Proximity-Based Hazard Detection for Older Vehicles

Group Seven

Members

Sebastien St Hilaire — EE

Patrik Regan — CPE

Michael Nelson — EE

Jonathan Joslin — CPE

Allison Oehmann — PSE

Reviewer Committee

Dr. Mike Borowczak ECE Associate Professor

Professor Mark Maddox ECE Adjunct Professor

Professor Darren Hudson CREOL Associate Professor

Mentors:

Dr. Lei Wei

Dr. Aravinda Kar

Chapter 1: Executive Summary

Under development.

Chapter 2: Project Description

This section outlines the group's motivation for the creation of this project, as well as the goals and objectives. Then the specifications and features as well as a comparison of this project to other products on the market is provided.

2.1 Motivation / Background:

With over 40,000 fatalities due to traffic accidents in just the year 2023 alone ([2] National Highway Traffic Safety Administration), the United States has a serious and often ignored or dismissed issue affecting countless families. The loss of a loved one from a tragic car crash may have been avoided if both parties had the most recent safety technology. But the potential life-saving technologies are kept out of reach of the average consumer because of the expensive cost. These technologies are a massive step up in safety for the average consumer and driver. They offer a serious change in the disturbing and tragically too common crash injury or fatality. If the majority of drivers on the road had access to these safety technologies, then maybe there would be a significant change to total crashes occurring and also the staggering number of traffic accident fatalities.

Not only is the loss of life frustrating to see, but the cost to our country as a whole is also staggering. According to the NHTSA data, serious and fatal traffic crashes cost the US a total of 1.85 Trillion dollars in value of societal harm. With 460 Billion dollars of that being economic costs and damages, and 1.4 Trillion in quality of life costs ([5] American Traffic Safety Services Association). Even a small percentage decrease in these numbers could mean huge benefits to the United States' economy as a whole. These safety features can not only save lives, but also save money for every consumer in general.

The expensive challenge that is gate-keeping the average driver is the cost of a new car. While new cars currently possess newer safety technologies, the average consumer cannot afford to drive to the dealer and drive off in a brand new car. According to Statista research, the average light car (gross weight of 8,500 pounds) cost approximately $47,000 in 2023 ([3] Statista). With interest rates included the total cost of a car loan for $47,000 could end up costing more than $60,000 over 60 months. This is not an easy expense for the vast majority of consumers. In 2023, the average American salary was approximately $59,423 ([4] Forbes). That means the average American would have to work at least one full year to afford a new car, which is not an option for the majority of consumers.

Once most consumers see the price tag attached to the shiny new car, they will be running in the other direction, sacrificing the amazing safety features that are available to them. The thought of average consumers not being able to protect themselves with more features available to them because of cost is a huge motivation of this project's undertaking. This project aims to enable consumers with an older model car that cannot afford the massive expense of a newer car the opportunity to upgrade the safety features in the current car they own. According to the Hedges & Company research survey, approximately 62% of all vehicles on the road in the United States are models from the year 2014 or older, and 23% of vehicles being over 20 years old ([1] Hedges & Company Research). We know in only the last 5-6 years that many of the incredible safety features have been included in car design with many of those years only offering the features through the most expensive trims and options.

So while these safety features are beginning to be implemented in newer model cars, there is still about two thirds of the consumer market that either cannot or will not purchase those newer vehicles. This makes the road today still unsafe compared to the possibility of the majority of consumers having access to these potential life-saving features. Our motivation and desire is to be able to arm the everyday consumer and driver with as many tools as possible to protect not only themselves, but other drivers on the road as well. If instead of only one third of drivers having the powerful safety features, everyone had access to these features, we predict a significant decrease to the number of total traffic accidents, which coincides with a decrease in total traffic accident fatalities as well.

The project design involves a modular system of printed circuit boards (PCBs) mounted on the vehicle's exterior and interior. A PCB mounted on the front bumper will collect and process visual data using a stereovision two-camera system to calculate distances to vehicles ahead and a camera system to be used to detect lanes. Up to four additional PCBs will be mounted on the quarter panels, each containing radar devices designed to detect objects in hazardous proximity, particularly to aid the driver when merging or changing lanes. This multi-sensor approach provides extensive coverage of the vehicle's surroundings, ensuring that the driver is aware of potential hazards on multiple sides.

The sixth PCB, located inside the vehicle, will interface with the sensor modules and provide feedback to the driver via a user interface (UI). This UI includes audio alerts through a speaker or buzzer, and visual data through a head-up display (HUD) projected onto the windshield. The HUD allows the driver to maintain focus on the road by displaying important alerts directly within their line of sight, eliminating the need to glance down at a screen or dashboard. The radar PCBs will be powered by a solar battery system, enabling continuous operation even in low-light conditions. The front bumper and interior PCBs, however, will be powered by the vehicle's 12-volt battery, utilizing proper power regulation and management to ensure efficient and reliable performance.

The goal is to develop a minimum viable product (MVP) that includes two radar modules, lane detection capabilities, and audio feedback. By offering a system that can be easily installed in older vehicles, this project seeks to make advanced safety features more accessible to the average driver, ultimately reducing the number of traffic accidents and fatalities on the road. If more drivers are equipped with these powerful tools, the result could be a significant decline in traffic accidents, injuries, and fatalities, making roads safer for everyone.

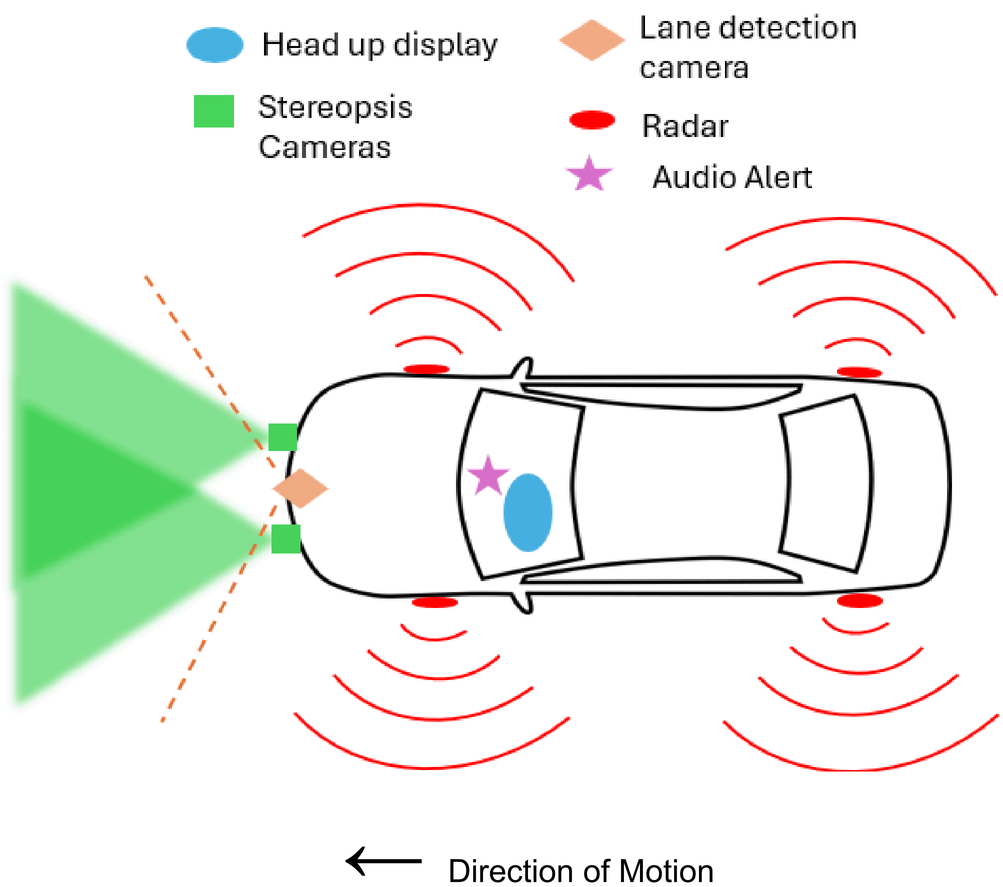


Figure 1. Sensor and UI layout

2.2 Goals:

For This project we proposed goals aimed at enhancing driver safety. We devised goals based on detecting and alerting of hazards, that being observance of other cars, people and animals, within a dangerous range of our subject's vehicle, as well as providing appropriate treatment based on the type of object detected. Other hazards might include lane straying and keeping a safe distance to vehicles immediately in front of our driver. To further the discrimination of detected objects to the point that proximity to a person or another vehicle should sound an alert while reasonable proximity to a guardrail or highway barricade should require a different treatment to its proximity. Other goals aim at the means by which the alert information is provided to the driver user. Our main goal is to provide multiple sensory feedback to the operator.

2.2.1 Basic Goals

1. Alert driver of hazards such as adjacent vehicles, nearby pedestrians and bicycles with multiple sensory feedbacks.
2. Provide blindspot detection for multiple vantage points of the vehicle.
3. Real time communication of hazards between wireless peripheries and UI.
4. Provide lane keeping assistance.

2.2.2 Advanced Goals

1. Provide a visual interface for operator accessibility that allows users to keep eyes on the road while receiving feedback from the device.
2. Provide 180 degrees (relative to the direction of the travel) of data for potential hazards.
3. Provide tailing distance (distance between operator's front bumper and the vehicle in front of them).
4. Provide dynamic tailing distance adjusted for rad speed.
5. Reduce power consumption and performance of the front module by optimizing the device for lane detection.

2.2.3 Stretch Goals

1. Provide more contextual and varied visual output based on hazard type.
2. Provide a system that stays on for extended periods of time.
3. Design with weather rating.

2.3 Objectives:

2.3.1 Objectives for basic goals

1. Implement a buzzer or speaker to sound when a sensor has detected a hazard, or hazardous situation.
2. Integrate 2 low power radar sensors into two external peripheries placed on the front quarter panel of the vehicle.

3. Implement a closed wifi network between the radar boards and the alar producing boards with a 2.4GHz wifi signal.

4. Use a 1280 X 720 RGB output camera to collect roadway visual data. Process images with greyscale, Sobel filter and Hough transform to detect road lanes and send feedback to the driver if needed.

2.3.2 Objectives for Advanced Goals

1. Design and implement Head Up Display **(HUD)** that projects on windshield in front of drivers point of view.

2. Implement a low power radar on each quarter panel to detect hazardous objects.

3. Use two cameras is a stereovision system to calculate depth and distance from camera to object using lens equations.

4. Use a GPS to calculate road speed. Use calculated road speed with stereovision data with the convention of 2 feet per mph to give operator tailing distance feedback.

5. Implement lane detection algorithms via logic on FPGA dedicated to lane detection. Paralleling algorithms to reduce computation time and optimizing unused components.

2.3.3 Objectives for Stretch Goals

1. Implement multiple changeable stencils for the HUD system. Use a motor to change between stencils based on the hazard being communicated.

2. Use a combination of solar power and power management to ensure peripheries that are not attached to the vehicle battery maintain operation. Even in low light and throughout the night.

3. Design enclosures with IP69 weather casing for practical outdoor use.

2.4 Engineering Requirement Specifications

This section is used to outline the main requirements of the project as a whole system, and to depict which requirements will be demonstrated in a final product demonstration, as highlighted.

Table 1: Engineering requirement specifications for the performance and physical features of the envisioned system

System Requirement	Requirement Specification	Unit

The system shall alert the user of hazards detected within the specified range.	2	meters
The system shall produce an audible alert within the specified time from detection.	1	second
The system shall detect objects with the specified level of accuracy.	85	%
The system shall draw no more than the specified power.	20	Watts
The system shall produce a visible alert within the specified time from detection.	1	second
The system shall remain functional for the specified amount of time when not exposed to direct sunlight.	5	minutes
The system shall provide a total detectable range of the specified degree of the whole car.	180	degrees

2.5 Component Performance Specifications

This section is used to outline the requirements of the project to work, separated out into individual subsystem requirements. These are the requirements of each subsystem needed to achieve the overall requirements outlines in the above section.

Table 2: Engineering requirement specifications for the components that will be used in this project to build the envisioned system.

Component(s)	**Parameter**	**Specification**
Radar units	Detection range	2 meters
Front cameras	FOV	45°
Head up display	Image size	0.5 in^2.

Audio alert	Decibel magnitude	80 dB
Solar panel	Output power	20 W

2.6 Features / Functionality

This system is designed to enhance driver safety by detecting potential hazards on the road and alerting the driver through two distinct alerting methods: visual and audio feedback. It incorporates five primary detection areas using cameras, radar units, and GPS to provide a comprehensive view of the vehicle's surroundings and driving conditions, ensuring both proximity awareness and lane awareness.

The system operates by analyzing data from multiple sensors mounted on the vehicle. One camera located on the front bumper collects real-time visual data of the roadway ahead, which is processed by onboard software or logic to detect lane boundaries and adherence. A second system of cameras incorporates stereovision to determine the distance from this front bumper to the vehicle in front. This enables the system to assess whether the driver is maintaining a safe following distance. Additionally, GPS data is collected and used in conjunction with these proximity measurements to refine the determination of safe tailing distances using the 2 feet per mph convention, ensuring greater accuracy based on speed and road conditions.

For enhanced side view detection, radar units are installed on both the left and right sides of the vehicle. These radars are tasked with detecting obstacles, particularly vehicles in adjacent lanes that may enter the driver's blind spots. The system is particularly useful for merging or changing lanes, where visibility is reduced and the risk of a collision increases.

A head-up display (HUD) is the primary visual alerting method. The HUD projects critical information onto the windshield, directly in the driver's line of sight. When a hazard is detected, the display provides clear and intuitive indicators about the nature and location of the hazard, allowing the driver to respond quickly without having to shift their focus from the road.

In addition to the HUD, a buzzer or speaker that provides audio feedback is used as a redundant alerting mechanism. The system emits beeps or ringing sounds when a hazard is detected, ensuring that drivers are notified even if their attention is diverted or visibility is reduced. This dual-mode alert system makes the system more accessible to drivers with either auditory or visual impairments, enhancing overall safety and usability.

The system’s architecture is designed to balance real-time responsiveness with low power consumption. Data from external peripherals such as cameras and radar sensors are transmitted wirelessly to a central processing unit located within the vehicle. The wireless transmission uses Wi-Fi technology, chosen for its high bandwidth and low latency, which is essential for ensuring real-time hazard detection and alerting. However, the higher power consumption associated with Wi-Fi necessitates a design where peripherals operate independently as much as possible. To conserve power, these external sensors only transmit data as an encoded flag when a potential hazard is detected.

The MCU within the central unit is responsible for analyzing the incoming hazard flag data and configuring the output on the human machine-interface. The HUD and buzzer then alert the driver with the detected information.

Figure 5. Bari Life Car Blind Spot Monitoring System

2.7 Existing product / past project

Products with overlapping features and scope include the crutchfieldBrandmotion FLTW-6000[1]. At $679.96 the FLTW-6000 utilizes two radar modules to detect hazards in the driver's blind spot and sends feedback to the driver via a buzzer and visual alert lights placed at the operator's discretion. The device is programmed to discern warnings vs alerts as only the light is illuminated if a vehicle is present while the alarm sounds if the driver starts moving in the direction of the detected hazard. All features are implemented via wires that must be run throughout the vehicle and pass though from interior to exterior in order for operation. The external units are IP69 water rated, something that is likely inaccessible at our price point. The field of view of this system is limited to the front quarter panels.

Figure 4. Crutchfield Brandmotion FLTW-6000

Bari Life provides the Car Blind Spot Monitoring System[2] **(CBSM)** at a price of $58.30. The Car Blind Spot Monitoring System employs 58 KHz ultrasonic sensors for obstacle detection. Feedback in this system is provided by two adhesive lights placed inside the vehicle preferable inside the door opposite the side mirror. A buzzer is also used to alert of immediate hazards. Both of these solutions run solely off the vehicles 12v power making power reliance simple. This in trade makes installation more complex as wires must be fed between the interior and exterior of the vehicle. The CBSM must also tie into the vehicle's brake lights for power. This wiring may make the device inaccessible for many especially those unfamiliar with vehicle wiring.

Past projects within UCF's ECE senior design include group 5 of the 2020–2021 design period Enhanced Driver Awareness Detection System **(EDADS)**. Their system implemented cameras for visual spotter assistance, proximity sensors via 58 KHz ultrasonic sensors for rear hazard detection and resistive temperature sensors for engine health monitoring. The premise of their project was aimed at the sport of off-roading and navigating difficult terrain as opposed to general road safety. They wanted to implement a system that could stand in for a terrain spotter and provide enough data to the vehicle operator to navigate tough and complex terrain. Team 5 used two front facing cameras and one rear facing IR camera for visual data. The ultrasonic sensors were used in tandem with the cameras for a more accurate judge of depth and distance from hazardous rocks than the camera could provide, especially in the low light IR settings. Their system was completely implemented with extensive wiring and modifications to the vehicle within which it was installed. The EDADS team used an LCD as well as a HUD to interface with the operator. In their table of specifications the HUD was used to display if hazards were within a 2 foot proximity while more intricate visual data was left to the lcd screen mounted on the dashboard. This approach was more practical with their goal as off-roading does not require

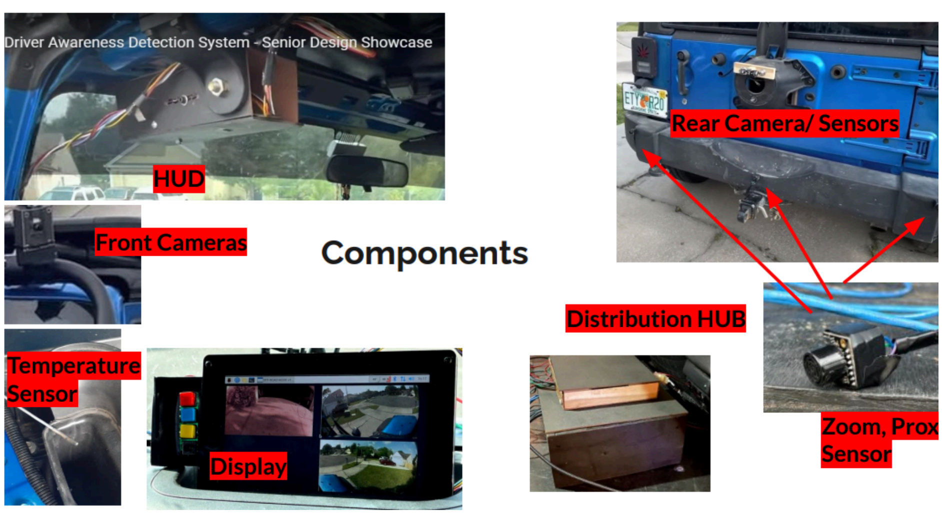


Figure 6. Enhanced Driver Awareness Detection System

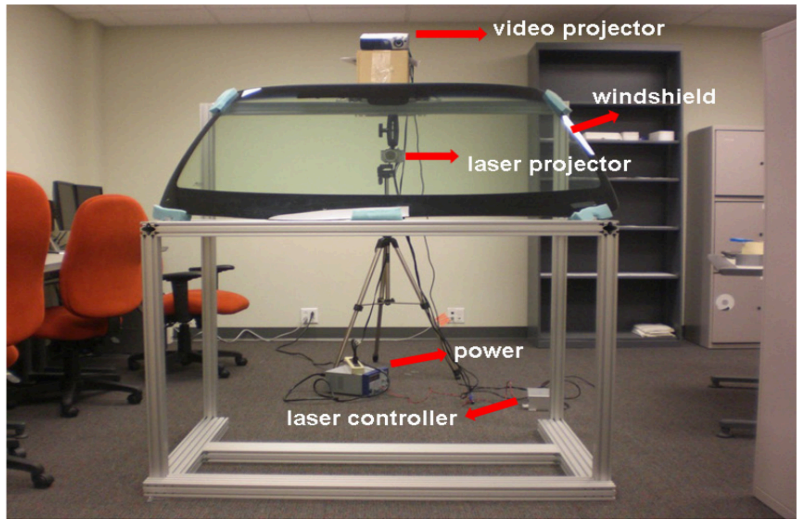


Figure 7. Prototype of Full windshield HUD

([8] Wu, Wen & Blaicher)

constant roadway line of sight, but rather close analysis of the terrain around you. You are generally moving much slower and are required and permitted to take time making your decisions. The EDADS team also included a thin film combiner on their windshield to enhance the visibility of their HUD system. Their HUD was two fold magnified and projected from an OLED screen. We hope by using a laser projection through a stencil we can produce a clearer, more vibrant image for the user.HUD systems are the most novel aspect of our design. While there do exist some aftermarket options most pedestrian vehicles that include HUD are only those luxury or EV models. Some manufacturers such as GM have experimented with incorporating systems as ambitious as full windshield HUD. These experiments seem to have taken place in 2010 but have lost traction. These HUD systems went as far as highlighting and projecting a circle around hazards detected by the camera when observed from the driver's seat. These hazards could be pedestrian signs, and other obstacles in foggy conditions. The windshield in this experiment incorporates a thin film with phosphorus coating which lights up distinctly under the photons shot by the laser projector.

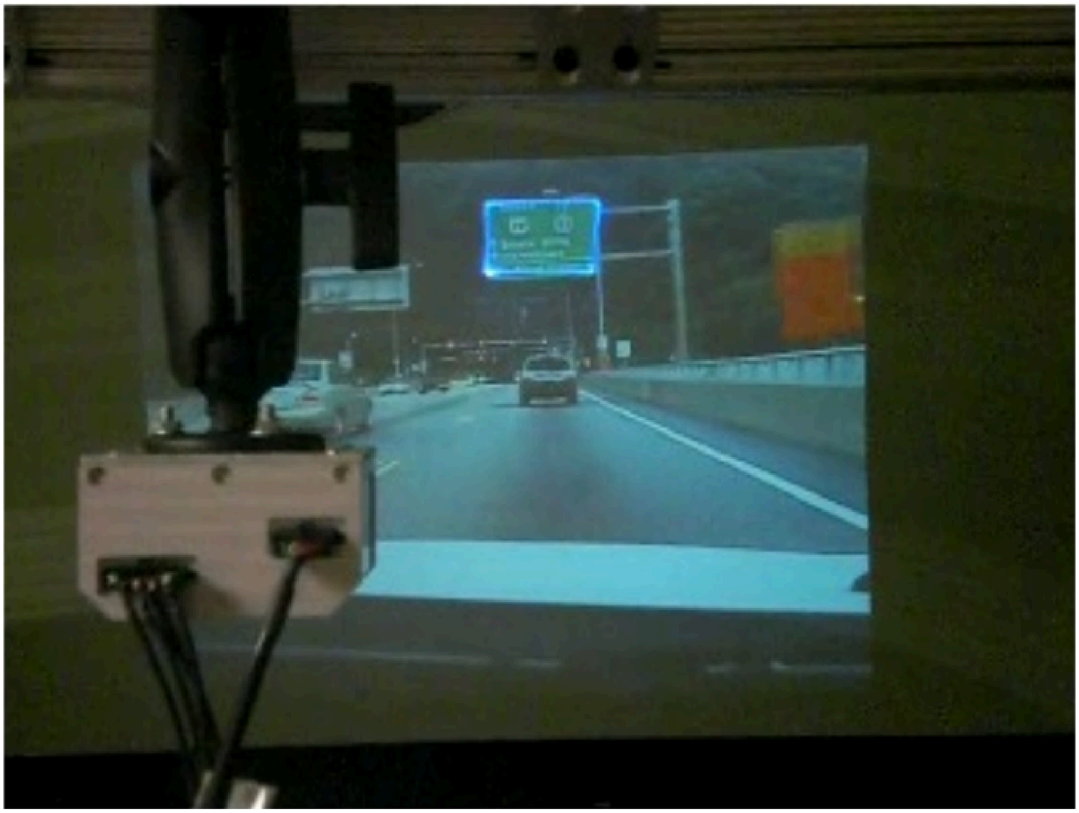


Figure 8. A road sign being highlighted by HUD

([8] Wu, Wen & Blaicher)

Many fully incorporated Advanced Driver Assistance System ADAS systems exist in the world today and features such as Automatic Emergency Braking **(AEB)** will be required by law in the United States by 2029. These systems directly interface with the operation of the vehicle with capabilities such as automatic braking and steering assistance. These systems can interface through the CAN (Controller Area Network) bus via codes which are usually proprietary to the vehicle designer / manufacturer. Modern vehicles also often use an electric line break which is easier to interface with software than the hydraulic brakes that dominated the market in the twenty tens and earlier, the market that this type of product would largely target. Because of the more mechanical implementation of car systems in older vehicles after markets ADAS are limited to alert features and observation assistance similar to our design.

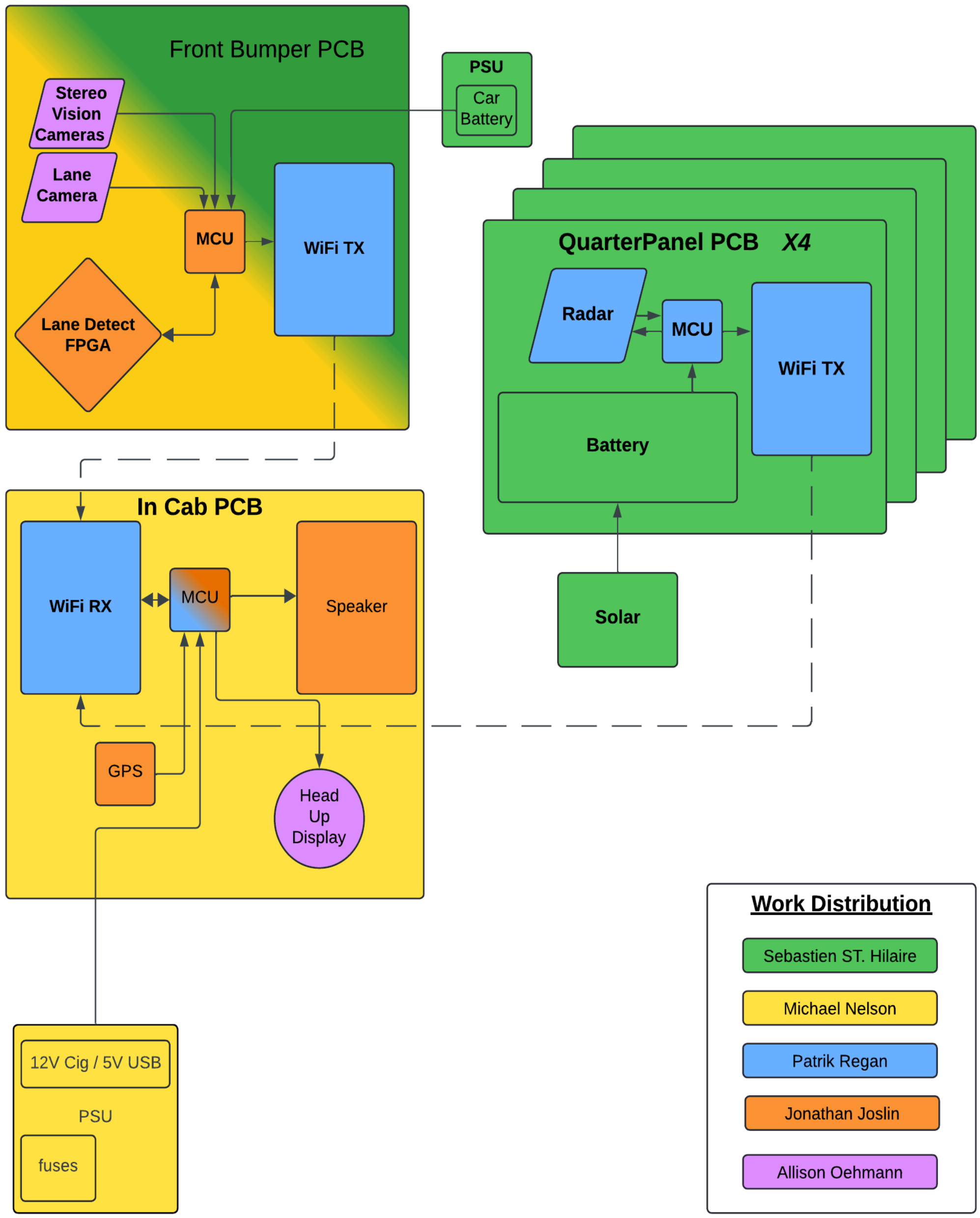
Other aftermarket HUD products are mostly limited to a variation of a 7 segment LCD display. They are generally used for displaying speed but some do interface with the CAN to read things such as check engine lights and battery level. Some of these datums may not transfer over to the device depending on whether things like fuel level are mechanically measured rather than an electronic sensor. From our research, there are currently no aftermarket HUDs available that will alert the user for hazards detected in their blind spots.

Our product stands out by offering a seamless interface that delivers both visual and audible feedback to the driver, covering not only obstacle detection but also lane following and tailing distance monitoring. Unlike competing products that typically offer these features individually and often require professional installation, our system aims to consolidate all of these safety features into a single, easy-to-install package. This design's most ambitious stretch goal is that any typical driver can set up the device in their vehicle without specialized assistance. By providing real-time, actionable information, the system enables drivers to respond more quickly and effectively to the numerous hazards they encounter on the road, promoting a safer and more informed driving experience

Figure 9: Commercially available head up display system

2.8 Hardware Block Diagram

The hardware block diagram illustrates the general system used to gather and present data for the vehicle operator. There are 5 wireless peripheries: four radar modules mounted on the quarter panels for blind spot detection. On the front bumper is a camera used for lane detection, and a system of two cameras used for stereo vision based distance calculation. Lenses used on cameras are to be optimized for purpose. Camera input for lane detention is sent to an FPGA logically programmed for lane detection processes such as Soble and hough transforms and CV. Work distribution is illustrated by a color coded key. Wireless peripheries are powered by dedicated batteries or attached to the car’s battery. Solar panels are used to recharge dedicated batteries.



2.9 Optical Schematic Diagrams:

Provided are the optical design schematics included for the three main optical components of this project. The first diagram shows the optical schematic for the inner workings of the Head Up Display, which utilizes the principle of fourier transform in a 4f lens system. The second and third diagrams represent the optical design that will be performed to design the lenses that will be used for the stereopsis camera systems on the front of the car.

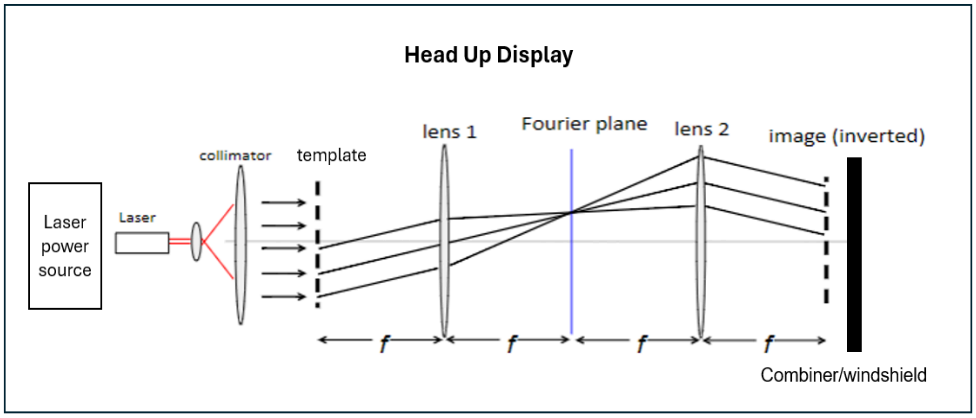


Figure 2: Head Up Display Optical Schematic

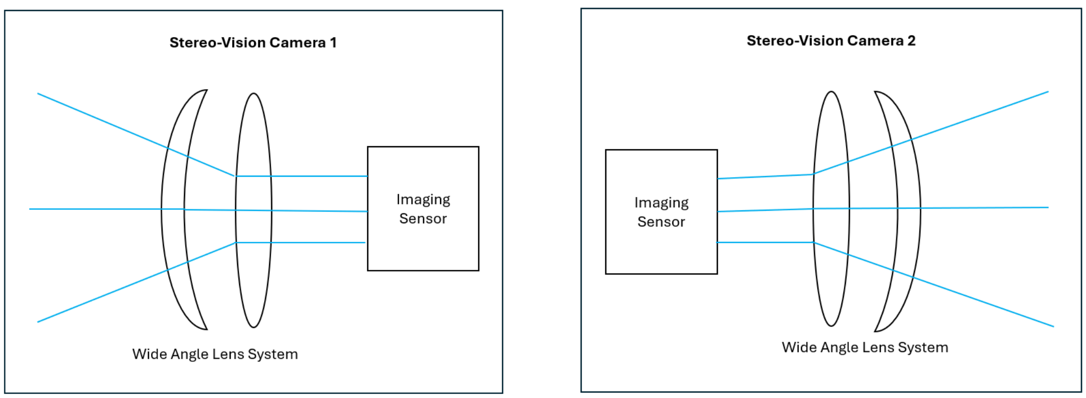
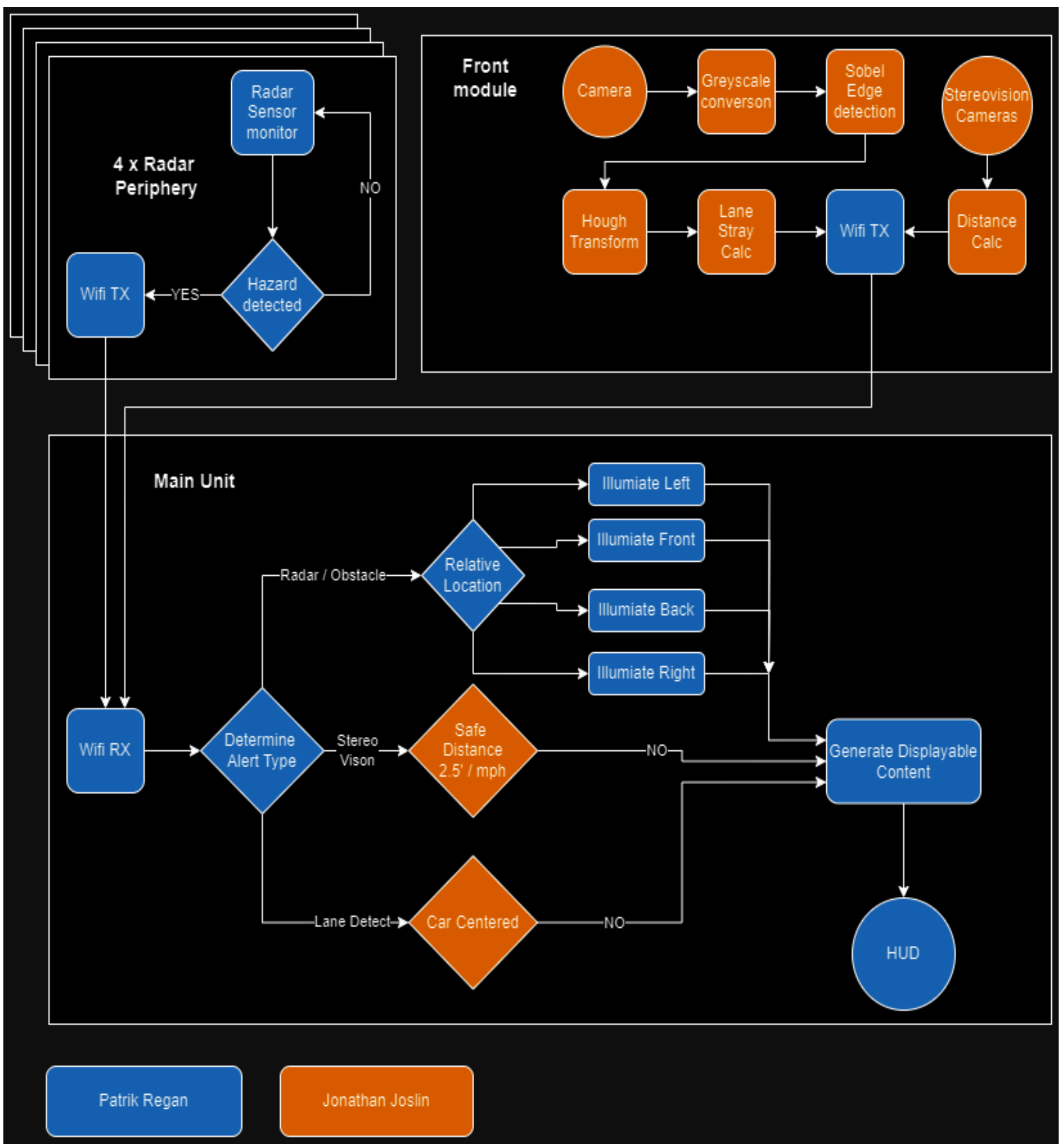


Figure 3: Stereo-Vision camera lens designs

The optical block diagrams depict the main optical components of the system, the head up display, and the wide angle lens systems for the stereo-vision cameras. The head up display consists of a red laser, coupled into a beam expander and a collimating lens, an inverted mask of the image to be displayed acting as the object of the system, two lenses of equal focal length aligned to create a 4f system, and the combiner on the windshield, acting as the image plane of the system. The design utilizes the principles of Fourier transform to project the desired image onto the windshield. The lens system to be added onto the cameras used for stereoscopic vision calculations will be designed to increase the field of view of the cameras, while minimizing distortions of the output. Introducing multiple lenses into the system will cause the distortions to accumulate, so the goal of the design will be to utilize as few lenses as possible while still obtaining the desired field of view.

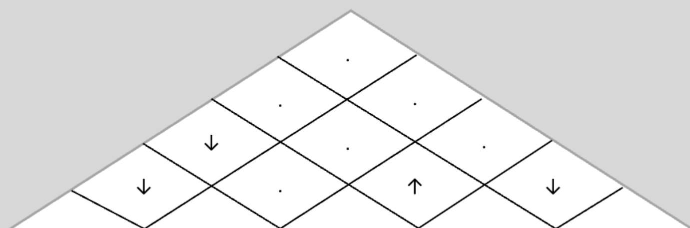
2.10 Software Diagram

With the software for this system, there are three different areas that will be worked on, the radar periphery, the front bumper module, and the main unit. With the software in the radar periphery, it will only be waiting for detection from a nearby obstacle, where it will then transmit to the main unit. With the front module, it will deal with software to detect if the driver is either straying out of their lane or if they are trailing behind the car in front of them too closely, then transmit it to the main unit. For the main unit, it will deal with software to determine what type of alert to send the user based on which peripheral sent the data.



2.11 House of Quality

The following table is a representation of our house of quality for our project design. In this, it lists the priority for both our customer and engineering requirements as we produce our design, and with it it will show each requirements desired polarity, being if we wanted to maximize or minimize the requirement. Within the table we have the correlations between the customer and the engineering specification, showing that depending on the section if the requirements correlate and how they will correlate. Next, there is the top part which shows the correlation, if there is one, between the engineering specifications shown.



Desired Polarity		-	-	+	+	-
Engineering Requirements → Customer Requirements ↓		Manufacturing Cost	Transmission Time	Accuracy	Camera Field of View	Dimensions
Affordability	-	↑↑	↓	↓↓	↓	↓↓
Ease of Install	+	↓↓				↓
Alert Time	-	↓	↑↑	↑		
Accessibility	+				↑	
Data Accuracy	+	↓		↑↑	↑	↑
Detection Range	+	↓↓		↑↑	↑↑	↓
Target Specifications		≤ $850	≤ 1 second	≥ 95%	≥ 25°	≤ 1.5 feet^2

Polarity:

+	-
Positive	Negative

Correlation:

↑↑	↑		↓	↓↓
Strong Pos	Positive	None	Negative	Strong Neg

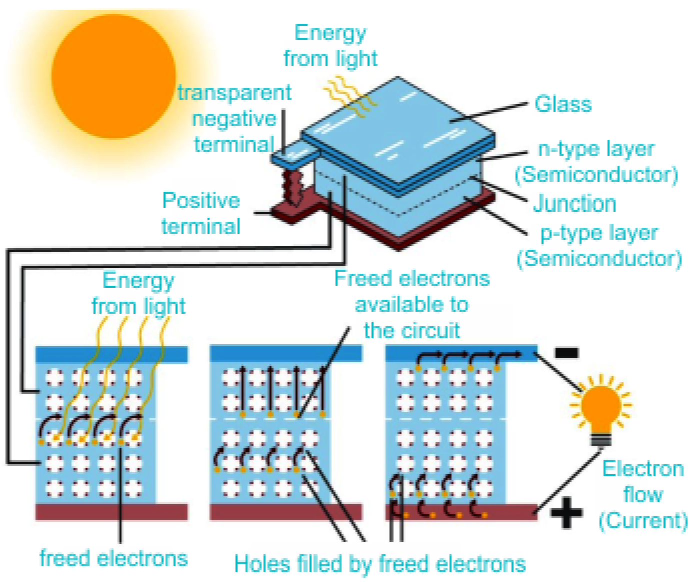
Chapter 3 – Research and Investigation

For the most optimized and practical implementation of our design we had to research technologies and investigate devices that could perform the jobs required by our design. Much research was performed for harmony of the whole system such as power characteristics, communication compatibility, facility limitations, and skillset limitations. As seen below many technologies or devices had traits, characteristics or specifications that made them unsuitable for out design.

3.1 Solar Panels

When light shines on a solar cell also known as photovoltaic cells, it converts direct sunlight to electrical energy. These photovoltaic cells can contain several semiconductor materials, and when light strikes the semiconductor a voltage can be produced using a process called photovoltaic effect. As photons from the light strikes the photovoltaic cells some will be reflected, absorbed, or pass right through the cell. The Photovoltaic Effect uses the absorbed photons to eject the electrons from its atom and allow the electrons to flow through a conductor as a current.

Factors such as cost, efficiency, power output, and size must be taken into consideration when deciding between the different types of solar cells. In today's solar cell market, we will see crystalline light-absorbing materials dominating the market due to their high efficiency and durability. There are three types of crystalline solar panels: monocrystalline, polycrystalline, and thin film. We will weigh the pros and cons between these three and decide which solar panel will be best to use for our project.



Inside a Photovoltaic Cell

3.1.1 Monocrystalline

Monocrystalline material is made up of a single piece of silicon resulting in fewer gaps giving us a higher efficiency than polycrystalline and thin film. Monocrystalline are also more reliable being that their solar cells have a life span typically longer than 25 years. The manufacturing process tends to be more complex compared to thin film, resulting in a higher cost.

3.1.2 Polycrystalline

While monocrystalline material is made up of a single piece of silicon crystal, polycrystalline is made of multiple silicon crystals. This results in the electron moving through different crystalline materials making the cell less efficient. Due to its simpler manufacturing processes, we will find that the polycrystalline modules are less than monocrystalline. Like the monocrystalline solar cells polycrystalline solar cells won't see any degradation typically after 25 years

3.1.3 Thin Film

Thin films are made of two materials called Cadmium (Cd) and Tellurium (Te). Thin film gets its name due to the material being able to absorb the same amount of sunlight while using thinner layers compared to other type of solar cells.Thin film is the least efficient of the three but it’s also the cheapest, the advantage of using a thin film module is found in its lightweight and flexibility while polycrystalline and monocrystalline modules are more rigid. This allows thin film to be applicable in areas without a flat surface. Given that thin film uses fewer materials to achieve its flexibility this results in lowering manufacturing cost.

3.1.4 Solar Panel Type Selection

Efficiency should be an important parameter when discussing the tradeoff between what solar panel to use. The definition of efficiency as defined by the Department of Energy is "The Conversion efficiency of a photovoltaic (PV) cell, or solar cell, is the percentage of the solar energy shining on a PV device that is converted into usable electricity ” [6, Solar performance and efficiency].

Temperature coefficients are another factor to consider when determining solar panel types. As temperatures increase, solar panel efficiency drops and the temperature coefficient allows us to measure that. The value given by the temperature coefficient determines the percentage of power loss per degree Celsius after 25°C (77°F) set by the Standard Test Conditions (STC). There are typically three different temperature coefficients given in solar panel specification sheets for open circuit voltage, short circuit current, and maximum power.

Type	Monocrystalline	Polycrystalline	Thin Film
Efficiency	20% - 22%	16% - 18%	8%-10%
Temperature Coefficient	-0.3%/°C to -0.4%/°C	-0.37%/°C to -0.5%/°C	~ -0.2%/°C
Average Cost Per Watt	$1 - $1.50	$0.70 -$1	$0.60 -$0.70

3.2.1 Solar Panel Selection

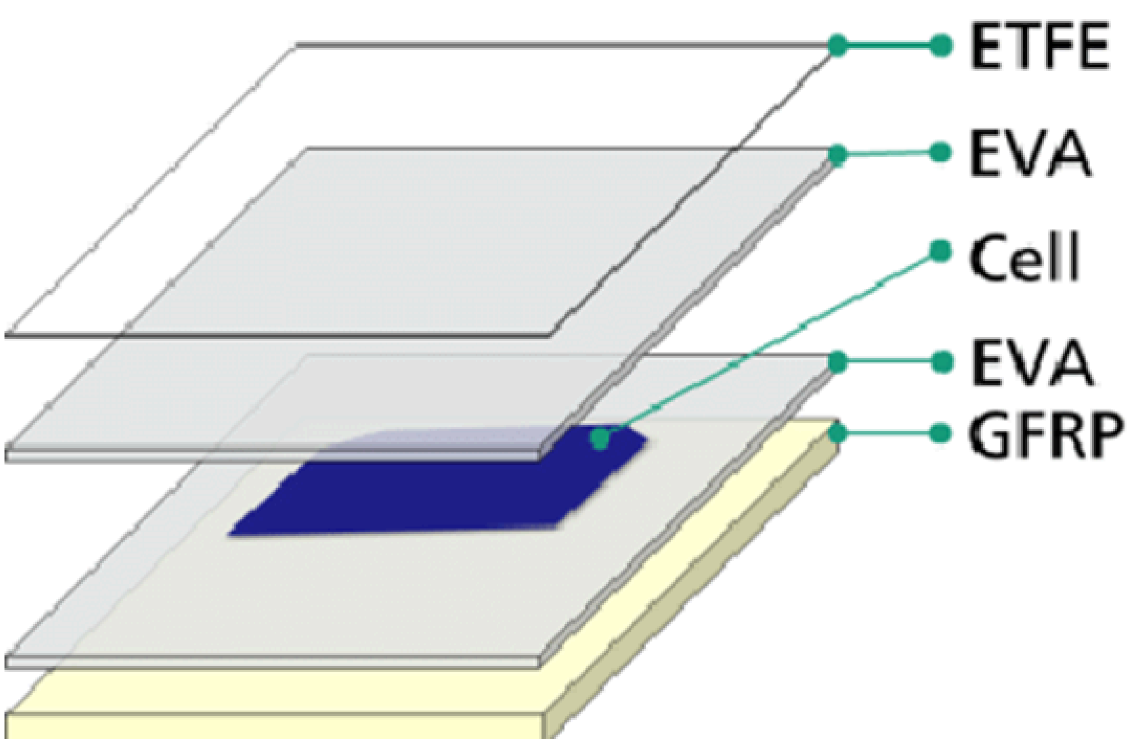
Keeping in mind that we will be powering multiple printable circuit boards we will need to make sure to choose a solar panel that can provide enough power. As of right now with all the components we have on the radar system it looks like we will need around 10 watts to power all four quarter panel PCBs. We will still need to consider power losses in other components not considered on the PCBs, such as wiring and losses through conversion. Even though these losses are insignificant, we should still look for a solar panel that exceeds the expected PCBs wattage.

	TPS-12-15W	TPS-24-30W	P120	P152
Manufacture	Tycon Systems	Tycon Systems	Voltaic Systems	Voltaic Systems
Efficiency	N/A	N/A	21.90%	22.80%
Maximum Power (W)	15W	30W	19.43W	25.00W
Open-Circuit Voltage	21.6V	45V	5.95V	19.70V
Voltage at Max power	17.6V	38.4V	4.69V	16.80V
Short-Circuit Current	0.90A	0.84A	4.48A	1.70A
Current at Max Power	0.85A	.79A	4.14A	1.50A
Dimensions (Inches)	14.6x14x0.7	21.3x20.1x1.4	17.17x10.79x.16	19.96x12.09x.67
Cost	$65.94	$150.95	$99.00	$59.00

Table : this table shows a comparison of all the solar panels in consideration and their power specification

When researching the solar panel, we came across different types of connectors like the DC output cable and an MC4 connector. Using a DC output cable allows ease of installation for the customer, where the customer will only be required to plug in the cable to the multiple PCB. If we end up using a solar panel that uses an MC4 connector, we will need to use additional cables that convert the MC4 connector to a DC Cable. The MC4 connector can be easy to plug in but very hard to unplug. To unplug the MC4 connector we will sometimes need a certain unlocking tool.

Researching between the two manufacturers we noticed that the voltaic system provides a more durable solar panel compared to tycoon systems. Voltaic systems use a coating called ETFE (Ethylene Tetrafluoroethylene) , this coating is applied to the photovoltaic module giving us a more durable solar panel. While this is more durable, the tradeoff is that it is more expensive than a standard solar panel.



3.3 Battery

A battery is a device that stores and transmits power. They are everywhere in average, everyday life. It powers a wide variety of devices from general electronics to electric powered vehicles (EV). Batteries incorporate one or more cells. Each unit includes an anode, cathode, electrolyte, and separator. When utilized in batteries, a chemical reaction takes place between the anode and the electrolyte. That is the source of electricity for electrical devices to be powered.

Battery management covers a wide variety of utilizations. Batteries are important to portable strength for consumer electronic devices which includes smartphones, laptops, and electric vehicles. These devices commonly use lithium-ion batteries. They are recognised for their impressive strength and durability. In renewable energy structures, batteries store excess electricity generated by means of solar panels or wind generators which provide stable power.

Batteries additionally play an essential role in many businesses and emergency programs. For instance, an uninterruptible energy supply (UPS) can use batteries to offer backup power all through a potential power outage. To protect sensitive devices in medicine, batteries are utilized in devices such as pacemakers. Constantly batteries are being researched and studied in an attempt to continue improvements in this sphere of power. With ultimate goals of providing alternatives to fossil fuel engines and other older technologies.

3.3.1 Lithium ion

Lithium-ion (Li-ion) batteries are a typical rechargeable battery used in most modern electronic devices. They are typically used in smartphones, laptops, tablets, electric vehicles, and other wireless devices.

Benefits of using lithium-ion batteries include a long life cycle, high energy density, low self-discharge rate, fast charging, and the “no memory effect” which reduces overall capacity of the battery over its lifetime per charge cycle.

Downsides to lithium-ion batteries include a higher cost than other battery models. As well as a dangerous potential sensitivity to higher temperatures. They also require complex battery management systems to operate at full potential.

3.3.2 Nickel-Metal Hydride

Nickel-metal hydride (NiMH) batteries are also utilized in modern electronic devices.

Benefits of using the nickel-metal hydride batteries include environmental friendliness due to the removal of toxic cadmium, which makes recycling or disposal of batteries easier. Also a high energy capacity and low self-discharge rate are highlights of nickel-metal hydride batteries. Cost is also much cheaper than lithium-ion batteries.

Negatives of nickel-metal hydride batteries include a shorter than best life cycle, and also a high sensitivity to extreme temperatures. Nickel-metal hydride batteries also suffer from a flat discharge curve which means the voltage can drop quicker than other batteries and be unstable powering some devices. They also suffer from a difficult charging complexity, charging rules and even specialized chargers are required.

3.3.3 Lead-Acid

Lead-acid batteries are one of the oldest and most used batteries in history. They are typically used in automotive applications and even backup power systems.

Lead-acid batteries are best when thinking of affordable cost, with a reliable and mature technology. They also have high surge currents and a stable chemistry. They are durable and able to withstand extreme weather and even severe physical stress. They also are very recyclable and have a good infrastructure for recycling these batteries.

Lead-acid batteries are weak in several areas, which include a heavy and large structure. They also have a much weaker energy capacity and require most constant maintenance to ensure safe, full operation. Lead-acid batteries also have a poor self-discharge rate and are much less efficient in charging and discharging.

3.3.4 Alkaline

Alkaline batteries are also used in common consumer products and electronic devices mostly due to convenience and performance.

Alkaline batteries are widely available and easy to obtain in the consumer market. They have an impressive shelf life for longer term storage before use. They have solidly stable performance and are very consumer friendly in terms of cost. They also have a low self-discharge rate and require no maintenance.

Alkaline batteries have major drawbacks like the inability to be recharged, they are single use. They have a lower energy density than most other batteries. They also struggle in high demand, high drain devices. This also means alkaline batteries struggle with voltage drop over time and even have a more negative impact on the environment. They contain harmful chemicals that need specialized disposal.

3.3.5 Battery Selection

After looking at the many options and checking over the scope and requirements of this project, we have narrowed down to 3 battery models that we are considering (shown in table x.x below). The table will compare the 3 battery models in several data points listed from each respective data sheet and specifications.

3.4 Charge Controller

An important component to have when implementing a solar panel to your project is a solar charge controller or also known as a charge regulator. The main purpose of a charge controller is to control the current flow into the battery and monitor the battery to make sure it does not overcharge; this component sits in between the solar panel and battery. Overcharging can reduce the battery life span, capacity, and performance. When deciding what charge controller to select, factors to consider are voltage required, type of battery, cost, and pulse width modulation (PWM) Vs Maximum Power Point tracking (MPPT). The three charge controllers that we have in consideration are BQ24650, LT8491, and BQ25820.

3.4.1 Pulse Width Modulation (PWM)

The PWM uses a voltage regulation set point to maintain the battery by rapidly switching it on and off. As the solar panel is generating power the pulse width modulation will lower the duty cycle to slowly reduce its charging current as the solar charger reaches its voltage point. Due to its lack of efficiency it's not usually used as a charge regulator. Advantages that can be found in PWM are that they are cheaper and can be applied to a wide range of applications.

3.4.2 Maximum Power Point Tracking (MPPT)

The MPPT is a newer technology compared to pulse width modulation. The MPPT extracts the maximum available power from the photovoltaic module. The MPPT is implemented in the charging algorithm maximizing the amount of current going into the battery. In a PWM charge controller as voltage reaches its voltage point the extra voltage is typically not used, in an MPPT the extra voltage is transformed into higher current which in turn charges the battery faster. This makes the MPPT charge controller more efficient than the PWM charge controller. What makes the MPPT an appealing option as a charge controller is that it can also function as a DC voltage converter. “Most modern MPTTs are around 93-97% efficient in the conversion and get a typical gain of 20-45% power increase in Winter and 10-15% in Summer over a PWM controller” [38].

3.4.3 Constant Current Constant Voltage (CCCV)

The constant current constant voltage purpose is to make sure power is delivered to the rechargeable battery in a safe way. While the MPPT and PWM focus more on obtaining the max power from the solar module, the CCCV manages the charging process through 3 or more phases depending on the charge controller. The first phase is typically the pre-charge, this is implemented when the battery capacity and voltage are low. The pre-charge charges the battery with a small current protecting it from possible damage. The second stage is called constant current (CC) charging, this is implemented when the battery voltage increases. The constant current charges the battery at a set current value till it reaches a specific voltage level. The third stage is called constant voltage (CV) charging, this is implemented when a certain voltage level is reached. The constant voltage charges the battery at a set voltage while the charging current decreases. When the charging current reaches a specific value, the charging would have been completed.

3.4.4 Charge Controller Selection

When selecting what charge controller we want to use, there are two peripherals' components we need to know and specs before choosing. Since we are using the solar panel as our power supply we need to make sure that voltage at max power is with the charge controller input voltage range. The second component is the battery, we need to see if the charge controller supports the battery type.

	BQ24650	**LT8491**	**BQ25820**
Input Voltage	**5V to 28V**	**6V to 80V**	**4.4V to 70V**
Output Voltage	**2.1V to 26V**	**1.3V to 80V**	**4.4V to 70V**
Max Charging Current	**0A to 10A**	**0A to 10A**	**0.4A to 20A**
Battery Type Support	**Li-Ion, LiFePO4, Lead acid**	**Li-Ion, Lead acid**	**Li-Ion, LiFePO4, Lead acid**
Efficiency	**90% to 95%**	**95% to 98%**	**80% to 98%**
MPPT or PWM	**MPPT**	**MPPT**	**MPPT**
Cost	**$5.99**	**$15.24**	**$7.82**

Looking through the different types of charge controllers we came across some charge controllers that implement inter-integrated circuit (I2C) and would require us to connect to an MCU. The benefit of using a charge controller that uses I2C is that it allows us to have more flexibility in how we want to charge the battery and configure certain parameters. Some charge controllers will need you to use I2C to operate certain features like MPPT and there are others that offer autonomous maximum power point tracking. We also came across a stand-alone charge controller, this type doesn't require us to integrate with the MCU. The downside of using a stand-alone charge controller is the lack of features and control over how we want to charge the battery. Another difference between a stand-alone charge controller and MCU integrated charge controller is found in how complex it is to rout the charge controller. While an MCU charge controller has a more complex PCB routing, the stand-alone charge controller has a simpler PCB routing, and this can be seen in the number of pin outs shown on their package.

Another feature we considered using that's offered by certain charge controllers is called direct power path management. The direct power path allows us to determine how we want to power our quarter panel PCBs. We can power them from the solar panel, the battery, or both. The downside is that this involves more complex routing of the battery and the load.

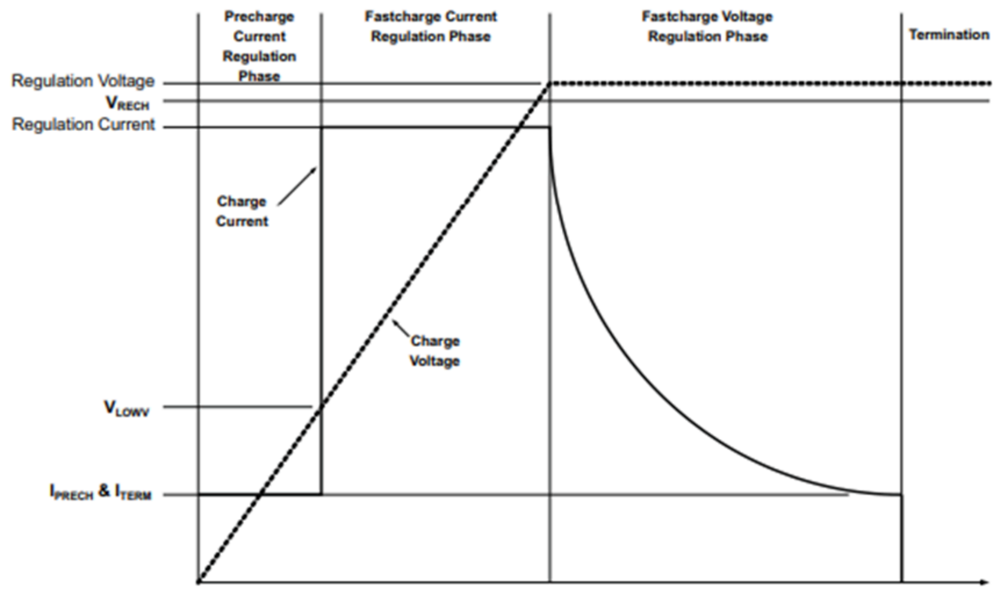


Figure : charging profile for the BQ24650 charge controller

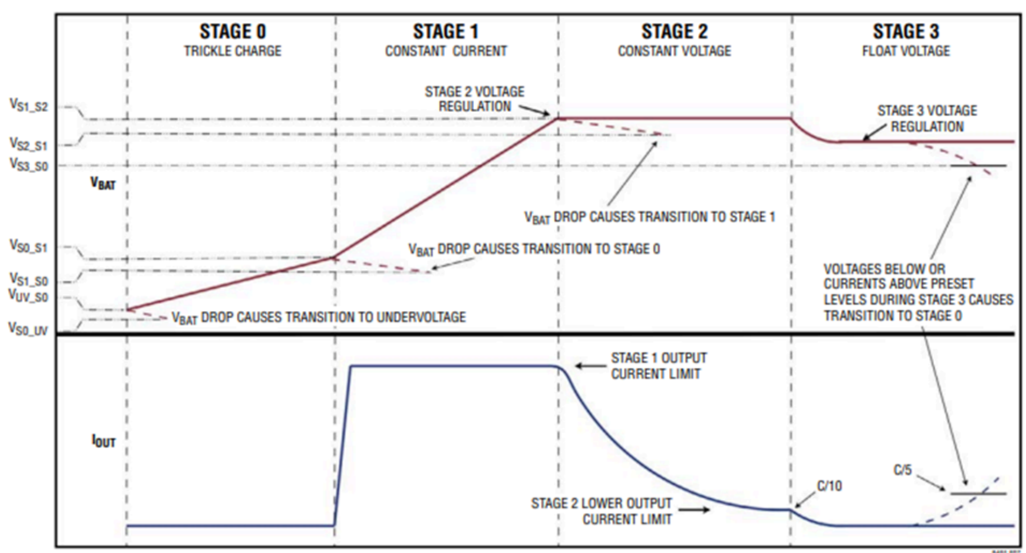


Figure : charging profile for the LT8491 charge controller

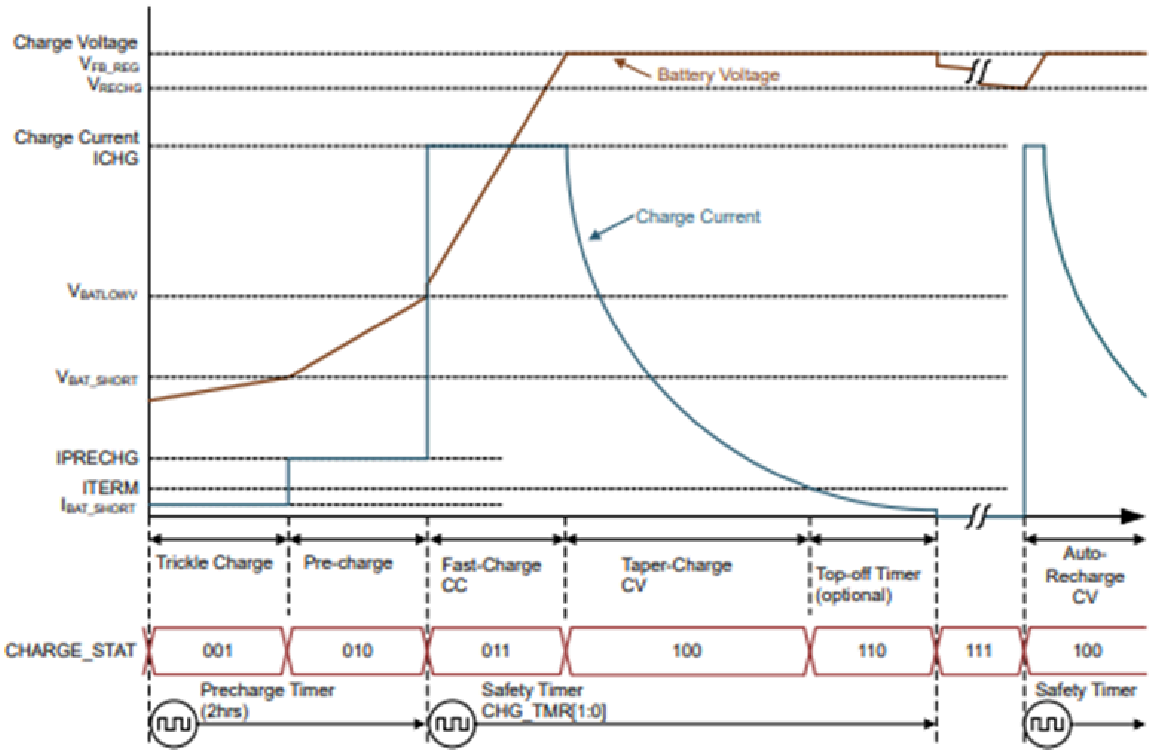


Figure : charging profile for the BQ25820 charge controller

3.5 *Voltage Regulator*

To ensure a steady voltage is applied to the load we would need to use a voltage regulator. The purpose of the voltage regulator is to make sure that the load is receiving constant and stable voltage since the solar panel is sending fluctuating voltages. This will make sure that the components are receiving appropriate voltage and won't be damaged by providing an excess of voltage. There are two types of voltage regulators that we will be considering: the linear regulator and switching regulator.

3.5.1 Linear regulator

The linear regulator acts as a variable resistor that changes as the input voltage fluctuates maintaining its output voltage regulation. Unlike the switching regulator, the linear regulator is a step down converter. The benefit of using a linear regulator is found in its low cost and low noise but it has low efficiency compared to the switching regulator.

There are three types of linear regulators to take into consideration when deciding which one to pick; the standard regulator, low dropout (LDO) regulator, and quasi-LDO regulator. The main difference between the three is the minimum voltage drop required across the regulator to maintain output voltage regulation. The linear regulator with the smallest voltage across it has the highest efficiency.

Out of the three linear regulators, the LDO regulator requires the least voltage across it. The tradeoff is that it has the highest ground pin current, this can be looked at as wasted current. The quasi-LDO comes second when looking at the drop-out voltage, but the ground pin current is low compared to the LDO regulator. The standard regulator has the highest voltage drop-out, but the ground pin current is very low compared to the other two voltage regulators. Texas Instruments state that "in battery-powered applications, LDO regulators are usually the best choice because they utilize the available input voltage more fully (and can operate longer into the discharge cycle of the battery)" []. The LDO regulator is by far the best of the three linear regulators to use in our PCB considering we will be using a rechargeable battery.

3.5.2 Switching Regulators

The switching regulator converts fluctuating power supply into a pulsed voltage that will be smoothed out by other components like capacitors and inductors. The difference in a switching regulator compared to a linear regulator is that a switching regulator uses switching elements to achieve its pulsed voltage. The advantage found in using a switching regulator is that they have higher power conversion efficiency.

There are many types of switching regulators, considering that we will need to step down and regulate the voltage we will just focus on three different switching regulators. buck regulator, push pull regulator, and flyback regulator all provide a step-down voltage compared to all the other switching regulators. The buck regulator and flyback regulator are commonly used switching regulators and the push pull regulator implements two transistors in its design.

If we were to decide to use the switching regulator, our first option would be the flyback regulator. The main feature of the flyback regulator is found in its transformer phasing, allowing us to create different voltage outputs making it very versatile. Our second option would be the buck regulator. The commonly used buck regulator steps down voltage very efficiently, but it's design can be complex and costly as it requires a post width modulation (PWM) control. Last we will consider the push-pull regulator, using two transistors to achieve a regulated voltage. This regulator is used commonly in low input battery powered systems, due to the switch resistor needing to handle twice the input voltage.

3.5.3 Technology Selection

We decided to implement the linear voltage regulator, specifically the low dropout regulator into our design as we believe that it will be the best application for a battery powered system. Any of the switching regulators would've been a great choice due to their efficiency, but due to the complexity of the design and cost we decided to stick with the linear regulator.

3.5.3.1 TPS7A20C

This linear regulator is a low-dropout regulator that sources 300ma of output current. It has an input voltage range of 1.6V to 6V making it compatible with our battery voltage input of xx. This low-dropout regulator also has a very low dropout voltage of 140mV at 300mA. A highlighted feature for the TPS7A20C is its low quiescent current making our quarter panel PCB more energy efficient. Since we are dealing with sensitive sensors such as radar transceivers, this linear regulator offers a very low output voltage noise of 7 micro Vrms.

3.5.3.2 MAX25302A

The MAX25302A is an automotive low-noise LDO linear regulator. It has an input voltage range of 1.7V to 5.5V and programmable output voltage of .6v to 5.0V. This voltage regulator provides efficient power delivery with its 47mV dropout voltage, as well as its 1.3mA no-load supply current. This LDO linear regulator has an output noise of 5.1 micro Vrms. Another feature highlighted was that it was automotive grade, considering that the PCBs enclosure will be exposed to environmental factors such as high temperatures, vibration, and dust.

3.5.3.3 TPS7C84-Q1

Another automotive Low-dropout regulator to consider is the TPS7C84-Q1. Compared to the other LDO regulator this one has a wide range of input voltage and two fixed output voltages at 3.3V and 5V. The TPS7C84-Q1 has a high output voltage noise compared to the other voltage regulator of typically 265 micro Vrms.

3.5.4 Voltage Regulator Selection

After looking at the three voltage regulators the TPS7A20C couldn't be considered an option anymore, due to the UCF reflow oven not being compatible with the ball grid array (BGA) surface mount device. The TPS7C84-Q1 most noticeable feature was found in its wide range of input voltage, considering we will be working with an input voltage of xx the wide range of input voltage shouldn’t matter. A big downside that the TPS7C84-Q1 had was its high noise compared to the other voltage regulators. MAX25302A was the most favorable option due to its power efficiency , its automotive grade, and low noise. The downside of using the MAX25302A is the cost. Given that we will be working with different components requiring different voltage rails, we will need multiple voltage regulators.

	TPS7A20C	MAX25302A	TPS7C84-Q1
Input Voltage	**1.6V to 6.0V**	**1.7V to 5.5V**	**2.1V to 40V**
Dropout Voltage	**140mV**	**100mV**	**480mV**
Output Voltage	**0.8V to 5.5V**	**0.6V to 5.0V**	**1.2V to 39V**
Output Current	**300mA**	**2A**	**150mA**
Output Voltage Noise (Vrms)	**7uV**	**5.1uV**	**265uV**
Quiescent Current (Iq)	**11uA**	**1.3mA**	**50uA**
Cost	**$0.29**	**$3.15**	**$0.98**

Table : this table shows a comparison of all the voltage regulator in consideration and their power specification

3.6 Speaker

Audio speakers work by converting electrical signals into sound through multiple components working together. A typical speaker includes a diaphragm, voice coil, magnet, and a frame. As the audio signal is sent to the speaker, it travels through the voice coil inside the magnetic field. While the electrical current flows through the voice coil, it also creates its own magnetic field which moves the coil by the clash of the two fields. The movement in turn pulls and pushes the diaphragm which makes it vibrate and displace air particles around it. The vibrations create the sound waves that travel to our ears. The frequency and amplitude of the diaphragm’s movement determines the pitch and overall volume of the specific sound that is created. Enclosure size, shape and material can affect the sound quality and type of sound produced. While other speaker types exist and use different methods of creating sound. The general operation of a typical speaker utilizes the electromagnetic principles and movement creating the audio we enjoy or in our case, rely on for information and alerting of potential dangers.

A crucial component of our system includes an audio warning. An efficient and powerfully loud speaker is necessary to accomplish this design function. The main function is to provide a clearly audible and easy to hear warning that can be heard while operating the vehicle. The most important factor is the overall power output of the speaker as a loud enough sound must be produced. Another key factor is the efficiency of the speaker. We want our overall system to be energy efficient and not too demanding. A speaker that can operate in an efficient and effective manner is very important. And the last factor of speaker selection is the overall cost. While most small PCB-mounted speakers are not too expensive, we wanted to find an efficient and powerful speaker which can cost more if not carefully researched.

3.6.1.1 PEEK (Polyetheretherketone)

The polyetheretherketone speaker cone material is a high performance polymer that contains excellent mechanical strength and consistent stiffness at higher temperatures. This material is used in typical automotive and even aerospace electronics. It's a premier choice for a powerful sound with consistent performance while remaining durable in intense conditions. While it has many spectacular qualities, it is on the more costly side of typical speaker materials.

3.6.1.2 Mylar

The mylar speaker cone material, also known as polyethylene terephthalate (PET) is commonly used in soda bottles as well as smaller to middle sized loudspeakers. This material is tough and has a very high tensile strength for this type of material. This material is also very cheap and easy to produce making it a great budgetary option.

3.6.1.3 Aluminum

The aluminum speaker is a stiff but lightweight speaker material type. It has solid rigidity which reduces the distortion generally but especially at higher frequencies as well. It is more typically used in subwoofers and tweeter speakers. They are also known for high quality clarity and sound detail. They are usually a higher performance and quality speaker. They also can handle higher temperatures without overheating and distorting. Some disadvantages include resonation at certain frequencies which will require additional damping materials to operate at a respectable level.

3.6.1.4 Paper

Paper cone speakers are lightweight and can be molded into a plethora of shapes and designs. They lack durability so they are treated/coated to increase durability and moisture resistance. They are typically applied in midrange driver speakers and subwoofers. They are known for a warm, natural sound and thrive when projecting vocals and acoustics. The paper speaker's fibrous material provides solid damping naturally, which means it responds well to a smoother frequency type. It can produce a rich, full sound which is popular with common listeners. Paper speakers lack durability over time and despite being treated to avoid moisture, are still vulnerable to high concentrations of moisture. This equates to a short lifespan of the speaker quality.

3.6.1.5 Rubber

Rubber speakers are known for flexibility and excellent damping qualities. It is capable of withstanding wear and tear, temperature changes, and even resist moisture. Rubber speakers are usually used in a surround sound system because of its qualities. It especially excels in usage as a subwoofer in those systems. It maintains accurate alignment and control during usage admirably. They are known for high sound quality and response time. They are known for a durable long lifespan which makes it popular for consumer usage. Some negatives around rubber speakers include higher costs for a high-quality rubber material used. Also the rubber used can easily be manufactured incorrectly which results in degradation and the rubber becoming stiff or brittle.

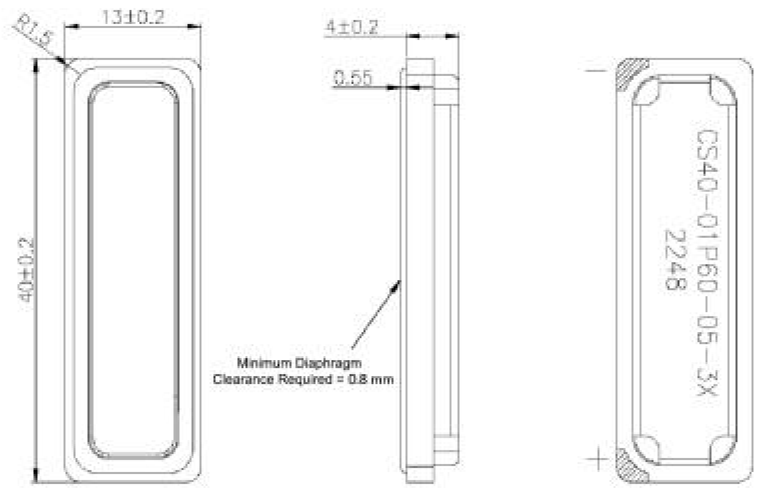
3.6.1.6 Titanium

Titanium speakers are exceptionally strong and lightweight. Its stiffness is top notch and is highly resistant to corrosion. It maintains its shape and structural integrity under high stress. It is commonly used in tweeter speakers and in dome or compression drivers. It possesses a high aptitude in producing high frequency sounds. This makes it common in high quality audio systems for professional level applications. Titanium speakers not only produce elite sound quality, but also have a high durability and resists distortion. Some disadvantages include its very high cost compared to most other options of speaker material. It also contains a complexity of manufacturing where if not done exactly correct, the speaker can have resonance issues. Sometimes titanium speakers also can have too high or bright sound some consumers would consider painful or annoying.

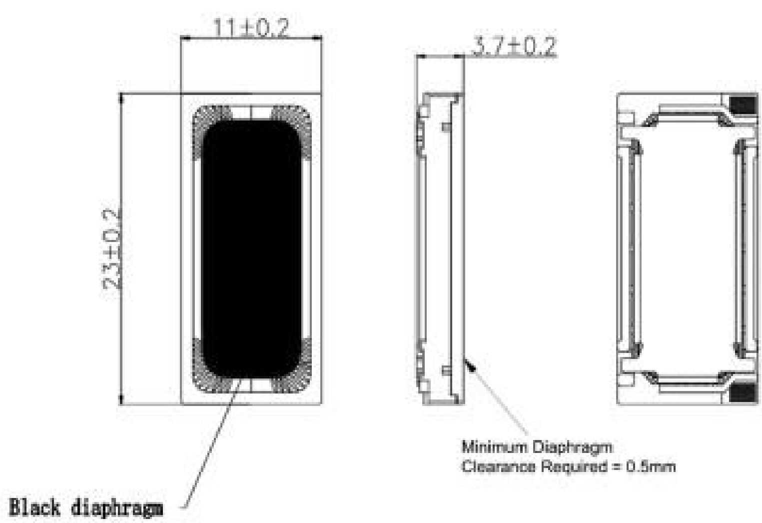
3.6.2 Speaker Selection

The two biggest design applications with our system is first, the ability for the sound alert to attain an 80dB or higher sound pressure level (SPL). The other application is to keep the system energy efficient and cost efficient. When selecting a speaker with those two factors in mind, we settled on two types of speakers. The first we decided on was the PEEK (polyetheretherketone) speaker cone. It contains the performance and output power necessary to achieve our goals for power and capability. The other option was the mylar (PET) speaker cone. It is a cheap and reliable material also capable of the required power output for a great cost. Below are diagrams of the four speaker options (two for each type) along with charts containing important information on the selected speakers. These drawing diagrams were obtained directly from the datasheets for each respective speaker.

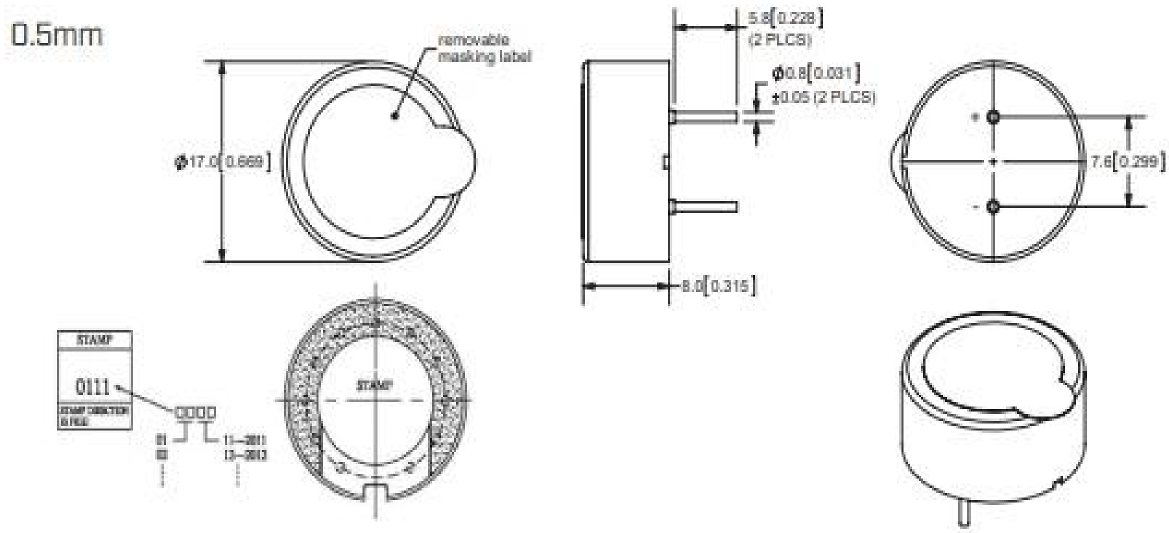
3.6.2.1 PEEK (Polyetheretherketone) Speaker [CS40-01P60-05-3X]



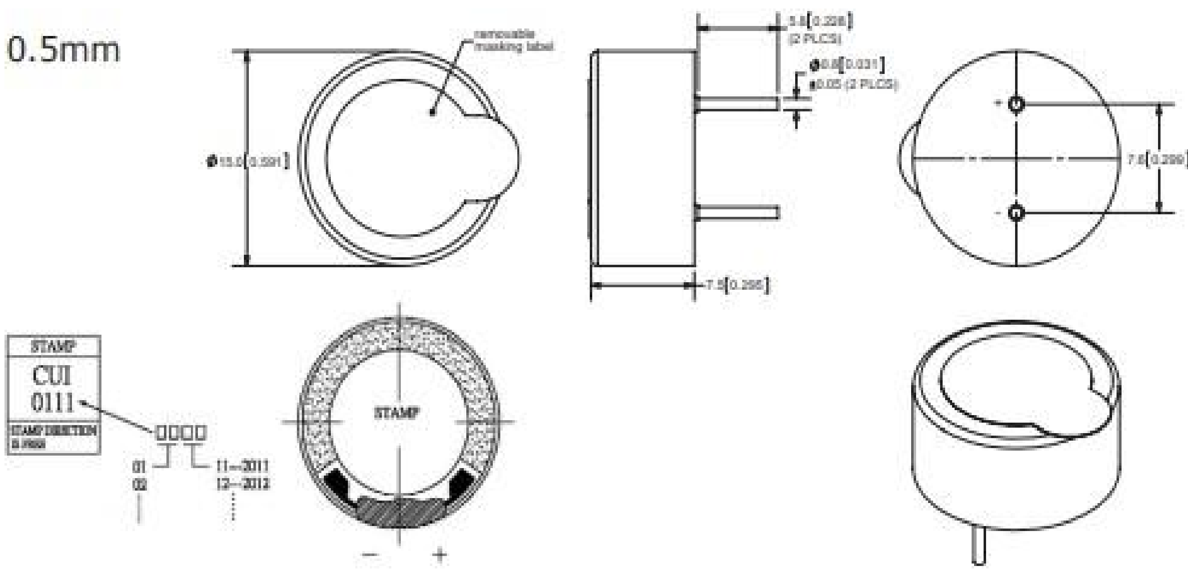
3.6.2.2 PEEK (Polyetheretherketone) Speaker [CS23-01P100-03-1X]



3.6.2.3 Mylar (PET) Speaker [CVS-1708]



3.6.2.4 Mylar (PET) Speaker [CVS-1508]



3.6.3 Speaker Comparison Chart

Speaker Model Number:	*Power Consumption:*	*Sound Pressure Level (SPL):*	*Operating Temperature Range:*	*Cost:*
CS40-01P60-05-3X	***1 Watt(s)***	***95 - 101 dB***	***-20 - 70*** ℃	***$3.55***
CS23-01P100-03-1X	***1.5 Watt(s)***	***100 - 106 dB***	***-20 - 60*** ℃	***$3.03***
CVS-1708	***0.5 Watt(s)***	***84 - 90 dB***	***-20 - 55*** ℃	***$3.07***
CVS-1508	***0.5 Watt(s)***	***84 - 90 dB***	***-20 - 55*** ℃	***$3.12***

These speakers are cost effective and are capable of achieving our system design ideals. These options should be able to operate at the desired sound pressure level (noise) and withstand higher temperatures. The speakers presented also are moderately power efficient and will not strain the overall system power draw.

3.7 Hazard Detection Technologies and Techniques

To implement real-time hazard alerts for the driver a system must be devised to continuously monitor and detect objects near and around the vehicle. To implement this several vantage points for mounting sensing devices were identified including the front bumper, front quarter panels, and rear quarter panels. Several technologies were considered for implementing this system, including LiDAR, cameras, ultrasonic sensors, and radar, then compared for the best solution.

Each method was evaluated based on its key characteristics, advantages, and disadvantages. The comparison included factors like cost, form factor, energy efficiency, tech specifications, and alignment with the IIHS (Insurance Institute for Highway Safety) standards for Advanced Driver Assistance Systems (ADAS). Although we aimed to meet IIHS standards, some requirements could not be fulfilled due to project constraints, including budget limitations, available lab equipment, and time restrictions.

While the system strives to meet IIHS standards as closely as possible, not all requirements could be fulfilled at this stage of the project. This was due to the practical limitations inherent in developing a prototype within the available resources. For example, certain higher-cost components were not feasible to integrate at this time, and specific IC mounting packages were beyond the current capabilities of the UCF senior design lab fasciitis. These compromises were made with the understanding that this implementation is a prototype, and future iterations will require modifications to fully comply with all safety standards.

3.7.1.1 LiDAR

LiDAR (Light Detection and Ranging) is a sophisticated object detection and distance measurement system that uses laser beams. It works by emitting a series of laser pulses, which reflect off obstacles and return to the sensor. A timing detector measures the delay between when the pulse is sent and when it is received. This delay is then used to calculate the distance between the sensor and the obstacle based on the speed of light, using the formula $D = \frac{\Delta t \times c}{2}$, where D is distance , t is time and c is the speed of light. Advanced LiDAR systems are capable of producing highly accurate 3D maps of their surroundings, which are particularly useful for detecting and identifying hazards, such as differentiating between vehicles and guard rails.

Despite its promising potential, LiDAR technology has several drawbacks and trade-offs. The first and most significant is cost. LiDAR systems capable of meeting our requirements—such as sensing distances up to 6 meters in daylight conditions with the necessary field of view—start at around $300. In comparison, radar modules that fit the same specifications can be found for as low as $10–$15. With our project budget set at $1000, incorporating at least four LiDAR units with the required field of view would exceed our budget by approximately $200, and this does not include the cost of other components. Thus, the high cost of LiDAR limits its feasibility for our system.

Another limitation is sensitivity to ambient light. Many LiDAR modules under $60 experience a significant reduction in accuracy and range in high ambient light conditions, such as bright daylight. Since most vehicles are driven during the day, this is a considerable drawback for our system. Additionally, affordable LiDAR modules often have a very limited scan angle—typically around 2°. This small field of view may be adequate for applications such as drone altitude measurement but is impractical for detecting vehicles, which vary widely in size and position relative to the sensor.

Environmental factors also present challenges for LiDAR systems. Although LiDAR is less affected by weather conditions than visible light sensors, it remains susceptible to obstructions such as rain, fog, and other forms of inclement weather. In particularly dense fog, water particles in the air can refract or distort the laser beam, leading to inaccurate measurements or reduced range. Finally, LiDAR modules generally consume more power than alternative distance-measuring technologies such as radar or ultrasound. For example, the TFmini-S ToF Single-Point Ranging Solid-State LiDAR Sensor from DFRobot operates at 5 volts, which would require us to use either two 3.3V batteries in series or a more complex power management solution. This module also draws an average of 0.6 watts, which would necessitate a large battery capacity, making it bulky and impractical for exterior mounting on the vehicle. Other methods had a peak power draw of only 0.189 watt and a supply voltage of 1.8 V making the LiDar unfit for our application.

3.7.1.2 Cameras and Stereo Vision

One method for forward hazard detection is a traditional stereo vision imaging system. This approach uses commercial off-the-shelf imaging sensors paired with a custom lens system that provides a wide field of view with minimal distortion. The system determines the distance to objects in the scene using stereopsis—the depth perception phenomenon humans experience.

In stereopsis, our eyes are separated, which leads to slightly different views of the same scene. The brain overlays these images to perceive depth. Similarly, in a stereo vision system, two imaging sensors are mounted on the same backplane, either horizontally or vertically aligned, with a fixed distance—known as the baseline—between their focal points. This separation causes objects to appear shifted between the two cameras' fields of view. By calculating pixel disparity (the difference in pixel positions of the same object in both images) and using known values like pixel size, focal length, and baseline, the system can compute the object's distance from the cameras.

To maintain accurate depth calculations, the cameras must remain a fixed distance apart and use identical lens systems. This ensures that differences in the images arise solely from the cameras' separation, not lens distortion.

While stereo vision offers accurate distance estimation, it comes with challenges. Weather conditions such as rain, fog, or smoke can obstruct visibility and reduce or even nullify the system's effectiveness. Additionally, processing two medium-to-high-resolution images is computationally expensive. It requires multiple passes of various image processing kernels and can involve floating-point arithmetic to produce results for each frame. The images also consume significant storage space: for example, greyscale images require approximately 900 KB per frame, while color images need around 2700 KB. With a target frame rate of 32 FPS for real-time hazard detection, the system demands a data transfer rate of nearly 1 GB/s.

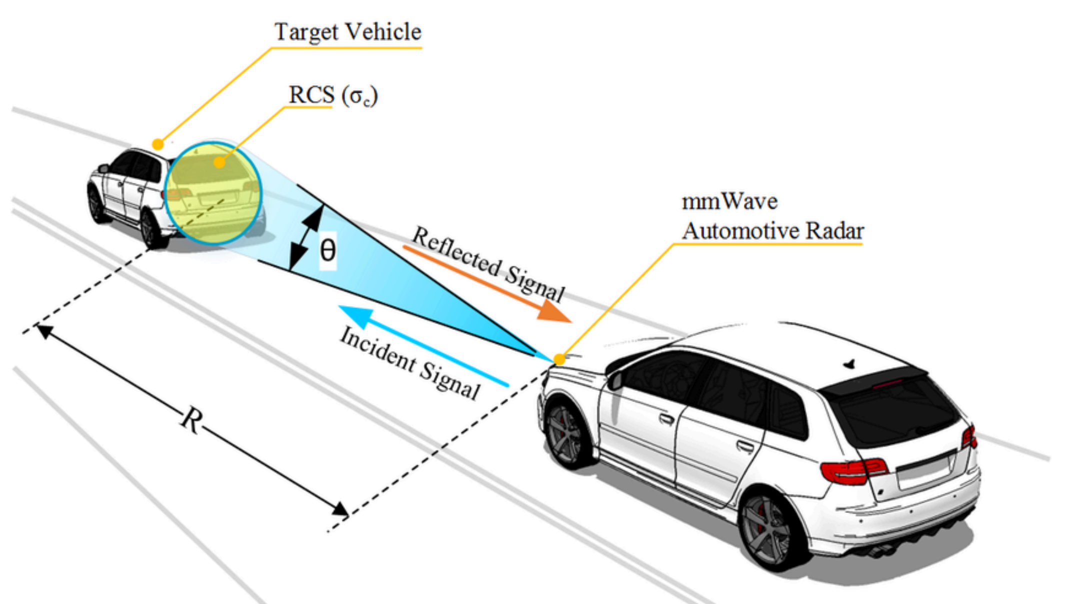
This high bandwidth requirement typically relies on specialized protocols like the Camera Serial Interface 2 (CSI-2) from the Mobile Industry Processor Interface (MIPI). However, most CPUs supporting the CSI-2 interface are packaged in Ball Grid Arrays (BGA), which are beyond the capabilities of UCF's senior design lab. To work around this, a potential solution involves using a Raspberry Pi System on Chip (SoC) to capture the images and downscale them to grayscale. The downscaled data can then be transmitted to an FPGA for further processing. The 18 GPIO pins on the Raspberry Pi and FPGA can be configured to transfer the grayscale image data at a suitable rate. While this setup avoids BGA limitations, it introduces additional complexity, requiring two Raspberry Pi devices and multiple FPGA units to handle the computer vision tasks effectively.

The FPGA also faces the BGA constraint of our lab, as any devices with more than 1,800 kilobits of memory utilize BGA packaging. Furthermore, FPGAs with sufficient memory to store an entire image cost over $3000—three times our total budget for this project. To address these limitations, we can work with smaller memory spaces using efficient pipelining and parallelism, which FPGAs excel at. By breaking the image into fragments, we can compute the necessary filters more effectively. Multiple filters can run simultaneously across different programmed modules and lookup tables (LUTs) on the FPGA. For example, once a pixel is processed by the hardware edge detection filter, it can immediately be processed by the hardware responsible for the Hough transform, rather than waiting for the entire image to be processed.

While this method is quite complex, it is a potential advanced goal due to the accessibility of the Artix-7 FPGA device used in UCF's FPGA lab, which provides access to a development board. Additionally, this process aligns well with our lane detection algorithm, which is part of our stretch goals, as it shares many of the same image processing techniques.

3.7.1.3 Radar

Radar (Radio Detection and Ranging) has emerged as one of the most widely



Radar Diagram

(Akram & Evans 2016)

adopted technologies for hazard sensing and obstacle detection in the Advanced Driver Assistance Systems (ADAS) market. Given its robust implementation across various automotive applications, radar is a strong candidate for our project. Understanding the reasons for its popularity within the industry reveals its significant advantages, which are rooted in both its technological capabilities and its adaptability to diverse driving conditions.

Radar systems function by emitting radio waves that propagate through the atmosphere at the speed of light (c). These waves travel until they encounter obstacles, such as other vehicles, pedestrians, or road infrastructure. Upon striking these objects, a portion of the waves is reflected back to the radar device, generating echoes that are detected by a receiver. The fundamental principle of radar operation lies in the Time-of-Flight (ToF) measurement. Similar to LiDAR technology, radar calculates the distance to an object by measuring the time taken for the transmitted wave to return after hitting an obstacle. This distance can be computed using the equation $D = \frac{\Delta t \times c}{2}$. This capability enables radar systems to perform real-time distance measurements, which are critical for collision avoidance and adaptive cruise control functionalities. As described by one manufacturer of automotive radar systems Texas Instrument "Millimeter wave (mmWave) is a specialized radar technology that utilizes short-wavelength electromagnetic waves. Radar systems transmit these waves, which are reflected by objects in their path. By capturing the reflected signals, the system can determine the range, velocity, and angle of the objects (Lovescu & Rao, 2020)."

In addition to distance measurement, radar technology can also evaluate the Doppler Effect, a phenomenon that describes changes in the frequency of waves in relation to an observer moving towards or away from the source. This allows radar to determine the velocity of moving objects with precision. For example, as an object approaches the radar sensor, the frequency of the returned echoes increases, while it decreases for objects moving away. Furthermore, radar can ascertain the angle relative to the transmitter, contributing to a comprehensive understanding of the surrounding environment.

The most substantial benefit of radar is its reliability and robustness to the outside environment. Due to its operation in the radio —or microwave ranges, radar is not influenced by visible light and range is not diminished in high ambient light environments such as bright sunlight. Radar is still, however, susceptible to attenuation (weakening of signal) due to heavy rain or fog. Smoke can also scatter radar signals

Radar is an established technology with a long history and many advancements and known methods for combating any shortcomings. Though radar is still susceptible to attenuation due to environmental factors techniques such as frequency adaptation can optimize the frequency for current conditions. For example higher frequencies such as 77GHz have higher precision and could provide better feedback in congested road conditions where every move counts for maintaining roadway safety. Conversely in inclement weather, such as heavy rain, higher frequencies are more susceptible to attenuation and noise artifacts making a frequency of 25 GHz more optimal for the current environment. While the lower frequency has less accuracy and precision, it is less susceptible to attenuation and noise from rain.

Radar is also relatively lower power compared to other considered methods with the exception of ultrasonic. Most considered radar devices used less than 0.2 watts. This makes the radar a strong contender for out battery powered wireless units. The battery and solar system would be able to power a radar device for an acceptable amount of time with only one 10,000 mA hr battery.

The biggest drawback of the radar devices was, like most of the other devices, the BGA SMT packaging. Radars operating at the 77GHz range all used the BGA packaging making them inaccessible for our senior design labs equipment. Further, even though the individual radar modules are inexpensive $10—20, development kits ran for no less than $200—almost a quarter of our entire budget.

3.7.1.4 UltraSonic Sensors

Ultrasonic sensors are another popular technology for object detection in modern vehicles equipped with ADAS—enhancing safety and navigation capabilities. Initially recognized as a leading solution by our team due to their prevalence and widely adopted use being implemented in various applications, including parking assist, but also obstacle detection in off-road environments. For instance, the UCF Senior Design Team, Group 5 of year(s) 2020–2021 project E.D.A.D.S: Enhanced Driver Awareness Detection System, utilized the MB 1003 HRLV Ultrasonic sensor for obstacle detection to assist in navigating challenging terrains in the sport of off-roading, such as boulders and tight walls that may be out of the operator's sight. By providing real-time feedback about the surrounding environment, ultrasonic sensors contribute to safer and more effective maneuverability in complex driving situations.

Ultrasonic sensors operate on principles similar to those of radar sensors but function within the sound spectrum. The system comprises a transmitter that emits ultrasonic signals—sound waves above the humane audible range, typically ranging from 20 kHz to 10 MHz. When these sound waves encounter an object, they are reflected back toward the sensor. The distance to the object is calculated using the Time of Flight (TOF) method, which measures the duration between the transmission of the wave and its reception after reflection. The fundamental formula used for distance calculation is similar to that employed in radar and LiDAR systems, with the speed of sound in air substituting for the speed of light in vacuum. This approach allows for accurate distance measurements over short to medium ranges.

Ultrasonic sensors offer several advantages that make them particularly suitable for specific applications. Firstly, they are generally accurate and effective for short to medium-range detection, making them a popular choice in parking assistance systems, where detecting nearby obstacles is crucial. Additionally, ultrasonic sensors are among the lowest power-consuming options available in object detection technologies, leading to more efficient electronic systems and reduced energy costs. They excel at detecting stationary objects, which is especially beneficial in scenarios where vehicles must navigate tight spaces or avoid collisions with nearby objects.

Despite their advantages, ultrasonic sensors also have notable limitations. They are susceptible to environmental variations such as temperature, humidity, and wind, which can distort air pressure and subsequently affect the speed at which sound propagates. These factors can lead to inaccurate measurements, particularly in dynamic weather conditions. Furthermore, background noise, especially prevalent on open roadways, can interfere with the sensor's ability to detect and accurately measure distances to objects. Rain can also scatter or dampen sound waves, compromising the sensor's functionality and accuracy. Additionally, soft objects, such as bushes or foliage, may absorb sound waves rather than reflect them, rendering the sensor ineffective in detecting such obstacles. Given these challenges, ultrasonic sensors are primarily recommended for short to medium-range detection, often struggling to identify other vehicles or obstacles located more than a few meters away.

While ultrasonic sensors have proven to be a valuable technology for specific applications, particularly in parking assistance and short-range and slow paced obstacle detection. However, their limitations in environmental adaptability and range make them less suitable for high-speed or long-range detection scenarios. Given these considerations, particularly in relation to environmental factors and range, ultrasonic sensors are mainly suited for parking assistance applications. Since our system does not target parking assistance, we have decided not to incorporate ultrasonic sensors into our design.

3.7.2 Selection

At the time of the 75 page submission, Radar and stereovision cameras are our primary candidates for system implementation. Radar can give us all of the hazard detection attributes we strive for in our goals due to its versatility, robustness and especially affordability. The implementation of a stereovision system remains an advanced goal, however it couples well with our lane detection goal and this is still on the table.

Technology	price	Light sensitivity	Weather sensitive	distance	FOV (typical)
Lidar	$30 +	Yes	highly	2 - 60 M	2 degree
Sonar	$10 +	no	highly	2cm - 5M	100 degree
Camera	$ 34 +	yes	highly	2 cm - 20 M	Module specific
Radar	$20	no	moderately	50 CM - 20 M	Antenna specific

3.7.2.1 Radar Module(s)

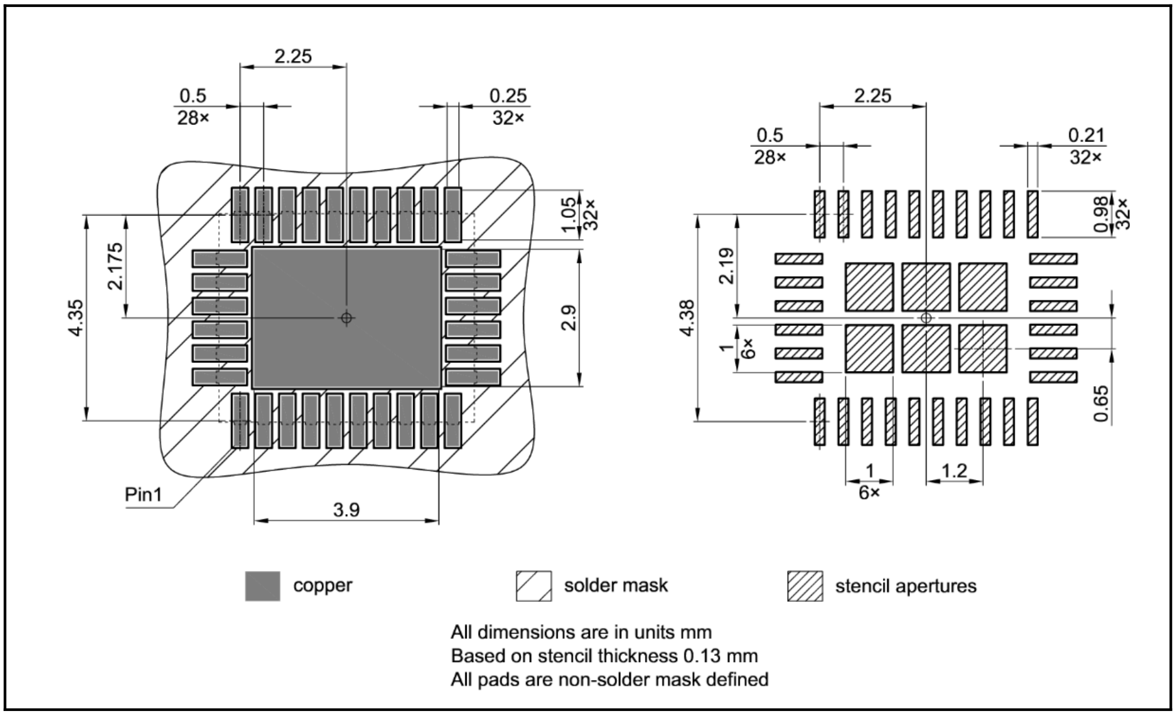
The radar modules on the design are used to detect hazards on to the side of the vehicle, especially when changing or merging lanes and, blind spot detection. Device selection was based upon price, power, and compatibility. We also needed to ensure the device could be installed and configured with the equipment available in the lab. Each of these aspects was weighed to choose the best option.

3.7.2.2 AWRL1432BDBGAMFRQ1 68-74 GHz Radar Module by Texas Instrument

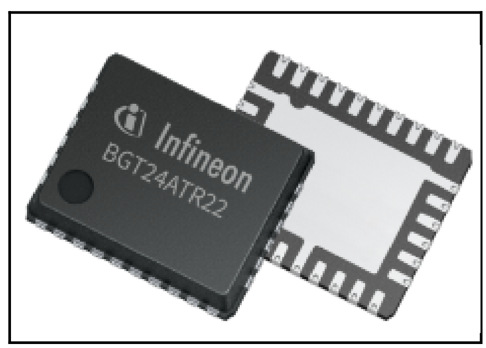
We initially decided upon the TI AWRL1432BDBGAMFRQ1 low-power automotive mmWave radar sensor due to its popular implementation in the already established industry for new vehicles. This module is a tx rx device operating from 76-81 GHz allowing it to see through inclement weather in a range of 10 - 15 meters. The drawback of this device is that it is designed to interface with a Ball Grid Array (BGA), a common surface mount technology (SMT) package especially in very small IC devices. BGA is beyond the capability of the facilities in the UCF Senior Design lab. While we could still move forward with this module and pay for a service to mount the IC, it would restrict us from making modifications to the design if needed, or at the very least, restrict the ease of modification, and become a money sink any time a modification were needed as the service would need to be re-purchased.

3.7.2.3 BGT 24ATR22

The BGT 24ATR22 is a 24 GHz radar module developed by Infineon, designed for short to mid range automotive applications. The module operates within a



voltage range of 1.76–3.465 V and draws 105–140 mA, depending on the selected mode of operation, making it compatible with our project's battery specifications. Overall this transceiver is well suited for our project design and real time hazard detection..



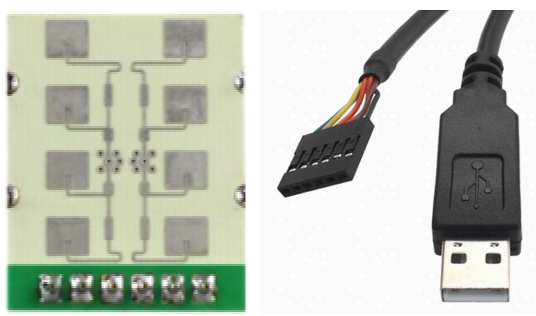
This module supports continuous-wave (CW) radar operation, which is essential for real-time monitoring and detection of nearby hazards, a key feature for vehicle safety systems. CW allows the module to detect and track the movement of nearby objects with high accuracy in the short to medium range which can help algorithms better scrutinize potential hazards and differentiate objects from other visual noise non-relevant to the system such as guardrails on the highway.The module is AEC-Q100 certified, ensuring it meets automotive industry standards for reliability in harsh environments.

The BGT 24ATR22 is housed in a PG-VQFN SMD package, which fits within the lab's capabilities. This package measures 5.5 x 4.5 mm, includes 32 terminals, and has a 0.5 mm pin pitch—the smallest pin pitch supported in our lab.

Despite meeting all technical requirements in the module itself, the 24ATR22 lacks an antenna. While we were able to find an RF antenna for our GPS device it was discovered that at frequencies as high as 24 GHz that custom antennas are often required. Infineon does offer a breakout board patch antenna within their demo package, however it is not offered separately and costs $331 per module. At 5 modules, this became a growing concern of its use in the project.

Resources are provided to design RF antennas into our PCB, however at 24 GHz, a special substrate such as Rogers RO4003C or RO4350B would be needed increasing the cost of the PCB order. While it is difficult to estimate a cost of a PCB without the entire design, when Google's (Alphabet INC) Gemini AI is prompted with the question "what would a good estimate for the cost of a 2 x 2 patch array made with a Rogers RO4003C or RO4350B substrate? … what range of cost would you give?" it responds "Based on the information provided about the BGT24ATR22 radar, a reasonable cost range for a 2x2 patch array would be between $1,000 and $3,000." Considering we would need an antenna for each of the 4 or 5 implemented radar modules, the Infineon solution is not practical for this project.

3.7.2.4 IMD-2000 Radar Module by InnoSent



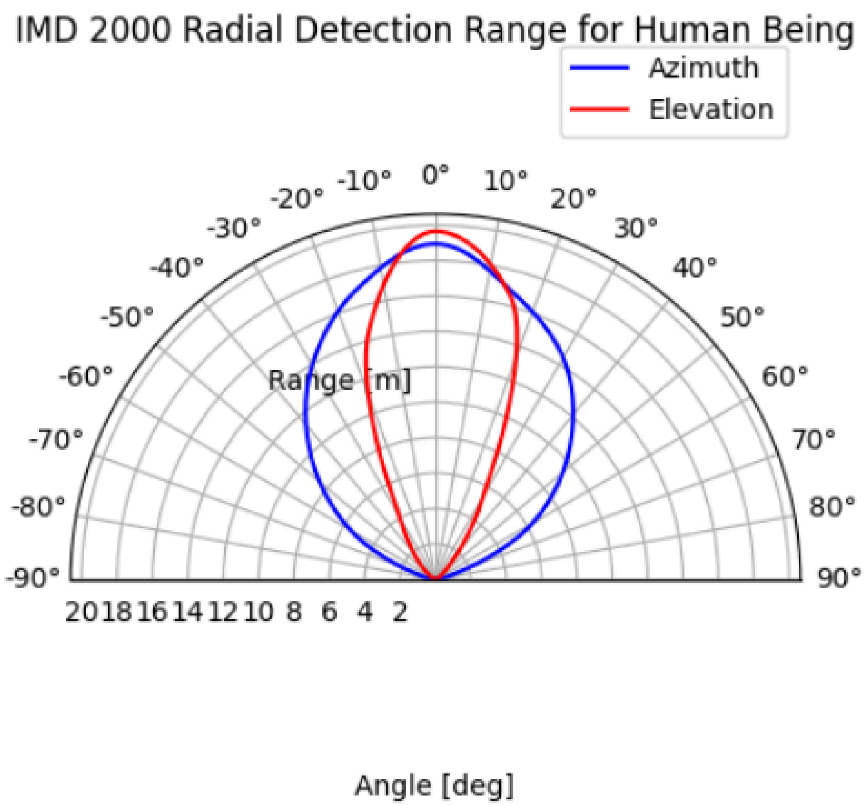
IMD-2000 evaluation board (left) with a 6 pin connector soldered to the 2mm pins, connection ttl-232r-3v3 (right)

The IMD-2000, a 25 GHz radar module from InnoSent, is commonly used in security applications, anti-intrusion systems, proximity detection, home automation, and escalator control. This module is capable of detecting moving objects and differentiating them by speed, direction, and range. It can track movement, velocity, direction, and distance relative to the sensor.

While the velocity detection is limited to 25 km/h (~15.5 mph), this limitation is not a critical factor for our project. The IMD-2000 can detect human presence at a typical distance of 20 m (~64 ft) and larger, more RF-reflective objects at a range between 0.5 to 50 m (~1.64 to 164 ft), making it well-suited for our application. Additionally, it meets our requirement for continuous wave (CW) mode.

The module comes with an easy-to-use evaluation kit, requiring only an FTDI TTL-232R-3V3 cable and a driver to interface with a computer via USB. It also complies with our lab's SMT (Surface-Mount Technology) capability constraints, thanks to its 2 mm pin spacing pitch. InnoSent provides a graphical user interface (GUI) for setup and programming, further simplifying its integration.

One of the major advantages of the IMD-2000 is that it comes with an integrated patch antenna, reducing the complexity of antenna design and implementation. This is particularly beneficial given the time constraints of our project. The radar has a specific field of view (FOV) in both the X and Y axes, with the horizontal FOV (Azimuth, shown in blue) covering approximately 100° at 10 m, which is acceptable for our application. The vertical FOV (Elevation, shown in red) is more limited, but since our project primarily focuses on ground-level hazards, this is not a significant concern. It can also be assumed that since vehicles are more reflective than humans that vehicles would have a modestly better radial detection range than that of the one provided for detecting humans.



The main drawback of the IMD-2000 is its cost. At approximately $53 per module, with five modules required, this radar solution would consume over a quarter of our project budget. Despite the cost, the IMD-2000 remains a strong contender, though we are also exploring more economical alternatives.

3.7.2.5 SMR-314 Radar Module by InnoSent

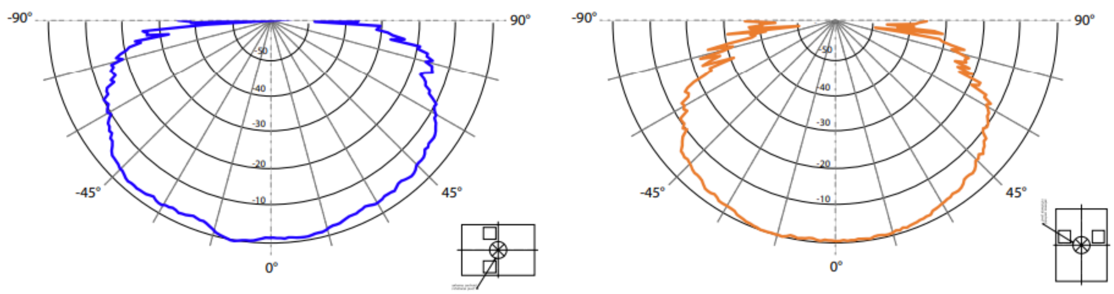
The SMR-314 is developed by InnoSent, designed for a variety of detection applications that support our project specifications. Operating in the 24.050 to 24.250 GHz frequency range, this module offers reliable performance in detecting movement, velocity, direction, presence, and distance. With a detection range of 10 to 20 meters, the SMR-314 is well within the requirements for our project, providing sufficient coverage for monitoring and hazard detection.

InnoSent offers two variations in the SMR series: the SMR-314 and SMR-334. The SMR-334 has a slightly greater detection range, but this comes at the expense of a narrower azimuth, resulting in a reduced field of view (FOV). The SMR-314, on the other hand, offers a broader FOV, which is more suitable for our application where wider coverage is critical. The wider FOV is more apt to provide blind spot detection. Between the two options, the SMR-314 stands out due to its combination of sufficient range and wide detection area, making it the optimal choice for our needs.

The SMR modules feature a 2 mm pin pitch, aligning well with the surface-mount technology (SMT) constraints of our lab environment. Its pin spacing makes it easy to handle and solder, allowing for efficient prototyping and assembly. Furthermore, the SMR-314 is well-documented, with detailed datasheets and user guides, ensuring that implementation and configuration can be performed with minimal difficulty.

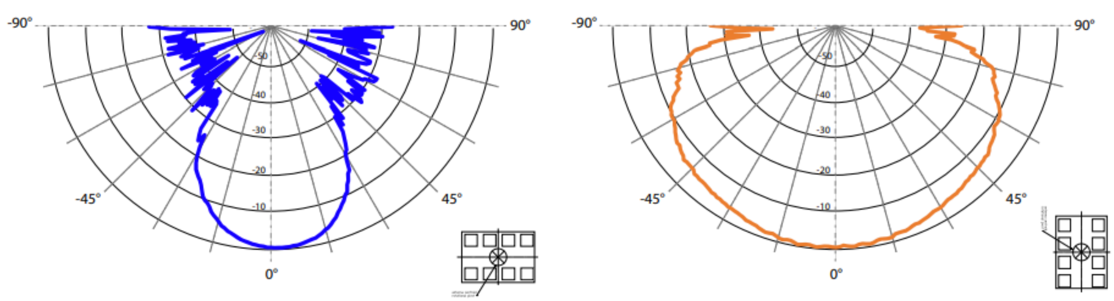
One of the key factors in choosing the SMR-314 is its superior radial field pattern compared to the SMR-334. The SMR-314 provides a much wider azimuth FOV of 121°, offering better lateral coverage, which is essential for our project's requirement of detecting objects across a broad area. In contrast, the SMR-334's narrower azimuth of 43° would limit the module's ability to detect objects at the periphery, reducing overall effectiveness. The SMR-314's wide FOV, therefore, ensures a larger detection area, increasing the likelihood of identifying hazards in time-critical situations with prolonged time of objects within the sensor range.

System Pattern SMR-314:



system pattern (-10dB)	azimuth	system_az		121		°
	elevation	system_el		111		°

System Pattern SMR-334:



system pattern (-10dB)	azimuth	system_az		43		°
	elevation	system_el		116		°

In terms of power consumption, the SMR-314 is efficient, operating within a voltage range of 3.2 to 3.4 V and drawing a supply current between 47 and 57 mA. This results in a total power consumption of approximately 194 mW, which is well within the capacity of our battery-powered system. The module's low power requirements ensure that it can operate reliably without placing excessive strain on our power budget, making it an ideal candidate for portable and energy-efficient applications.

Finally, the SMR-314’s affordability is a major advantage. Priced at approximately $23 per module, it represents a cost-effective solution for our project. Given our budget constraints, the SMR-314’s price point is highly attractive, especially when compared to more expensive options like the IMD-2000, which, although offering comparable features, would significantly increase overall project costs. The SMR-314 provides the functionality we need at a fraction of the cost, making it a practical and economical choice.

3.7.3 Selected Device

After evaluating all radar module options, we've chosen the SMR-314 for our project. It meets the required specifications, offering a suitable detection range, wide field of view, and reliable tracking of movement and distance. At approximately $23 per module, it provides a cost-effective solution while maintaining solid performance. The SMR-314 also eliminates the need for custom antenna design, simplifying its integration into our PCB, and its 2 mm pin pitch aligns with our lab's assembly capabilities.

Additionally, the SMR-314's low power consumption fits within the limits of our battery–solar power system, ensuring efficient operation without straining energy resources. Overall, the SMR-314 balances performance, cost, and ease of implementation, making it the best option for our radar needs.

Pt. No.	Frequency	FOV	price	packaging
AWRL1432B DBGAMFRQ 1	69-74 GHz	No Antenna	N/A	BGA
BGT 24ATR22	24 GHz	No Antenna	$16.50	QFVD
IMD-2000	25 GHz	Azimuth: 80 Elevation: 111	$24.00	10-pin
SMR-334	24 GHz	Azimuth: 121 Elevation: 111	$22.16	SMT
SMR-314	24.4 GHz	Azimuth: 43 Elevation: 116	$22.16	SMT

3.8 Vehicle Velocity Measuring

To maintain a safe following distance, the system must accurately determine the vehicle's speed. Measuring speed without directly interfacing with the vehicle's CAN (Controller Area Network) bus poses several challenges, limiting the available methods.

Initially, it was hypothesized that an accelerometer could be used to calculate speed through basic physics equations. However, accelerometers are highly sensitive to vibrations, which are amplified by the vehicle's engine and road imperfections, leading to unreliable data. Another proposed method involved tracking tire speed using a camera or monitoring the vehicle's surroundings. However, this approach requires significant computational power for image processing and accurate reference points, making it impractical.

After considering various alternatives, GPS (Global Positioning System) was selected as the optimal solution for velocity measurement. GPS provides precise speed measurements within an acceptable margin of error, even if positional accuracy is limited. GPS relies on a network of around 24 satellites, and a device's location is calculated through signals from at least four satellites. This process, called trilateration, uses the time and position data from each satellite to compute the device's location.

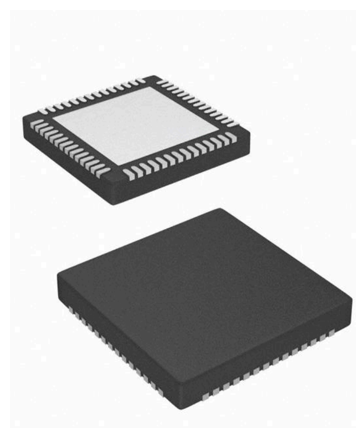
Although consumer GPS devices typically have a positional accuracy of 16–20 feet, the relative error between consecutive readings remains consistent, allowing for accurate displacement calculations. By dividing this displacement by the time between readings, the system can reliably compute speed.

3.8.1 GPS Module Selection

When selecting a GPS module, key considerations included power consumption, interface compatibility, lab facility and equipment constraints, and cost. Several GPS modules were evaluated based on these criteria.

3.8.1.1 STA8089GADTR

The STMicroelectronics STA8089GADTR initially stood out due to its "Automotive Grade" classification, which would ensure compliance with AEC-Q100 and AEC-Q101 specifications. These standards certify that the device operates reliably in harsh environments, such as extreme temperatures (-40°C to +125°C) and vibrations commonly encountered in vehicles (AEC Council, 2013). However, despite its appealing specifications, the STA8089GADTR is sold only in large quantities, with a minimum order of 2,500 units, making it financially impractical for this project.



STA8089GADTR

3.8.1.2 YIC31612EBGG

The YIC31612EBGG was also considered, offering the lowest cost at $5.98 per unit. It supports multiple global navigation systems, enhancing reliability. However, the module's 9600 baud rate limits its data throughput, which could become a bottleneck in situations where rapid speed updates are required. Additionally, the module has lower positional accuracy compared to other models.

3.8.1.3 TESEO-LIV4FTR

Ultimately, the TESEO-LIV4FTR was selected as the most suitable option, priced at $16.19 per unit. This module offers several advantages, including sub-meter accuracy, aided by an onboard temperature-compensated crystal oscillator (TCXO) and a reduced time to first fix (TTFF), thanks to its dedicated real-time clock (RTC) oscillator (STMicroelectronics, 2020). The TESEO-LIV4FTR also supports A-GNSS (Assisted Global Navigation Satellite System), improving performance in challenging environments.

Additionally, the TESEO-LIV4FTR's 18-SMD package can be easily integrated into the UCF Senior Design Lab using available reflow soldering equipment, making it both practical and cost-effective.

	Active	Automotive Grade	price
STA8089GADTR	Yes	Yes	$5000
YIC31612EBGG	No	No	$5.98
TESEO-LIV4FTR	Yes	No	$16.19

3.8.1.4 GPS Antenna

As our GPS device operates using RF (radio frequency) signals, an antenna is essential for reliable satellite communication. We have selected the TESEO-LIV4FTR GPS module, which recommends the use of an active GNSS antenna with a gain less than 36 dB and a noise figure below 1.5 dB. These specifications ensure better signal reception from satellite constellations, crucial for achieving the sub-meter accuracy the module is designed for. The lower noise figure helps maintain signal integrity, leading to improved accuracy.

An active antenna, unlike a passive antenna, has a built-in amplifier powered by an external source. This amplification enhances the incoming signal, improving performance and accuracy. Passive antennas, on the other hand, rely solely on the power provided by the transceiver and the incoming radio waves. For high-precision applications like sub-meter GPS, the added amplification of an active antenna is particularly beneficial.

3.8.2 Antenna Types

There are various types of RF antennas, including dipole, patch, chip, horn, cone, and loop antennas, each with unique radiation patterns and applications. Given the need to minimize the size of our system, we primarily focused on patch and chip antennas, known for their low-profile designs. Additionally, we required an SMD (Surface-Mount Device) antenna that could be soldered directly onto our PCB to streamline the design and assembly process.

3.8.2.1 SGGP.18.4.A.08

The first antenna considered was the SGGP.18.4.A.08 it operates at the required 1.575 GHz of the transceiver for the GPS L1 range. Its gain is 3.1 dB. It was discovered that this was not an active antenna despite its higher power draw of 8 W. The system could still work, but we would like to make the optimal selection.

3.9 Head Up Display

The secondary method of alerting the driver to a hazard that has been detected either on the road in front of the car or in the blind spot of the driver is the use of a head up display (HUD). A head up display is a method by which an image is projected onto the windshield of a car in the driver's field of view, so that information can be displayed to the driver without them having to look away from the road. Head up displays are becoming a more prominent feature in newer cars, as they increase the level of safety when driving.

A head up display is a display device used in automotives, aircraft, and other transport vehicles. It was initially utilized in helicopters and military aircraft, but now is moving towards more commercial uses. A head up display provides the driver with a view of multiple types of information on the windshield, so that they do not need to take their eyes off the road while operating the vehicle.

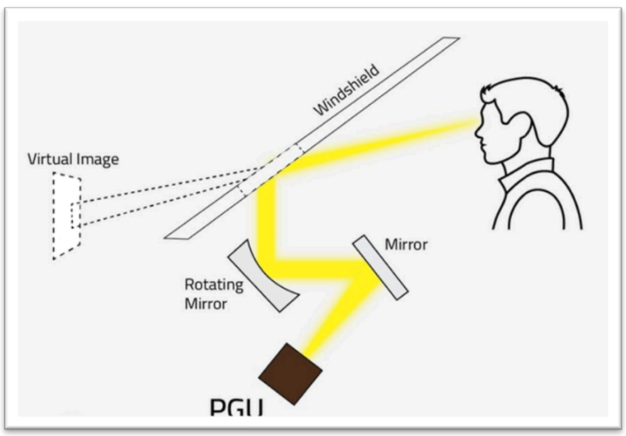


Figure #: Common design of a HUD

The first element of a traditional head up display is a PGU, or a picture generation unit. This is a device that combines all the data from the devices in the vehicle to be projected onto the windshield by the system. In the past, cathode ray tubes were used as the picture generation unit in a head up display. A cathode ray tube converts an electrical signal into a pattern of light to be displayed. This is done by using either magnetic or electrostatic deflection on a beam of electrons, causing a spot of light to appear on its phosphorescent screen. To produce color, three different electron beams are used, each one corresponding to one of the three primary additive colors, red, green, and blue. The manipulation of the electrons that make up these three beams in various combinations is what allows for the appearance of color on the screen, similar to the way RGB pixels work in modern displays. The use of a cathode ray tube is relatively outdated, and the majority of head up display systems now utilize liquid crystal displays, or LCDs. This is because liquid crystal displays have multiple benefits when compared to cathode ray tube technology, in that they are much thinner, more lightweight, less volatile, and overall consume less energy. A liquid crystal display produces an image using a backlight and utilizes the principle of blocking light as opposed to emitting light. An LCD screen is made up of many pixels, with each pixel consisting of three subpixels. Each subpixel corresponds to red, green or blue. These pixels work together to form the color of the larger pixel. The pixels are turned on and off and liquid crystals are used to rotate polarized light from the backlight when subjected to electric current. This allows for the desired light to pass through to produce colors on the display screen. Another commonly used PGU for traditional head up displays is an LED screen. An LED screen is a flat panel made up of light emitting diodes that turn on or off to produce an image, as a result of electrical signals being directed through their pins. LED screens are complicated to build, and are largely electrical and computer based, as opposed to optics.

The next part of the head up display is referred to as the relay optics. Relay optics are used to collimate the incident light from the picture generation unit. A collimated beam of light is one in which the rays of light are traveling parallel to each other. An uncollimated beam of light is one in which the light rays either converge toward a point or diverge from a point. The best method for collimating a beam of uncollimated light is to use a lens. This can be done by placing the lens exactly one focal length away from the source of the light. The focal length of a lens is proportional to the radius of curvature of its surfaces. Once the beam of light is collimated, then the image will remain the same size throughout the system, unless encountered by another lens. In the same way that uncollimated light becomes collimated when placed one focal length away from the lens, collimated light after passing through a lens will focus to a point exactly one focal length away from the lens.

The next component of the optical system which makes up a head up display system is a fold mirror. Fold mirrors are generally plane mirrors, simply used to increase the path length of the beam, while keeping the overall mechanical size of the system small. A plane mirror has a flat, non-powered reflective surface. When rays of light strike a plane mirror, the angle of incidence is equal to the angle of reflection. This allows for the collimated beam of light to be redirected at an angle based on the orientation of the mirror, without changing size or distorting the image. In the context of head up displays in commercial vehicles, fold mirrors are necessary to make the function possible while staying confined to a small space.

Finally, the last component of the head up display system is the combiner, or the windshield in the case of commercial vehicles. This is where the image focuses, and is in view of the driver, in a way such that they can view the road and the image without having to move their head.

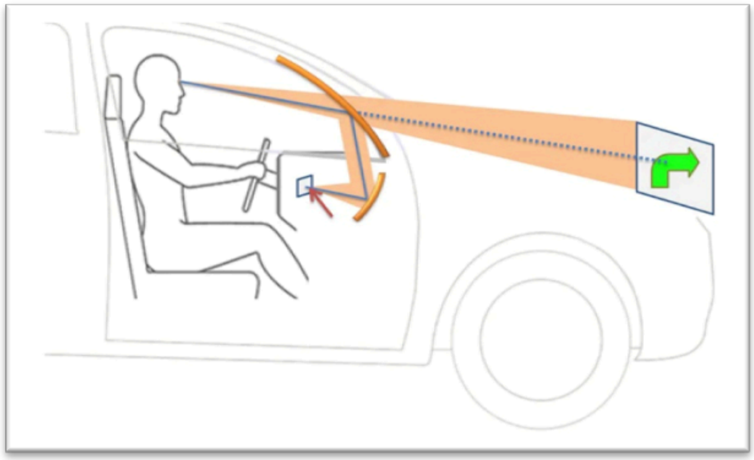


Figure #: Head up display system in context of a commercial automobile.

There are multiple different types of optics that can be used when building a head up display system. The configuration and the needs of the system in use determine which type of optic is best. Mirrors are a common optic used in head up displays, used to take the incoming light from a display and reflect it towards the user's field of view. This allows the user to see both the image from the mirror and the real world simultaneously, which is the principle upon which the concept of a head up display is built. Another common optic utilized in the design of head up displays are lenses. A lens is used to focus light to a specific size, and then direct it toward the area of interest. This is helpful when working with a system that requires the image seen by the user to be larger or smaller than the output image of the original display. Prisms are also a common type of optic used in head up display systems. A prism bends incoming light in a new direction, to create an image. In circumstances where the user's field of view is offset from the original display device, a prism can be used to project the image to the correct spot for maximum effectiveness.

Instead of a traditional layout, the head up display design that is being utilized for this project is a laser in conjunction with a 4F system. This uses the fundamentals of Fourier transform to produce an image at the end of the system, to be projected onto the windshield to alert the driver of potential hazards. The basic components of a 4F system are a laser, a beam expander, an object plane, 2 lenses of equal focal length, and an image plane. Multiple factors were considered in the decision process when selecting the components for each element of the system.

3.9.1 Laser

Any laser can be compatible with a 4F system, and all would work under the same guiding principles. However, the selection of lasers to use was first limited by the applications of our project. In our system, the head up display is being used as a visible alert to the driver, therefore the laser used to produce the image must be of a wavelength that falls within the visible spectrum. This means that the wavelength must be between approximately 380 to 780 nanometers. This rules out any infrared lasers, and ultraviolet lasers. Luckily, the lasers in those wavelength ranges tend to be more expensive, so using a visible laser will help the budget of this project as well.

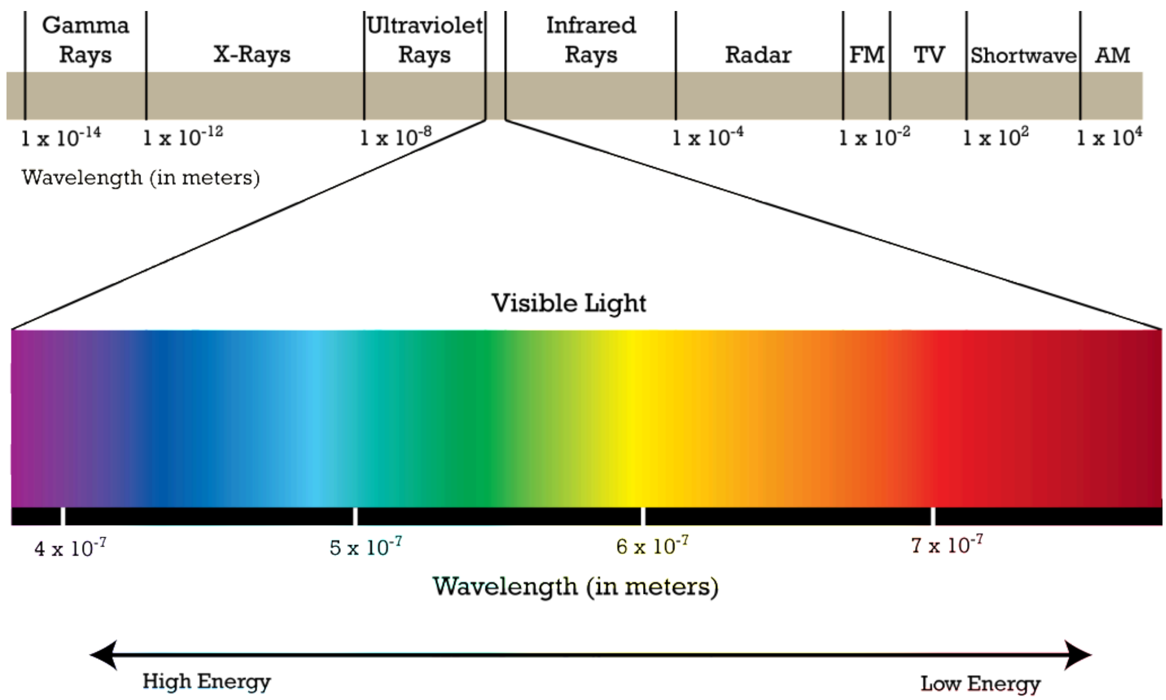


Figure #: Portion of the electromagnetic spectrum, revealing the wavelengths of visible light and their corresponding colors.

Within the visible spectrum, the common lasers are the Helium-Neon laser, diode lasers, and argon ion lasers. It was decided that using a red colored image would be ideal. This allows the image to be more easily distinguished from the background, and red is the universal warning or hazard color. This color preference eliminated the option of using an argon ion laser, which only emits at a wavelength of either 488 nm or 514 nm. These are the wavelengths that are perceived as blue and green light, respectively. Helium-neon lasers emit at a wavelength of 632 nm, which is perceived as red light, therefore it remains a viable option for the source of the head up display system. Finally, the laser diodes can be designed to emit a large variety of wavelengths, so they are another viable option of a source on the basis of color.

A helium-neon laser is a type of gas laser, consisting of a tube in which helium is used in conjunction with electrical signals to excite neon atoms. These excited atoms produce photons in a process known as stimulated emission. Helium-neon lasers are commonly used in labs for visual alignment purposes. They are widely available, but because they rely on the tube of gas to produce light, they tend to be in larger volume packages, which is not ideal for this project. The entire HUD system is constrained to the volume of the dashboard of the car it is being installed into. The HeNe laser was not chosen to be used for this project on the basis of size constraints.

Laser diodes can be fabricated to fit a variety of different parameters, so they are the best solution for this project. The diode selected must be in the visible spectrum, give off a red color light, and be eye safe. Eye safety is a very important feature for this application, because it will be used on the road. T must be harmless if accidentally directed into the eyes of the driver, or any other passing cars. Laser diodes also generally come in small packages, so this will also be ideal to meet the size constraints of this project.

The laser diode selected for use in this project is the VLM-650-01 LPT from Quarton Inc. This diode produces laser light at 650 nm, is a Class II eye safe laser, and has a package size of 10.4 x 18.4 mm. It requires a drive current of only 35mA, for an output of ~1mW.

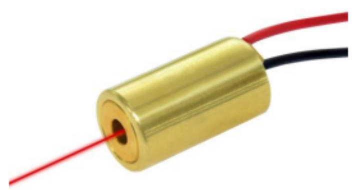


Figure #: Laser diode selected for use in the HUD

PN	HNL020RB	VLM-650-01-LPT-ND	VLM-520-03LPT-ND	38-1005-ND
Type	HeNe	Laser diode	Laser diode	Argon ion
Manufacturer	Thorlabs	Quarton	Quarton	US-Lasers
Wavelength	632.8 nm	650 nm	520 nm	808 nm
Package size	44.2 x 271.78 mm	10.4 x 18.4 mm	7 x 21 mm	10.4 mm
Drive current	6.5 MA	35 mA	80 mA	25 mA
Output intensity	2 mW	1 mW	1 mW	5 mW

Class	Class IIIa	Class II	Class II	Not listed
Cost	$1767.15	$17.64	$19.70	$54.32

3.9.2 Beam Expander:

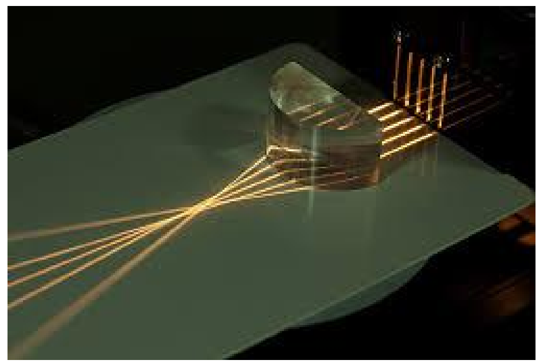
There are many different ways to expand a laser beam. You can build a telescope with a positive and a negative lens, you can buy a standard beam magnifier, or you can use a microscope objective. For this project a microscope objective is being used, along with a collimating lens. The main constraint for the selection of a microscope objective was driven by budget. The purpose of the beam expander in the optical design of the head up display is solely to increase the diameter of the laser's output beam, in order to overfill the mask in the object plane. By overfilling the template here, the system is able to process and output the image that will be seen at the image plane, on the windshield of the car. The objective selected for use is a 20x objective from AmScope, part number A20X-V300. This is an achromatic microscope, which has low levels of distortion, which aids in the performance of this project. The collimating lens selection will be discussed in the lens selection section of this paper, as it is dependent on the lenses selected for the rest of the optical setup.

PN	**A20X-YX2-V460**	**A40X-490**	**#43-904**	**#43-903**
Manufacturer	AmScope	AmScope	Edmund Optics	Edmund Optics
Magnification	20x	40x	40x	10x
Cost	$29.99	$29.99	$130.00	$100.00

3.9.3 Lens Selection:

The volumetric size of the head up display is largely determined by the characteristics of the lenses used in the system. Because the design of the head up display employs the principles of a 4f system, the length of the system is directly related to the focal length of the lenses in the system. The head up display system has to fit on the dashboard of a car, so it must be overall shorter than 12 inches of length. For this reason, three lenses with focal lengths of 25.4 mm were selected. The first will be used as a collimating lens placed after the microscope objective before the object plane. The second lens will be placed one focal length away from the object plane. Then, a distance of two focal lengths, in this case 2 inches, is placed between the second and third lenses. This is known as the Fourier domain, because where the light comes to a focus between the lenses, is where the Fourier transform of the image can be found. The third lens collimates the light, so that an image of constant six is produced. However, the image will be at its best focus exactly one focal length away from this final lens.

The height of the head up display system also plays a factor into the lens selection for this project. This is because the driver must be able to easily see over the system when it is placed on the dashboard. The main objective accomplished by using a head up display for this project is so that the driver can receive information without taking away from their view of the road. This is why it is important that the system not obstruct the driver's view of the road. For this reason, a diameter of 2 inches or less was desired of the lenses to be selected for use in this system.



Another feature of the lenses required by the design is that they must be Plano convex lenses. This means that one face of the lens has an infinite radius of curvature, or is flat. The opposite face must have a positive radius of curvature, meaning that the face curves outward, causing the side profile of the lens to be shaped like the capital letter D. When light rays are collimated when entering a Plano convex lens, the light converges to a point at the focal plane, and then diverges back. It is this quality of Plano convex lenses that produces the image formation process used in a 4f system.

After comparing the options available across multiple lens catalogs, Edmund optics was found to have the largest variety of spherical Plano convex lenses with small diameters and focal lengths. Their lens selection was also the most cost effective. The final selection of the lenses to purchase was the three of the #49-847 lens's from Edmund Optics. These are spherical Plano convex lenses, with a diameter of 25.4 mm, and a focal length of 25.4 mm. They are uncoated, which is fine for the wavelength of the laser diode selected for use in this project. The price for each lens was $31.00, which is reasonable considering the cost of lenses from other sellers.

PN	**#49-847**	**#29-094**	**LA1805**	**LA1401**
Manufacturer	Edmund Optics	Edmund Optics	Thorlabs	Thorlabs
Diameter	25.4 mm	50.8 mm	1 in	2 in
EFL	25.4 mm	50.8 mm	30 mm	60 mm

Glass type	N-SF11	N-SF11	N-BK7	N-BK7
Lens shape	Plano-Convex	Plano-Convex	Plano-Convex	Plano-Convex
Cost	$31.00	$47.50	$26.50	$42.18

3.10 Wireless Communication Methods

In this section, we will discuss the different types of wireless communication methods that we have looked into as a part of our research for this design, causing us to go over three different types of methods, being Wi-Fi, Bluetooth, and Zigbee. With these different types of options, we will look extensively into the different aspects of it, involving the data rate, the number of devices that it can connect to at once, and most importantly, the latency of the device. While we will be looking at all of these aspects as a priority, our overall priority will be focusing on the latency that each communication method has, as we believe that this is the most important aspect to focus on to help reduce the travel time of the data that alerts the driver of the obstacle, causing a quicker response and a reduction in the risk of accidents from the user.

Before we discuss this, we will first discuss a topic known as modulation, something that is heavily used in wireless communication. Modulation is helped to send the transmitted encrypted data wirelessly, with the use of radio signals, to the destination that will process this data and decrypt the information and use it as needed, along with the different forms of modulation that exists, or at least the ones that are the most prevalent.

3.10.1 Modulation

As a part of wireless communication, it heavily relies on a topic called modulation, which is a method that takes the radio signals that it received wirelessly from the radio waves and converts it into data to be used and processed by the system. This can come in multiple ways, such as receiving the radio waves from a phone playing audio and transmitting the audio waves into a wireless headset to play the audio, using the modulation technique to decode this data and allow it to play.

There are several modulation methods to choose from, all of which act differently from each other and have their own specific use cases. These different types that we will talk about are frequency-hopping spread spectrum (FHSS), direct sequence spread spectrum (DSSS), orthogonal frequency-division multiplexing (OFDM), and quadrature amplitude modulation (QAM).

3.10.1.1 Frequency-Hopping Spectrum Spread

An important aspect that is used in wireless applications is something known as FHSS, or frequency-hopping spectrum spread. FHSS is used within the wireless connection between two devices to ensure that the connection of the two devices stay between the two devices to prevent anyone from eavesdropping by rapidly changing the channels that the two devices are in.

To achieve this, the frequency band is divided up into differently and often evenly spaced frequency channels. With this, the two devices that are connected to each other are able to jump between these frequencies together. This band jumping technique has proven to be extremely vital in preventing signal jamming and techniques for breaking in and listening to conversations.

Trying to get into these channels as an external source has been proven to be very troublesome and difficult for users that are outside of the system due to the several variables involved with the channel hopping process, such as the hop duration, hop length, and the number of channels that can be used, with all of the devices attached in the system using the same values to ensure proper transmission of the data.

From the segments that will be seen later on, frequency-hopping spread spectrum is used in both Wi-Fi and Bluetooth, but predominantly used in Bluetooth. FHSS was used once in the first iteration of Wi-Fi, being 802.11, and ever since that it has used a different modulation technique. This is mainly because FHSS has tended to be the least complex and most power efficient modulation algorithm compared to the others that will be talked about, leading for it to be the modulation technique used.

3.10.1.2 Direct Sequence Spread Spectrum

For modulation technique known as direct sequence spread spectrum (DSSS), it will take the data that will be sent wirelessly to the specific device that is receiving this data, and turn it into a radio frequency that will have the data spread across the entire signal being sent wirelessly, and having this frequency get decrypted upon arrival. The way that this created is by multiplying the frequency with a chipping code, creating a frequency that is much larger than the intended bandwidth from both the transceivers and receivers, and when it is received by the receiver it will be decrypted with the use of the chipping code so it can receive the data from the frequency.

Direct Sequence Spread Spectrum provides a lot of benefits in regards to modulation techniques, such as providing a much stronger form of security to prevent people from intercepting the signal. Along with this, DSSS provides a better signal integrity that is being transmitted, resulting in a signal frequency that has a lower likelihood of interference and noise being picked up by the signal upon decryption of the system.

With direct sequence spread spectrum, it has plenty of uses but is mainly prevalent in a few. This tends to be more frequently used in Wi-Fi communication, specifically 802.11b, in GPS signals to make sure that the signal integrity being extremely important to get you to the correct location safely, and finally with cellular networks since it allows for an improved signal quality for using the networks for each user specific case.

3.10.1.3 Orthogonal Frequency-Division Multiplexing

Another important wireless modulation technique is known as Orthogonal Frequency-Division Multiplexing (OFDM), which will take the information that is being sent to a different device and split it across multiple narrowband channel frequency to send the information, that of which will allow it to be sent in different formats such as in parallel or simultaneously. Because of this format sending multiple frequency signals, it will allow for a much quicker decryption rate, allowing for the information to be processed a lot faster than the previously mentioned modulation techniques.

With orthogonal frequency-division multiplexing, it will have the signal that is being sent be processed through multiple sections, each having its own dedicated decryption zone for the receptor to deal with the information and process it as necessary. These dedicated zones have guard intervals, or periods where no decryption will occur, to prevent any interference between the signals as to not mix up the data. This process helps to increase the speed of which the data is sent and processed as a system, since the specific zones of which the frequency is encrypted is seen as a generally fast way of dealing with this data, especially when compared to other modulation techniques.

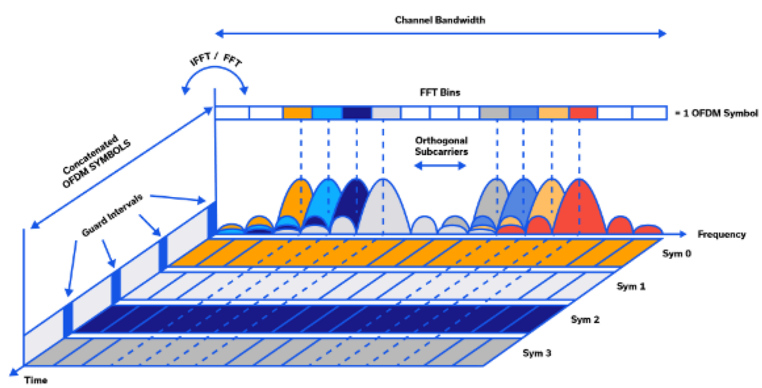


Figure [number]: Figure depicting the process of OFDM modulation

Orthogonal Frequency-Division Multiplexing is used in some of the faster ends of wireless data transmission, particularly when dealing with cellular and Wi-Fi networks, mainly in part due to its fast-processing speed from its decryption and radio frequency methods. With cellular, it is mainly used in LTE and 5G networks, which is what is seen as the most modern cellular communication methods, and for Wi-Fi it is most prevalent in 802.11a, 802.11g, and 802.11n.

3.10.1.4 Quadrature Amplitude Modulation

The final modulation that will be talked about is a method known as quadrature amplitude modulation (QAM). QAM has been seen as the most widely developed modulation method in recent history, with it being used in the most advanced and modern technology in the modern day. This advancement in QAM modulation has led to even future projects being developed to use advanced and theoretical versions of QAM that are yet to come out yet.

In quadrature amplitude modulation, it includes two analog carriers that will contain the data of the signal to be transmitted, and two carrier waveforms that will contain the superimposed data obtained by adjusting the amplitude of the data. In QAM, there are also a certain amount of amplitude states in these signals that are organized by powers of two that also affect the naming scheme of QAM, such as 2 bits per symbol resulting in 4-QAM, or 4 bits per symbol resulting in 16-QAM. All of these factors help to determine the data rate that is possible by these frequencies and how quickly the information is processed and dealt with by certain devices.

With the number of states in the different bits per symbol, it helps to determine how the data is processed and at which point based on how the waveform is manipulated. With this if frequency is depicted as 4-QAM, it will mean that the state in which the waveform is in is determined by the current state that the bits are in, being either 00, 01, 10, or 11. With these states, it will determine which part of the combined signals, along with how the amplitude is affected, will be adjusted to transmit out the proper information when being processed. This results in a plethora of waveforms that are being processed and are being worked on, in order to achieve the proper signal.

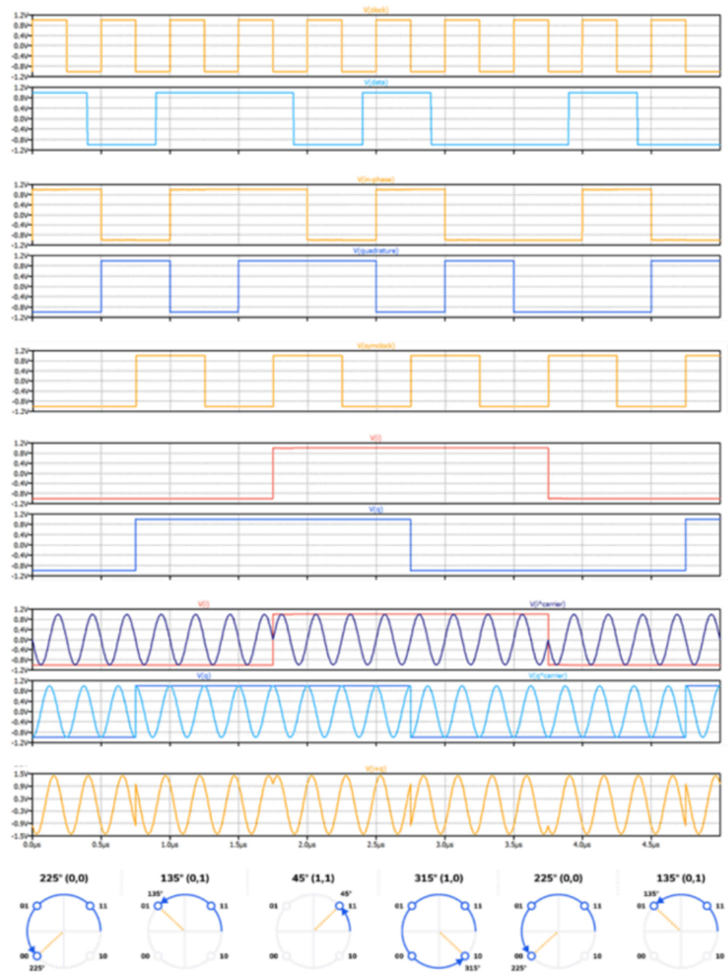


Figure [number]: Figure depicting the format of how 4-QAM is processed

The method of quadrature amplitude modulation is used in the modern versions of primarily in modern 802.11 standards for Wi-Fi communications. These have tended to be present in 802.11ac, 802.11ax, and are currently being used to develop future Wi-Fi standards. In these versions, it has used 256-QAM for 802.11ac and 1024-QAM for 802.11ax, being seen as having 8 bit states and 10 bit states respectively, something that is very complex, yet results in greatly increased data rates.

3.10.2 Wi-Fi

Wi-Fi is a wireless communication service that provides the exchange of data between electronic devices wirelessly through a network with the use of radio waves. With the use of Wi-Fi, there are several different types of communication standards that have been developed since its creation, involving IEEE 802.11 standards. With these standards, it allows for several specifications and options to choose from, allowing for options between frequency, data rate, and bandwidth.

Since the 802.11 standard conception in 1997 with, it has been adapted and updated several times within its 27-year lifespan. With this, every update has added some sort of functionality or upgrade to its previous version, such as a standard 802.11g adding an increased data bit rate for up to 54 Mbit/s from 802.11b having a limit of 11 Mbit/s, while 802.11n added a 5 GHz frequency and 40 MHz bandwidth option from it's predecessor, 802.11b. Despite there being all of these different types of versions of the 802.11 standard, the ones that are most commonly applied to today are the 802.11b and 802.11g standards, from 1999 and 2003 respectively.

	Year	**Frequency Band**	**Bandwidt h**	**Data Rate**	**Modulation**
802.11	1997	2.4 GHz	20 MHz	2 Mb/s	FHSS, DSSS
802.11b	1999	2.4 GHz	20 MHz	11 Mb/s	DSSS
802.11a	1999	5 GHz	20 MHz	54 Mb/s	OFDM
802.11g	2003	2.4 GHz	20 MHz	54 Mb/s	OFDM, DSSS
802.11n	2009	2.4 GHz, 5 GHz	20 MHz, 40 MHz	600 Mb/s	OFDM
802.11ac	2013	5 GHz	20 MHz, 40 MHz, 80 MHz, 160 MHz	6.93 Gb/s	QAM
802.11ax	2019	2.4 GHz, 5 GHz	20 MHz, 40 MHz, 80 MHz, 160 MHz	9.6 Gb/s	QAM

Table [number]: Table depicting the different 802.11 Wi-Fi standards

With Wi-Fi communication, there have been plenty of iterations of it throughout it's time, beginning with the original 802.11 standard, which provided the basic Wi-Fi communication standards, such as 2.4 GHz. Every following new version of the 802.11 standard were typically amendments to the previous ones, expanding on the iteration of the standard. These updated standards typically included things like expanding to 5 GHz and increasing the data rates of the standard.

With Wi-Fi having plenty of iterations of standards that improve on it, one of its best benefits is that it is able to connect a large quantity of devices onto it at the same time, being about 250 devices onto a single router. While this is mainly used in regards to working with providing a connection to the internet for the users, there can be several other use purposes to allow for the customization of the specific application that is needed.

Wireless connections via Wi-Fi also provide greatly reduced latency compared to some other wireless options, with the 2.4 GHz frequency having a median value of about 6.22 ms latency, and the 5 GHz frequency having a 0.90 ms latency. Within the scope of this project we are designing, latency is the top priority that we want to focus on between the transmission of information, seeing as the driver would need to react appropriately to avoid a potential incident.

3.10.3 Bluetooth

Bluetooth is a wireless communication method that specializes in the transmission of data between primarily short-range devices, with capabilities for transmitting primarily audio streaming and data transfer, with options for location services and device networks in certain instances. Both of these are classified into two separate versions, Bluetooth Classic and Bluetooth Low Energy, with each of them having their own unique properties for their own special use cases.

Bluetooth was first developed in 1994 for the use of creating short-ranged connections with nearby devices that also supported Bluetooth to give it a variety of applications. Since its inception it has used 2.4 GHz bandwidth for its connection purposes to transmit its data, the same bandwidth that most Wi-Fi devices use. It wasn't until 1999, however, for Bluetooth to be first introduced for consumer use with a wireless headset.

Despite Bluetooth being a fairly revolutionary invention, its first iteration, Bluetooth 1.0, had its fair share of issues. These issues were fairly prevalent issues involving a very limited range of 10 meters, a bit rate of less than 1 megabit, and obstacles preventing the connection from being secure. As Bluetooth became more developed it would eventually overcome these glaring obstacles to adapt to what we recognize it as in the modern day, along with greatly boosting the capabilities and ranges of the data rate and connection range.

Through these different uses of Bluetooth and its development over time, the existence of Bluetooth Classic and Bluetooth Low Energy has helped to develop and increase the applications of the technology. With these developments, it has helped to create networks of Bluetooth devices to transmit data from one node to another, through different types of communication and positioning methods.

3.10.3.1 Bluetooth Classic

Bluetooth Classic is the standard and most commonly used version of Bluetooth, at least for most consumer applications. Some of these applications would typically involve using streaming audio wirelessly with headphones or a speaker or connecting a video game controller to a computer or video game console.

With Bluetooth Classic, it is primarily used for its point-to-point communication methods, allowing for wireless communication from one node to another, allowing for direct communication between the two. This helps to maximize the data rate between devices, allowing for the source to maximize its strength and use capabilities for the user.

With regards to the bandwidth and channels used for its communication, Bluetooth Classic is able to take advantage of having bit rates of up to 3 Mb/s with a 2.4 GHz bandwidth with 79 channels containing 1 MHz spacing. This spacing allows for a quicker frequency-hopping spectrum spread to allow for a more secure connection between wireless devices. With the 79 channels that are in the frequency band, the devices that are connected with Bluetooth Classic will jump between the different channels in the spectrum randomly, preventing any outsiders from using any sort of exploit or hacking method to get within the private network. Bluetooth Classic also contains a latency of approximately 100 ms, something that matters most to us in the development of this system.

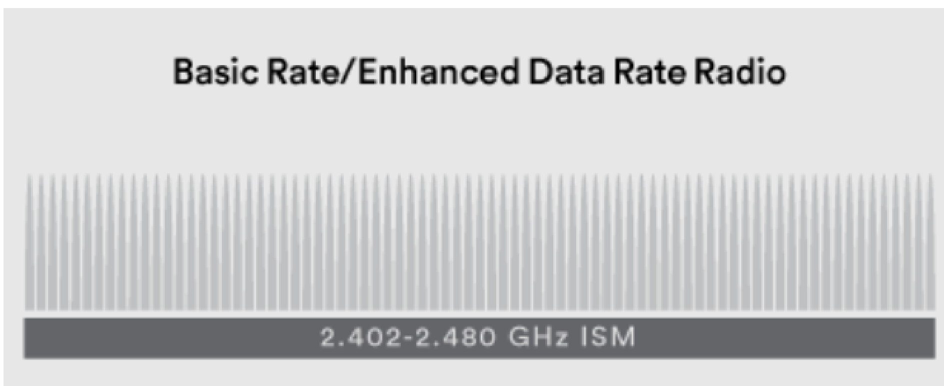


Figure [number]: Figure depicting the frequency band for Bluetooth Classic

3.10.3.2 Bluetooth Low Energy

Bluetooth Low Energy is another variant of Bluetooth transmission, but this allows for a lower power operation of frequencies. With Bluetooth Low Energy, it introduces new device communication and positioning methods to create more advanced and in-depth networks for the creator to choose from, allowing for newer solution areas for each specific use case, such as location services and networks of devices. The new methods that are present in Bluetooth Low Energy are not available in Bluetooth Classic, except for point-to-point, making everything else exclusive.

With the new device communication methods that comes with Bluetooth Low Energy, it includes the previous version of point-to-point from Bluetooth Classic, but also broadcast and mesh. Broadcast communication contains broadcasting a singular piece of data throughout the whole system simultaneously, so it gets to every point within a reasonable time, rather than going from one point to another one device at a time. The other communication method is mesh, which will create a network between the different points in the network to allow for the information to travel in an expected manner.

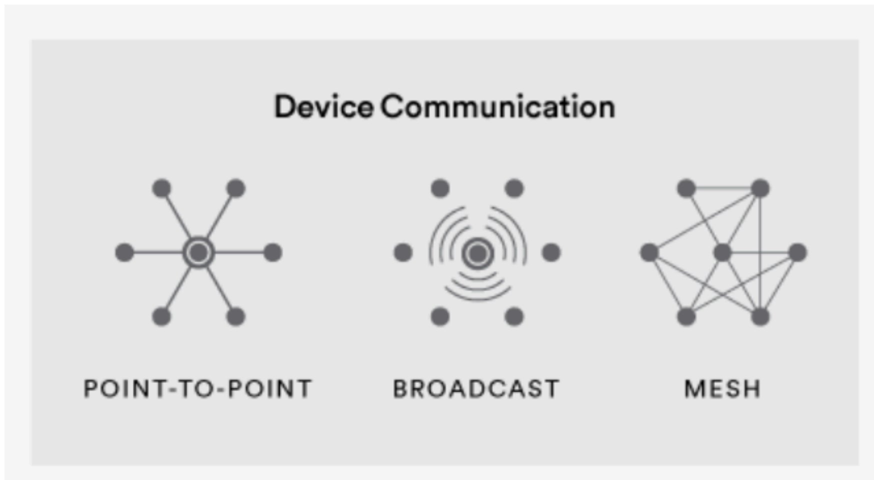


Figure [number]: Depiction of different device communication methods for Bluetooth Low Energy

Along with the device communication technologies present in Bluetooth Low Energy, it also introduces three types of device positioning methods that aren’t prevalent in Bluetooth Classic, being presence, distance, and positioning. For presence positioning, all the network has to do is detect the existence of another compatible device for it to become a part of the network and be able to be used for the developer's intended purposes. There is also distance positioning, which detects a device for the network based on where it is located and treats the device accordingly and keeps it within the network and how it functions based on the distance it is from the network. Finally, there is also direction positioning, where the device for the network is detected and used based on if it is pointing in the direction of the nearest node, and if it is it will be added and used for it.

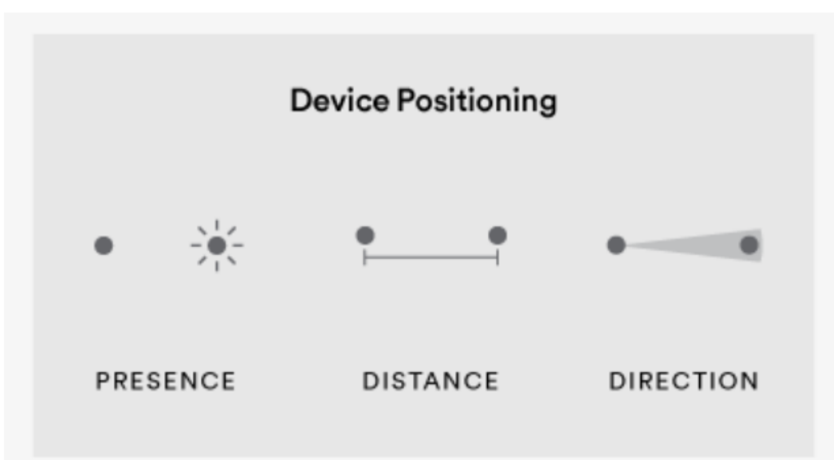


Figure [number]: Depiction of different device positioning methods for Bluetooth Low Energy

Bluetooth Low Energy also contains a 2.4 GHz frequency band that is used for transmission and reception, having 40 channels with 2 MHz spacing between them.

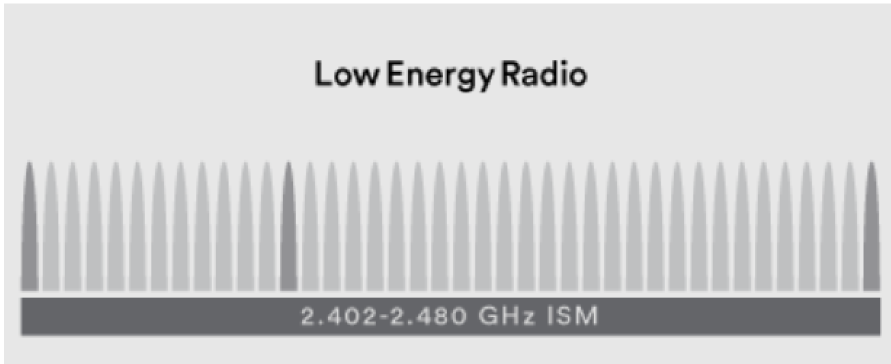


Figure [number]: Figure depicting the frequency band for Bluetooth Low Energy

With the 40 channels that are present, three of the channels are reserved for advertising channels with the other 37 used for data channels. The advertising channels within the frequency band are channels that contain information about the device and send it to other devices without actually forming a connection to these devices to broadcast this information. They help to reduce the amount of energy in the connection, since creating this wireless connection would draw more energy to the network, which would not be ideal for a network running on Bluetooth Low Energy

Bluetooth Low Energy also provides data rates of up to 2 Mb/s and as low as 125 Kb/s, allowing for a range of choices for the designers so they are allowed to choose how to properly design the system, and be able to bring the energy levels down as low as possible. When in regards to the latency of the system, Bluetooth Low Energy also allows for latency levels of approximately 6 ms, a value that looks to be very important for our system in the measurements that we would be taking.

3.10.3.3 Bluetooth Classic versus Bluetooth Low Energy

After going through the differences between Bluetooth Classic and Bluetooth Low Energy, it came to the decision that Bluetooth Low Energy would be the best version of Bluetooth to use in this system, mainly in part due to its focus on creating a network of devices to work together compared to Bluetooth Classic’s focus on audio and video streaming for devices. With this focus on creating a network for specific use purposes, Bluetooth Low Energy has a much lower latency of approximately 6 ms when compared to Bluetooth Classic’s approximately 100 ms, a value that we are most interested in focusing on for our project.

While Bluetooth Classic does have a few benefits over Bluetooth Low Energy, such as a higher data rate, more channels within the frequency band, and a lower frequency spacing, it was determined that these benefits did not matter as much to us in the design for this project, with our focus wanting to remain intent on creating a low latency, wireless connection network.

	Bluetooth Classic	**Bluetooth Low Energy**
Freq. Band	2.4 GHz frequency band	2.4 GHz frequency band
Channels	79 channels	40 channels (37 data channels and 3 advertising channels)
Bandwidth	1 MHz spacing	2 MHz spacing
Channel Encryption	Frequency-Hopping Spectrum Spread (FHSS)	Frequency-Hopping Spectrum Spread (FHSS)
Data Rate	1 Mb/s 2 Mb/s 3 Mb/s	125 Kb/s 500 Kb/s 1 Mb/s 2 Mb/s
Latency	Approx. 100 ms	Approx. 6 ms
Communication Methods	Point-to-point	Point-to-point Broadcast Mesh
Positioning Methods	None	Presence Distance Direction
Number of Nodes	7	Unlimited
Range	30 meters	50 meters

Table [number]: Table depicting the differences between Bluetooth Classic and Bluetooth Low Energy

3.10.4 Zigbee

Zigbee is another form of wireless communication method, focusing especially on creating personal access networks that will deal with smart devices used primarily within a home, such as light bulbs, smart thermostat, and smart locks. It has typically been used for creating simple connections between devices, to do simple tasks like turning on the device or changing the color for a light bulb.

While Zigbee creates fairly simple wireless communication networks, it allows it to come at an advantage of being able to create low-power and low-cost wireless systems, compared to the power and cost that other wireless alternatives, such as Wi-Fi or Bluetooth, tend to create. With this, it creates a wireless mesh network that will target a wide area of devices for the purposes of controlling and monitoring its activity, with the help of the IEEE standard 802.15.4, which allows for the use of mesh networks.

With Zigbee, it allows for more diverse options when wanting to create a network of personal devices and its own benefits, ones that are typically not offered by most other wireless communication methods. As talked about previously, Zigbee’s low-power capabilities have allowed for the devices that use this communication method to have a battery life of up to 10 years. Along with this, Zigbee allows for a massive network capacity, allowing up to 65,000 devices to be connected into a singular network, seeming massive compared to other wireless communication methods we have discussed.

Another important part of Zigbee is that with the way the communication method is designed, it provides a great amount of stability within its network, allowing for when a device leaves or disconnects from the network, it will be able to reroute the pathing between devices, causing the system to basically self-heal. And as mentioned before, another massive benefit with Zigbee is the cost effectiveness of the devices that use this methodology, providing a great benefit to the consumer and the producer.

As discussed previously, the latency of a wireless communication method is what we have been monitoring as our most important trait that we want to focus on, so we looked into this very seriously. With the latency that Zigbee has, the latency that it has is dependent on two variables, the size of the network and the size of the payload. When looking at a small network with a small payload, it took up to 90 ms to send the entire data amount, with a large network with a moderate payload taking approximately 130 ms to send the full data amount, and a small network with a moderate payload taking up to 130 ms to send. This can be looked at as fairly promising, since these low latency networks are seen as extremely valuable in our network systems as it allows for the driver of the car to react accordingly to the alert from the system.

3.10.5 Comparison of Wireless Communication Methods

After going through all of the applicable methods and the ones we believe would be the most beneficial of the system, we have decided on which type of wireless communication we will use, being Wi-Fi. While each form of wireless communication has its own benefits over each other, such as Bluetooth Low Energy having a different options for device communication and Zigbee being very beneficial in large network and low-energy scenarios, the latency that we are able to get from Wi-Fi communication is what we deemed as our biggest deciding factor, coming in at around 0.90 ms on average with a 5 GHz band. Along with this, we are allowed up to 255 devices to connect to the same Wi-Fi network, which we feel is more than enough to get through for our requirements that will have about six devices.

	Wi-Fi	**Bluetooth Classic**	**Bluetooth Low Energy**	**Zigbee**
Frequency Band	2.4 GHz, 5 GHz	2.4 GHz	2.4 GHz	2.4 GHz
Bandwidth	20 MHz, 40 MHz, 80 MHz, 160 MHz	1 MHz	2 MHz	2 MHz
Data Rate	Up to 9.6 Gb/s	Up to 3 Mb/s	Up to 2 Mb/s	250 Kb/s
Channel Encryption	FHSS, DSSS, OFDM, QAM	FHSS	FHSS	Advanced Encryption Standard (AES)
Number of Devices	255	7	Unlimited	65,000
Range	45 meters	30 meters	50 meters	300 meters
Latency	0.90 ms	100 ms	6 ms	130 ms

Table [number]: Table comparing different wireless communication methods

Chapter 4: Standards and Design Constraints

This chapter explores the standards and constraints related to the design process and market for the Proximity-Based Hazard Detection System for Older Vehicles (P.B.H.D.S.O.V). Our goal is to adhere to these guidelines to ensure user and bystander safety and to maintain the project's high regard. Compliance with these standards will help prevent any harm or negative outcomes associated with the system. We will list and analyze the relevant standards and discuss their impact on the design of the P.B.H.D.S.O.V.

4.1 Standards

The following sections below demonstrate the type of standards that we will be working with through out our design process for our system. These standards are used to help grow and develop new technologies as time goes on, with it advancing and creating revisions every few years. With standards, it has also greatly helped developers to create new products, as standards provide clear and concise goals that are needed to help create ease of development and ease of use for the consumers.

4.1.1 - IEEE 802 Communication Standard

The IEEE 802 standard is seen as a vital part of development for access to communication protocols such as Wi-Fi, ethernet, and Bluetooth. All of these communication protocols that are listed were built with the use of Local Access Networks (LAN), which creates a network of devices to connect a user from one point to another for its own applications.

When discussing the origins of IEEE 802, it had its true beginnings in 1979, when the Local Area Network Standards Committee met to discuss the standardization process of the idea to allow for a set of guidelines for developers. Since 1979, and its official adoption in 1980, the LAN/MAN Standards Committee has helped to create new standards to the IEEE 802 standards that will drive technology forward in the ever-changing landscape.

With IEEE 802, it has helped to pioneer and develop the modern existence of communication within a network since its inception in 1980. With its creation, it helped to create a set of rules and guidelines to allow for these networks to innovate into what we recognize today with connecting our Bluetooth headphones to our phones to listen to music or connect our laptop to a Wi-Fi router to have it connected to the internet for each user's own specific use cases.

With the IEEE 802 standard, it has allowed for the mass development and innovation of specific categories in particular, being IEEE 802.1, 802.11, and 802.15. All of these listed IEEE 802 standard groups have allowed for its innovation in its own ways, each of which will be talked about. There have been previous IEEE 802 standards besides these seven however, but these will not be talked about as they will not have a large application to this project.

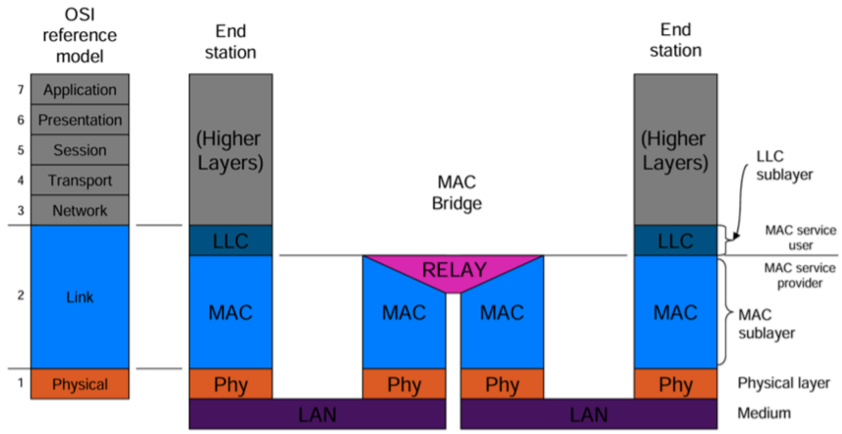


Figure [number]: Depiction of LAN Architecture

The IEEE 802.1 standard is the first major standard developed under IEEE 802, with a large focus on the bridging standards between the LANs together and describes how they connect and function. With the bridging, there are three main categories that these bridges are put into depending on what field they are worked into, being traditional bridging, audio video bridging (AVB), and data center bridging (DCB). With the IEEE 802.1 standard, it has helped to create bridges between different sections of a network to a different part, within under a second.

With traditional bridging, it helped to bring plenty of benefits to the consumer and developer sides of products by advancing how quickly a reconfiguration can occur, on an average of 50 milliseconds, and creating an expanse bridged network for the service providers to extend their reaches for providing coverage, all with the help of the implementation of the shortest path trees to allow for easy and quicker bridging. With AVB, this helped to develop the audio-visual systems to allow for a shorter transmit time and better synchronization abilities for the networks, along with standards dealing with streams for a multitude of applications. Finally, there is DCB, which deals with massive data centers that contain servers that hold all sorts of information, such as running a search browser and all the information contained in it, along with how the data flow operates to attempt to minimize the latency of using these.

Next would be IEEE 802.11, which focused on the development and creation of the standards related to Wi-Fi. In IEEE 802.11, it creates the standards and information necessary for what the developers should follow when wanting to create devices that will either create a Wi-Fi signal or connect to a Wi-Fi router, and the necessary specifications, such as the bandwidth, the band size used, and the data rate of the version. Because of this. Each new version of IEEE 802.11 improved or retained the aspects of the previous forms, such as increasing the data rate or bandwidth each update. These advances in IEEE 802.11 have really helped to develop and create new uses for up-and-coming technology, such as artificial intelligence and machine learning, augmented and virtual reality, and ambient power-enabled internet.

Finally, there is IEEE 802.15 which deals with wireless specialty networks, such as Bluetooth, Zigbee, mesh networks, and Internet of Things (IoT). These standards have helped to further develop personal devices and wearable items that use these features listed above, such as your smartphones and wireless headsets. The most commonly deployed version of IEEE 802.15 tends to be standard 802.15.4, which focuses on the development of low-rate wireless networks. With 802.15.4, we have been able to design and adapt with the portability of these Bluetooth and mesh networks to allow for it to reach for all specific use cases that the designer would need it to be intended for, and similarly includes new updates to the standard every few years so it can improve on both the designer and consumer side.

4.1.2 Roadway Safety

Our product aims to enhance driver awareness and safety for vehicles that lack Advanced Driver Assistance Systems (ADAS) incorporated by their Original Equipment Manufacturer (OEM). This automotive system must comply with roadway standards specific to the operational environment. ISO 26262 establishes safety standards for automotive systems, ensuring that software failures do not lead to external processes that could potentially harm individuals or property. It mandates that these systems be simple, reliable, maintainable, and testable [33].

While ISO 26262 does not specify discrete systems or implementations, its principles can be applied as described. This standard is crucial for our system's ability to reliably and accurately alert drivers to hazards in real-time, allowing sufficient time for reaction. Minimizing delay is essential to maximize the driver's response time. Additional robustness features should include soft-fail routines, where, if the system misses an alert deadline, it refrains from signaling a late alert. Rousing the driver at an inappropriate time could cause more harm due to erratic reactions.

Moreover, the system should effectively differentiate between various objects, such as guardrails, roadside trees, and actual in-lane hazards like merging vehicles. Faulty warnings can jeopardize both the driver's safety and that of surrounding vehicle operators.

4.1.3 Laser Safety

ANSI Z136.1-2022 Safe Use of Lasers: This American National Standard was released by the Laser Institute of America and is a set of guidelines for safely operating lasers. It classifies lasers based on their hazard level, and how to handle each class safely. Class I and II lasers can be safely viewed without a need for safety glasses, as long as the user does not stare directly into the beam path. For the uses of this project, the laser being used is a Class II, so that it will be safe to use on the roadway.

ANSI Z136.6 Safe Use of Lasers Outdoors: This standard uses the principles of Z136.1 and applies them to laser uses outdoors, factoring in weather, atmospheric conditions, and area containment. These factors have a slight impact on the project because the roadway is outdoors, but Z136.1 is having a larger impact on safety considerations when making parts selections.

IEC 60825-1: This is a standard published by the International Electrotechnical Commission that applies to all lasers that produce radiation in the 180 nm to 1 mm wavelength range. This standard holds laser manufacturers to standards about the hazard level of the laser, and proper labeling to warn users about the potential hazards of their products. All the laser products purchased for use in this project are held to this standard.

Class	Basis for classification	Signage
Class 1 SAFE Visible/non visible	Lasers which are safe under reasonably foreseeable conditions of operation. Generally a product that contains a higher laser class system but access to the beam is controlled by engineering means.	**CLASS 1 LASER PRODUCT**
Class 1M SAFE WITHOUT VIEWING AIDS 302.5 to 4000nm	Protection for the eyes is normally provided by the natural aversion response, including the blink reflex, which takes approximately 0.25 seconds. Beams are either highly divergent or collimated but with a large diameter. May be hazardous if optics are used within the beam.	**CLASS 1 LASER PRODUCT**
Class 2 LOW POWER Visible only	For CW lasers, protection of the eyes is normally afforded by the natural aversion response, including the blink reflex, which takes approximately 0.25 seconds. (These lasers are not intrinsically safe) AEL = 1mW for a CW laser.	**LASER RADIATION DO NOT STARE INTO BEAM CLASS 2 LASER PRODUCT**
Class 2M SAFE WITHOUT VIEWING AIDS Visible only	Safe under reasonably foreseeable conditions of operation. Beams are either highly divergent or collimated but with a large diameter. May be hazardous if optics are used within the beam.	**LASER RADIATION DO NOT STARE INTO BEAM CLASS 2 LASER PRODUCT**
Class 3R LOW/MEDIUM POWER 302.5nm to 1mm	Risk of injury is greater than for the lower classes but not as high as for class 3B. Up to 5 times the AEL for Class 1 or Class 2.	**LASER RADIATION AVOID DIRECT EYE EXPOSURE CLASS 3R LASER PRODUCT**
Class 3B MEDIUM/HIGH POWER Visible/non visible	Direct intrabeam viewing of these devices is always hazardous. Viewing diffuse reflections is normally safe provided the eye is no closer than 13cm from the diffusing surface and the exposure duration is less than 10 seconds AEL = 500mW for CW lasers	**LASER RADIATION AVOID EXPOSURE TO BEAM CLASS 3B LASER PRODUCT**
Class 4 HIGH POWER Visible/non visible	Direct intrabeam viewing is hazardous. Specular and diffuse reflections are hazardous. Eye, skin and fire hazard.	**LASER RADIATION AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION CLASS 4 LASER PRODUCT**

Chapter 5: Use of ChatGPT with other Similar AI Platforms

As an emerging technology AI has taken the world by storm starting largely with the release of chat GPT on November 30, 2022. It is the personal opinion of the team that AI is a great resource for research and digesting information. It is however also a tremendous liability for reliable information if not scrutinized appropriately and sufficiently.

One CPE member used Open Ai's Chat GPT and Google's Gemini for research and found many benefits but also several pitfalls, most prominently in inaccurate or blatantly false information. It is important to be cautious with information obtained from these sources and to verify them with other more reliable media.

5.1 AI Benefits

We did experience many benefits of incorporating generative AI into our design plan. Its use streamlined and an pacened the the research and investigative processes largely by compiling data as well as performing other automated tasks such as citation generation.

Citation Generation

One exceptionally helpful use of generative AI was citing sources. Typically for these reports, the process of citing information can be tedious and time consuming. With the use as demonstrated in Appendix-C prompt 2, Chat GPT was quickly able to cite the given link. This takes out the time consuming process of filling out block forums such as Cheggs Citation machine which require tedious and scrupulous effort to locate the information for each box. This also eliminates the need to change between tabs or dropdown menus to select between source types such as book, article or website. It also takes out some guesswork as to the formatting of the citation.

All this being said, it is still important to scrutinize the result. We did experience a citation result that had the incorrect publication date. It should be noted however that ChatGPT warned to check the publication date suggesting something in the system identified the lack of correct information but such is speculation.

5.2 AI Setbacks

Use of generative AI also came with a few setbacks. These setbacks were primarily limited to incorrect information or made up sources. Below some of these setbacks in detail

5.2.1 Standards lookup

Considering the portion of this project to research and follow standards relevant to the design and implementation, Chat GPT was prompted with the request “where can I find standards on automotive radar systems to see if my system complies?” (Prompt 1, Appendix C). It responded with a lengthy list of various standards organizations and different cases and a brief description of the topic covered by the standar.

One such example was “SAE J2948,” which was described as specifying performance requirements for forward-looking radar systems used in automotive applications, such as adaptive cruise control (ACC) and collision avoidance. However, upon further investigation, SAE J2948 was found on the SAE website, to be a standard regarding Keyless Ignition Control Design [32]. It turns out that Adaptive cruise radar systems control are actually covered in standard J2399_201409. It was further verified that the mixup was not caused by an out of data information, as revisions are denoted by an underscore with no modification to the original 5 characters, that being jXXXX_revision.

Despite the mixed up or false information, we were still able to use the information to narrow down our search. Where we were unsure where to begin and what organizations handled standards specific to our project, we now had a list that was at least accurate as to which agencies we should investigate.

Chapter 6: Hardware Design

Chapter 7: Software Design

Chapter 8: System Fabrication/Prototype Construction

Chapter 9: System Testing and Evaluation

Chapter 10: Administrative Content

10.1 Milestones

The following tables represent the milestones that we plan on achieving throughout both Senior Design 1 and Senior Design 2. In these tables, it shows the tasks, start date, anticipated end date, and the duration of each section

Optical Fabrication Milestones

Task	Start Date	Anticipated End Date	Duration
Component	9/6/2024	9/20/2024	2 weeks

Selection			
Order Components	9/6/2024	9/20/2024	2 weeks
System Testing	9/20/2024	10/04/2024	2 weeks
Optical Midterm Demo	10/08/2024	10/08/2024	1 day
Finalize Design	10/08/2024	11/15/2024	5.5 weeks
Final Optical Demo	11/21/2024	11/21/2024	1 day

Project Fabrication Milestones

Task	**Start Date**	**Anticipated End Date**	**Duration**
Individual System Design	09/28/2024	10/26/2024	4 weeks
Individual System Testing	10/27/2024	11/17/2024	3 weeks
BreadBoard prototyping	10/21/2024	11/11/2024	3 weeks
Prototype Project Testing	11/11/2024	11/26/2024	2 weeks
PCB Design/ Ordering	11/12/2024	12/03/2024	3 weeks
PCB Testing	01/06/2025	TBD	TBD
System Testing	TBD	TBD	TBD

Practice Demo	TBD	TBD	TBD
Final Presentation	TBD	TBD	TBD

Project Documentation Milestones

Task	**Start Date**	**Anticipated End Date**	**Duration**
Brainstorming	08/20/2024	08/22/2024	2 Days
Divide and Conquer Document	08/22/2024	09/06/2024	2 Weeks
20 Page Milestone	09/06/2024	09/20/2024	2 Weeks
50 Page milestone	09/20/2024	09/27/2024	1 Week
75 Page milestone (Research and Investigation)	09/27/2024	10/11/2024 Due Date: 10/25/2024	2 Weeks
120 Page Milestone	10/11/2024	10/25/2024	2 Weeks
150 Page Milestone (Full report)	10/25/2024	11/12/2024 Due Date: 11/26/2024	2.5 Weeks

10.2 Financing

Budget

Description	Quantity	Budget
Radar	4	70
Camera	1	35
MCU	6	70
LaneDetect FPGA	1	55
GPS Module	1	10
HUD	1	200
WIFI Module	6	50
Speaker	1	5
PCB Board	6	195
Battery	4	80
Solar	4	60
Total		830

Proposed Bill of Material

Part Description	**Part**	**Quantity**	**Price**
Radar	AWRL1432BD	4	66.36
Camera	Arducam Me	1	34.99
MCU	MSP430F6459	6	67.29
LaneDetect FPGA	TBD	1	50.40
GPS Module	TBD	1	5.30
HUD	TBD	1	200.00

WIFI Module	ESP32	6	48.00
Speaker	TBD	1	5.00
PCB Board	TBD	6	195.00
Battery	MakerFocus	4	79.96
Solar	P124	4	55.80
		Total Cost:	**808.10**

10.3 Work Distribution Table

Electrical Engineering	
Sebastien St Hilaire	Front Bumper PCB
	Quarter Panel PCBs
	Solar Power
Michael Nelson	Main PCB unit
	Front Bumper PCB
Computer Engineering	
Patrik Regan	Radar Detection
	Local Wifi connections
Jonathan Joslin	Stereo Vision processing
	Lane Detection

	Audio Alert system
Optical Engineering	
Allison Oehmann	HUD design
	Camera lens designs

Chapter 11: Conclusion

Appendix–A

Citations:

[1] Admin, “Average age of cars on the road,” *Hedges & Company.*, Mar. 02, 2024. https://hedgescompany.com/blog/2024/02/average-age-of-cars-trucks/

[2] “Early estimate of motor vehicle traffic fatalities in 2023,” *Crash Stats NHTSA (Nation Highway Traffic Safety Administration)*, Apr. 2024. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813561#:~:text=A%20statistical%20projection%20of%20traffic,as%20shown%20in%20Table%201 (accessed Sep. 02, 2024).

[3] “U.S.: average selling price of new vehicles 2023 | Statista,” *Statista*, Jun. 19, 2024. https://www.statista.com/statistics/274927/new-vehicle-average-selling-price-in-the-united-states/#:~:text=In%20the%20United%20States%2C%20the,in%202023%20than%20in%202022

[4] B. Wong JD, “Average salary by state in 2024,” *Forbes Advisor*, May 01, 2024. https://www.forbes.com/advisor/business/average-salary-by-state/

[5] “Traffic fatalities up 25% from a decade earlier; fatal and serious crashes cost nearly $1.9 trillion, new report shows - ATSSA,” *ATSSA*. https://www.atssa.com/news/traffic-fatalities-up-25-from-a-decade-earlier-fatal-and-serious-crashes-cost-nearly-1-9-trillion-new-report-shows/#:~:text=Utilizing%20data%20from%20a%202023,%2Dof%2Dlife%20costs.%E2%80%9D

[6] “Solar performance and efficiency,” *Energy.gov*. https://www.energy.gov/eere/solar/solar-performance-and-efficiency

[7] K. Zweibel and National Renewable Energy Laboratory, “Thin film photovoltaics,” conference-proceeding, Sep. 1998. [Online]. Available: https://www.nrel.gov/docs/fy99osti/25262.pdf

[8] Wu, Wen & Blaicher, Fabian & Seder, Thomas & Cui, Dehua. (2009). A Prototype of Landmark-Based Car Navigation Using a Full-Windshield Head-Up Display System. 21-28. 10.1145/1631005.1631012.

[9] Lovescu, C., & Rao, S. (2020). The fundamentals of millimeter wave radar sensors. Dallas; Texas Instruments.

[10] Al-Hourani, Akram & Evans, Rob & Sithamparanathan, Kandeepan & Moran, Bill & Eltom, Hamid. (2016). Stochastic Geometry Methods for Modeling Automotive Radar Interference. IEEE Transactions on Intelligent Transportation Systems. PP. 10.1109/TITS.2016.2632309.

[11] AEC Council. (2013). *Failure mechanism based stress test qualification for discrete semiconductors (AEC-Q101 Rev. E)*. http://www.aecouncil.com/Documents/AEC_Q101_Rev_E_Base_Document.pdf

[12] STMicroelectronics. (2024). *Teseo-LIV4F: Tiny dual-band GNSS low power and measurement engine modules* (Rev. 6). https://www.st.com/resource/en/datasheet/teseo-liv4f.pdf

[13] Tektronix, Inc., "Wi-Fi Overview: 802.11 Physical Layer and Transmitter Measurements," Primer, [Online]. Available: https://www.tek.com/en/documents/primer/wi-fi-overview-80211-physical-layer-and-transmitter-measurements. [Accessed: Sept. 24, 2024].

[14] J. Edwards, "802.11x Wi-Fi standards and speeds explained," *Network World*, Mar. 8, 2022. [Online]. Available: https://www.networkworld.com/article/964778/80211x-wi-fi-standards-and-speeds-explained.html. [Accessed: Sept. 24, 2024]

[15] IEEE Standards Association, "The evolution of Wi-Fi technology and standards," *Beyond Standards*, Oct. 29, 2021. [Online]. Available: https://standards.ieee.org/beyond-standards/the-evolution-of-wi-fi-technology-and-standards/. [Accessed: Oct. 1, 2024]

[16] B. Mitchell, "How many devices can share a Wi-Fi network?" *Lifewire*, Aug. 23, 2021. [Online]. Available: https://www.lifewire.com/how-many-devices-can-share-a-wifi-network-818298. [Accessed: Oct. 1, 2024]

[17] I. Grigorik, "WiFi," *High Performance Browser Networking*. [Online]. Available: https://hpbn.co/wifi/. [Accessed: Oct. 1, 2024]

[18] Bluetooth Special Interest Group, "Bluetooth technology overview," *Bluetooth.com*. [Online]. Available: https://www.bluetooth.com/learn-about-bluetooth/tech-overview/. [Accessed: Oct. 7, 2024]

[19] Auris, "The history of Bluetooth," *Auris Blog*. [Online]. Available: https://theauris.com/blogs/blog/the-history-of-bluetooth. [Accessed: Oct. 7, 2024]

[20] TechTarget, "Frequency-hopping spread spectrum (FHSS)," *SearchNetworking*. [Online]. Available: https://www.techtarget.com/searchnetworking/definition/frequency-hopping-spread-spectrum. [Accessed: Oct. 7, 2024]

[21] Rohde & Schwarz, "Hopper signals: Frequency-hopping spread spectrum," *Rohde & Schwarz Technology Fundamentals*. [Online]. Available:

https://www.rohde-schwarz.com/us/knowledge-center/technology-fundamentals/hopper-signals/hopper-signals_256050.html. [Accessed: Oct. 8, 2024]

[22] Semfio Networks, "BLE advertisement channels," *Semfio Networks Blog*. [Online]. Available: https://semfionetworks.com/blog/ble-advertisment-channels/. [Accessed: Oct. 11, 2024]

[23] MOKOSmart, "Bluetooth vs. Bluetooth Low Energy: A detailed comparison," *MOKOSmart*. [Online]. Available: https://www.mokosmart.com/bluetooth-vs-bluetooth-low-energy-a-detailed-comparison/. [Accessed: Oct. 11, 2024]

[24] Intel Corporation, "Differences between 802.11a, 802.11b, 802.11g, and 802.11n standards," *Intel Support*, May 21, 2023. [Online]. Available: https://www.intel.com/content/www/us/en/support/articles/000005725/wireless/legacy-intel-wireless-products.html. [Accessed: Oct. 11, 2024]

[25] Cisco Meraki, "Wireless fundamentals: Modulation," *Meraki Documentation*. [Online]. Available: https://documentation.meraki.com/MR/Wi-Fi_Basics_and_Best_Practices/Wireless_Fundamentals%3A_Modulation. [Accessed: Oct. 12, 2024]

[26] NinjaOne, "What is Direct Sequence Spread Spectrum (DSSS)?" *NinjaOne IT Hub*. [Online]. Available: https://www.ninjaone.com/it-hub/endpoint-security/what-is-direct-sequence-spread-spectrum-dsss/. [Accessed: Oct. 12, 2024]

[27] Mini-Circuits, "The basics of orthogonal frequency division multiplexing (OFDM)," *Mini-Circuits Blog*, Mar. 16, 2023. [Online]. Available: https://blog.minicircuits.com/the-basics-of-orthogonal-frequency-division-multiplexing-ofdm/. [Accessed: Oct. 12, 2024]

[28] Mini-Circuits, "A primer on quadrature amplitude modulation (QAM)," *Mini-Circuits Blog*, Sept. 12, 2023. [Online]. Available: https://blog.minicircuits.com/a-primer-on-quadrature-amplitude-modulation-qam/. [Accessed: Oct. 12, 2024]

[29] Vesternet, "What is Zigbee?" *Vesternet*. [Online]. Available: https://www.vesternet.com/en-global/pages/what-is-zigbee. [Accessed: Oct. 21, 2024]

[30] Silicon Labs, "Mesh network performance," *Silicon Labs*. [Online]. Available: https://www.silabs.com/wireless/multiprotocol/mesh-performance. [Accessed: Oct. 21, 2024]

[31] Google Gemini AI, "AI-generated response on [Estimating 2x2 patch array cost for RO4003C or RO4350B substrate]," Oct. 2024. [Online]. Available: https://g.co/gemini/share/25e3fd0b937d.

[32] SAE Standard J2948: Common Performance Criteria - Vehicle-to-Vehicle Communications for Safety Applications, SAE International, Jan. 12, 2021. [Online]. Available: https://www.sae.org/standards/content/j2948/. [Accessed: Oct. 22, 2024].

[33] "A quick guide to ISO 26262," Feabhas, [Online]. Available: https://www.feabhas.com/sites/default/files/2016-06/A%20quick%20guide%20to%20ISO%2026262%5B1%5D_0_0.pdf. [Accessed: 22-Oct-2024].

[34] IEEE Standards Association, "IEEE 802: Overview," *IEEE Standards Association*. [Online]. Available: https://standards.ieee.org/featured/ieee-802/. [Accessed: Oct. 21, 2024]

[35] T. Jeffree, "Overview of the IEEE 802.1 standards," presented at *GlobeCom 2009*. [Online]. Available: https://www.ieee802.org/misc-docs/GlobeCom2009/IEEE_802d1_Jeffree.pdf. [Accessed: Oct. 22, 2024]

[36] Semiconductor Engineering, "IEEE 802.15: Wireless specialty networks (WSN)," *Semiconductor Engineering Knowledge Center*. [Online]. Available: https://semiengineering.com/knowledge_centers/standards-laws/standards/ieee-802-15-wireless-specialty-networks-wsn/. [Accessed: Oct. 24, 2024]

[37] IEEE Standards Association, "IEEE 802.15.4-2020 - IEEE standard for low-rate wireless networks," *IEEE Standards Association*. [Online]. Available: https://standards.ieee.org/ieee/802.15.4/7029/. [Accessed: Oct. 24, 2024]

[38] A. Gates, “What is Maximum Power Point Tracking (MPPT),” *NAZ Solar Electric*. https://www.solar-electric.com/learning-center/mppt-solar-charge-controllers.html/

[39] Texas Instruments Incorporated, *BQ24650 Stand-Alone Synchronous BucK Battery Charge Controller for solar power with maximum power point tracking*, REVISED. Texas Instruments Incorporated, 2020. [Online]. Available: https://www.ti.com/lit/ds/symlink/bq24650.pdf

[40]

Appendix–C Generative AI

ChatGPT

Prompt 1:

where can I find standards on automotive radar systems to see if my system complies?

Answer 1:

To ensure your automotive radar system complies with industry standards, you can refer to several organizations and documents that set the requirements for automotive radar systems. Here are key resources where you can find relevant standards:

1. SAE International

SAE J2948: This standard specifies the performance requirements for forward-looking radar systems used in automotive applications, such as adaptive cruise control (ACC) and collision avoidance.

SAE J3016: Defines levels of automation, which might guide radar requirements based on vehicle autonomy level.

SAE J1739: Focuses on Failure Mode and Effects Analysis (FMEA) in automotive electronics, which includes radar systems.

SAE J3018: Describes the operational design domain (ODD) and environmental sensing requirements for autonomous vehicles, including radar.

Where to find: You can access these standards through the SAE International website.

2. ISO Standards

ISO 26262: This is the international standard for functional safety in automotive electronics. Radar systems used in safety-critical applications, like collision avoidance, should comply with this standard to ensure functional safety.

ISO 17387: Specifies requirements for lane change decision aid systems (LCDAS), which often use radar systems for object detection in blind spots.

ISO 21448 (SOTIF - Safety of the Intended Functionality): Addresses the safety of systems, like radar, where their intended functionality could present hazards (e.g., sensor limitations or environmental conditions).

Where to find: These can be purchased from the ISO website.

3. Federal Communications Commission (FCC)

The FCC regulates the frequency bands for automotive radar systems in the U.S. The primary frequency band for automotive radar is 24 GHz and 76–81 GHz, and it's important to ensure your system operates within these regulated bands.

Where to find: Visit the FCC website and search for specific frequency allocation and radar standards (Part 15.245 and Part 95 for radar).

4. ETSI (European Telecommunications Standards Institute)

ETSI EN 301 091-1: Specifies radar equipment operating in the 24 GHz band for automotive applications, ensuring that radar systems comply with European regulations.

ETSI EN 302 264: Focuses on short-range radar equipment operating in the 77 GHz to 81 GHz frequency range, commonly used in newer radar systems for more precise detection.

Where to find: Available on the ETSI website.

5. UNECE (United Nations Economic Commission for Europe)

UNECE Regulation No. 79: Addresses steering systems that include radar-based driver assistance technologies, such as lane-keeping and lane departure systems.

UNECE Regulation No. 152: Pertains to advanced driver-assistance systems (ADAS), which often utilize radar for functions like emergency braking and obstacle detection.

Where to find: UNECE standards can be found on the UNECE website.

6. IEEE Standards

IEEE 2020.1-2021: A standard for radar performance parameters, including automotive radar systems, focusing on radar cross-section, clutter, and interference.

IEEE 802.11p: This standard specifies wireless communication protocols used for vehicle-to-vehicle (V2V) communication, which may include radar data integration.

Where to find: Available through the IEEE Standards Association.

7. Automotive OEM and Supplier Specifications

Many automotive original equipment manufacturers (OEMs) and suppliers have their own internal standards or testing protocols for radar systems. If you're working with a specific manufacturer, you should consult their documentation for compliance.

Additional Considerations:

Regional regulations: Make sure your radar system complies with the regulatory requirements in your target market. For example, different regions have varying restrictions on electromagnetic emissions and safety standards.

Automotive EMC/EMI Testing: Ensuring your radar system complies with electromagnetic compatibility (EMC) and electromagnetic interference (EMI) standards (e.g., CISPR 25, ISO 11452) is crucial in automotive electronics.

By referencing these resources and standards, you can ensure that your system complies with the necessary regulations for automotive radar systems.

Promt 2:

can you site this website for me in IEEE format https://www.sae.org/standards/content/j2948/

Response 2:

Here is the citation in IEEE format for the website you provided:

[1] SAE Standard J2948: Common Performance Criteria - Vehicle-to-Vehicle Communications for Safety Applications, SAE International, Jan. 12, 2021. [Online]. Available: https://www.sae.org/standards/content/j2948/. [Accessed: Oct. 22, 2024].

Prompt 3:

i need an antenna for this radar BGT24ATR22

Response 3:

For the **BGT24ATR22** 24 GHz radar sensor, you'll need a high-frequency antenna capable of operating efficiently at 24 GHz. Here are a few antenna options that could work for your radar application:

1. **Patch Antennas:**

- **PCB Patch Antennas** are a popular choice for 24 GHz radar sensors due to their compact size and ability to provide a directional beam.

- Example: **2x2 or 4x4 Patch Array** antennas provide higher gain, which is suitable for applications requiring longer range detection or a more focused beam.

2. **Horn Antennas:**

- **Horn Antennas** offer high gain and a narrow beam, making them ideal for applications needing precise directionality and higher power in a specific direction.

- Example: **WR-42 Horn Antenna** is commonly used for frequencies in the 18–26.5 GHz range and is compatible with radar sensors like the BGT24ATR22.

3. **Monopole or Dipole Antennas:**

- **Monopole/Dipole Antennas** can work for 24 GHz radar applications, particularly for shorter-range detection and applications where compact design is crucial.

- These antennas provide an omnidirectional radiation pattern, making them more suitable for detecting objects in a wider area, though they will have lower gain compared to patch or horn antennas.

When selecting the antenna, consider the gain, radiation pattern, and whether you need a directional or omnidirectional solution for your radar system. The **patch array** or **horn antennas** are generally preferred for radar systems like the BGT24ATR22 due to their higher gain and more focused radiation patterns, which are useful for longer-range and more precise object detection.

Google Gemini

Prompt 1:

does the smr-314 by innosent suppoert a continuous wave mode?

Response 1:

The **SMR-314** by InnoSenT does **not** support a continuous wave (CW) mode. It operates in a frequency modulated continuous wave (FMCW) mode, which allows it to detect both moving and stationary objects and measure their distance, velocity, and direction.

The SMR-314's FMCW mode provides more information than the CW mode, making it a better choice for applications that require detailed object information. However, if you only need to detect motion and don't require distance, velocity, or direction information, the SMR-333, which is a CW radar sensor, might be a more suitable option.

Here's a summary of the key differences between the SMR-314 and SMR-333:

Feature	SMR-314	SMR-333
Mode	FMCW	CW
Object detection	Moving and stationary	Moving only
Distance measurement	Yes	No
Velocity measurement	Yes	Yes
Direction measurement	Yes	Yes
Antenna pattern	Wide	Narrow

I hope this helps!

A throw away page to keep cut Items until we have agreed to remove them permanently.

Design will include independent audio notification of hazards and be capable of alerting the typical driver.

1.) Design will include operational Heads-Up-Display (HUD) to notify when hazard is occurring and where the hazard is occuring.

2.) Design will include battery charging from mounted solar panels to power peripheral radar devices.

3.) Design will be considered affordable in comparison costs to a new car or mainstream upgrades.

4.) Wifi communications will be capable of communication and notification in less than one second.

5.) Design of prototype will be configurable to fit and operate on most sedans, crossovers, SUV’s, and even trucks.