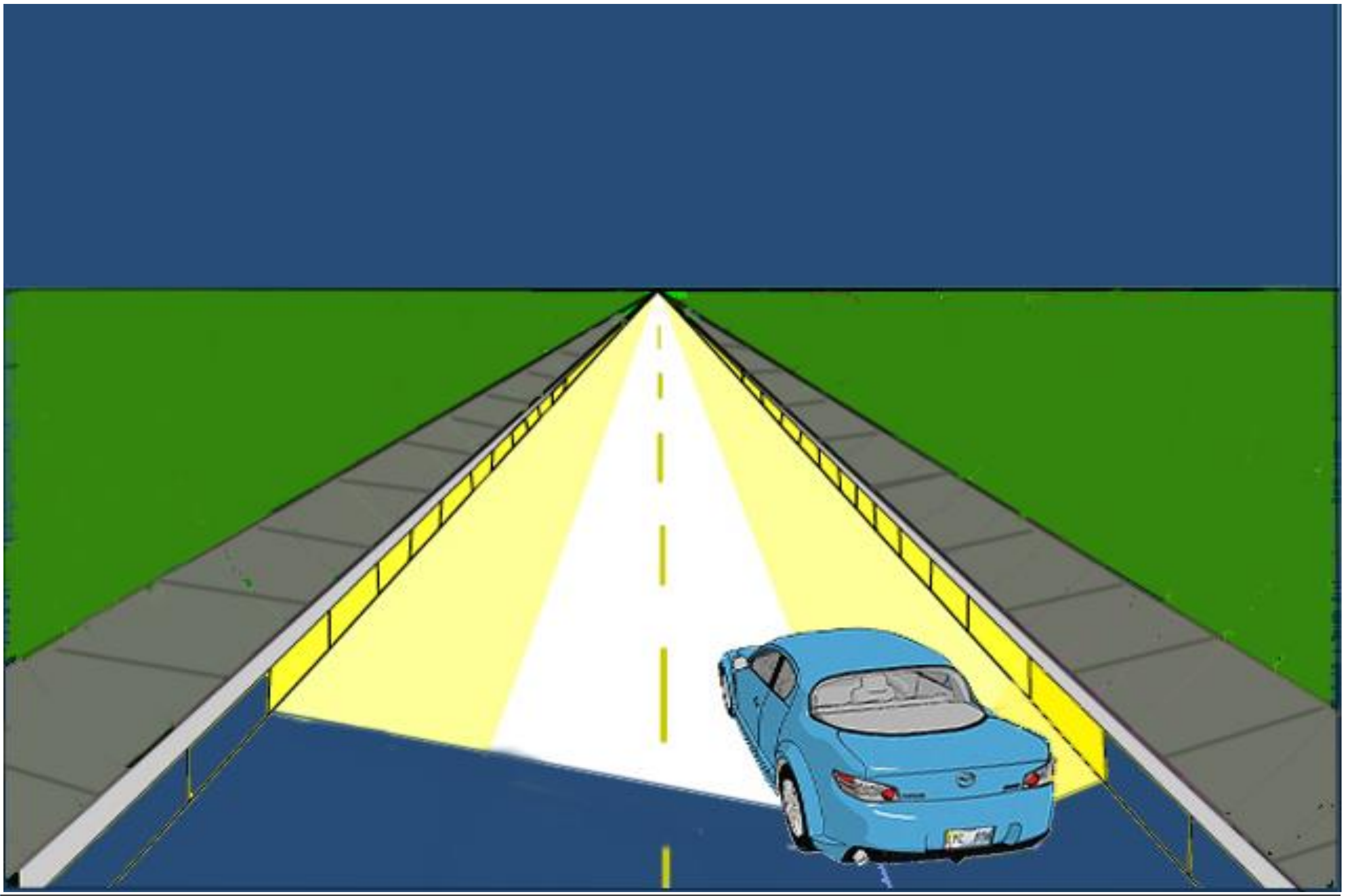

# Interactive LED Street Lighting System


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**Technical Report** **CCDP2100E- Alex Myers** **August 8, 2014**

## Summary

As cities are becoming more environmentally and economically conscious, they are transitioning away from inefficient High Pressure Sodium (HPS) lamps, and are adopting Light Emitting Diodes (LEDs). LEDs are a great alternative as they are more efficient than HPS lights. LEDs also have great colour reproduction, and due to the direct nature of the light they emit, LEDs can reduce the current problem of light pollution. As good as LEDs are, they still fail to transform the obsolete lighting systems currently in use.

The current street lighting design is a static system. The proposed Interactive LED Street Lighting (ILSL) System will revolutionize current road lighting by creating interactive and highly efficient streetlights. The proposed design will only illuminate when cars are present in order to avoid wasting electricity on empty roads. The multicolored LEDs will allow information relay between the road and the drivers. White light will illuminate the road, yellow light will inform drivers to take caution and red will tell the drivers to immediately stop due to a danger on the road ahead. Having access to the colour changing LEDs will improve traffic control for Emergency service vehicles. This system is possible thanks to a series of components working together.

In order to further improve the efficiency of LED lights, the Interactive LED Street Lighting System is incorporated into the curbs so that its infrared sensors can detect the presence of vehicles. By emitting beams of infrared light and detecting their reflection off the cars, the system will be able to illuminate only the road ahead of the vehicle in order to save energy. To keep the LEDs and sensors safe, the system will be enclosed in a metal casing. This will protect the electronics from damage due to corrosion, the elements, and cars on the road. The shape of the casing of the ILSL System will prevent dirt build up on the lights. By having an angled lip, Newton's Second Law will cause the particles to fall away from the light due to gravity. In reality, no matter how durable and well designed the casing is, maintenance is inevitable. To facilitate easy maintenance the ILSL System will be fitted with electro-permanent magnets. These specific types of magnets will firmly hold the LED panels in place. When the panels need to be replaced, the magnets can be turned off using a single jolt of current. Using this magnetic technology, the energy efficiency of the system will not be negatively affected. As explained, every component of the design leads to an efficient and interactive street lighting system.

The Interactive LED Street lighting System is the future of city lighting. It is a system that takes advantage of the efficiency of LEDs and further improves them by only turning them on only when cars are present on the roads. This dynamic system will also facilitate communication with drivers by changing the color of light used to illuminate the road. Over all, the ILSL System will create safer and more efficient roads.

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## Nomenclature

| | |
|---|---|
| $\boldsymbol{\theta_i}$ | Angle of incidence in degrees |
| $\boldsymbol{\theta_r}$ | Angle of refraction in degrees |
| **A** | Ampères |
| **a** | Symbol for Acceleration ($m/s^2$) |
| **B** | Symbol for magnetic Field |
| **D** | Symbol for distance (m) |
| **F** | Symbol for Force (N) |
| **G** | Symbol for conductance (siemens) |
| **k** | Symbol for the absorption coefficient of atmosphere |
| **m** | Unit of distance (Meters)<br>Symbol for mass (kg) |
| **N** | Unit of force called Newtons |
| **n** | Symbol for index of refraction |
| **p** | Symbol for a city's population |
| **Pa** | Units of pressure (Pascal) |
| **R** | Symbol for resistance (Ω) |
| **s** | Unit of time (Seconds) |
| **S** | Unit of conductance (siemens) |
| **T** | Unit of magnetic strength (Teslas) |
| **U** | Empirical parameter used for equation 3.31 |
| **V** | Symbol and unit for voltage (electrical potential)<br>Empirical parameter used for equation 3.31 |

# 1 Introduction

## 1.1 Purpose

The purpose of this technical report is to explain how the Interactive LED Street Lighting (ILSL) System will work. It will also explain how this *system* improves upon the current lighting arrangement regarding safety and *energy* efficiency. This report will cover, in detail, each *system* component; its purpose and the engineering principles that need to be considered in the design of each component.

## 1.2 Context

As required by the CCDP2100 course, each patent group was asked to improve upon an existing patent related to the automotive industry. The goal was to alter the original patent in order to improve upon its safety or *energy* efficiency. Group P7, decided to revolutionize the current street lighting *system* by not only improving on its *energy* efficiency, but also improving on its safety aspects.

## 1.3 Background

The current street lighting *system* uses high-pressured sodium (HPS) lamps to light the roads. The HPS lamps are costly as they need to be replaced frequently. The original patent (8057074), improved on the current lighting *system* by replacing the HPS lamps with LED panels [1]. By doing so, they reduced the *energy* used to light the roads by 85% [2].The original patent is currently being used in the city of Los Angeles, where they have replaced 141 089 HPS lights with LEDs and are currently saving 9.5 million dollars annually in *energy* and maintenance costs [3]. Although the original patent improved on the *energy* efficiency aspect to a certain degree, the ILSL System further increases the *energy* efficiency of street lighting and also creates a safer driving environment.

## 1.4 Document Overview

This report will cover the following sections; the System Overview that explains how the system works and describes the purpose of each component, the Feature Description that presents the engineering principles that were used, and the Conclusion that will emphasize the need for the ILSL system in the cities of tomorrow. Throughout the document certain words are hyperlinked and in italic. Clicking on these words will take the reader to the Glossary.

# 2 System Overview

## 2.1 System Description

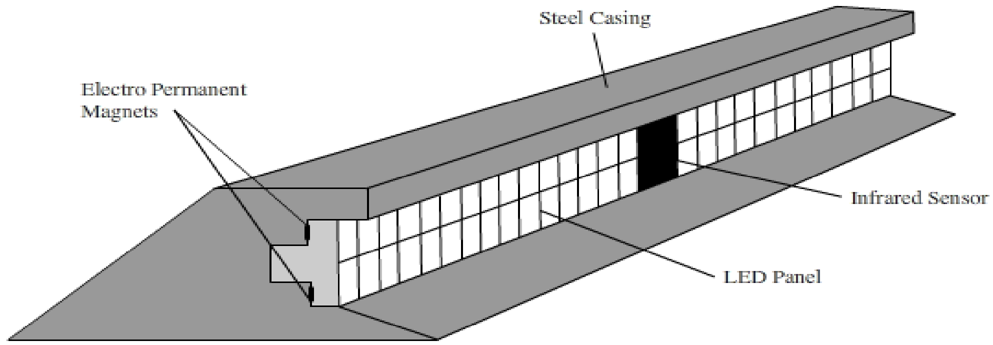


*Figure 2.1: Interactive LED Street Lighting System labeled diagram.*

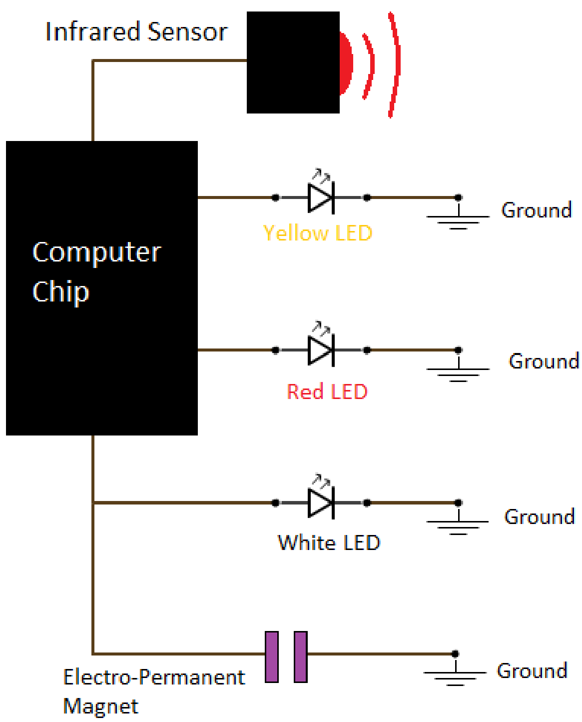


*Figure 2.2: System diagram for electronic components*

The ILSL System is composed of four main components: steel casing, infrared [sensor](), LED panel, and electro permanent magnets. The infrared [sensor]() is mounted in the middle of the LED panel and is used to detect whether or not there is a vehicle present on the road. There are 60 mini LED housings on the panel and each holds two separate LEDs. The top row of housings will hold white and yellow LEDs. The bottom row of casings will hold white and red LEDs. With this arrangement, the white lights are used to illuminate the roads in normal conditions and the colored lights are used to warn drivers of possible hazards on the road. For more details please refer to section 3.2. The electro permanent magnets are used to mount the LED panel into the steel casing that protects it from weather conditions and possible collisions with vehicles. Each segment of the *system* as shown in figure 2.1 will be three feet long and will be mounted in the curb of the road. The short segments make the panels easy and cheaper to replace if a panel were to be damaged. All the components in this design are chosen to maximize energy efficiency and safety.

The *system* works in a way that minimizes *energy* use, while making the roads a safer way to commute. To understand how the ILSL System operates, how it would react when a car is on the road must be analyzed. First, the infrared *sensor*s will detect whether a vehicle is on the road or not. If so, it will send a signal to the *system*'s computer, which in turn will light the upcoming 50 LED panels or 150 feet of road ahead of the vehicle. If the *sensor* does not detect a car, the lights will remain off. This avoids wasting *energy* on lighting up empty roads. As the vehicle travels, the panels behind it will shut off and the panels further ahead will light up. If there is a hazard on the road ahead, emergency responders may access the panel control *system* in order to change the color of the light emitted by the LEDs. They can emit yellow light to warn drivers to slow down or red to inform the drivers to pull over immediately.

The ILSL System's benefits are both safety and efficiency orientated. Regarding safety, the current street lighting *system* relays no information to the driver about hazards on the road. However, the proposed *system* will warn drivers of these potential hazards by emitting colored light. This can inform them to either slow down or stop. Although this *system* does improve upon the safety of the roads, its primary achievement is the improvement it makes on *energy* efficiency. By using LED lights rather than HPS lamps, we save 85% on *energy* consumption [4]. To add, we further improve on *energy* efficiency by turning the lights off when the road is not in use.

## 2.2 System Components

### 2.2.1 LED Lights

In order to illuminate the road, the Interactive LED Street Lighting System uses 120 LEDs. These are built into panels that can be easily replaced. Figure 2.3 illustrate what these panels will look like.

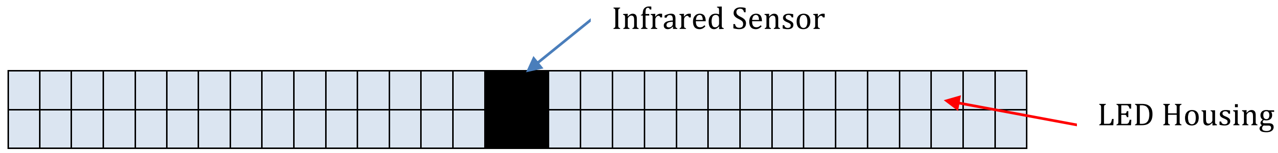


*Figure 2.3: Front view of LED panel with housing label*

On each panel there are 60 LED housings which are represented by the small blocks on the panel. Within each of these blocks there are two LEDs connected together in a specific way to produce the colours necessary. Please refer to section 3.2 for further detail on the connection of these LEDs. It is required from each LED panel to produce 3 colours. The top row of housings must produce white and yellow light while the bottom row must illuminate red and white. Each of these colors have a meaning. White will be used to light up the road ahead of the vehicle, yellow will be used to tell drivers to proceed cautiously as there may be a danger ahead, and red will ask the drivers to stop due to an emergency on the road. By using this tri-colored *LED system*, it is possible to produce a dynamic lighting alternative that is highly *energy* efficient and safe.

### 2.2.2 Infrared Sensor

One of the major advantages to the ILSL System is the unprecedented amount *energy* savings created by only illuminating the road ahead of the vehicles. This means that *energy* will not be wasted on lighting up empty roads. To detect the presence of the vehicles, the ILSL System uses infrared *sensor*s. The *sensor*s emit beams of *infrared light* that bounce off vehicles and back into the *sensor*s. For further detail about how this *system* works, please refer to section 3.1. Once the vehicle is detected, a set of *LED* panels will illuminate the road ahead of the vehicle. Eventually, when the vehicle has passed the *sensor*, the lights will turn off to save *energy*. As seen in figure 2.3, the *sensor*s will be placed at the center each *LED* panel. By using *LED*s and turning them off when they are not in use, cities will be able to save millions of dollars in *energy* costs. This is both beneficial to tax payers and to the environment.

### 2.2.3 System Algorithm

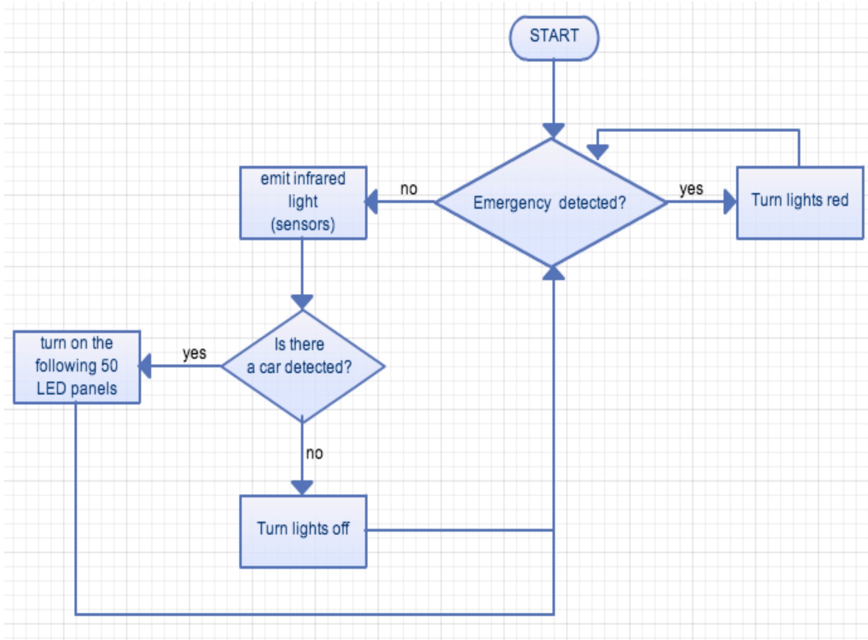


*Figure 2.4: The flow chart that represents the system's logic*

Since the Interactive LED Street Lighting System is a smart solution, it needs an algorithm that it can follow. Figure 2.4 illustrates the algorithm that the system will use. This is represented using a flow chart. One of the most important features of the ILSL System is its ability to inform drivers about emergencies ahead. This can be used by emergency services to slow or stop traffic before they reach a region where emergency crews are present. For this reason the system needs to first check if an emergency is detected. If there is an emergency, the red lights will illuminate. If not, the system uses the infrared sensors to detect the presence of vehicles on the road. If a vehicle is detected, 50 LED panels will light up ahead of the vehicle. If a vehicle is not detected then the lights will stay off. Using this algorithm, cities can transition away from the static system in use today.

### 2.2.4 Electro Permanents Magnets

Electro Permanent magnets are used in the design as a connector for the LED panel to the steel casing. Instead of using a metal clasp system that may need to be replaced after repeated use, a non-moving, electro permanent magnet system is used to couple the panel with the steel casing. This magnetic system uses minimal energy, and maintains a strong hold on the panels. Since attaching and detaching the panels only requires a pulse of electricity, the electro permanent magnets are extremely efficient. For more detail about these magnets please refer to section 3.4.

### 2.2.5 Wiring

The Interactive *LED* Street Lighting System will be wired in parallel to avoid having all the streetlights go out in the case of a single malfunction. Wiring in parallel ensures the safety of the drivers and is the standard for all street lighting *system*s today. In figure 2.5 you can see the basic layout of the wiring. The reason behind the reliability of this *system* is explained in section 3.3.

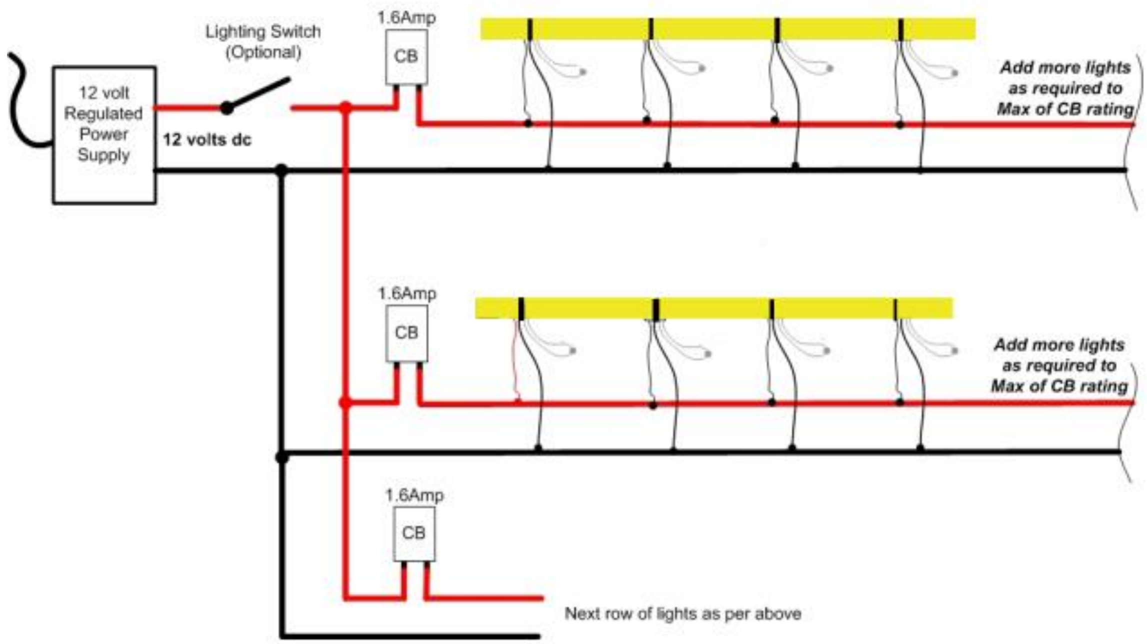


***Figure 2.5: Modified Street Light Wiring Diagram [5]***

### 2.2.6 Steel Casing

As previously mentioned, each three feet long section of the *system* will be mounted in the curb of the road in order to minimize the amount of *energy* wasted to light *pollution*. As a result of this, the *LED* lighting *system* is in danger of being damaged by many conditions. These conditions include vehicles making contact with the curb and weather conditions such as rain and temperature. To deal with these extreme conditions, the casing will be made of tool steel. Tool steel was chosen due to its exceptional tensile strength that allows it to withstand extreme forces without breaking, buckling, or distorting. The strength and durability of the steel casing is crucial as it is used to protect the *LED* panel, which contains both the *LED* lights and the infrared *sensor*. For detailed information on the design of the steel casing, please view section 3.6 and 3.8.

## 2.3 System Summary

Each component described in section 2.2 is important in the design of the ILSL System and is essential for it to operate at its optimal performance. In summary, the infrared *sensor*s will detect whether a vehicle is on the road or not. If a vehicle is present, the *system*'s computer will light the upcoming 50 *LED* panels or 150 feet of road. This will create an illuminated path in front of the vehicle. With this *system*, empty roads will not be lit up and thus *energy* will not be wasted. As the vehicle travels, the panels behind it will shut off and the panels further ahead will light up. For driver safety, the multi-coloured *LED*s can be accessed by emergency personnel to inform drivers of dangers ahead. With this *system*, yellow lights can warn drivers to slow down and red lights can ask drivers to pull over immediately. Together, the components make a dynamic, safe, and environmentally responsible lighting system.

# 3 Feature Description

## 3.1 Electromagnetic waves [Seyed-Ali Nouri]

### 3.1.1 Problem Statement

By only illuminating the road ahead of the car, the Interactive *LED* Lighting System can prevent cities from wasting *energy* on lighting up empty roads. To be able to do this, a device is needed to detect the presence of vehicles on the road.

### 3.1.2 Solution

Infrared *sensor*s are the ideal solution to this problem. These *sensors* emit a segment of the electromagnetic field called *Infrared light*. The vehicle is detected when the emitted waves reflect off a vehicle and bounces back into the *sensor*.

### 3.1.3 Science Behind Solution

To better understand how these *sensor*s work, *electromagnetic waves* need to be discussed. *Electromagnetic waves* are everywhere. Visible light that is detected by the human eye is a small category of *electromagnetic waves* [6]. With this in mind, most electromagnetic waves cannot be detected by the human eye. These waves are composed of electric fields and magnetic fields traveling perpendicular to each other [7] as seen in figure 3.1.

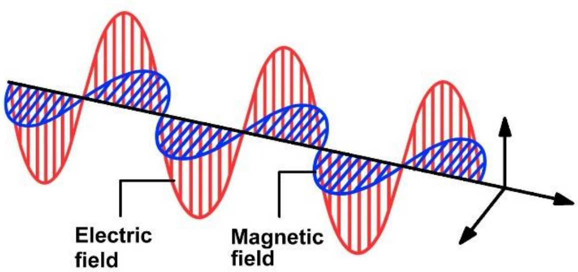


*Figure 3.1: Electromagnetic waves [7]*

*Electromagnetic waves* carry *energy* that can be very useful in many applications. For instance radios, microwaves, and infrared *sensor*s all use these waves to accomplish tasks such as emitting data [8]. It is important to choose the appropriate type of *electromagnetic wave* in order to create a safe but effective device. The electromagnetic spectrum is used to organize the different types of *electromagnetic waves*.

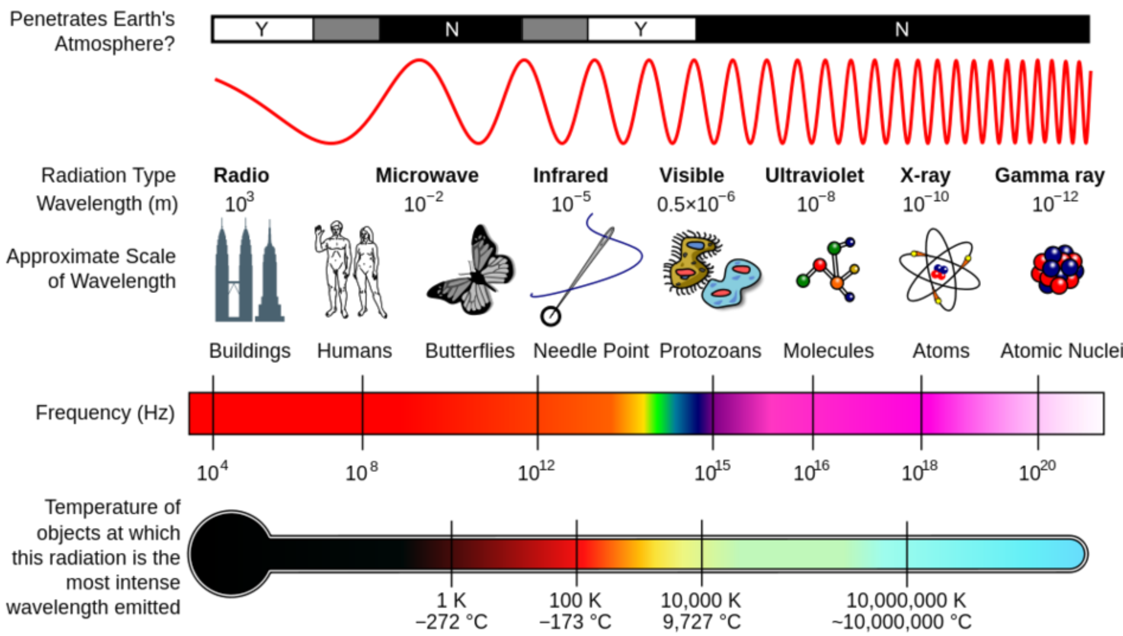


*Figure 3.2: Electromagnetic Spectrum [6]*

Figure 3.2 illustrates the organization of the electromagnetic wave spectrum. This scale is organized using the *wavelength* of these *energy* waves. The *wavelength*s determine the amount of *energy* that the waves carry [6]. In general, more *energy* is carried by shorter *wavelength*s. For example, gamma rays with *wavelength*s the size of a single atom, have very high *energy* levels and are thus harmful to humans [6]. Exposure to this type of *electromagnetic wave* can actually cause cancer and even death. On the other hand, radio waves, the size of the Empire State Building [9], carry very little *energy*.

The *sensor*s in the proposed *system* will be using infrared waves. These rays are perfect for the application of detection. With a *wavelength* the size of a needle point [8], they carry harmless amounts of *energy* and are invisible to the human eye [10]. This allows for *sensor*s that are invisible to the drivers and are safe for public use [5]. Like all other *electromagnetic waves*, *infrared light* travels at the speed of light ($3x10^8$m/s) [12]. This makes it possible for the *system* to detect the vehicles without any noticeable delay. The following calculations illustrate the time that it will take for the beam of *infrared light* to be emitted and reflected into the *sensor*. In this case the vehicle will be 2 lanes (7.2m [13] ) away from the curb.

| | | |
|---|---|---|
| [12] | $Time = \frac{Distance}{Speed}$ | Eq. 3.1 |
| | The time it would take is the result of the distance divided by the speed | |
| | $Time = \frac{2 * 7.2\,m}{3 * 10^8 m/s}$ | Eq. 3.2 |
| | The total distance is the distance to the vehicle and back. (2*7.2 m). The speed is ($3*10^8$ m/s) | |
| | $Time = 4.8 * 10^{-8} s$ | Eq. 3.3 |
| | This is the time it would take for the light to travel to the vehicle and be reflected back. | |

As the result of the calculation shows, the car would be detected quickly. This will prevent any delay between the presence of the car and the switching on of the lights.

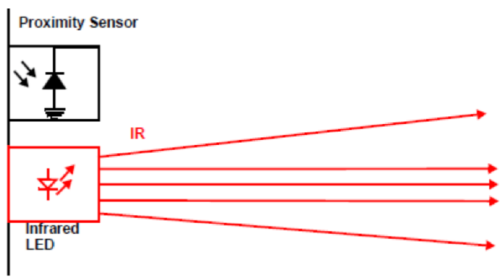


***Figure 3.3: No object detected by sensor [9]***

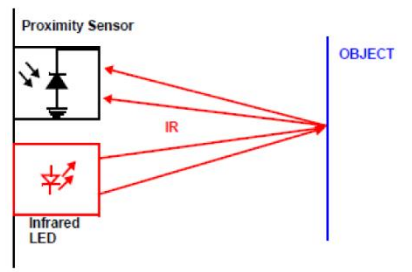


***Figure 3.4: Object reflecting the Infrared rays back into the sensor [9]***

The principle behind the infrared *sensor*s in the *LED* panels is very simple. As seen in figure 3.3, the *sensor* will have an infrared *LED* to emit the rays and a *sensor* to receive them [9]. The infrared *LED*s will emit infrared rays towards the road as seen in figure 3.3. Once a vehicle passes in front of the *sensor*, the infrared beams will reflect back into a receiver (figure 3.4). This will in turn notify the *system* about the presence of the vehicle.

The infrared *sensor*s will sit in the middle of each *LED* panel. When a car is detected, the *system* will illuminate the road ahead of the car and will turn off the *LED* panels behind it. This will allow for greater *energy* savings.

## 3.2 Electrical Conductance [Seyed-Ali Nouri]

### 3.2.1 Problem Statement

In order to relay information to the drivers, the Interactive *LED* Street Lighting System needs to produce 3 colours. White will illuminate the road, yellow will caution the drivers, and red will inform them to stop immediately due to a danger ahead. Unfortunately, *LED*s can only produce one colour due to the way they are built [15]. A solution was needed to produce 3 colours using current *LED* technology. In the proposed *system*, the top row of the *LED* panel will illuminate as white or yellow and the bottom row will illuminate as white or red.

### 3.2.2 Solution

Using the electrical properties of *LED*s it is possible to place two of them in parallel but in opposite directions. This would allow the user to choose what colour to illuminate by changing the direction of the *current*.

### 3.2.3 Science Behind Solution

Electrical conductance describes how easily electricity flows through a material [14]. Its units are known as siemens [14]. Conductance has an inverse relationship with resistance, as seen in equation 4.

| [19] | $G = \frac{1}{R}$ | Eq. 3.4 |
|---|---|---|
| G represents conductance and R represents resistance [19] | | |

This means that objects with high resistance have low conductance. To better understand these properties, figure 3.5 needs to be analysed.

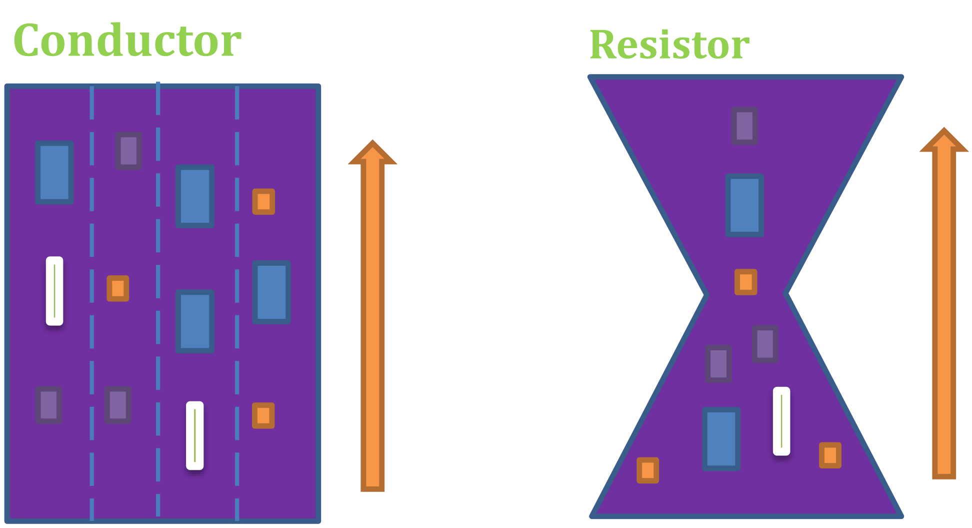


*Figure 3.5: conductors vs. resistors.*

Objects that have good conductance allow *electrons* to flow through them easily. These are similar to four lane highways that allow traffic to flow smoothly as seen in figure 3.5. *Resistors*, on the other hand, don't allow *electrons* to flow easily. They are like a four lane highway suddenly becoming one lane. This slows down traffic dramatically. The following calculations can be used to compare the conductance values of a *resistor* and a *conductor*. In this case the *conductor* will be a copper wire with a resistance of 1.7 × $10^{-8}$ Ω [16]. The *resistor* will have a resistance of 100 Ω.

| **Copper (conductor)** | |
|---|---|
| $G = \frac{1}{R}$ | Eq. 3.5 |
| The general equation for conductance. G is conductance and R is resistance | |
| $G = \frac{1}{1.7 \times 10^{-8}}$ | Eq. 3.6 |
| The copper wire has a resistance of 1.7 × 10-8 Ω | |
| $G = 5.9 * 10^{7}$ | Eq. 3.7 |
| It is evident that the conductance value of a 1m long copper wire is very high. This shows that copper will allow electricity to flow through itself easily. | |

| **Resistor (100 Ω)** | |
|---|---|
| $G = \frac{1}{R}$ | Eq. 3.8 |
| This is the general equation for conductance. G is conductance and R is resistance | |
| $G = \frac{1}{100}$ | Eq. 3.9 |
| The resistor has a resistance of 100 Ω | |
| $G = 5.9 * 10^{7}$ | Eq. 3.10 |
| It is evident that the conductance value of a 100 W resistor is very low. For this reason resistors don't allow electricity to flow through them easily. | |

Unlike most objects, *LED*s can have both these properties at the same time. As seen in figure 3.6, *LED*s have two ends. From the top they are perfect *resistor*s and from the bottom they are *conductors*. Using the highway analogy once again, it can be said that if the vehicles were entering from the top, they would hit a road block. On the other hand, they would be able to drive through from the bottom. This property makes it possible to produce two colour from the same LED housing.

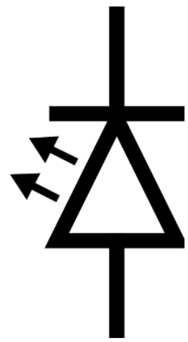

*Figure 3.6: The electrical symbol of an LED*

The colour that an LED produces is depended on the material that it is built with [15]. For this reason they can only produce one colour at a time. A solution to this problem is placing two LEDs in the same housing. This would have to be done by placing them in parallel but opposite directions as seen in figure 3.7 and figure 3.8.

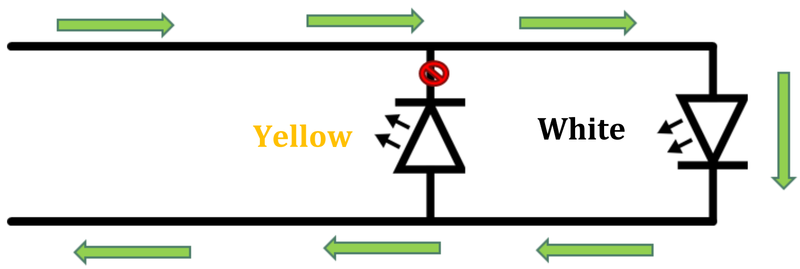


*Figure 3.7: Turning on the white LED*

Using this set up, when the current is run in the clockwise direction, the white LED acts as a conductor and allows the electrons through. In turn the white LED will turn on. To turn on the yellow LED, the current would then have to be run in the counter-clockwise direction as seen in figure 3.8. This will make the yellow LED a conductor, and the white LED a resistor.

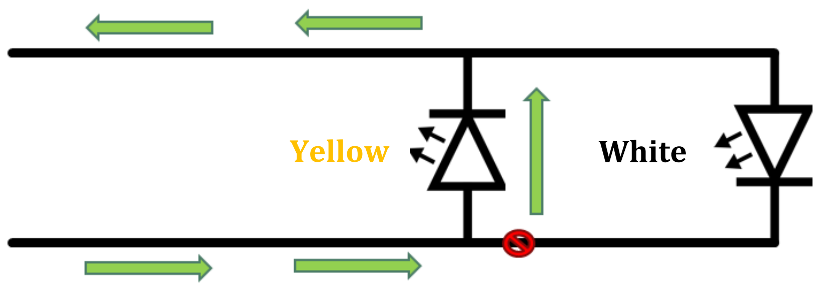


*Figure 3.8: turning on the yellow LED*

By using the resistivity and conductivity of the *LED*s it becomes possible to produce two different colours from each *LED* housing. By implementing this arrangement, the Interactive *LED* Street Lighting System will be able to produce white, yellow, and red light. Choosing the colours of light to produce would then be as easy as changing the direction of the *current* in each row of the *LED* panel. Figures 3.9-3.11 illustrate the different possibilities of lighting using this arrangement of *LED*s.

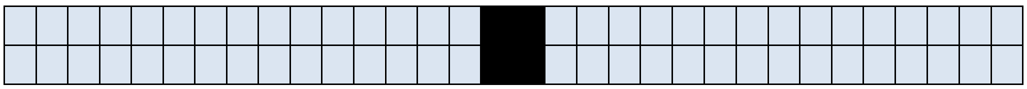

***Figure 3.9: White LEDs used to illuminate the road***

***Figure 3.10: Yellow LEDs used to caution drivers about dangers ahead***

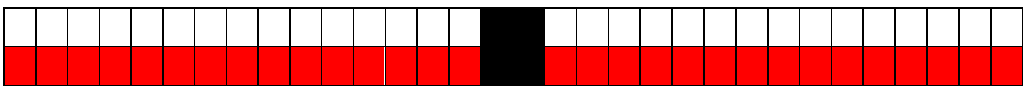

***Figure 3.11: Red LEDs used to tell drivers to stop due to a danger ahead***

Conductivity is an important property when dealing with electrical components. Opposite to common belief, low conductivity (resistance) is not always an annoyance. It can sometime prove to be helpful as it does when trying to implement dual coloured *LED*s in the proposed design.

In conclusion, the proposed panel will have 60 housings (each small block in figure 3.9) to enclose the 120 coloured *LED*s. In each housing there will be two *LED*s connected in parallel, but in opposite directions. This will allow the *system* to choose which colour to illuminate by changing the direction of the *current*.

## 3.3 Kirchhoff's Law [Arthur Daniel]

### 3.3.1 Problem Statement

In order to ensure that the Interactive *LED* Street Lighting System is safe and reliable, wiring and connectivity are important factors in the final design. Considering that all the panels in this *system* are linked through one mainframe, there is a challenge wiring each panel. If the *system* is wired poorly, a single issue with one of the panels could knock out the whole lighting *system*, creating a major hazard for drivers. This can be likened to older Christmas tree lights; if one bulb is removed, the whole string of lights is useless and you are stuck searching for the burnt bulb.

### 3.3.2 Solution

The street lighting *system* consists of multiple *LED* panels that are linked electrically and managed at one local control center. The control center can independently control any of the thousands of individual panels and check for any problems in the *system*. This mainframe is where colour changing emergency vehicle signals will be sent.

A solution to this issue is to connect the *LED*s in a way that allows each panel independent *voltage* from the main control center. This is achieved by wiring in parallel. Parallel wiring involves connecting each panel into its own circuit loop meaning that if one of the panels stops working, the others are unaffected.

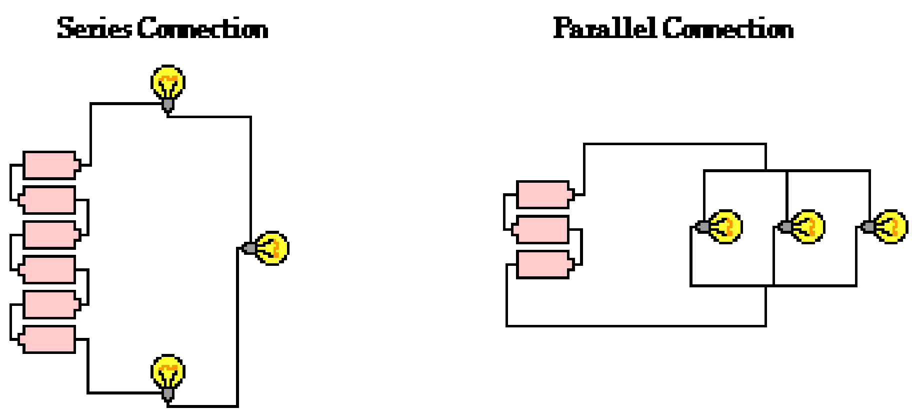


*Figure 3.12: Comparing Series and Parallel Wiring [17]*

### 3.3.3 Science Behind Solution

This independence of light panels can be achieved because of Kirchhoff's two circuit laws, the *voltage* and current laws. The current law states that charge in a circuit is conserved, and can also be stated that *current* entering a node will be equal to *current* exiting a node. Thus, in a parallel circuit the *current* is evenly distributed amongst the panels, and if one of the panels burns out the charge will be redistributed without all of the panels loosing charge. Kirchhoff's voltage loop rule states that in a closed circuit loop, like the one in parallel circuits, the sum of the potential differences is zero. Put more simply, the *voltage* gained in a loop is always equal to *voltage* dropped. This means that the *voltage* from the power source will be equivalent to each of the *LED* circuits allowing any to be damaged without disrupting the other panels.

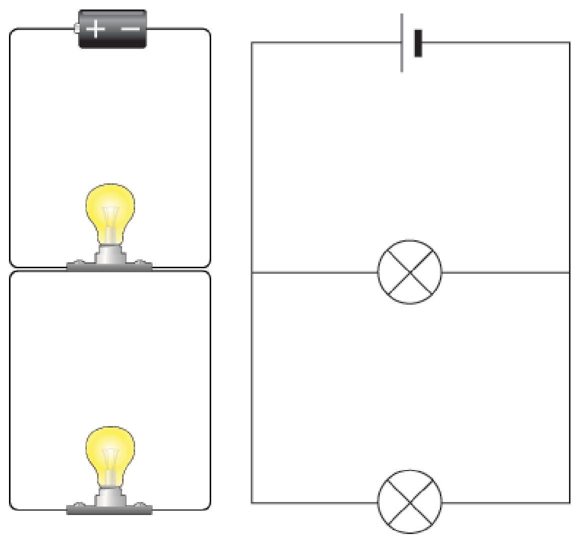


*Figure 3.13: Parallel Circuit Example [18]*

*Voltage* across each *LED* will remain the same regardless of any other light in the circuit:

| | | |
|---|---|---|
| [20] | $V_{power\ supply} = V_n$ | Eq. 3.11 |
| [20] | $V_{power\ supply} = V_{n-1}$ | Eq. 3.12 |
| | thus | |
| | $V_n = V_{n-1} = V_{power\ supply}$ | Eq. 3.13 |

Therefore, if a panel breaks down, the potential difference across each panel will remain the same. This means that the function of the other light will not be disrupted.

## 3.4 Electro-Permanent Magnetism [Arthur Daniel]

### 3.4.1 Problem Statement

The Interactive *LED* Street Lighting System consists of an *LED* panel attached to a steel casing that is integrated into roadside curbs. A challenge when designing the casing and panel, was to find a simple way to attach the panel to the casing. Understanding that the panels are near the road, there is a greater chance for damage to occur. It was assumed that *LED* panels would receive damage and could be broken, so replacement will need to be easy. The initial plan of using a mechanical latching *system* was rejected because moving metal parts are also subject to defect and damage so additional costs will be added just for replacing latches.

### 3.4.2 Solution

In order to make the replacement process as simple as possible, electro permanent magnets are used to hold the panels in the casing. The *magnets* are extremely strong and are used in many industrial applications such as scrap yard sorting and mag-crane lifts. Another convenient feature of an electro permanent magnet coupling *system* is that the locking mechanism requires no moving mechanical parts, increasing longevity, reliability and saving money in the long run. The *magnets* will be located on the back of the panels, and on the metal casings, and create an active *current* when the two conductive surfaces meet.

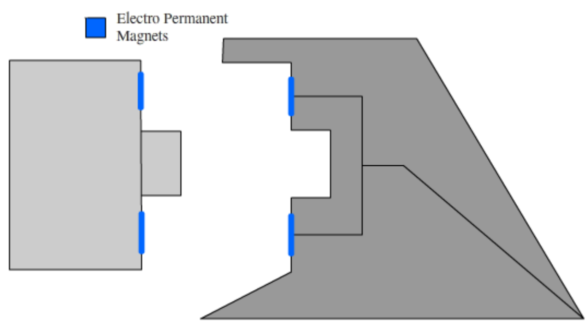


*Figure 3.14: Electro Permanent Magnet Coupling System*

### 3.4.3 Science Behind Solution

Electro permanent magnets consist of two separate *magnets*. The first is a dual material permanent magnet. Permanent *magnets* are made from ferromagnetic minerals found in nature, such as iron nickel and cobalt. These metals are electrically manipulated to align the *electrons* and create a magnetic north and south. The dual material magnet has a middle section that is made of a magnetically "soft" ferromagnetic metal that can be separately manipulated by a magnetic field to change its polarity.

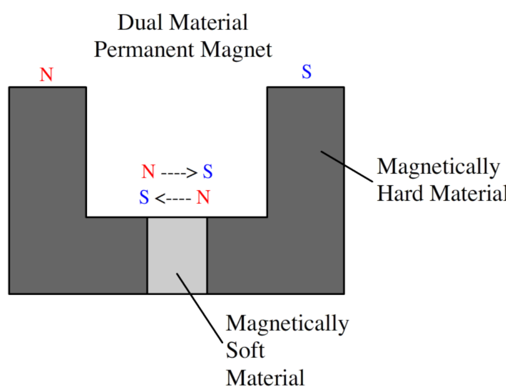


Figure 3.15: Dual Material Permanent Magnet

The second type of magnet is an electro magnet. An electro magnet produces an electric field when a *current* flows through a wire wrapped around a *conductor*. This type of magnet only produces a magnetic field with a flow of electricity, so this will act as the on off switch for the electro magnet coupling *system*.

There are two states that the electro permanent magnet can be in, on or off. The off state is achieved by sending a pulse of *current* through the electro magnet such that it will change the polarity of the magnetically soft section of the dual magnet opposite to the rest of the permanent magnet, breaking the magnetic loop and making the net magnetic force zero. The on state is achieved when the *current* travels in the opposite direction through the electro magnet, switching the polarity of the magnetically soft section of the permanent magnet back in line with the rest of the magnet completing the magnetic loop, creating a strong magnetic force. The electro permanent magnet saves *energy* because it only needs a single pulse of electricity to change the state of the magnet, it does not need a constant electric *current* running through it.

The holding force of the electro permanent magnet *system* must be strong enough to firmly hold the 2.5 kg panel in the steel casing and resist vandals from stealing them. This holding force can be calculated using the following formula:

| | | |
|---|---|---|
| [22] | $F = \frac{B^2_{saturated}ab}{\mu_0}$ | Eq. 3.14 |

Where $B_{saturated}$ is the magnetic field at its maximum strength after the electric pulse is delivered to the electro magnet. Also, $a$ is the length of the permanent magnet arm, and $b$ is the width – these dimensions give the cross sectional area of the permanent magnet. Finally, $\mu_0$ is the magnetic permeability constant with a value of:

| | | |
|---|---|---|
| [22] | $\mu_0 = 4\pi * 10^{-7}\ T \cdot m/A$ | Eq. 3.15 |

Magnetic permeability is the measure of a materials ability to hold a magnetic field within itself.

| **From Sample data [22]** | | | |
|---|---|---|---|
| $B = 1.26\,T$ | $a = 0.05\,m$ | $b = 0.02m$ | $\mu_0 = 4\pi * 10^{-7}\ T \cdot m/A$ |
| [22] | $\boldsymbol{F} = \frac{B^2_{saturated}ab}{\mu_0}$ | | Eq. 3.16 |
| | $\boldsymbol{F} = \frac{(1.26^2)(0.05\,m)(0.02\,m)}{4\pi * 10^{-7}\ T \cdot m/A}$ | | Eq. 3.17 |
| | $\boldsymbol{F} = 1263.4\text{N}$ | | Eq. 3.18 |

To better understand this number, 1200 N of force can hold about 122 Kg [23] of weight.

To make ILSL system an economical and practical investment, the design needed to incorporate an effective, and cheap light panel replacement *system*. The ILSL System magnetic coupling *system* maximizes efficiency and minimizes repair costs with its easy removal, replacement, and minimization of moving mechanical parts. Electro permanent magnets are an integral part of the final design contributing to the *system*s efficiency and reducing costs.

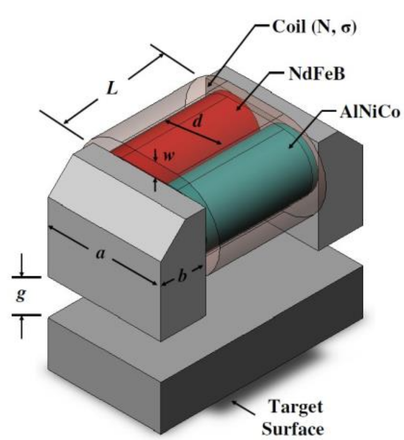


*Figure 3.16: Electro Permanent Magnet [19]*

## 3.5 Snell's Law [Ryan Toonders]

### 3.5.1 Problem Statement

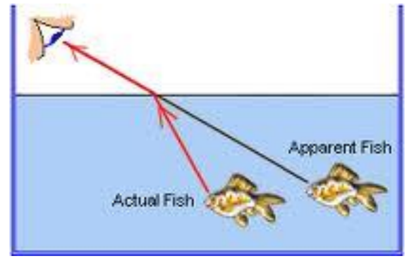


*Figure 3.17: Example of light refraction [29].*

When light travels through two or more *mediums*, the light waves refract, meaning its path deviates from its original direction. A common example of the refraction of light is when light travels from the air and into water. Changing from air to water causes the light to partially deflect which causes problems when trying to catch fish with a spear. The refraction of light is an issue with the proposed *system*, because the light emitted by the *LED* lights travels through two *mediums*: the Plexiglas sheet that shields the lights and then travels through the air. If the light gets refracted it might not illuminate the desired area.

### 3.5.2 Solution

The solution to this problem is to use very precise machinery to fabricate the Plexiglas shield for the *LED* panels. It is important that the Plexiglas sheet has an even thickness throughout each piece. If the Plexiglas is flush with the panel the light will not refract and the desired area of the road will be illuminated, but with a slight deformation in the glass, the light with refract.

### 3.5.3 Science Behind Solution

Snell's law is also known as the law of refraction. Light is only refracted when it travels through two or more *mediums*. Once a light wave changes *mediums* the wave will deviate from its path. How much the wave will deviate depends on two factors: the indices of refraction of the *mediums* and the angle at which the wave enters the next medium. The refractive index is a property of matter just like color or density is and the more the medium is dense, the higher the refraction index will be [28]. This concept is proven by Snell's equation:

| | | |
|---|---|---|
| [25, pp.5] | $n_i * \sin(\theta_i) = n_r * \sin(\theta_r)$ | Eq. 3.19 |

Where n represents the indices of refraction of the media, $\theta$ represent the *angle of incidence* (i) or *refraction* (r).

| **Example:** | | |
|---|---|---|
| Light travels from the air and enters the water at an angle of 55°, Snell's equation will be used to calculate the angle of refraction. | | |
| $n_{air} = 1.00$ | $n_{water} = 1.33$ | $\theta_i = 55°$ |
| $n_{air} * \sin(\theta_i) = n_{water} * \sin(\theta_r)$ | | Eq. 3.20 |
| $1.00 * \sin(55) = 1.33 * \sin(\theta_r)$ | | Eq. 3.21 |
| $\theta_r = 38°$ | | Eq. 3.22 |

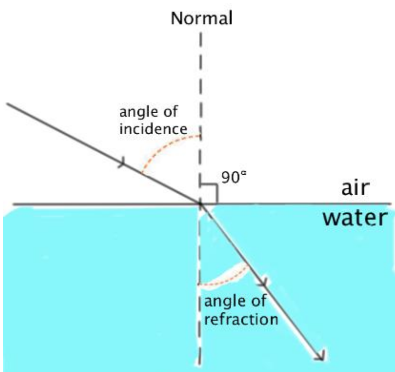


***Figure 3.18: Refraction of light travelling through air and water.***

Now that the concept of Snell's law is understood, the application of Snell's equation in the *LED* panels needs to be discussed.

As previously stated, the light emitted travels through two *mediums*: the Plexiglas sheet and through air. To optimize the propagation of the light emitted by the *LED* lights and to reduce lighting unwanted areas, the *angle of refraction* must be equal to zero ($\theta_r = 0$).

| **Proof Of Theory:** | |
|---|---|
| With $\theta_r = 0$, | |
| $n_{Plexi} * \sin(\theta_i) = n_{air} * \sin(0)$ | Eq. 3.23 |
| $\sin(\theta_i) = 0$ | Eq. 3.24 |
| $\theta_i = \sin^{-1}(0)$ | Eq. 3.25 |
| $\theta_i = 90°$ | Eq. 3.26 |

This formula manipulation states that in order to avoid the refraction of light, the light must change *mediums* at a perfect 90° angle. This proves the need for the Plexiglas to be perfectly parallel with the *LED* panel.

## 3.6 Newton's 2nd Law [Ryan Toonders]

### 3.6.1 Problem Statement

A common problem that relates to all kinds of lighting devices is the possibility of an accumulation of dirt that would cause the light emitted by those lights to be blocked. In consequence, the lighting efficiency of the lights would diminish. As a result of being mounted on the ground and into the curb of the road, the *system*'s *LED* panels are at risk of being affected by dirt or garbage. In figure 3.19, it is shown where the accumulation of dirt or garbage would affect the lights.

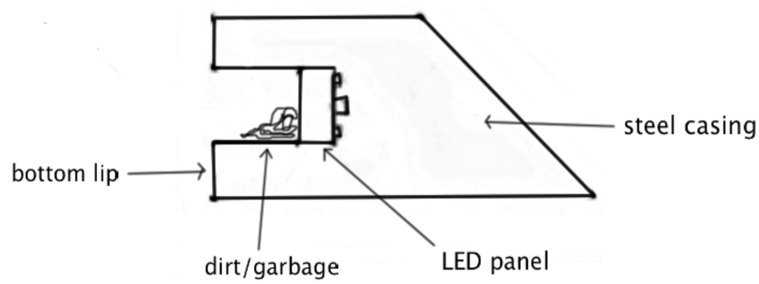


*Figure 3.19: Cross section view of system without slope.*

### 3.6.2 Solution

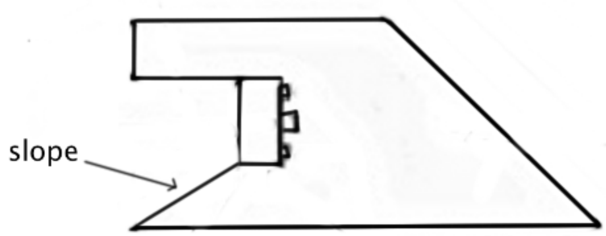


*Figure 3.20: Cross section view of system with slope.*

Due to the accumulation of matter on and in front of the *LED* panel, the structural design of the steel casing that holds the panels needed to be modified. The solution to the issue was to have a slope on the bottom lip of the steel casing (Figure 3.20) rather than having it level with the ground (Figure 3.19). The lip will now be sloped downwards towards the road.

### 3.6.3 Science Behind Solution

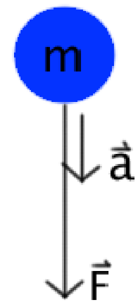


*Figure 3.21: Elements of Newton's 2nd law.*

Newton's 2nd law of motion needed to be taken in consideration when deciding to alter the physical shape of the casing. Let's first understand the basics of Newton's 2nd law.

Newton's 2nd law relates to forces applied on an object created by an *acceleration* that acts on its particular mass. This principle is best known for the following equation.

| | | |
|---|---|---|
| [24, pp. 1] | $F = m * a$ | Eq. 3.27 |
| Where **F** is the force, **m** is the mass and **a** is the acceleration. | | |

A common application for Newton's 2nd law is gravity. A gravitational force acts on every object that has a mass. The force is created by the gravitational *acceleration* that is present on earth, which is known to be $9.81m/s^2$ [25, pp .1]. This force is what causes people to get pulled back down towards the ground after a jump.

| **Case Study** | | |
|---|---|---|
| Analysis of the force that acts on a person with a mass of 75kg: | | |
| $m = 75kg$ | $a = 9.81m/s^2$ | $F = ?$ |
| $F = m * a$ | | Eq. 3.28 |
| $F = 75kg * 9.81m/s^2$ | | Eq. 3.29 |
| $F = 735.75\ N$ | | Eq. 3.30 |
| With the gravitational acceleration of $9.81m/s^2$ and the mass of 75kg, a force of 735.75N will act on the body. | | |

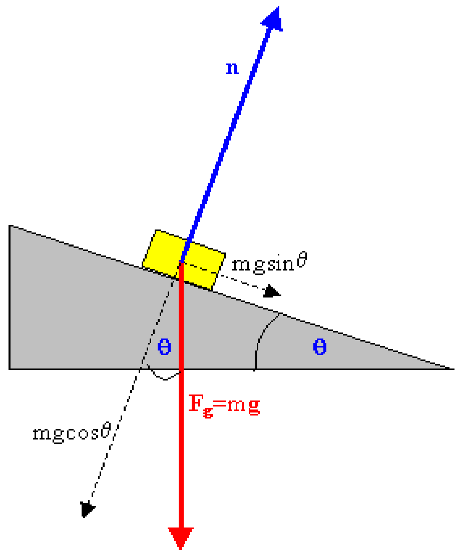

*Figure 3.22: Gravitational force on a sloped surface.* *[26]*

Since the bottom lip of the *LED* panel is slanted, the gravitational *acceleration* that exists on Earth creates a force on the dirt, garbage or water that might be obstructing the light emitted by the *LED* lights. This force pulls the matter away from the *LED* panel and down onto the road. A diagram of gravitational force applied on a sloped surface can be found in figure 3.22. If the bottom lip were not slanted, unwanted matter would accumulate and obstruct the light's path. Although the sloped casing helps clear matter away, there is another aspect to consider. In the future, it is important to study the friction coefficient of steel. The friction coefficient of a material determines how much force is caused by friction between two materials. This is important to take in account, because it would be used to calculate the ideal angle of the slope and optimize its effectiveness.

## 3.7 Light Dispersion [Atif Siddiqui]

### 3.7.1 Problem Statement

The problem with the current street lighting situation, the High Pressure Sodium lamp is that they have very low efficiency. What that translates into is a) they cost more as compared to the proposed *LED* alternative, and b) they are bad for the environment. The efficiency is visible via the light *pollution* of the High Pressure Sodium lamp. The U.S. Department of Energy (Energy Efficiency and Renewable Energy) reported that, as much 30% [30] of the light produced from High Pressure Sodium lamps is lost to *pollution*.

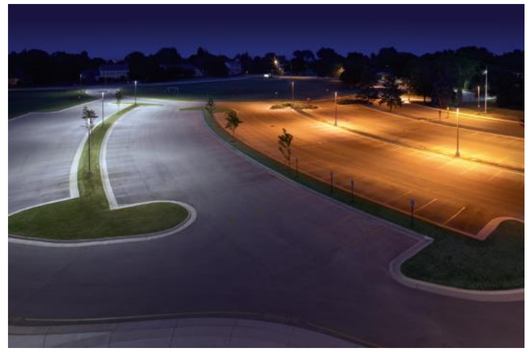

***Figure 3.23 LED vs. HPS lights [33]***

### 3.7.2 Solution

The Interactive LED Street Lighting System feature *LED*s attached to a steel casing. These *LED*s have a distinct advantage over their High Pressure Sodium lamp counterparts; they feature a 100% downward luminaire vs. 70% - 81%. What this means is less light is lost to *pollution*, and translates to a lower cost overall.

### 3.7.3 Science Behind Solution

Light Dispersion occurs when different *wavelengths* of light take different paths through any sort of medium, resulting in the light being split. While light *pollution* is relatively subjective from person to person, we can apply simple models to the phenomenon.

$$B = a\sqrt{p} \cdot \left(\frac{U}{D^2 + h^2} + \frac{V}{\sqrt{D^2 + h^2}}\right) \cdot e^{(-k \cdot \sqrt{D^2+h^2})} \qquad \text{Eq.3.31}$$

Where B is the sky brightness, a is a proportionality constant, p is the city's population, h is the effective height of scattering, D is the distance from the observation point to the city, k is the absorption coefficient of the atmosphere, and U and V are empirical parameters. Although complicated, what this yields is a unit of Stars per Square Degrees, the quantitative means to determine light *pollution* relative to a city.

## 3.8 Stress [Atif Siddiqui]

### 3.8.1 Problem Statement

For the Interactive *LED* Street Lighting System, *LED*s will be laid into strips of steel and placed alongside roadways. Because of this, exploring the tensile strength of various grades of steel is paramount to the success of the ILSL System. Environmental factors, vehicles on the road, construction equipment are all examples of factors that could come into contact with the proposed *system* and its steel-based components. Using the incorrect grade of steel could make the *system* unsafe and/or unreliable, and conversely using a higher (stronger) but expensive grade of steel could render the design inefficient and impractical for cities.

### 3.8.2 Solution

The tensile strength of a material is the maximum amount of *stress* that it can take before breaking, or being warped beyond functionality. Tensional *stress* is when the object, in this case the steel component, is stretched outwards. Compressional *stress* is when the steel component would be pushed inwards, such as another vehicle making contact with the component. Finally, shear *stress* is when an object would scrape by the component; weather for example could cause shear *stress* to the component. As mentioned above, exploring the tensile strength of various grades of steel will determine which can handle the most *stress* within an affordable context. Amongst the four types of steels, Carbon, Alloy, Stainless, and Tool; Tool Steels had the highest tensile strength (640 MPa – 2000 MPa [31]). Since tool steels are widely used within the construction industry, it is affordable and maintains the same manufacturing conditions required for public safety.

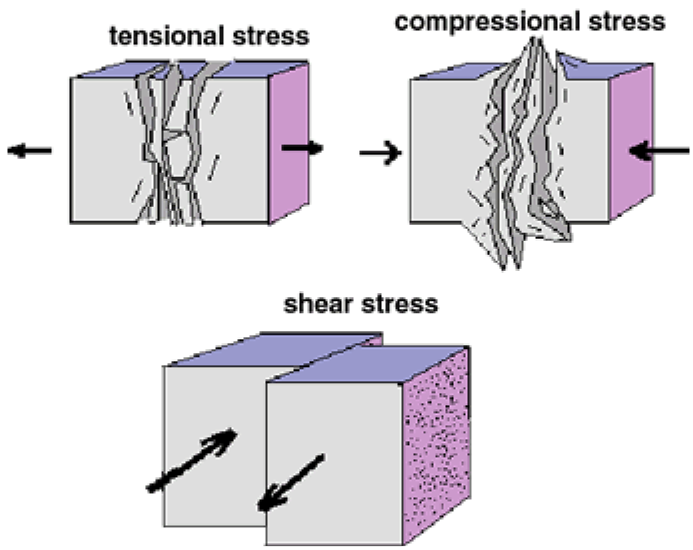


*Figure 3.24: Tensile strength [34]*

### 3.8.3 Science Behind Solution

*Stress* is the force per unit area on an object that causes it to change shape. *Stress* is similar to pressure in that it uses the same unit (Pascal – *Pa*), but it is pressure applied with specific direction.

| | |
|---|---|
| $Stress = \frac{Force}{Area}$ | Eq.3.32 |
| $Pa = \frac{N}{m^2}$ | Eq.3.33 |

**Example:**

A 1500kg car is dropped on a small area of Tool Steel (10 cm x 10 cm). (We assume the entire weight of the car is dropped on the block of steel).

| | |
|---|---|
| $F = ma$ | Eq. 3.34 |
| $F_{car} = (1500\ kg) \cdot \left(9.81 \frac{m}{s^2}\right)$ | Eq. 3.35 |
| $F_{car} = 14715\ N$ | Eq. 3.36 |
| $Stress = \frac{F_{car}}{Area_{block}}$ | Eq. 3.37 |
| $Stress = \frac{14715\ N}{(0.10\ m\ \times\ 0.10\ m)}$ | Eq. 3.38 |
| $Stress = 14715000\ Pa$ | Eq. 3.39 |

Therefore, we can conclude that since the downward *stress* of 14.7 MPa is less than 640 MPa (lower range for tensile strength of Tool Steel) the proposed component will be able to support the weight of an average vehicle[1] (assuming 100% of its force is directed through a contact patch of 10 cm x 10 cm).

# 4 Conclusion

With the exponential growth of technology in the modern world, it is surprising that street lighting *systems* have not changed in decades. With the use of some widely available and inexpensive technologies, the Interactive LED Street Lighting System changes the current static *system* into a safer, dynamic lighting solution.

Much of the design process was spent focusing on making the *system* as efficient and economical as possible. Making use of *LED* panels increases efficiency and reduces light *pollution*, and integrating the lights into curbs further reduces light *pollution*. By using electro permanent magnets to attach the *LED* panels, long-term costs are reduced since no mechanical fasteners will need to be replaced. The infrared *sensors* on each panel are highly efficient and will tell the *system* which lights need to be turned on, allowing for all the other lights to remain off.

In addition to being efficient, the Interactive LED Street Lighting System is designed to improve safety. Using the multi-coloured *LEDs*, the ILSL System can alert drivers of potential hazards prior to approaching the danger. The *system* will also tell drivers when emergency vehicles are in their vicinity.

In the future, team P7 hopes to see a revolution in street lighting. Having *LED* panels with smart interactive technologies in every city and country is the only solution. The ILSL System plans to target other markets with different needs. For instance, in the future team P7 is looking towards implementing the *LED* panels in street light posts in order to deal with winter road conditions and to illuminate sidewalks for residential areas.

The Interactive LED Street Lighting team hopes that this technical report demonstrates the wealth of opportunity involved with having this lighting *system* in your township or city. The team believes that the future of the Interactive LED Street Lighting System is bright, and is happy to address any questions or concerns you may have. Feel free to contact the members of team P7 for any clarifications.

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## Glossary

| | |
|---|---|
| **Acceleration** | The change of velocity (speed) over time [35] |
| **Angle of Incidence** | The angle between the normal (line perpendicular to the surface) and the ray of light. [36] |
| **Angle of Refraction** | The angle between the normal (line perpendicular to the surface) and the refracted ray of light. [37] |
| **Conductor** | Any material that does allow electrons to flow through it. [38] |
| **Current** | The rate of charge flow through a specific point in a circuit. Its units are Coulomb per Second. [39] |
| **Electromagnetic Waves** | Electrical Field and Magnetic Field traveling at a right angle (90 degrees) to each other. [7] |
| **Electrons** | Basic unit of electric charge. It is also the smallest subatomic particle. [40] |
| **Energy** | In physics it is defined as the capacity to do work. [41] |
| **Flow chart** | An illustrations that allows the reader to follow logic step by step. [42] |
| **Frequency** | The number of waves that pass through a point over a period of time. Its unit is Hertz. [43] |
| **Infrared Light** | A specific type of Electromagnetic Wave that is just below visible light on the electromagnetic spectrum. [6] |
| **LED** | Short form for Light Emitting Diode. It is used as an efficient light source in many electronic devices. [44] |
| **Magnets** | Materials that can attract iron [45] |
| **Medium** | Something that has the means of carrying something. Air is an example of a medium. [46] |
| **Pollution** | Adding anything to the environment. This can includes, gas, heat, and even light. [47] |
| **Resistor** | Any material that doesn't allow electrons to flow through it easily [38] |
| **Sensor** | An electronic device that measures physical properties such as heat and pressure. [48] |
| **Stress** | It is the force applies to a unit of area. [49] |
| **System** | A group of components working together to accomplish a task. [50] |
| **Voltage** | It is the electrical potential difference. It is the reason that electrons flow through a circuit. [51] |
| **Wavelength** | The distance between two corresponding point in a wave. It can determine how much energy the wave carries. [52] |