser can permanently damage the retina of the eye. Therefore, proper use of the laser is definitely needed. The wavelength of the laser needs to be safely decided and the power of the light needs to be low enough that it causes negligible or no damage. As part of the verification, we measured our laser diodes with a photodetector and we got 18.3 μA at 808nm and 14.4 μA at 850nm. The photodetector responsivities approximately were 0.401 A / W at 808nm and 0.45 A / W at 850nm. [6] Resulting measured optical power calculated using the responsivities were 0.0456 mW at 808nm and 0.032mW at 850nm. The maximum permissible exposure formula for 700 - 1050 nm is $10^{0.002*(\lambda-700)}$ mW * cm^{-2} [7] which results in 1.644 mW * cm^{-2} at 808nm and 1.995 mW * cm^{-2} at 850nm. Our system had 0.0372 mW * cm^{-2} at 808nm and 0.026 mW * cm^{-2} at 850nm. Since these values are below our limits, we were able to verify the eye safety of the laser system.

We abided by the IEEE Code of Ethics and there are specific points from the Code that we would like to mention.

Since our design involved laser, we assured that it will not cause any harm to people according to IEEE Code of Ethics #1 and #9 [8].

We made our judgements on safety as IEEE Code of Ethics #3 requires. We were realistic to our safety claims and we were honest about those concerns.

5. References

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Appendix A. Requirements and Verification Table

AA Batteries

Requirements	Verification
1. 4.5V input voltage. 2. Batteries can power the bike light in regular mode for 2 hours.	1. Connect the 3 AA batteries in series and use a multimeter to measure the voltage drop. Confirm that it's 4.5V. (Tolerance: ± 0.5V) 2. Turn on the bike light in regular mode and confirm that the light is on after 2 hours.

Voltage Regulator

Requirements	Verification
1. TL1963A-33DCYR generates 3.3V output voltage with 4.5V input voltage. 2. TL1963A-33DCYR maintains 3.3V output voltage when the input voltage goes down. 3. TL1963ADCQT generates 2.85V output voltage with 4.5V input voltage. 4. TL1963ADCQT generates 2.85V output voltage when the input voltage goes down.	1. Use a DC voltage supply to generate 4.5V DC voltage as input. Use a multimeter to confirm that the output voltage is 3.3V. (Tolerance: ±0.2V) 2. Use a DC voltage supply to generate 4.0V DC voltage as input. Use a multimeter to confirm that the output voltage is still 3.3V. (Tolerance: ±0.2V) 3. Use a DC voltage supply to generate 4.5V DC voltage as input. R1 is a 4k resistor and R2 is a 5300 ohms resistor. From the equation above, output should be 2.85V. Use a multimeter to confirm that the output voltage is 2.85V. (Tolerance: ±0.2V) 4. Use a DC voltage supply to generate 4.0V DC voltage as input. R1 is a 4k resistor and R2 is a 5300 ohms resistor. Use a multimeter to confirm that the output voltage is 2.85V. (Tolerance: ±0.2V)

Light

Requirements	Verification
1. 314lm luminous flux with 700mA forward current for a single LED.	1. Use a DC voltage supply to generate 2.85V DC voltage and use a multimeter to check if the current is 700mA. After that, use a light meter to confirm that the luminous flux is 314lm. (Tolerance: ±50lm)

Control System

Requirements	Verifications
1. Microcontrollers should work at a given input voltage of 3.3 V. 2. Microcontroller should be able to control multiple LEDS. 3. Microcontroller should be able to successfully read data from photodiodes. 4. Based on backscatter, microcontroller should be able to turn on required LEDs as fog has been detected. 5. Read voltage from potentiometer to allow for manual control of LEDs. 6. Microcontroller needs to turn on laser diodes in alternating fashion.	1. We will use an oscilloscope to measure input voltage and current to make sure that the microcontroller is being turned on at that range. 2. Write program to switch LEDS on and off based on voltage input provided. 3. Test using different wavelength objects, to result in different values of the voltage for the photodiode which should be reflected by the microcontroller. 4. Based on the empirical backscattering data, decide on a threshold over which the fog lights would be turned on. Program the microcontroller for the above and test by shooting the laser through the humidifier. 5. Print out the readings from the potentiometer to make sure they are changing as desired. 6. Run the microcontroller's code for switching diodes. Connect to the oscilloscope and acquire the time versus voltage graph and check the duty cycle.

Transmitter

Requirements	Verifications
1. Output power needs to be eyesafe. 2. Laser is outputting at right wavelengths.	1. Tools : Optical Power Meter After laser and heat absorbing glass is in series, check the power level. It needs to be less than 0.39mW but greater than 0. 2. Tools: Wavelength Meter Measure the laser. See if it outputs right wavelength. Tolerance : ±1nm

Receiver

Requirements	Verifications
1. Collimating lens needs to converge at the focal length.	1. Tools : Light source, Ruler Shine a divergent light towards our lens. Since it's a biconvex lens, it doesn't matter which side you shine at. Measure the point of convergence from the center of the lens. Tolerance : ±0.3cm

Amplifier

Requirements	Verifications
1. Amplification is as expected.	1. Using an oscilloscope, on one of the channels, connect to where a photodiode is. On the other, connect to the end of the feedbacking resistor. Do a division of those two channels and see if it nears the gain factor we've set. Error range : 5%

Manual Gain Control

Requirements	Verifications
1. 10k ohms potentiometer 2. 4k ohms constant resistor	1. Use a multimeter to confirm that the maximum resistance of potentiometer is 10k ohms. (Tolerance: ±5%) 2. Use a multimeter to confirm that the resistance of constant resistor is 4k ohms. (Tolerance: ±5%)

Appendix B. Source Code for the Software

```
#define LD1 8
#define LD2 9
#define LED A4
#define PD A5

bool LD1_ON false;
int PD_values[2];

int threshold = 10;

void setup() {
  pinMode(LED, OUTPUT);
  pinMode(PD, INPUT);
  pinMode(LD1, OUTPUT);
  pinMode(LD2, OUTPUT);

  Serial.begin(9600);

  PD_values[0] = 0;
  PD_values[1] = 0;
}

void loop() {
  // put your main code here, to run repeatedly:
  if (LD1_ON) {
      digitalWrite(LD1, HIGH);
      PD_values[0] = analogRead(PD);
      LD1_ON = false;
      digitalWrite(LD1, LOW);
      }

  else {
      digitalWrite(LD2, HIGH);
      PD_values[1] = analogRead(PD);
      LD1_ON = true;
      digitalWrite(LD2, LOW);
      }

  if abs(PD_values[0] - PD_values[1]) > threshold digitalWrite(LED, HIGH);
  else digitalWrite(LED, LOW);
  delay(500);
}
```