

Proximity-Based Hazard Detection System for Older Vehicles

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Chapter 1: Executive Summary

Older vehicles lack sufficient safety features compared to newer vehicles you see on the road today, the Proximity-Based Hazard Detection System for Older Vehicles (P.B.H.D.S.O.V) looks to close that gap. While people today don't have the luxury of purchasing a brand-new vehicle with modern safety features, we tend to see more people settling for purchasing an older vehicle. this product will utilize multiple sensors placed throughout the vehicle to obtain the necessary data that will notify the driver of any hazardous information while driving. This product can alleviate any financial stress for any consumer who's considering the safety features between a used vehicle vs a new vehicle, as well making the road a safer place to drive.

We came across multiple components to use to improve the safety features and provide hazard detection of older vehicles such as lidar modules, ultrasonic sensors, cameras, and radar sensors. After considering all four of these components we decided to apply just the cameras and radar sensors. Both components provide enough safety capability to bring older vehicles up to standard to modern vehicles while maintaining a desirable budget. These components will be covered with more information and reasons for our selection throughout this report.

We aim to provide a post stock safety system, where anybody can easily apply it to their own vehicle. This design will involve six printable circuit boards (PCBs) with multiple purposes. We will have an in cab PCB, communicating with the driver through the head up display projected on the window, speaker, and buzzer. A front bumper PCB that will integrate with the camera to determine the distance between the car and vehicle ahead as well as lane detection. Four Quarter Panel PCB that will monitor the blind spot of the vehicle, notifying the driver of any vehicle when merging. Powering the system will come from multiple power supply units (PSU), both using the car's electrical system as a power source and a solar panel that will be mounted on the top of the vehicle.

Concerns that came to mind when researching this system were adhering to the different standards, constraints, latency, etc. understanding these concerns and working with them in mind allows us to build a safe product that consumers can trust. These concerns will be addressed throughout the report.

Overall, the Proximity-Based Hazard Detection System will have an impact not only on the safety of the driver but also lower the risk of accidents on the road by introducing safety features that other modern vehicles have. This report will cover our goals, research, standards and constraints, design, testing, etc.

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 (Head Up Display) projected onto the windshield. The Head Up Display 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.

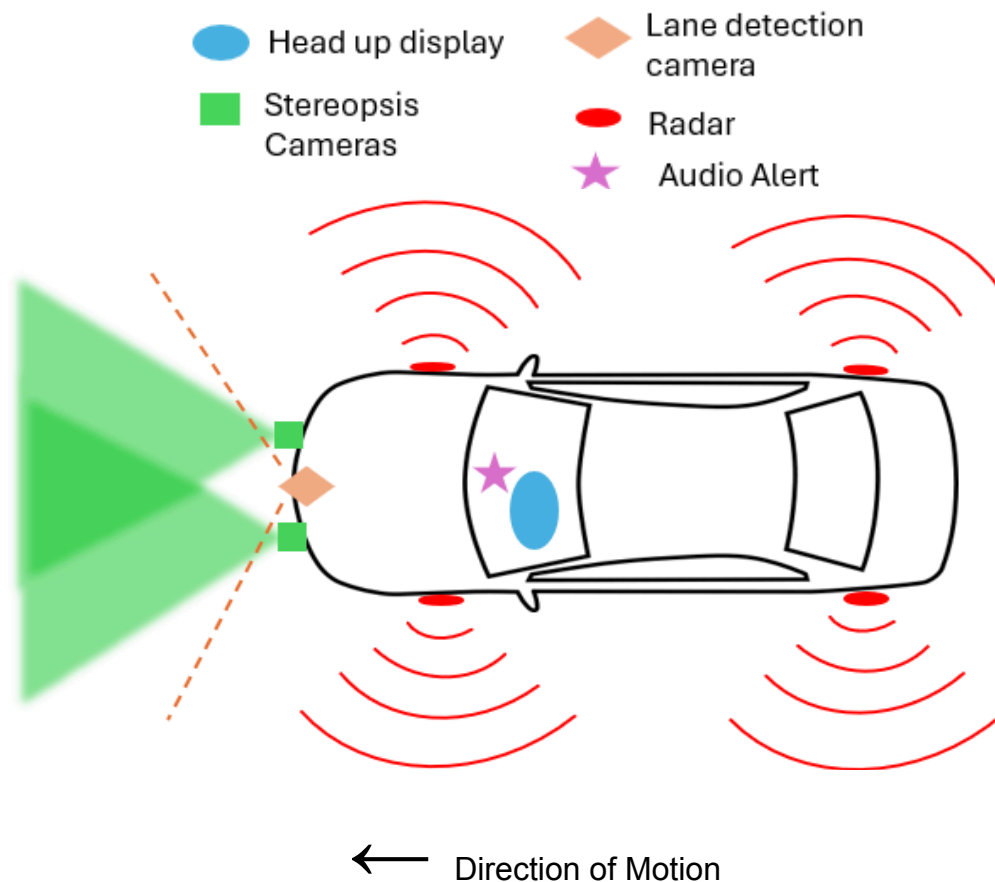


Figure 2.1a: Sensor and UI layout

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 (**Head Up Display**) 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 in 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 Head Up Display 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 peripherals 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 2.4a: 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	2	meters

within the specified range.		
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 outlined in the above section.

Table 2.5a: 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 (Head Up Display) is the primary visual alerting method. The Head Up Display 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 Head Up Display, 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 Head Up Display and buzzer then alert the driver with the detected information. We believe this setup will best interface with the driver to keep them informed of their surroundings.

2.7 Existing product / past project

Products with overlapping features and scope include the crutchfieldBrandmotion FLTW-6000¹. 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 through 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. Bari Life provides the Car Blind Spot Monitoring System² (**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



Figure 2.6a: Bari Life Car Blind Spot Monitoring System



Figure 2.7a: Crutchfield Brandmotion FLTW-6000

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 Head Up Display to interface with the operator. In their table of specifications the Head Up Display 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 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 Head Up Display system. Their Head Up Display 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.

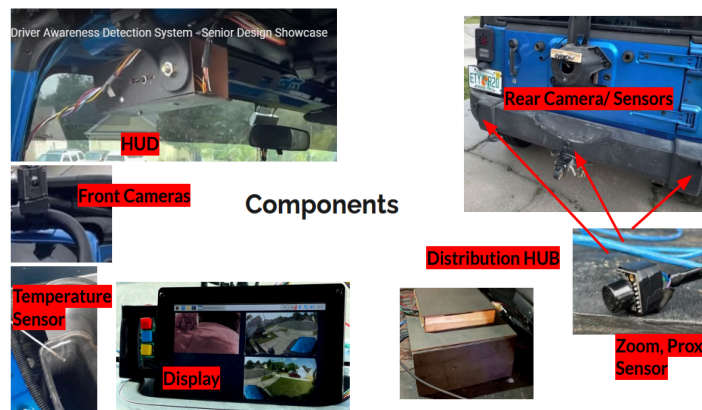


Figure 2.7b: Enhanced Driver Awareness Detection System ECE Senior design group 5 2020–2021

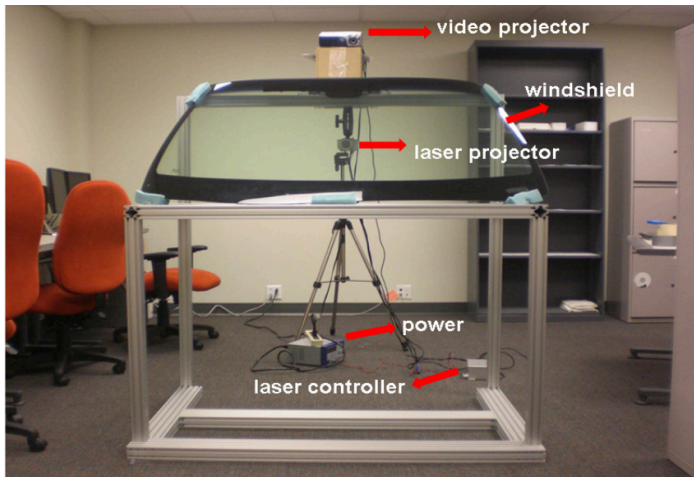


Figure 2.7c: Prototype of Full windshield Head Up Display

((8] Wu, Wen & Blaicher)

Head Up Display systems are the most novel aspect of our design. While there do exist some aftermarket options most pedestrian vehicles that include Head Up Display are only those luxury or EV models. Some manufacturers such as GM have experimented with incorporating systems as ambitious as full windshield Head Up Display. These experiments seem to have taken place in 2010 but have lost traction due to their complexity and expense to

incorporate. These Head Up Display 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 a phosphorus coating which lights up distinctly under the photons shot by the laser projector. That is the phosphorus is excited by the laser diode to present a vibrant image for the driver.

The system uses imaging filters and has known parameters of glass shape to know how to distort the projection in order for it to appear flat when projected. In the image below there is a representation of what this should look like to a driver when some gps route needs a driver to take the exit. From the driver's perspective it should appear as if the highway sign is being highlighted. This is intended to keep the driver informed and prevent last minute dangerous decisions to correct routes such as late exit ramp merging. Many fully incorporated Advanced Driver Assistance System ADAS systems exist in the world today

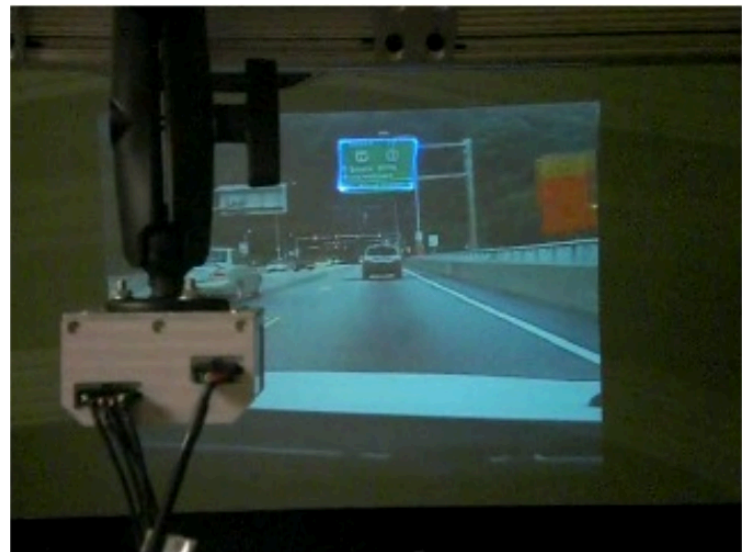


Figure 2.7d: A Highway highlighted by Head Up Display phosphorus projection system

((8] Wu, Wen & Blaicher)

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.



Figure 2.7e: Commercially available head up display system

Other aftermarket Head Up Display 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 Head Up Displays 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

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

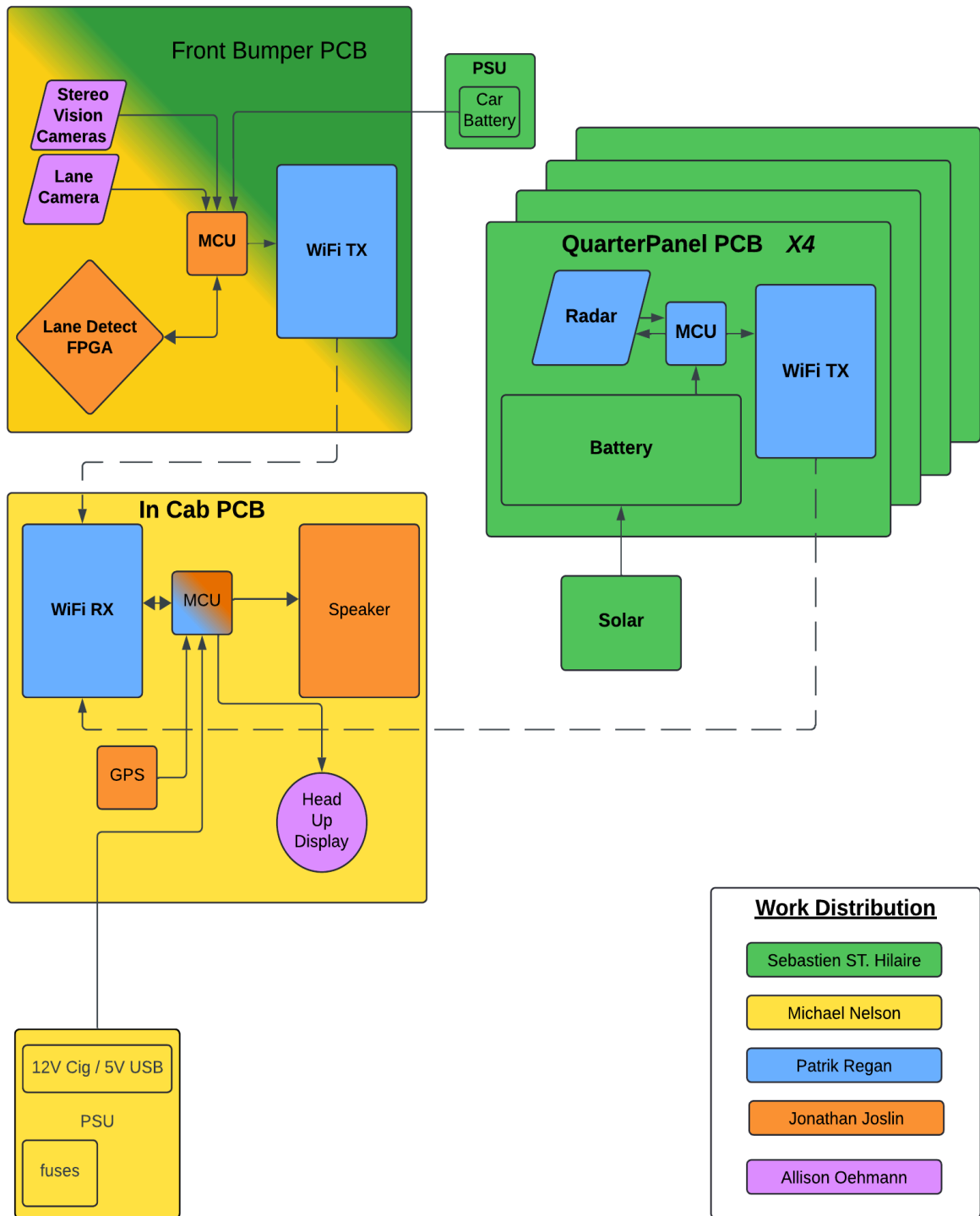


Figure 2.8a: Depiction of Hardware Block Diagram

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 detection is sent to an FPGA

logically programmed for lane detection processes such as Sobel 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.

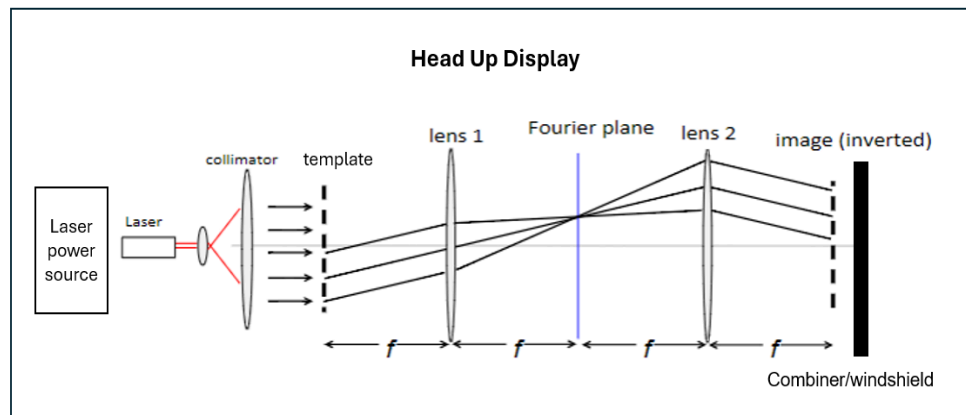


Figure 2.9a: Head Up Display Optical Schematic

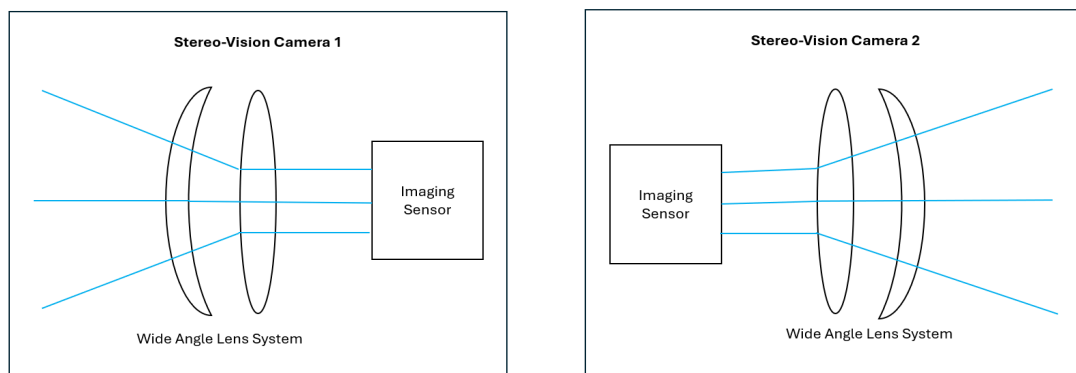


Figure 2.9b: Stereo-Vision camera lens designs

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

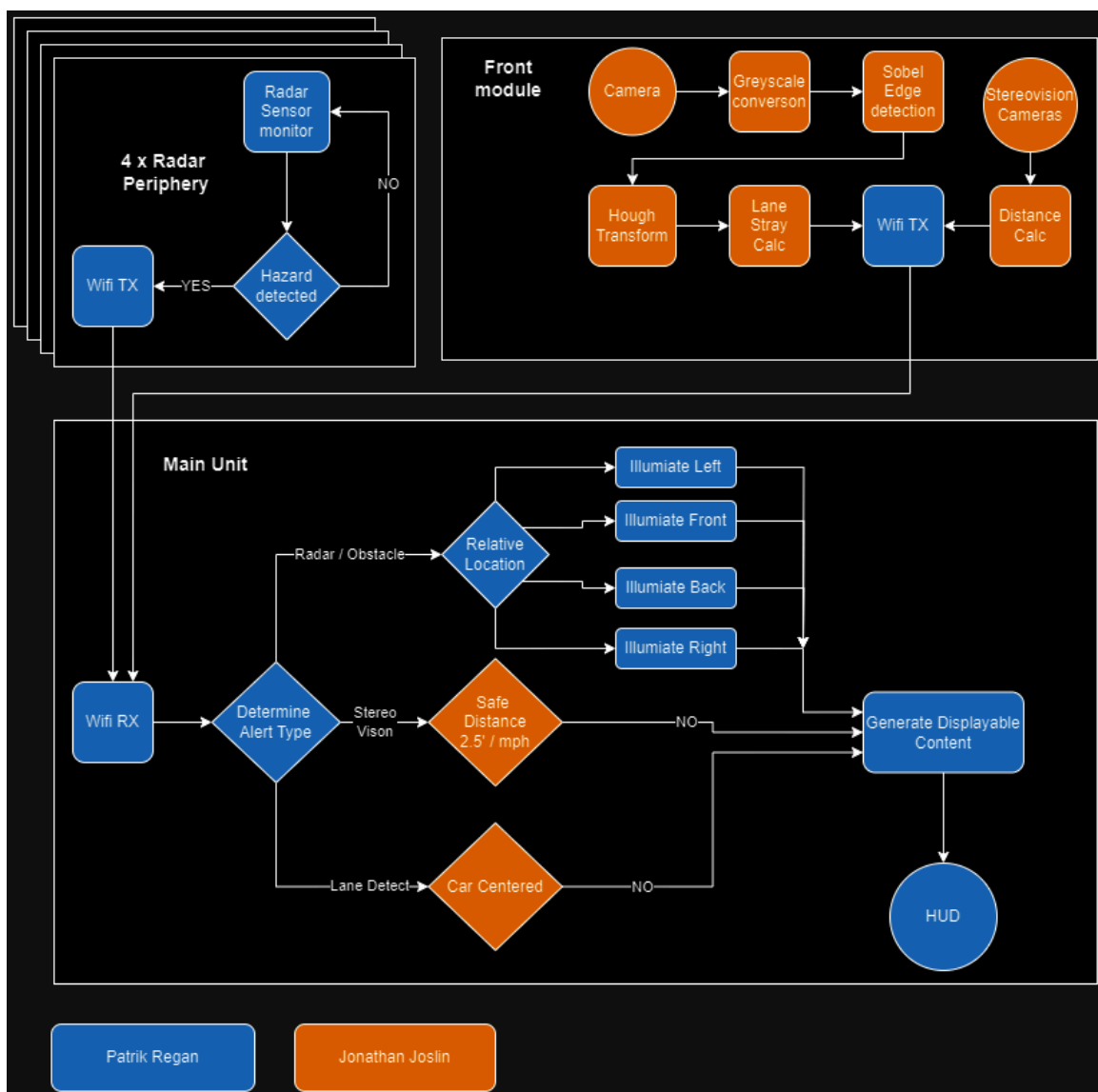


Figure 2.10a: Depiction of Software Block Diagram

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.



Figure 2.11a: House of Quality Diagram

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 our 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.

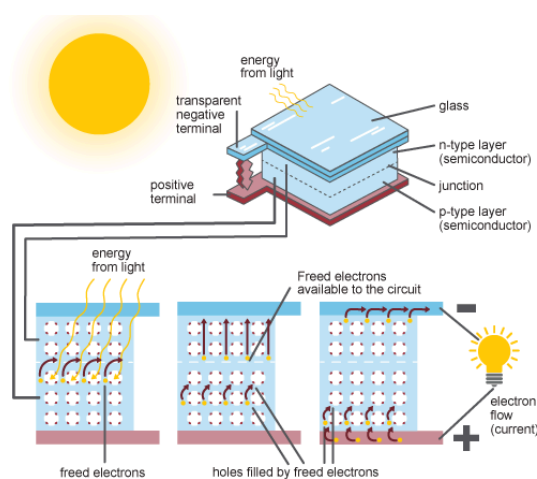


Figure 3.1a: a photovoltaic cell

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].

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

Table 3.1.4a: this table shows a comparison of all the solar panels types

3.2 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 3.2a: 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.

3.2.1 P152

This solar panel is a size like a large laptop, being the second largest solar panel option. This solar panel also has the second largest power output and the highest

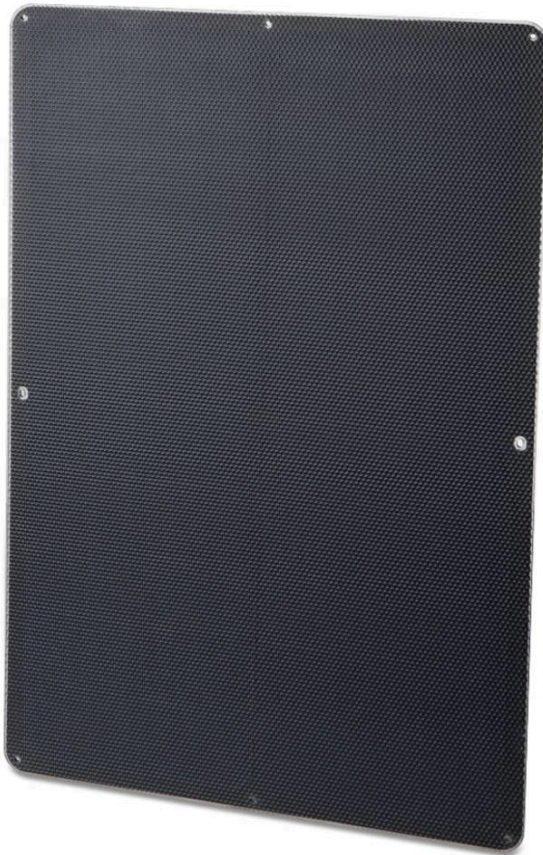


Figure 3.2b: an ETFE (Ethylene Tetrafluoroethylene) Solar Panel

efficiency with the P152. An advantage is that this solar panel is lower in cost compared to all the other solar panels. Like the P150 this solar panel uses an MC4 connector, requiring us to use an additional connector. Unlike the P120 the P150C doesn't use a DC output cable, instead uses an MC4 connector. Also, this type of connector can be easy to plug in but very hard to unplug, to unplug the MC4 connector needs a certain unlocking tool.

3.2.2 P120

This solar panel uses a 3.5mm x 1.1mm DC output cable allowing ease of installation for the customer, where the customer will only be required to plug in the cable to the multiple PCB. What is different about this solar panel compared to all the other options is the ETFE coating. Voltaic Systems provides two types of solar panel, a standard solar panel

and an ETFE (Ethylene Tetrafluoroethylene) solar panel. The ETFE is a coating applied to the photovoltaic module, offering a much more durable solar panel. While ETFE is more durable and resistant in outdoor applications, the tradeoff is that it is more expensive than a standard solar panel.

3.2.3 TPS-24-30W

This solar panel also utilizes a different type of ethylene coating to provide a more durable solar panel. The TPS-24-30 doesn't provide any type of connector, just a junction box. This gives us the freedom to choose how we want to connect to the PCB and allows us to avoid the MC4. Due to its design and frame the TPS-24-30 is easier to mount compared to the voltaic systems solar panels, the downside is that it's more bulkier and heavier than its counterparts.

3.2.3 TPS-12-15W

Identical to the TPS-12-15W uses an ethylene coating and doesn't use any type of connector. What this solar panel provides is in its lightweight, still providing an easier installation. Considering we want to still make installation easy for anybody using this product, the tradeoff is found in its low maximum power.

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 Lithium Polymer

Lithium polymer (LiPo) batteries have many similarities and differences from lithium ion batteries. Lithium polymer batteries are known for the versatile and malleable form in which they can be applied. They are typically used in drones, RC vehicles, portable electronics and many other applications that require compact, efficient storage of energy with remarkable density. They carry a significant amount of energy in an efficient and small size. They also are very lightweight compared to most batteries, including lithium ion. They have a unique flexibility in their form which allows for innovative design opportunities. They possess high discharge rates with a low self-discharge rate over time making them reliable and efficient. They are also safe and have many protections when it comes to overcharging or short circuiting.

Some of the downsides to the lithium polymer battery is that while they are safe from overcharging and short circuiting, they are susceptible to puncture, or catching fire when mishandled or physically impacted. Because of this they require safe storage and protection from very high temperatures. They also have a lower life span than other batteries, on average about 300-500 cycle charges. This can impact long life expectations in certain applications. Lithium polymer batteries also are more costly than other battery options available. Some lithium polymer batteries are vulnerable to voltage sag. Voltage sag occurs at high discharge rates, the voltage will drop sharply and impact system performance overall, which can be detrimental to device operations.

3.3.6 Battery Selection

After looking at the many options and checking over the scope and requirements of this project, we chose to utilize lithium polymer batteries in our system. We needed powerful batteries with flexibility and compact design form that can fulfill our power demands while being able to take up minimal space. The lithium

polymer batteries we chose fulfill our design demands in the best cases but did require higher costs than other battery options. Below is a table that compares different models of batteries that we considered and their specifications.

	Lithium Ion	Lithium Polymer	Nickel-Metal Hydride	Alkaline	Lead Acid
Operating Voltage	3.6 V	3.7 V	3.6 V	6 V	4 V
Operating Current	2.4 A	1.5 A	0.6 A	2.2 A	4.5 A
Dimensions	1.95"L x 0.54"W x 0.54"H	1.95"L x 1.3"W x 0.39"H	1.95"L x 1.64"W x 0.54"H	2.29"L x 2.07"W x 0.57"H	1.75"L x 1.75"W x 4"H
Battery Capacity	2400 mAh	2000 mAh	800 mAh	2200 mAh	4500 mAh
Discharge Rate	1 C	1 C	1 C	1 C	1 C
Cost	\$11.00 ea	\$6.00 ea	\$15.00 ea	\$9.65 ea	\$10.50 ea

Table 3.3.6a: Battery comparison table

Looking at these important characteristics and specifications of similar battery sizes and capacities, we determined the lithium polymer battery gives us the best upside while also keeping our total unit costs appropriate. Not only was this option cheaper than others, the overall capacity holds up with the other options. This along with the flexible and unique design capabilities make the lithium polymer battery we chose the most optimal option for our design.

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

Table 3.4.4a: this table shows a comparison of all the charge controller in consideration

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 route 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.

In addition, the solar panel company voltaic systems which we are obtaining our solar panel from provides an in-depth guide on how to use their solar charger which incorporates the BQ24650. The BQ24650 doesn't provide any Pspice model making us unable to simulate anything to make sure our design is operating correctly. This guide provides more information on how to obtain our maximum power point , compatible battery, etc. this will provide more confidence in our design since we will not be able to use any type of simulation.



Figure 3.4.4b: Voltaic System Solar Charger

3.4.4.1 BQ24650

The first option for a solar charge controller we have in mind is the BQ24650 from Texas Instrument. “The BQ24650 is a highly integrated solar input lithium-ion or lithium-polymer battery charge controller, it can also implement maximum power point tracking” [1]. The BQ24650 charge controller is also compatible with the voltage level that the solar panel provides.

This BQ24650 implements a basic constant current constant voltage charging method. The charging profile has three stage precondition, constant current, and constant voltage. While the BQ24650 uses the maximum power point tracking it can also use a constant frequency synchronous PWM, giving us the option on how we want to extract power from our solar module.

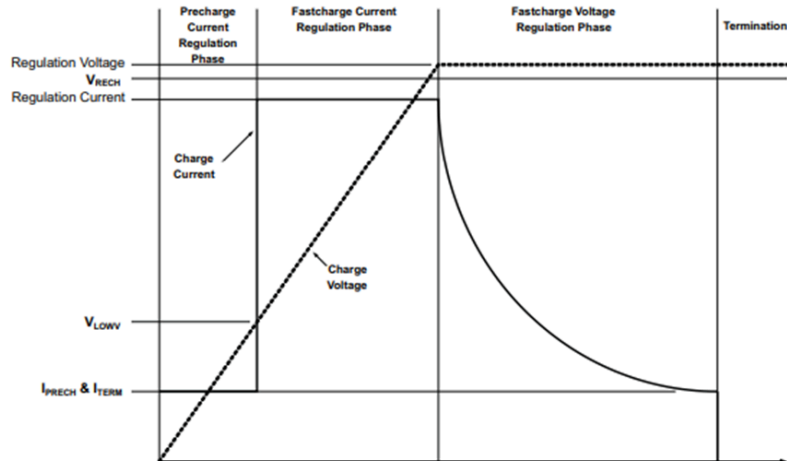


Figure 3.4.4.1a: charging profile for the BQ24650 charge controller

3.4.4.2 LT8491

The second option that we looked at was LT8491 charge controller from Analog device. Like the BQ24650 the LT8491 charge controller offers MPPT method for solar power charging. This charge controller has an intra-integrated circuit (I2C) that allows us to have more flexibility in how we want to charge the battery and configure certain parameters.

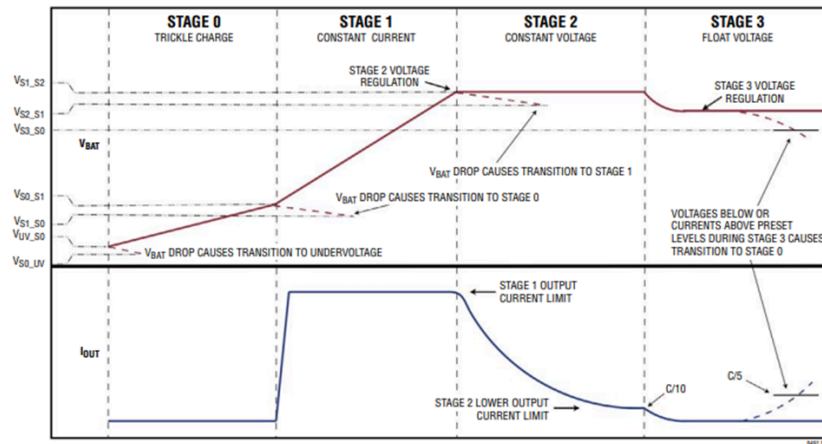


Figure 3.4.4.2a: charging profile for the LT8491 charge controller

This charge controller implements constant current constant voltage method in four different stages compared to the basic three stages. Stage 0 or the Trickle charging, charges the battery with reduced constant current. Trickle charging occurs between 35% to 70% of the battery voltage. Stage 1 or full constant current charges the battery with full constant current, this occurs between 70% to 98% of the battery voltage. Stage 2 or constant voltage charges the battery at a constant voltage, this occurs after 98% of the battery voltage. Last, we have stage 3 or the reduced constant voltage, this is optional and will have to be

enabled through a register. Stage 3 charges the battery with reduced constant voltage.

3.4.4.3 BQ25820

For our third and final controller in consideration, we have the BQ25820 charge controller from Texas instrument. Like the LT8491 charge controller the BQ25820 implements I2C, this allows for more control of how we want to charge the battery and allows us to use direct power path management. Direct power path management is a feature offered by the charge controller that allows us to power the PCBs directly from the solar panels, the battery, or both to power the system. Additionally, this charge controller offers autonomous maximum power point tracking like the BQ2560.

This battery charging management implements a constant current constant voltage in a five-stage method trickle charge, pre-charge, constant current, constant voltage, and top-off trickle charging. The additional stage is the trickle charge which applies a reduced constant current. The second additional stage is the top-off trickle charging, which is a programmable timer that applies a low current, allowing the current to reach the termination target and not over charge.

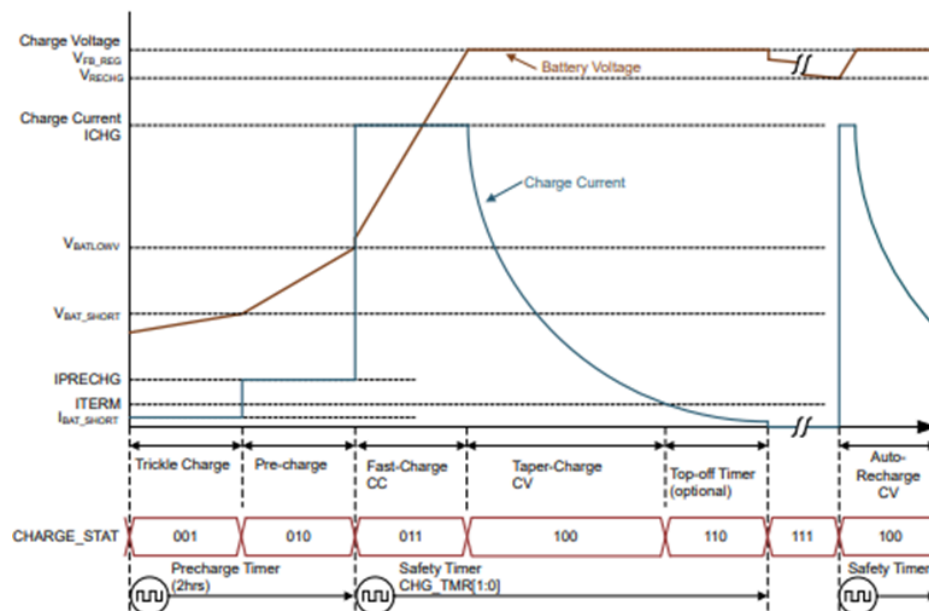


Figure 3.4.4.3: charging profile for the BQ25820 charge controller

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)" [40]. 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 its design can be complex and costly as it requires a pulse 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.

3.5.4 Voltage Regulator Selection (Part 1)

One of the factors to consider when determining what voltage regulator to pick is the output voltage noise. Since we will be dealing with sensitive sensors such as a radar transceiver a low output voltage noise should be one of the factors to look for. Having one of our stretch goals being able to power the four quarter panel PCBs through our solar panel, having a low quiescent current would make our PCBs more energy efficient.

	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
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Table 3.5.4a: this table shows a comparison of all the voltage regulator in consideration

After looking at the three-voltage regulator 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.

Having the PCBs set on the quarter panels of the vehicle we know it will be exposed to environmental conditions. If available we should consider using an automotive grade component for voltage regulators or any other components. With automotive grade components parts can withstand temperature, humidity, vibration, etc.

Working with four PCBs the cost can quickly rise, especially if you need more than one voltage rail. With all the components requiring a 3.3V input, this allows us to use one voltage rail and lower the cost of the project. The voltage regulator can see more current draw since having all the components on one voltage rail. The load regulation is another important specification to look at if we are dealing with sensitive components.

3.5.4.1 TPS7A20C

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.

3.5.4.2 MAX25302A

The MAX25302A is an automotive low-noise LDO linear regulator. 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. Additionally, to configure this regulator is very simple compared to the other regulators in consideration. Depending on how we connect SELA and SELB we have nine different voltage outputs to choose from.

Table 1. MAX25302A Output Configuration Table (continued)

1.8	Hi-Z	GND
2.5	Hi-Z	Hi-Z
3.0	GND	GND
3.1	GND	IN
3.3	GND	Hi-Z
4.0	IN	GND
5.0	IN	IN

Figure 3.5.4.2a: an ETFE (Ethylene Tetrafluoroethylene) Solar Panel

3.5.4.3 TPS7C84-Q1

Another automotive Low-dropout regulator to consider is the TPS7C84-Q1. This charge controller offers a programmable soft-start capability, this helps protect any sensitive components on the quarter panel PCBs. Like the MAX25302A this charge controller is also automotive grade, making it more robust than its counterparts.

3.5.5 Voltage Regulator Selection (Part 2)

Another separate component of the project design requires a much larger and intense power provided for the ultrasonic sensors utilized in potential design. The sensors require up to 80 volts peak-to-peak and can operate with an input current range of 6.5 to 9 milliamperes. This means a much larger scale output of power and voltage change is required. We decided to build a two-stage switching regulator circuit that can provide us with an output voltage of 60 volts peak-to-peak that provides the suitable current to properly power and operate the ultrasonic sensors we plan to utilize in our design. The regulator we chose was used for both stages of this circuit. It is the analog boost regulator model “LT8331” from LINEAR Analog Devices.

The LT8331 regulator is a powerful and useful tool for converting low voltage to a higher voltage. It features wide input voltage ranges from 4.5 volts to 100 volts, making it a perfect candidate for low voltage input systems. It can boost voltages far more than a factor of one. It is very efficient in multiple ways, it has up to 85 percent efficiency in converting lower voltages to higher voltages. It also is quite small and takes up minimal space in overall footprint and is perfect for design space constraints. It even has an integrated switch and inductor, which provides stability and makes the necessity for external components much lower. This regulator also is a common application circuit design, meaning it is widely available and thoroughly tested and tried in many circuit applications.

While there are several positives to choosing this regulator for our design, some of the downsides include its inability to boost the voltage enough which is requiring a multi-stage circuit involving two of these regulators. This regulator is also susceptible to noise and ripple on the output results. While this can be

handled with stability capacitors and design innovation. This is a real challenge that can cause issues if not prepared for and handled properly. The LT8331 regulator also is not as precise as other options, it tends to vary in more complex designs and may fluctuate in voltage levels slightly. The last concern with this design and regulator is the thermal implications. Despite it being quite the efficient regulator, as it boosts larger voltages, thermal management is a serious concern and challenge.

We have already tested simulations of the two-stage circuit that can produce a 60 volt peak-to-peak sine signal that should be sufficient to power the ultrasonic sensors this regulator circuit is designed to. While there are other options, this is one of the most efficient and sensible designs we could create that would be capable of fulfilling the requirements listed. The LT8331 voltage regulator should be able to aid in our design goals and prove to be a crucial part of the system design.

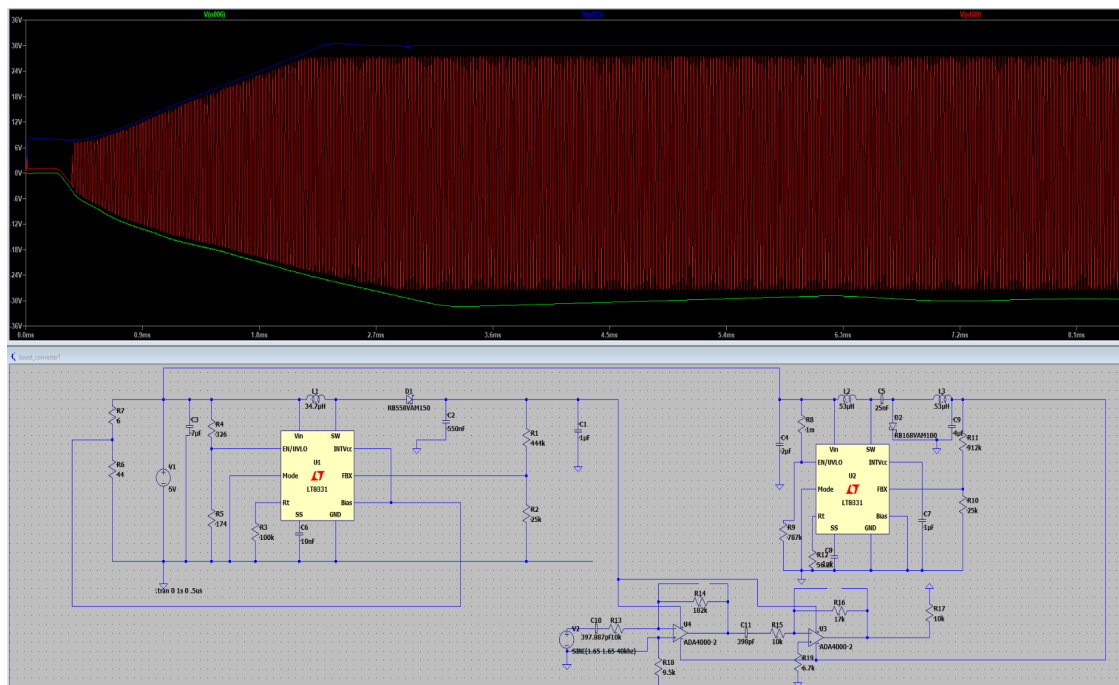


Figure 3.5.5a: LT8331 Two-Stage Regulator Circuit and Waveform

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 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.

3.6.2 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.

3.6.3 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 resonance at certain frequencies which will require additional damping materials to operate at a respectable level.

3.6.4 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.

3.6.5 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.

3.6.6 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]

The CS40-001P60-05-3X speaker is quite powerful and durable. It is a surface mountable speaker with an SPL of over 95 dB. The speaker is also quite efficient with a power consumption of about 1 watt. This speaker is a real “bang for your buck” option that sacrifices little while not costing you a lot.

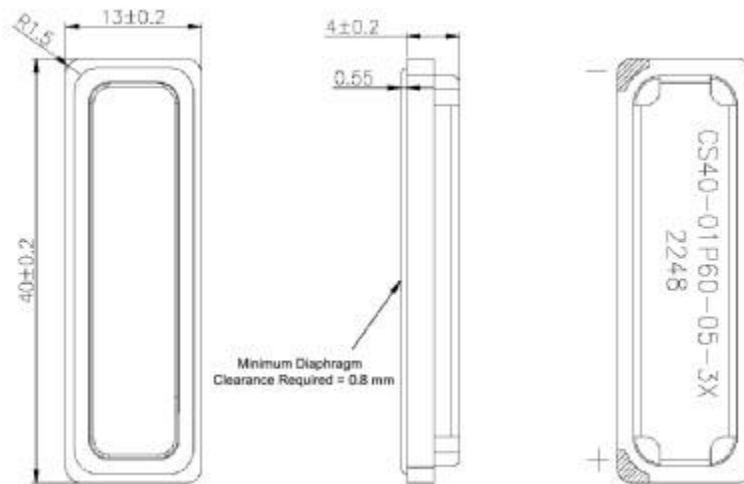


Figure 3.6.2.1a: Depiction of PEEK Speaker [CS40-01P60-05-3X]

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

The CS23-01P100-03-1X speaker is similar to the previous speaker, however it is a little more expensive and a little bit more powerful when it comes to SPL maxing out at over 103 dB. This speaker consumes more power at 1.5 watts, but makes up for it in its even louder capability.

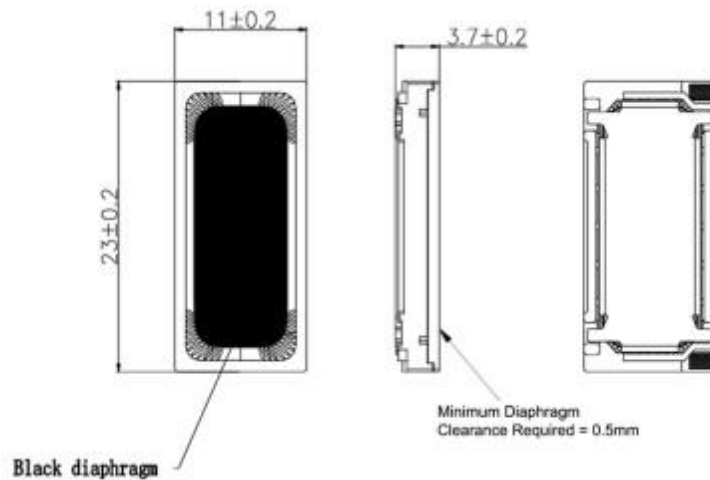


Figure 3.6.2.2a: Depiction of PEEK Speaker [CS23-01P100-03-1X]

3.6.2.3 Mylar (PET) Speaker [CVS-1708]

The CVS-1708 is a simple, effective, easy to use speaker that still packs a loud punch. With a SPL range of 84-90 dB, this speaker is an efficient, simple option that only consumes 0.5 watts but still meets our design goals.

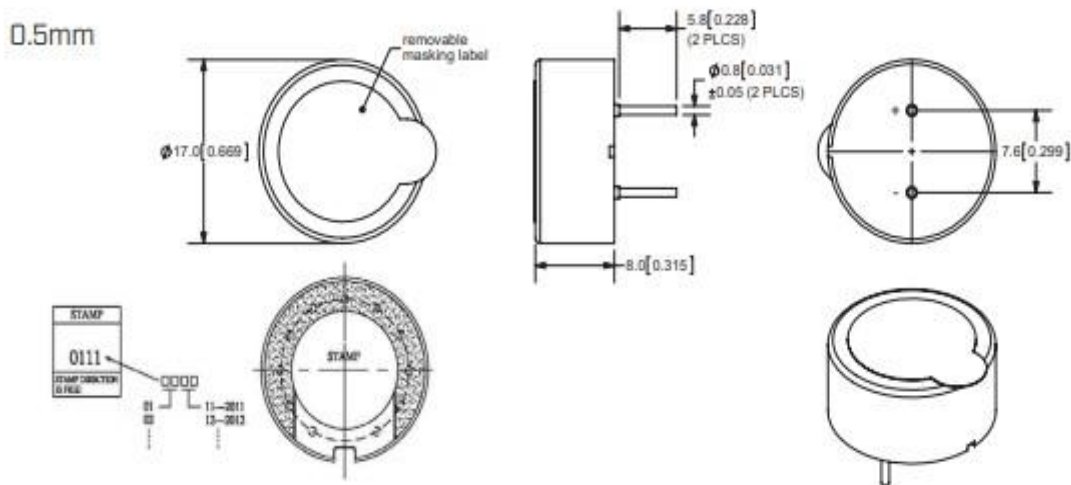


Figure 3.6.2.3a: Depiction of PET Speaker [CVS-1708]

3.6.2.4 Mylar (PET) Speaker [CVS-1508]

The CVS-1508 is again a similar option to the CVS-1708, in fact they share almost all the same capabilities except for design, cost, and tolerance, the CVS-1508 operates with a lower resonance frequency that makes it a better candidate for human ears.

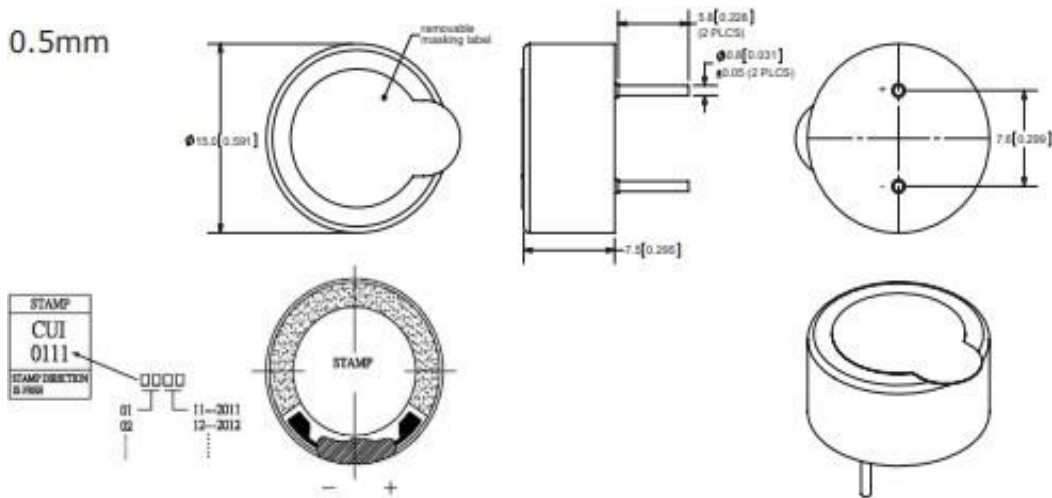


Figure 3.6.2.4a: Depiction of PET Speaker [CVS-1508]

3.6.2.5 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 °C	\$3.55
CS23-01P100-03-1X	1.5 Watt(s)	100 - 106 dB	-20 - 60 °C	\$3.03
CVS-1708	0.5 Watt(s)	84 - 90 dB	-20 - 55 °C	\$3.07
CVS-1508	0.5 Watt(s)	84 - 90 dB	-20 - 55 °C	\$3.12

Table 3.6.2.5a: Comparison of Speakers

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.

3.6.3 Speaker Selection Revision

After applying a more powerful amplifier and creating our circuit that can provide up to 3.2 watts of power. We decided to upgrade our speaker selection from what we previously chose. We still went with the Mylar cone speaker, however we

were able to find a micro speaker with a unique magnetic component not researched previously in our speaker research.

Neodymium Iron Boron (NeFeB) magnetic speakers in combination with Mylar cone components make for a great speaker combination. Primarily used in small electronics, smartphones, tablets and gaming devices, this speaker type is powerful, small, and durable. This speaker type is truly a very special design type.

The AS01808AO-SC18-WP-R model speaker provided by PUI Audio is a step above anything we previously researched. It can handle up to 1.2 watts of power with 8 ohms of impedance. This means it can tolerate and handle the increased power output provided by an audio amplifier and utilize it to produce sound pressure levels (SPL) of 93 to 99 dB while only weighing 1.8 grams total. This powerhouse speaker is not only lightweight, but it is also small in dimensions and footprint. This speaker is only 18 millimeters long, 13 millimeters wide and only 2.8 millimeters thick. This speaker is even dustproof and IP65-rated water proof on its face. It operates in the frequency range of 500 to 15,000 hertz which should easily handle the signal sent for human ears to alert the potential vehicle operators.

This speaker is an absolute upgrade from the previous options researched which were solid choices, but with the amplifier being established and more overall power being available to our speaker and audio alert system, the AS01808AO-SC18-WP-R is an exceptional option to provide the lofty sound pressure level goals while being efficient and compact in PCB footprint and weight. This speaker is a high quality speaker that will prove a great asset to our design system.

3.6.3.1 Mylar Neodymium Iron Boron Speaker [AS01808AO-SC18-WP-R]

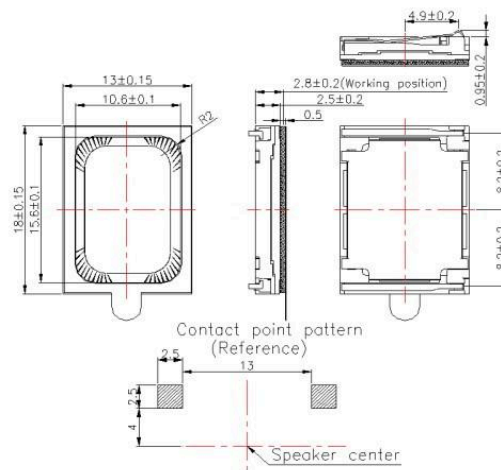


Figure 3.6.3.1a: Mylar Neodymium Speaker [AS01808AO-SC18-WP-R]

3.7 Audio Amplifiers

To implement the required power to the speakers aforementioned is not as simple as driving the speaker from the esp32 board. The esp32 cannot output enough power to properly drive the speaker needed to produce the desired SPL. The simplest and best answer to the issue at hand is an amplifier, specifically an audio amplifier that was designed for speaker driving with strong power output with simplicity and minimal noise involved.

We researched and evaluated a few options of amplifiers but focused on options within the Class D audio amplifier selection. Overall power output, supply voltage ranges, efficiency, and signal-to-noise ratio (SNR) are all major factors in our assessment and research of each option of amplifier for project viability.

3.7.1 TPA3116D2 (Texas Instruments)

The first amplifier researched was the TPA3116D2 by Texas Instruments. The TPA3116D2 amplifier is considered one of the most powerful and efficient audio amplifiers available. The TPA3116D2 is capable of versatile design options that include a stereo channel with an output of 50 watts or a mono bridge mode that can output 100W of power. Its supply voltage ranges from 4.5 volts to 26 volts. It is an integrated circuit with protection and impressive thermal protection. The TPA3116D2 is also known for a high signal-to-noise ratio (SNR) with greater than 90 percent efficiency and minimal heat dissipation.

Some of the downsides of the TPA3116D2 amplifier in our specific design case include the fact that we are aiming for power efficiency, the speakers we are looking to implement only require 0.5 watts to 5 watts. Another negative of this amplifier in our specific case includes a rather large PCB footprint required because of the high power operations. The TPA3116D2 also requires external passive filtering components to be implemented. As well as the digital to analog conversion to make it operate correctly as the ESP32 communicates in I2S and the amplifier is analog. While this amplifier is exceptional overall, in our case it just seems too large scale.

3.7.2 PAM8302A (Diodes Incorporated)

The next amplifier we observed is the PAM8302A by Diodes Incorporated. This amplifier is a lower power, compact amplifier that can be utilized in smaller, lower power applications. It can output power up to 2.5 watts in the supply voltage range of 2.5 volts to 5.5 volts. The PAM8302A amplifier is also quite efficient with about 85% efficiency and no heat sink required because of the lower power operations. Some other upsides of the PAM8302A include a small footprint and compact form along with a very simple integration, requiring minimal external components necessary.

Some negative points regarding the PAM8302A include the minimal versatility and lower power output. However in our design case, we are looking for output power around the PAM8302A amplifier's range. Another downside of this amplifier is the inability to operate in I2S communication directly, it is analog only. This makes the overall integration more complex with a digital to analog conversion (DAC) required.

3.7.3 MAX98306 (Maxim Integrated)

The next amplifier researched is the MAX98306 by Maxim Integrated. This amplifier is very specific in usage with it being another lower power option. The MAX98306 amplifier outputs up to 3.2 watts per channel as another benefit of this amplifier is the stereo ability with multiple channels. The MAX98306 also operates at the supply voltage range of 2.7 volts to 5.5 volts. Efficiency is also a massive benefit in this amplifier with over 90% efficiency and significant thermal protections and short-circuit protections.

Another common downside of a lot of these amplifier options is that the MAX98306 also operates in analog format which means a digital to analog conversion is required. Another negative aspect to the amplifier is the more complex integration into PCB design.

3.7.4 MAX98357 (Maxim Integrated)

The next amplifier researched is the MAX98357 by Maxim Integrated. This amplifier is similar to the other Maxim amplifier we also researched and evaluated. However there are a few key differences that make this amplifier interesting to our design team. One of the big differences is that this amplifier operates with an input type of I2S which is exactly the communication method we want to utilize with the esp32 board. It can support 16, 24, or 32 bit data between sampling rates of 8,000 hertz to 96,000 hertz. The MAX98357 also provides 3.2 watts of power in the supply voltage range of 2.5 volts to 5.5 volts. It also has above 90 percent efficiency rate with small heat dissipation. This amplifier also provides protection for under-voltage situations. It is capable of automatic clock and format detection. It is compact and lightweight and easy to implement into a PCB.

The MAX98357 is not perfect, there are downsides but most of these "downsides" are not negatives to the design we are looking to implement. A low output power compared to other amplifiers is one, another is the mono-only operations meaning stereo applications are not possible.

3.7.5 Amplifier Selection

The choice for our audio amplifier was actually very easy to make. We only required up to 3 watts of output power for our smaller, more efficient speakers. We ideally wanted an efficient amplifier that did not have a large amount of heat

dissipation. And a huge deciding factor was the input type, wanting to keep design simple in this aspect was a huge goal of our design. We decided the MAX98357 was the ideal audio amplifier we wanted in our design. It provides the proper output power in the necessary voltage range keeping the design simple and intuitive.

While it only can provide mono output audio, that is all that is required in our design case. It also is highly efficient and does not require thermal dissipation alternatives with over 90 percent efficiency. And the best and most useful quality the MAX98357 possesses is the ability to take I2S input for audio production. This defining characteristic was the largest reason we selected the MAX98357 amplifier.

The MAX98357 is one of the most popular class D audio amplifiers in the market today. Being commonly used in portable electronics and other portable and low power systems. It provides quality power at an impressive efficiency and is exactly what we are looking for in this design project. Comparison to the other explored options makes the choice even clearer. Below is a table comparing the four evaluated amplifiers.

	MAX98306	MAX98357	PAM8302A	TPA3116D2
Supply Voltage Range	2.7 V - 5.5 V	2.5 V - 5.5 V	2.5 V - 5.5 V	4.5 V - 26 V
Output Power	3.2 W	3.2 W	2.5 W	50 W
Output Configuration	Stereo	Mono	Mono	Stereo
Input Type	Analog	I2S Digital	Analog	Analog
Efficiency	>90%	>90%	>85%	>90%
Cost	\$2.50 ea	\$2.91 ea	\$1.70 ea	\$1.84 ea

Table 3.7.5a: Amplifier comparison table

While the cost of the MAX98357 is the highest of the options researched. The simplicity of the potential design and efficiency alone make up for the slightly higher costs. This amplifier is ideally suited for our design case and will work well with the esp32 board we are using to operate this portion of our system design.



Figure 3.7.5b: MAX98357 produced for public use by ElectroPeak

3.8 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 facilities. 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.

3.8.1 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.

3.8.2 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.

3.8.3 Radar

Radar (Radio Detection and Ranging) has emerged as one of the most widely adopted technologies for hazard sensing and obstacle detection in the Advanced Driver Assistance Systems (ADAS) market. Given its robust implementation

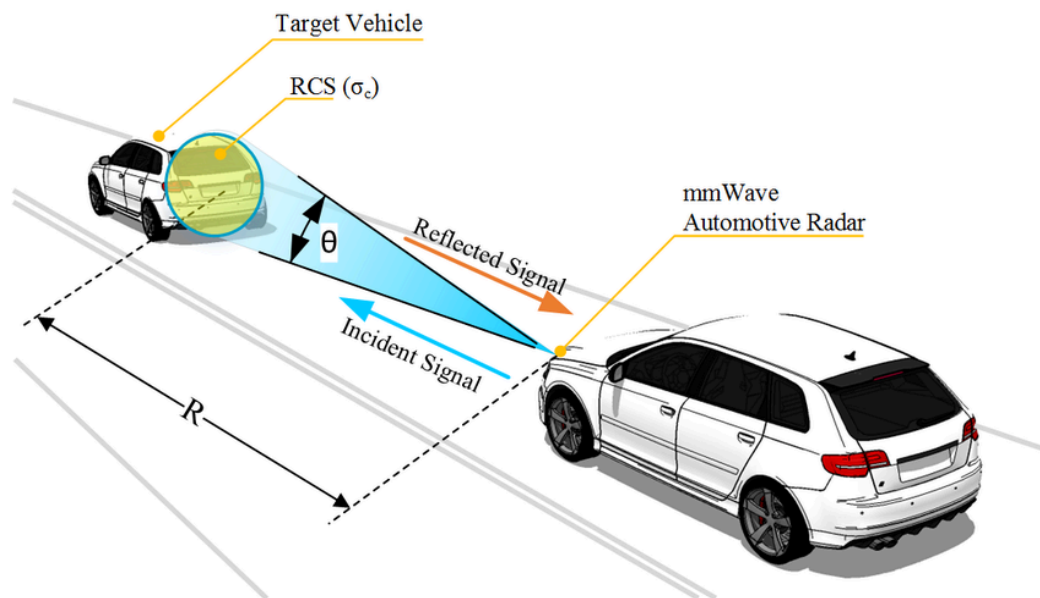


Figure 3.8.3a: Depiction of Radar Technology
(Akram & Evans 2016)

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.

3.8.4 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.

3.8.5 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.

Further into the project, it was discovered that our selection of the SMR-314 radar may not fit the needs of our project due to the complexities of RF design. In response to this discovery we pivoted back to an Ultrasonic sensor due to its ease of use especially with a lower frequency such as 40KHz. While we still believe that a radar sensor would be best suited for the application of this project,

due to the costs and complexities of developing a PCB capable of handling the 24GHz signal of the radar, we chose to go with sonar late into the Senior Design semester one design phase. The Ultrasonic sensor will still enable us to detect distance and multiple sensors will allow us to calculate relative direction, albeit at a lower resolution than the radar. The ultrasonic sensor is also less power efficient as it operates close to 80 Vpp.

Technology	price	Light sensitivity	Weather sensitive	distance	FOV (typical)
Lidar	\$30 +	Yes	high	2 - 60 M	2 degree
UltraSonic	\$3	no	high	2cm - 5M	120 degree
Camera	\$ 34 +	yes	high	2 cm - 20 M	Module specific
Radar	\$20	no	moderate	50 CM - 100 M	Antenna specific

Table 3.8.5a: Comparison of hazard detection technologies

3.9 Hazar Detection Module Selection

When selecting a particular device to implement our design, we looked at various models and compared them based on price and performance for our needs. Below we list and describe the characteristics of the devices we considered and what went into the final decision of which device made the cut.

3.9.1 Ultrasonic Module Selection

The Sonar modules on the design will be used to detect the location of potential hazards surrounding the vehicle. Device selection will be based on price, performance, power consumption and compatibility with the entire system. Unlike radar, all ultrasound devices that we've considered are through-hole so integration to the PCB will be easy. We will weigh and compare each option to find the option best suited for our purpose.

3.9.1.1 CUSP-TR80-15-2500-TH by Same Sky

The CUSP-TR 80-15-2500-TH by same sky is an ultrasonic sensor combination unit. This means that it contains both the technology for transmitting the signal and receiving the signal. This will save us space on the PCB and cost for the additional parts required when separate units are needed for sending and receiving. The unit operates at 40KHz, a standard ultrasonic range and enough detail for our project. The unit also operates up to an 80Vpp and produces a

Sound Pressure Level (SPL) of 115 dB. The SPL correlates the sensing distance with greater SPL able to detect objects at further distances. The main concern of using ultrasonic as opposed to radar was the road noise interfering with the reflections however this SPL level should be suitable for the job. While 80Vpp is quite high compared to the 3v3 or 5v0 output of our MCU we should be able to use a boost converter DC-DC to drive the sensors. The cost of the sensor is also very reasonable at only \$3.77, it will be very economic to implement. The device also has a beam angle of 80° that is the angle turned from line emitting out the center point top of the device perpendicular to its base line. This is a broad angle and will provide a good sensing area.

3.9.1.2 H2KA300KA1CD00 by Unicon Technologies

The H2KA300KA1CD00 is another transducer like the CUSP-TR80-15-2500-TH meaning that it handles both transmission and reception. This module offers a much greater detail and could be useful for close range driving in tight spaces such as city streets. The device also performs at a lower power being more efficient for our system and battery power. However it only has a beam angle of 5° which would require many more modules around the vehicle to provide a complete coverage of the blind spot areas of the vehicle. The H2KA300KA1CD00 is also priced at \$15.60 making it three times as expensive as our other considerations. Due to its cost it will be passed over for consideration for implementation on our project.

3.9.1.3 CUSA-T80-130-3000-TH by same sky

The CUSA-T80-130-3000-TH by same sky has much in common with the CUSP-TR80-15-2500-TH however it operates with an SPL of 120 dB allowing it to measure out to 20 meters, the usual maximum usage of ultrasonic sensors. More delay is seen at this range as the speed of sound is 343 m/s means the best time round trip for the sound wave is 100ms and this does not include processing time. This device has a beam angle of 55° making it sufficient, but not as broad as the CUSP-TR80-15-2500-TH. It also uses more power to generate its max SPL, which would put more pressure on our power system.

3.9.1.4 Ultrasonic Sensor Selection

Due to the lower power consumption, suitable range, and broad beam angle, we have decided to select the CUSP-TR80-15-2500-TH. It is also the most economic choice. The 40KHz while not the highest precision will be able to provide sufficient data for detecting distances between the vehicle and surrounding obstacles. The 80° beam angle will be able to cover the entire blind spot region with two devices per side of the vehicle. With an additional sensor on the front of the vehicle this is less than a \$20 investment as well making it an easy decision financially. Again, mmWave or continuous SMFR radar device the SMR-314 would have been our choice had RF design not been as complicated as it is.

Part Number	CUSP-TR80-15-250 0-TH	H2KA300KA1CD00	CUSA-T80-130-3000-T H
Manufacturer	Same sky	Unictron Technologies	Same sky
Frequency (KHz)	40	300	40
Beam Angle (°)	80	5	55
Max Voltage Vp-p	80	50	150
SPL (dB)	115	120	120
Distance (m)	15	1	20
Precision mm	3 - 5	0.1	3 - 5
Price (USD)	\$3.77	\$15.60	\$4.08

Table 3.9.1.4a: Comparison of ultrasonic sensors

3.9.2 Radar Module(s) selection

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.

3.9.2.1 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.

3.9.2.3 **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.

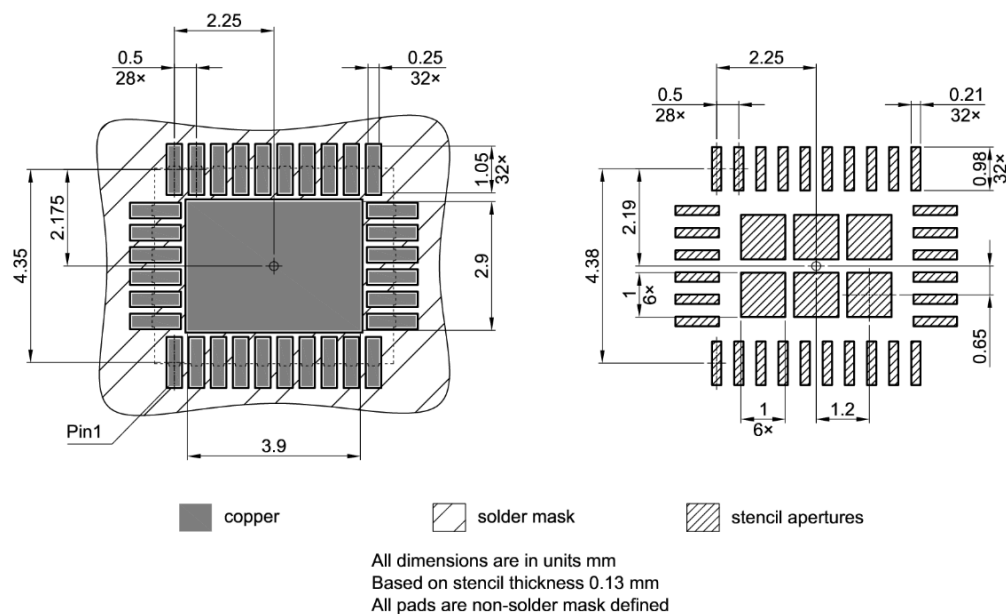


Figure 3.9.2.3 A SMD pad of **BGT 24ATR22**

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.

3.9.2.4 IMD-2000 Radar Module by InnoSent

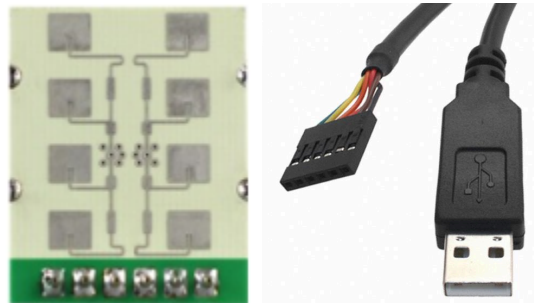


Figure 3.9.2.4a: IMD-2000 evaluation board (left) with a 6 pin connector soldered to the 2mm pins, connection ttl-232r-3v3 (right)

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.

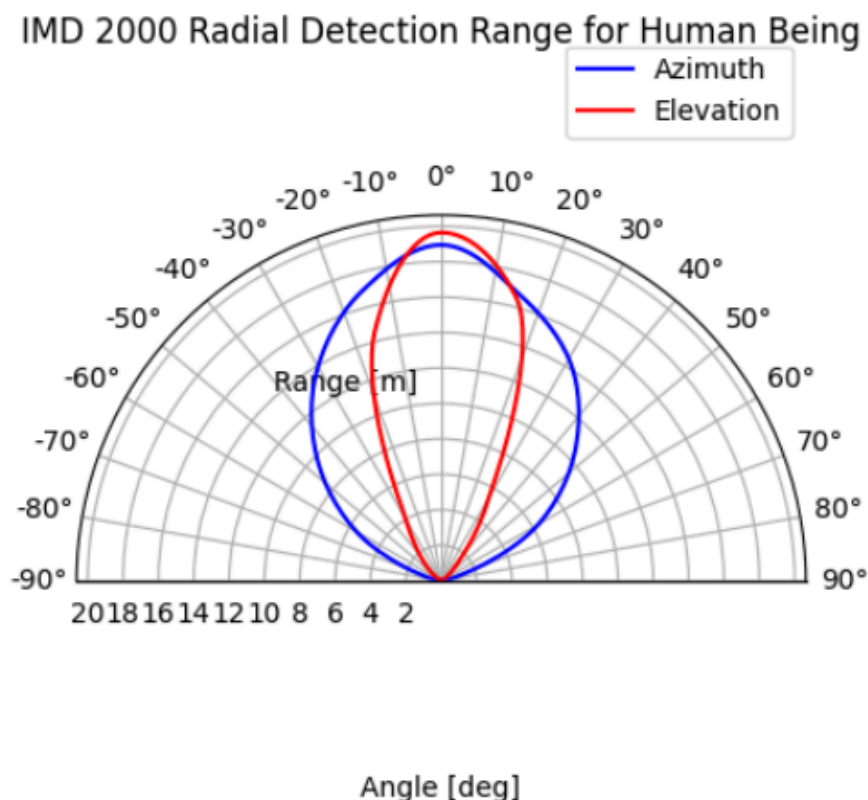


Figure 3.9.2.4b: IMD 2000 detection range

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.

3.9.2.5 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.

System Pattern SMR-314:

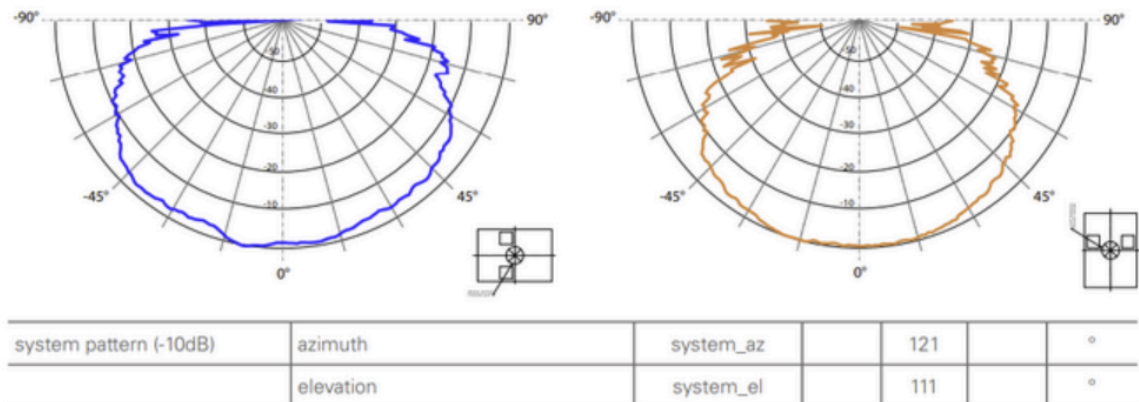


Figure 3.9.2.5a: SMR-314 system pattern

System Pattern SMR-334:

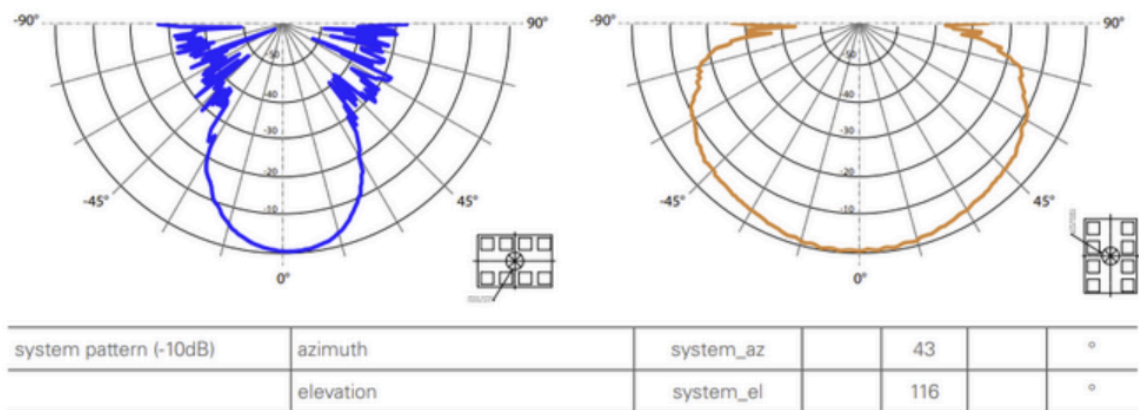


Figure 3.9.2.5b: SMR-334 system pattern

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.

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.

3.9.2.6 Selected Radar 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.

Part Number.	AWRL1432B DBGAMFRQ1	BGT 24ATR22	IMD-2000	SMR-334	SRM-314
Manufacturer	Texas Instrument	Infineon	innoSent	innoSent	innoSent
Frequency	69-74 GHz	24 GHz	25 GHz	24 GHz	24 GHz
Packaging	24 GHz	QFVD	Through-hole	SMT pad	SMT-pad
Field Of View	N/A	N/A	Azimuth: 80 Elevation : 111	Azimuth: 43 Elevation: 116	Azimuth: 121 Elevation: 111
Price	\$16.97	\$16.50	\$24.00	\$22.65	\$22.65

Table 3.9.2.6a: Comparison of radar modules

3.10 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.

3.10.1 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.

3.10.1.1 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 $+125^{\circ}\text{C}$) 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.

3.10.1.2 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.

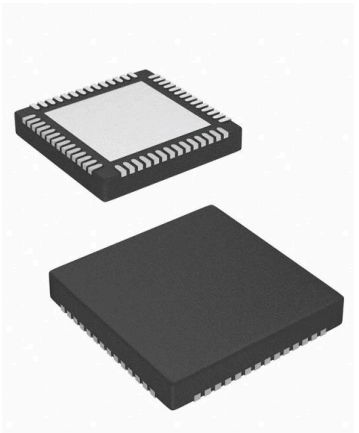


Figure 3.10.1.1a: STA8089GADTR Component

3.10.1.3 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.

Product Number	STA8089GADTR	YIC31612EBGG	TESEO-LIV4FTR
Manufacturer	STMicroelectronics	YIC	STMicroelectronics
Communication protocol	I2C UART	UART	I2C UART
Baud rate	115200	9600	115200
Passive / Active	passive	passive	active
Automotive Grade	Yes	No	No
Price	\$5000	\$5.98	\$16.19

Table 3.10.1.3a: Comparison of GPS modules

3.10.2 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.

3.10.2.1 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.

3.10.2.2 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.

3.11 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 (Head Up Display). 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 automobiles, 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.

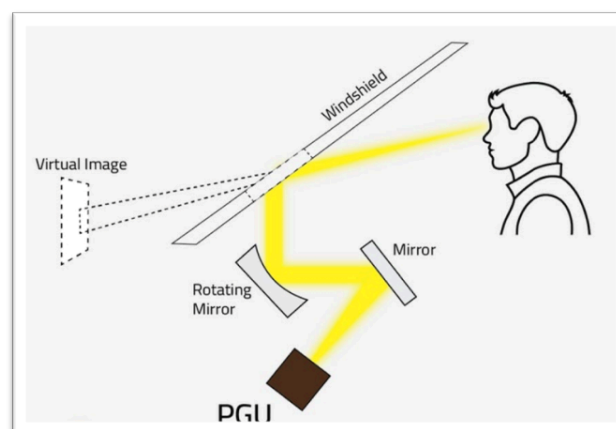


Figure 3.11a: Common design of a Head Up Display

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.

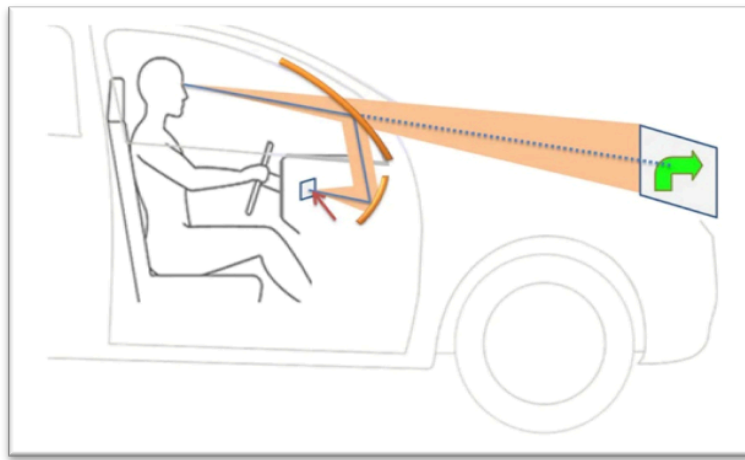


Figure 3.11b: Head up display system in context of a commercial automobile.

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.

3.11.1 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.

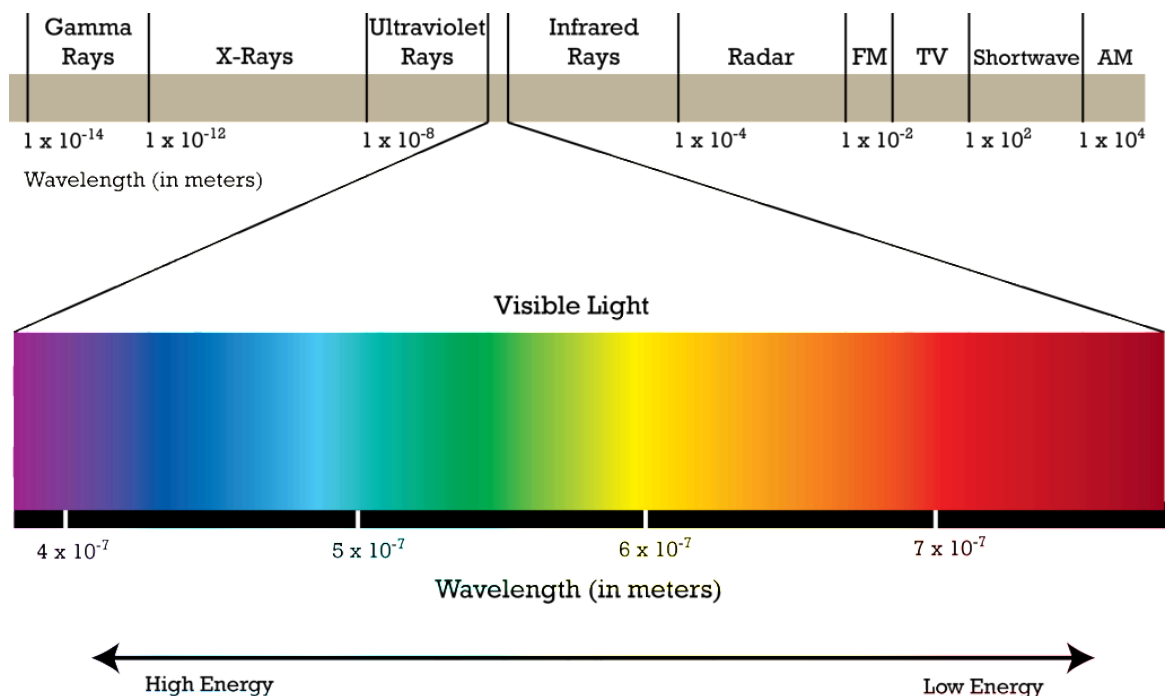


Figure 3.11.1a: Portion of the electromagnetic spectrum, revealing the wavelengths of visible light and their corresponding colors.

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 Head Up Display 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. It 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.

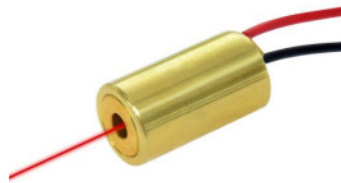


**Figure 3.11.1b: Laser diode
selected for use in the Head Up
Display**

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

Table 3.11.1c: Comparison of laser diodes

3.11.2 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
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Table 3.11.2a: Comparison of beam expanders

3.11.3 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 size 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.

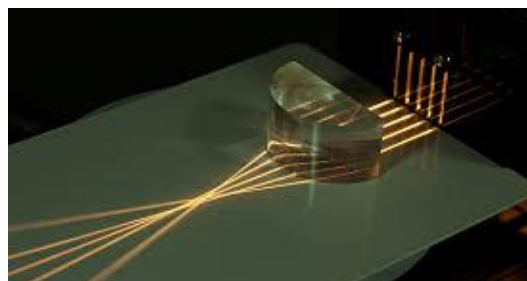


Figure 3.11.3a: Visual of how a plano convex lens bends light.

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

Table 3.11.3b: Comparison of lens

3.12 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.

3.12.1 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).

3.12.1.1 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.

3.12.1.2 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.

3.12.1.3 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 so 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.

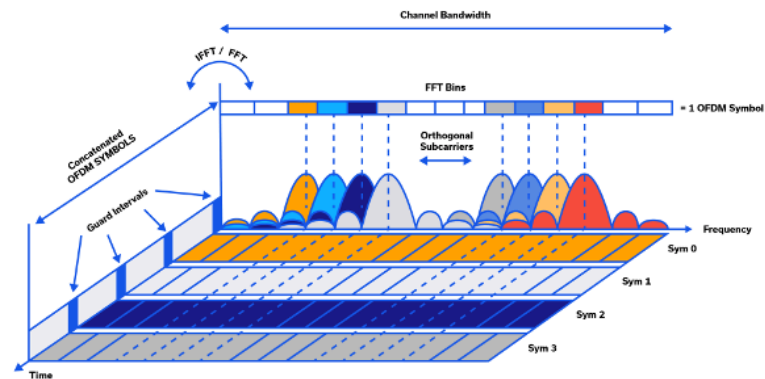


Figure 3.12.1.3a: Figure depicting the process of OFDM modulation

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.

3.12.1.4 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.

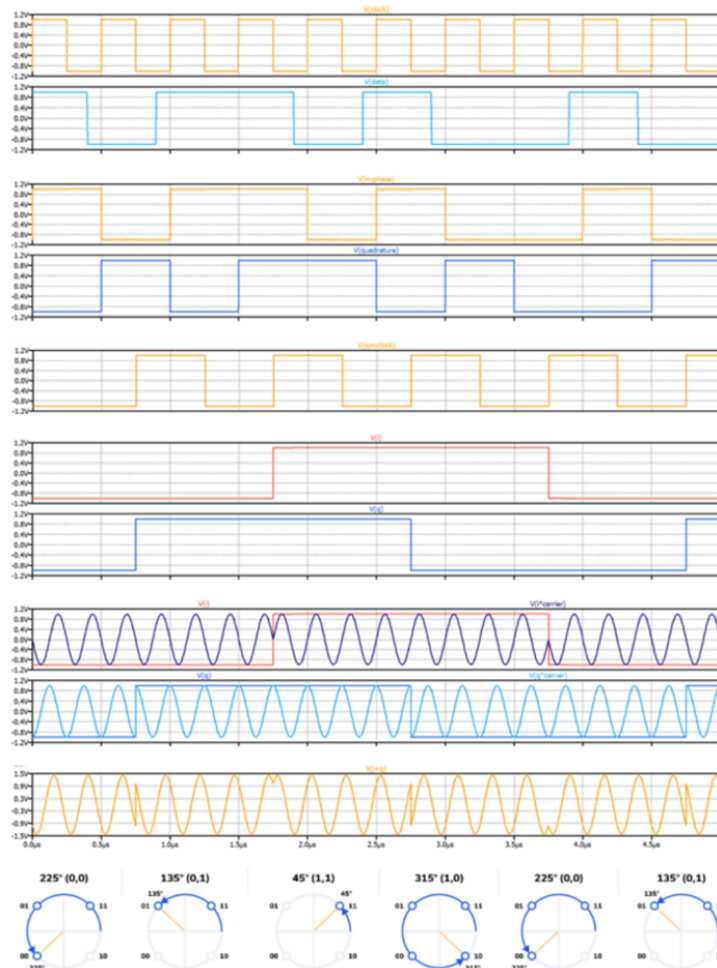


Figure 3.12.1.4a: Figure depicting the format of how 4-QAM is processed

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.

3.12.2 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 its 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	Bandwidth	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 3.12.2a: Table depicting the different 802.11 Wi-Fi standards

With Wi-Fi communication, there have been plenty of iterations of it throughout its 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.

3.12.3 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.

3.12.3.1 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.

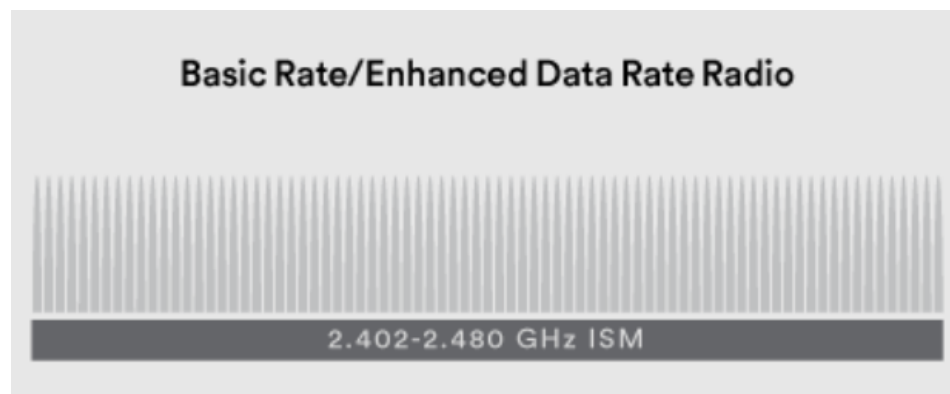


Figure 3.12.3.1a: Figure depicting the frequency band for Bluetooth Classic

3.12.3.2 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.

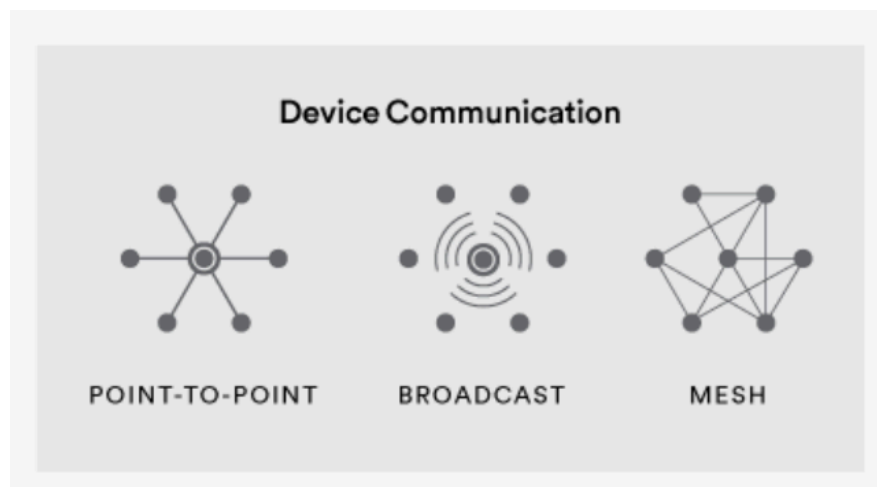


Figure 3.12.3.2a: Depiction of different device communication methods for Bluetooth Low Energy

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.

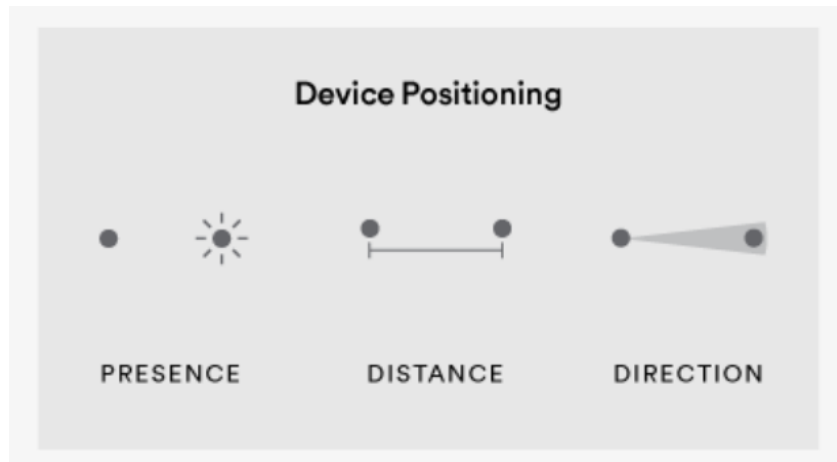


Figure 3.12.3.2b: Depiction of different device positioning methods for Bluetooth Low Energy

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.

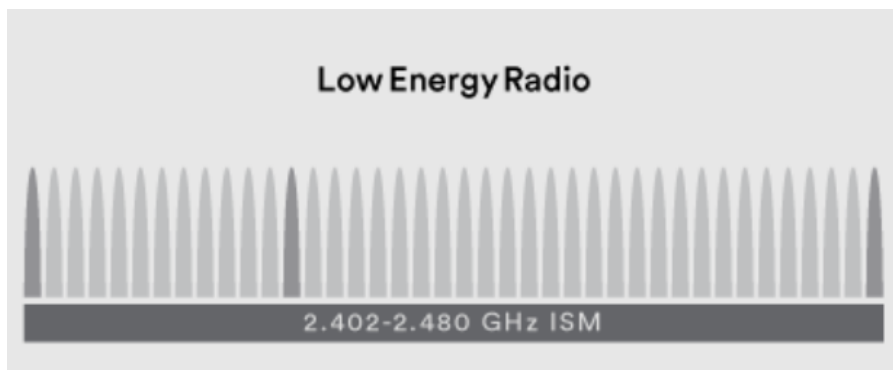


Figure 3.12.3.2c: Figure depicting the frequency band for Bluetooth Low Energy

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.

3.12.3.3 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 3.12.3.3a: Table depicting the differences between Bluetooth Classic and Bluetooth Low Energy

3.12.4 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.

3.12.5 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 3.12.5a: Table comparing different wireless communication methods

3.12.6 Wi-Fi Module Part Selection

When going through the different options for components to use regarding our Wi-Fi modules, there are a few that came to mind, particularly with the ESP line of products as we have had previous hands-on experience with them in the past. The table that is represented below shows the different parts we were considering and each of their own differences.

	ESP32-WROOM-32E-N4	ESP8266EX	ESP32-MINI-1U-
Type	Module	SoC	Module
Wi-Fi Protocol	IEEE 802.11 b/g/n	IEEE 802.11 b/g/n	IEEE 802.11 b/g/n
Temperature	-40~80 °C	-40 ~ 125 °C	-40 ~ 85 °C
GPIO	26	17	28
Flash memory	4 MB	0 MB	4 MB
SRAM	520 KB	160 KB	520 KB
ROM	448 KB	0 KB	448 KB
PSRAM	0 MB	0 MB	0 MB
Frequency	240 MHz	160 MHz	240 MHz

Size	18*25.5*31 mm	QFN32 (5*5) mm	13.2*13.5*2.4 mm
Voltage	3.0 ~ 3.6 V	2.5 ~ 3.6 V	3.0 ~ 3.6 V

Table 3.12.6a: Comparison of possible components to select

With the following info above regarding our possible parts, we have determined that we will use the ESP32-WROOM-32E-N4. We believe that this model will allow us to get exactly what we need to get across for our system, as it meets our personal specifications for components, including the size and the complexity of the device.

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 throughout 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.

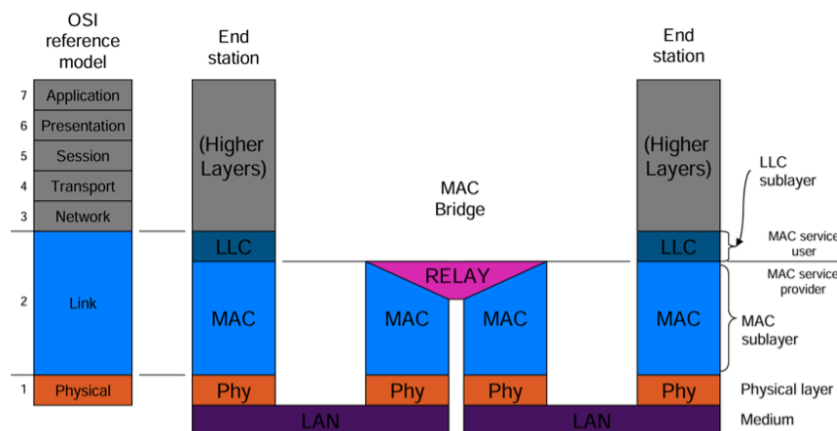


Figure 4.1.1a: Depiction of LAN Architecture

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 Standards

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

Figure 4.1.3a: Laser safety standards

4.1.4 SPI Communication

The Serial Peripheral Interface, otherwise known as SPI, is a hardware communication method that allows for the communication between devices such as a wireless transmitter/receiver or card readers. With SPI communication, it has allowed for the ideal communication method between microcontrollers and sensors to communicate properly, especially when there aren't mass amounts of data being sent at once.

Devices that are part of SPI communication end up being in a master-slave relationship, containing a singular master system that dictates things such as the clock and the slaves itself, while the slaves will send this info that they contain either directly back to the device or through daisy-chaining. This results in there being at least four wires in the communication between the SPI devices, being the Master Output/Slave Input (MOSI) for the master to send data to the slave, Master Input/Slave Output (MISO) for the slave to send data to the master, the clock (SCLK) for the clock signal, and the Slave Select/Chip Select (SS/CS) for the master to choose which slave to send the data to.

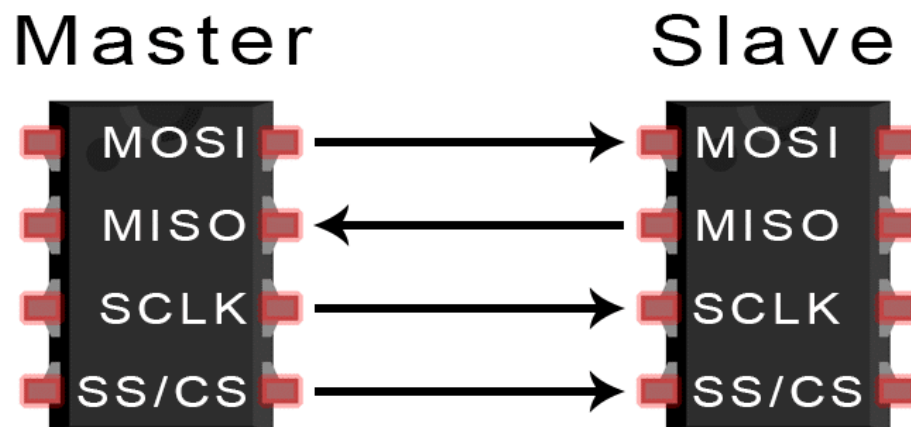


Figure 4.1.4a: Communication between Master and Slave devices in SPI

With SPI communication, there are some scenarios that there are multiple SS/CS ports on the master, allowing for it to directly communicate with each of the slaves that exist, known as parallel communication. There are also scenarios where there is only one SS/CS port on the master device despite the possibility of multiple slaves, resulting in the MISO to go into the MOSI port for each of the slaves until it reaches the last one, where the MISO port of the last slaves goes into master device.

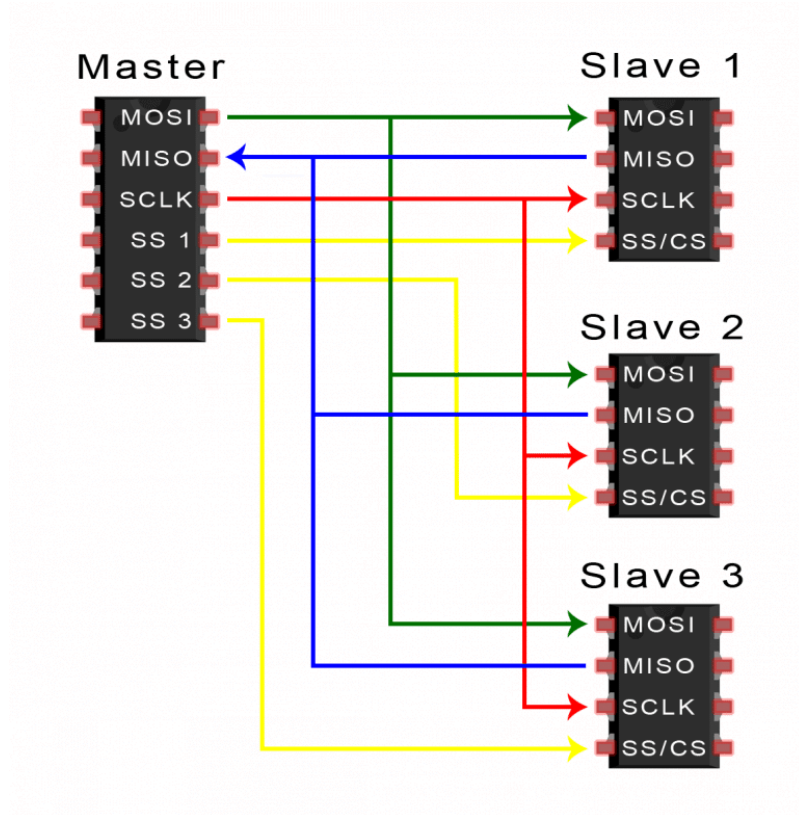


Figure 4.1.4b: Parallel SPI communication

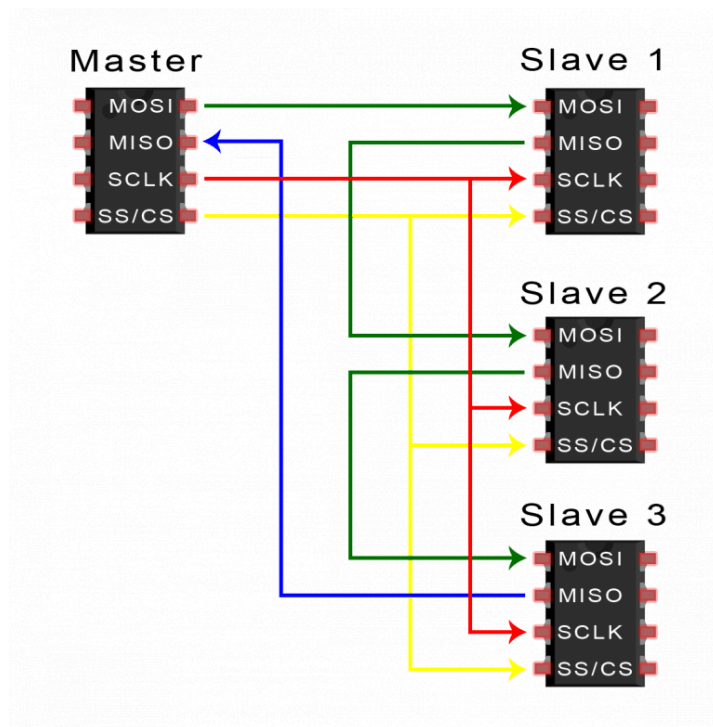


Figure 4.1.4c: Daisy-chained SPI communication

When sending the data between the master and slave devices, there would be a constant signal through the clock alternating the signal and a one through chip select to signify that this is the device that is communicating. When there is a signal being sent from the master to the slave, it will go starting from the most significant bit going on every positive edge from the clock, while sending data from the slave to the master will go starting from the least significant bit and will go from the negative edge from the clock.

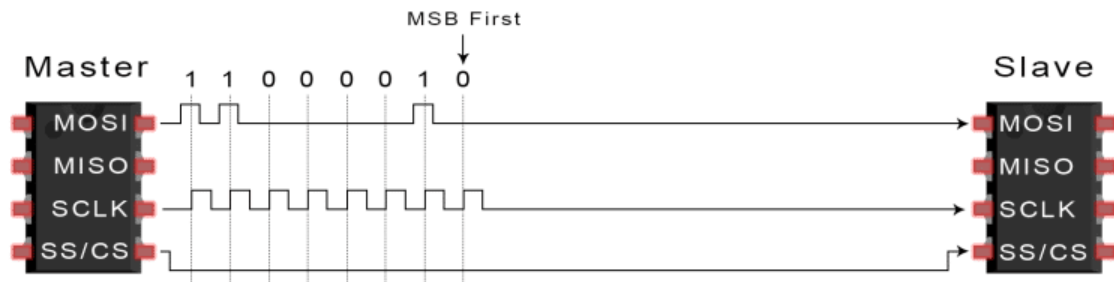


Figure 4.1.4d: Master sending values to slave

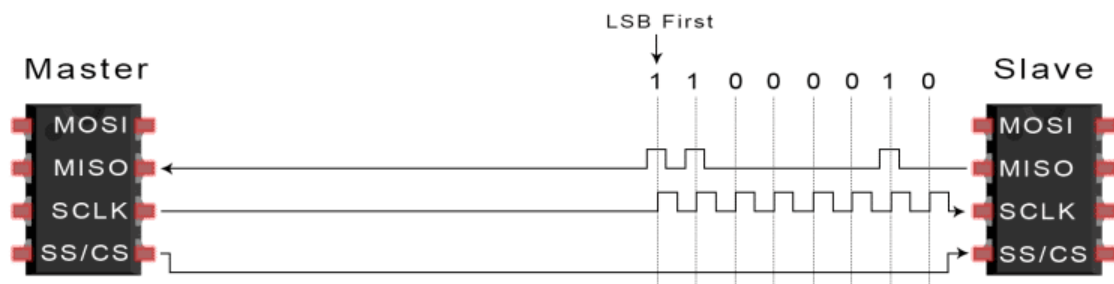


Figure 4.1.4e: Slave sending values to master

4.1.5 UART Communication

The Universal Asynchronous Receiver/Transmitter, known as UART, is a form of communication methodology that relies on a direct connection between the two devices, such that they will directly communicate with each other asynchronously through the transmitter and the receiver on the devices. This causes there to be only two wires and two ports that are needed for communication, the transmitter and receiver port, no need for a clock wire or signal, something that is needed in both I2C and SPI communication. With UART, there can only be a singular set of devices however, being one master and one slave, making it a very simple form of communication.

During the communication process of UART, there is a packet that deals with all of the transfer of information, containing multiple sections dedicated for each specific task in the packet. Within the packet, it goes in the order of the start bit, the data bits, the parity bit, and the stop bits. All of the bits that are sent and bits that are received either come from the data bus or are stored in the data bus depending on if the device is transmitting or receiving information.

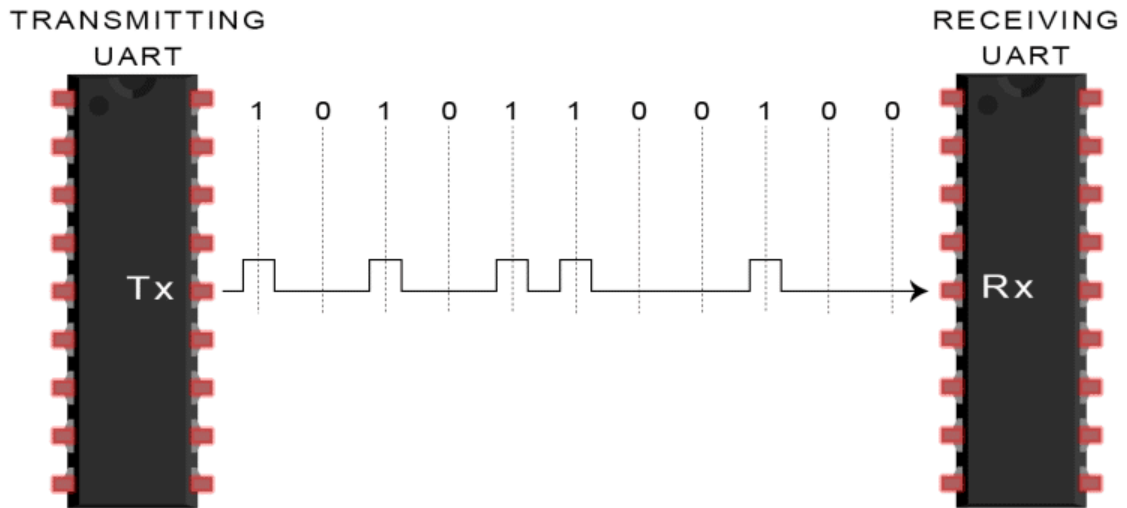


Figure 4.1.5a: How data is sent through UART

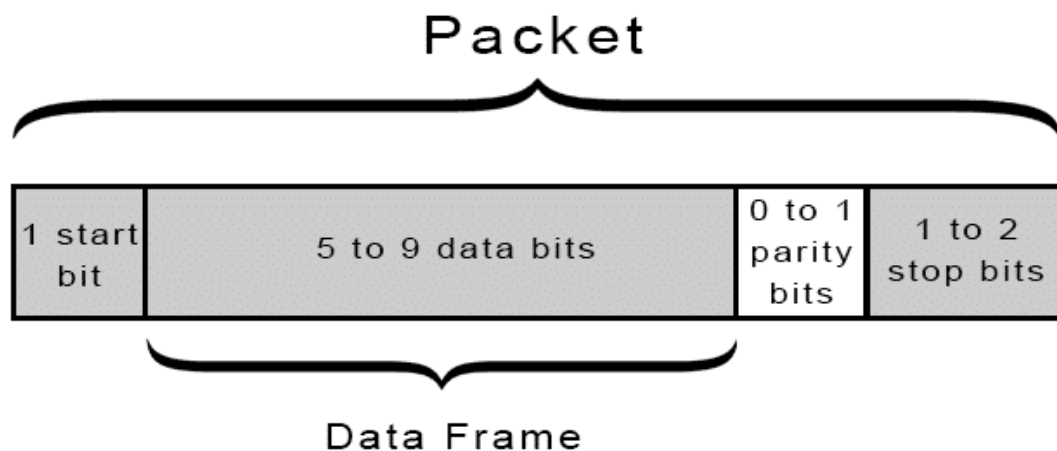


Figure 4.1.5b: Data packet sent through UART

Although UART is able to provide a direct, asynchronous communication between devices, it can come at some severe disadvantages, namely that there is only one master and one slave, causing for some severely limited use cases if you were to want to have multiple devices in a system. Along with this it also has a very limited data frame, only along 9 bits at once, creating possible issues to occur if there are more than 9 bits and a reduced baud rate compared to other communication methods that currently exist.

4.1.6 I2C Communication

The Inter-Integrated Circuit, otherwise known as I2C, is another form of device communication that allows for the ability to communicate with several different devices while only using two wires, taking aspects of both UART and SPI as we

have previously discussed. With I2C having two wires, it combines the transmitter and receiver wire into a single wire, becoming the serial data wire, also represented as SDA, while the second wire will now belong to a dedicated clock wire that is attached to every device that is apart of the communication, causing it to rely on synchronous communication, similar to SPI. With communication when there are multiple devices, there will be an address sent out to all devices that are attached, and the the communication will begin between the master and the slave when an acknowledge bit is sent back to the original transmitter, causing the communication between the two to begin.

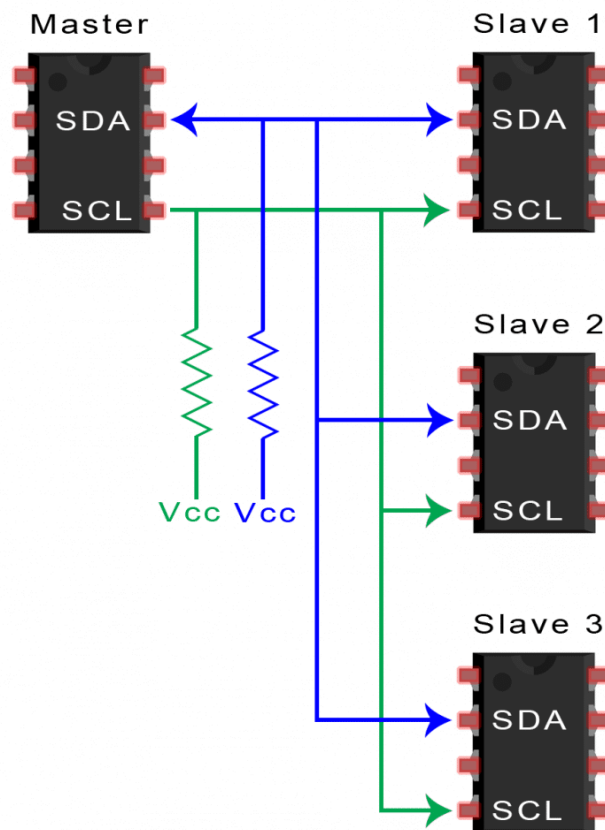


Figure 4.1.6a: I2C communication with one master, multiple slaves

With I2C, it contains its own form of data packet that will be used depending on every message being sent between masters and slaves. This involves there being multiple data frames to transmit the full message across, along with other parts attached to it that are not seen in other forms of hardware communication methodologies. With I2C, it will always start with the address that will go to the intended device it wants to communicate to, and once the address reaches the correct spot, the device will send back an acknowledgement bit to signify that it has been received. Once this happens, there will continue to be 8 bit data frames that are sent to the device, with an acknowledgement bit being set at the end of every data frame. Once all data frames have been properly transmitted, the

acknowledgement bit will signify that there are no more bits to send, signaling the end of the communication between the devices.

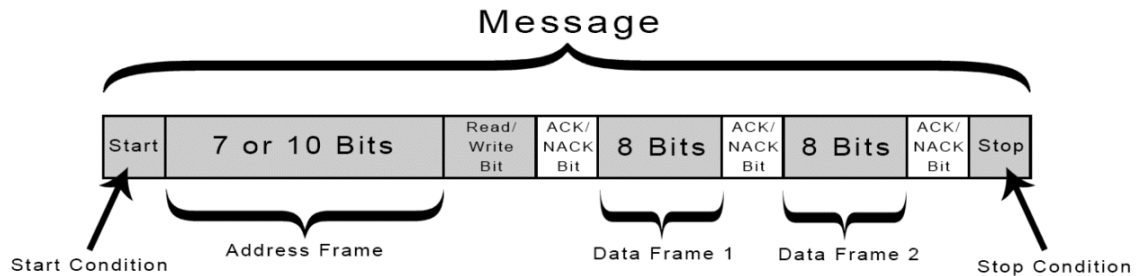


Figure 4.1.6b: I2C data message packet

4.1.7 IEEE 1562 - Sizing of a stand-alone photovoltaic (PV) Systems

When implementing solar panels as a power supply to your system we must consider IEEE standards 1562 for sizing a photovoltaic system. IEEE 1562 gives us an overview of what factors to consider when using a stand-alone PV system as a charging source. Understanding this standard allows us to choose an appropriate PV System using a certain procedure to achieve cost effectiveness and improve performance. This standard also informs you of different components to protect the battery from being over or under charged. IEEE 1562 also covers selecting the appropriate battery depending on your charging parameters.

Before being able to size a stand-alone PV system we must determine the actual load to avoid under or over designing. The IEEE 1013 is another standard incorporated in the IEEE 1562 that is the recommended practice for sizing lead-acid batteries for standalone PV Systems. We will be referencing this standard only to determine our load, since we will be using a Lithium-Ion Polymer battery type. The first thing to consider is the duty cycle that the battery will be encountering throughout the day, without any external power source provided. Once we have an idea of what the load profile diagram will be over a period of 24 hours, we can determine the size of the battery and make sure it can sustain the maximum daily load sequence.

Using solar radiation data is recommended when determining the size of the solar panels. We can find this data from multiple public and private sources. When looking at this data there are a few things we need to consider, one is if the load is going to be constant throughout the day and is the solar panel going to be fixed or tilted.

Once we have gathered both the load data and solar radiation data, the IEEE 1562 goes in depth on PV array sizing. IEEE 1562 states that "Selection of the PV modules takes into consideration price, available space, module mounting/dimensions and voltage (nominal, open circuit, and maximum power)

ratings” [44]. Other factors to consider when selecting your PV array charge controller, system losses, temperature effect on modules.

When implementing a battery into your design, it is recommended to use a charge controller. The IEEE1562 recognizes that certain charge controllers have more control of the parameters and how we want to charge the battery. This standard goes in depth on the charge controller technology like shunt regulator, series regulator, PWM regulator, and MPPT charge controller. All the information is referred to another standard IEEE Std 1361 which is more focused on battery selection, charging, and testing for Lead-acid batteries.

Typical losses from a solar panel come from shading reducing the amount of sunlight available for the solar panel, dust accumulation on the solar panel, snow blocking the sunlight, etc. IEEE 1562 considers most of these losses and gives them a value of 10% to 35%, these losses should be applied when determining the performance of a solar panel.

Like system losses there are many factors to consider when determining the temperature effects on modules. Most PV modules are rated at standard test conditions (STC) which is 25 °C. Most module temperatures vary from – 40 °C to 80 °C and PV modules will operate differently depending on the temperature. IEEE 1562 considers this and refers to a table provided by the National Electrical Code (NEC) to obtain a correction factor when looking at the open circuit voltage. This table and the equation provided to determine the module output voltage at certain temperatures help obtain the maximum module output from the solar panel.

Table 690.7 Voltage Correction Factors for Crystalline and Multicrystalline Silicon Modules

Correction Factors for Ambient Temperatures Below 25°C (77°F). (Multiply the rated open circuit voltage by the appropriate correction factor shown below.)		
Ambient Temperature (°C)	Factor	Ambient Temperature (°F)
24 to 20	1.02	76 to 68
19 to 15	1.04	67 to 59
14 to 10	1.06	58 to 50
9 to 5	1.08	49 to 41
4 to 0	1.10	40 to 32
–1 to –5	1.12	31 to 23
–6 to –10	1.14	22 to 14
–11 to –15	1.16	13 to 5
–16 to –20	1.18	4 to –4
–21 to –25	1.20	–5 to –13
–26 to –30	1.21	–14 to –22
–31 to –35	1.23	–23 to –31
–36 to –40	1.25	–32 to –40

Figure 4.1.7a: Voltage factors for modules

4.2 Design Constraints

Throughout the project, we encountered several design constraints, including cost, complexity, time, and the capabilities of available facilities and resources. While pushing these boundaries can often yield impressive results, it typically comes with trade-offs—most notably, increased economic expense.

Additionally some constraints were self-imposed by our team to ensure the project was practical given our skill level and experience. Others were external, such as limitations of the senior design lab facilities or deadlines dictated by the course schedule.

In the following sections, we will discuss these constraints—the ones we established, the rationale behind them, and how we adapted to constraints imposed externally. Examples of how the constraints became apparent or how a particular constraint affected our project is also discussed.

4.2.1 Financial and Economic Constraints

When designing a complex system involving significant research and development, higher expenses often lead to better-performing devices. For instance, an NVIDIA Jetson excels in image processing tasks compared to a Raspberry Pi, particularly for applications such as vehicle and hazard detection. The Jetson's 128-core GPU offers vastly superior parallel processing capabilities, whereas the Raspberry Pi 4 primarily relies on its 4-core CPU for such tasks, resulting in slower performance. However, the Jetson's enhanced capabilities come at a much higher cost, with the most economical model, the Nano, now priced at approximately \$500, compared to the Raspberry Pi 4's more accessible \$75 price point.

As college students with part-time jobs and limited budgets, we had to opt for the Raspberry Pi for our image processing needs. This decision required us to adapt our project to work with lightweight models like NanoDet, which are optimized for resource-constrained devices such as the Raspberry Pi 4B.

Cost constraints influenced multiple aspects of our project. To address these limitations, we conducted thorough research to identify components that meet our performance requirements while staying within budget. This approach necessitated optimizing the performance of affordable parts and exploring efficient software solutions.

In some cases, the scope of the project had to be adjusted to align with financial realities. While reducing scope is a common practice in real-world engineering projects to manage costs, it must be balanced against the expectations of stakeholders. In our case, the senior design review committee serves as our "customer," setting expectations that cannot be compromised. This dynamic mirrors real-world negotiations, where maintaining a balance between cost, functionality, and customer satisfaction is crucial. As we delved further into the

research of the sensors and parts that would provide the functionality of our project some adjustments needed to be made.

4.2.2 Timing and Deadline Constraints

The timing constraints of the Senior Design project is amongst the most pressuring and taxing with its ever approaching deadline hurtling toward us with the power to decide our future for the next few years. Always in mind, it is pertinent that the deliverables of our project are received promptly and readily in operating form. To ensure that we meet these expectations, it must be ensured that our team works cohesively to put together a prototype by the end of 2024. We must also order the PCBs in December. Most PCB estimates we have reviewed have given 2 to four weeks plus a 7–10 days shipping. As this is an external factor we can't control it is of utmost importance that we provide sufficient padding for any issues with these third party resources. This leaves us with a month to finish our pcb layouts and order out boards from the time of writing (October 30th, 2024).

To meet the deadline for PCB ordering, our EE members (not exclusively but most prominently) must design our PCB schematic with all our selected devices and sensors as well as other circuitry necessary to properly power the ICs used. Some devices do not have footprints readily available so drawing from data sheets must be assessed and drawn up in our CAD software to properly fit into the layout. Design verification must then be run and PCB vendors assessed and service secured. With the use of the 24GHz radar, it is necessary for us to use specialized PCB materials for high frequency signals that are low loss. These materials can be in shorter supply as not all vendors keep them regularly stocked. This could extend the manufacturing time of our PCBs. It has also been brought to the students attention that it is frequently needed to redo a circuit because of mistakes such as damaging a PCB when soldering. Needing to order a new PCB last minute would be disastrous to our timing constraint. To mitigate this concern we have opted, as have most SD students, to order our PCB in triplicate or more. As we have multiple radar modules needing a breakout for each one, five in the audacious stretch goal, we have opted to order ten, while this is only double the maximum possible count, it is over three times the base goal count. We hope that as the radar breakout boards are identical, we will become less error prone with iteration. We made this choice as the high frequency low loss PCBs are priced at a premium and we had to be mindful of our cost constraint mentioned earlier.

Documentation is also another exceptional time commitment of this project. Requiring 150 pages of content related to the project, our approaches to the project and other passing thoughts related to the execution of a large scale project (respective to a students experience) must be documented regularly. This can be an overwhelming or daunting task if not approached steadily and regularly. Again we hold each other accountable for our portions of the writing material. Each student is responsible for thirty pages of the document but some

leeway is considered for additions such as graphics and appendix material. These materials are also necessary but included in the overall document page count.

Lastly intimidating, we are all still in our student careers and must find a balance between our commitment to this project, all our other classes, and for some of us, our jobs that keep food on the table for our families even be it our pre-collegiate hourly jobs. Seeing as a failure to pass another class still results in delay of graduation for the failing student when credits are not met. To ensure proper balance we have been keeping regular communication and meeting with one another largely via Discord. We hold each other accountable for our duties to the project and keep one another informed promptly of any incidents that might otherwise delay our project or a deliverable on the project. This constant flow of communication helps us to navigate our goals and move up tasks if unexpected delays happen on another task thread. This then ensures we are all using our time effectively to promote a timely implementation of our project.

4.2.3 Facility Constraints

Being a college lab, and despite the best efforts of our faculty and professors, our school does not necessarily have top-of-the-line equipment. This imposed an external constraint on our project, most notably in terms of the device packages we could use for our PCBs. One of the first facility constraints we encountered was the inability to use BGA (Ball Grid Array) packaging, as the soldering patches would often overlap, causing shorts in the ICs. This significantly limited our selection of ICs, as BGA is one of the most popular packaging types for microcontrollers, radars, and many other devices.

Additionally, we are restricted to a minimum size of 0805 for components and a 0.5mm pitch. While 0805 is a commonly used size (2.0 mm x 1.3 mm), the smallest standard size, 0402 (0.4 mm x 0.2 mm), is about one-fifth the size. This size limitation created issues, particularly when stability capacitors needed to be placed close to other device leads, but the 0805 capacitors were too large to fit while still maintaining the required distance for traces and SMD pads.

To navigate these constraints, we explored several approaches. For the BGA ICs, we considered designing a breakout board that could interface with our main PCB using pins, allowing us to have the breakout board assembled by the PCB manufacturer. This would sidestep the issue of using BGA directly. However, during the design phase, we discovered that BGA fanout was a complicated task and would require microvias and multi-layer PCBs. These features would increase the manufacturing costs substantially, as they require high-precision devices and laser drilling for blind microvias. This constraint ultimately led us to abandon the idea of including an FPGA in our design.

For components smaller than 0805, we utilized pre-assembled or partially pre-assembled options. One such example is the SMR-314 radar devices, which operate at 24 GHz—a relatively high frequency. The high frequency of these

devices makes them more susceptible to losses and sensitive to trace widths and component sizes, particularly capacitors. In this case, the 0402-sized capacitors at the inputs to operational amplifiers were required, but they fell below the minimum size allowed by our senior design lab. To address this, we designed a breakout board for the SMR-314 based on the manufacturer's evaluation kit. We then specified that the smaller components, such as capacitors, be pre-soldered by the PCB manufacturer, allowing us to use these specialized devices without breaching lab constraints. This approach helped us meet performance needs while also allowing us to assemble the rest of the PCB ourselves.

Even with the use of pre-assembled components, a significant portion of the assembly remained our responsibility. For example, when using all five radars, we faced the need to solder approximately 500 devices, which ensured that we gained hands-on experience with PCB assembly despite the constraints.

4.2.4 Environmental Constraints

When designing this product there are some environmental constraints we should consider. Understanding how certain environmental conditions can affect our product gives us a chance to develop a more robust system.

The quarter panel PCB, the front bumper PCB, and solar panel would need to be able withstand rain, dust, and vibration. In addition, an environmental constraint specifically for the solar panel is the amount of sunlight it will receive, as this could lead to a lack of power generation on a cloudy day. When we are designing the quarter panel PCB and the front bumper PCB it is important that we consider automotive grade components that are more durable compared to their counterparts. As for the heads-up display, severe weather like heavy rain can make any of the virtual images difficult to see.

Wires and sensitive sensors set on the exterior of the vehicle will have to be considered when discussing environmental conditions like temperature, humidity, and vibrations. Wires running throughout the vehicle will encounter vibrations leading to wearing of the conductors and connection issues. Temperature and humidity can have an impact on sensors as they increase altering their accuracy.

The solar panel will directly connect to four PCBs, choosing a durable connector and enclosures to be able to withstand different weather conditions is important to consider. The International Electrotechnical Commission (IEC) has created a rating system to determine the resistance of an enclosure against dust or liquid called the ingress protection (IP) ratings. The first digit of IP rating represents protection of the enclosure against solid. The second digit represents protection of the enclosure against liquids or moisture.



Figure 4.2.4a: Ingress protection ratings guide

The use of ultrasonic devices can also be irritating to wildlife in the environment and cause hazards. Consideration was made in the selection of the device that would emit high sound pressure levels that could be detectable by some animals in the environment.

4.2.5 Safety Constraints

There are a multitude of safety constraints to be considered in the process of designing our system. The first, and arguably most important factor is eye safety. Previously discussed in this paper are the laser eye safety standards that are driving our component selection. Because this system contains a laser whose energy will be directed towards the windshield, and ideally directed back at the driver, eye safety is extremely important. Not only do we have to ensure that the optical density of the laser diode output is within the safety threshold to not be damaging to the viewer's eyesight, but also we have to make sure that the intensity of the light will not be distracting or cause night-blindness in the driver if the system is being utilized at night. This is somewhat difficult to accomplish while still ensuring that the intensity of the light output will still be enough to be

able to be seen in broad daylight. Finding the balance of the “just right” intensity level is the driving factor of the laser diode selection.

Another major factor, as briefly discussed above, involves roadway safety. There are fewer dedicated standards related to this particular aspect of safety, especially because in the context of our project, the safety involves the field of view of the driver. The overall objective driving the use of the head up display for alerting the driver visually to hazards is so that the driver will not have to look away from the road while driving, as well as not be impaired in their view of the roadway, such as if there was a screen they had to look at on their dashboard. While a screen sitting on the dashboard could attain the same goal of not requiring the driver to look away from the road, because the screen is not translucent, then there is the potential that the driver’s view could be partially blocked by the screen, therefore introducing unnecessary risk into the driving experience. A head up display solves this issue by presenting an image to the driver, in their field of view, while also remaining transparent so that no part of the roadway is blocked, allowing for a safer driving experience.

Along with the roadway safety constraints, there is also the safety factor of roadway distraction. This safety constraint is two-fold. For one, the driver must not be distracted by our device. This is mainly accomplished by producing a visual alert on the windshield in the field of view of the driver, so that their eyes never have to leave the road. This safety feature is an element that sets our product apart from similar products on the market, as discussed in a previous chapter of this paper. Other devices on the market that provide a visual alert for hazards to the driver generally involve a device that is installed on the side mirrors of the vehicle or that are placed to either side of the driver. While these devices accomplish the goal of alerting the driver to obstacles in a visual format, they all require the driver to avert their eyes from the roadway, introducing the risk of an accident when the driver is not fully paying attention to the road ahead of them. The second factor involving roadway distraction is from the opposite perspective. Our device must not produce a signal intense enough to distract other drivers on the road. The optical design choice to incorporate a combiner screen placed at the image plane of the head up display system is to minimize the risk for this type of distraction. The combiner screen collects and redirects the laser output of the head up display system, allowing it to be more visible to the driver, as well as preventing it from passing straight through the windshield. As discussed earlier, the laser diode selection for this system was made to ensure that no one could be blinded or sustain eye damage in the event that our laser light is directed into their eyes, but the combiner screen acts as an additional element of safety for our system. This safety consideration is also taken into account when selecting the material for the housings of our systems. To minimize risks of blinding or stray light reflections, matte, or non-reflective surfaces such as plastic will be used instead of metals for our outer casings. When driving in a car, sunlight and headlights can be incident on our products from a variety of angles, and producing our system with outer housings to minimize this risk of reflections is the safest option.

In addition to the basic weather and environmental safety factors discussed above, if this project was to be produced to be distributed to a wider audience, an instruction manual would have to be included. This manual would include basic information such as the procedures for setting up, calibrating, installing, and testing the equipment. From a safety standpoint however, there would need to be a section incorporated that gives an overview of the parameters for use of this system. It would be made clear that this system is not designed to replace standard safe driving practices, and that the accountability of driving safely does not transfer to the manufacturer of this product, rather the responsibility remains with the vehicle operator. This distinction is standard practice for products used to enhance the safety of vehicle operation, because the operator must be clear about their responsibility to drive safely, and to identify hazards themselves first, rather than to rely primarily on our system.

4.2.6 Manufacturability Constraints

While large-scale manufacturability is outside of the scope for this project, it is important to ensure that our product is able to be manufactured with existing machine tools and manufacturing methods, in a cost-efficient manner. This constraint is a very large driving force of the scope of this project, alongside our time and budget constraints described above. Many of our competent selections are from existing components that are commercially available off the shelf. Those components that do not fit within the parts readily available to us must be analyzed for their producibility by existing companies, within our time frame. For example, all of the lenses used in this project are available from lens manufacturers, and not custom designed. Many of the custom housings to be used in this project are to be 3D printed, so that they remain cost effective and producible within our time constraints. Conversely, this project incorporates multiple custom PCB designs, the designs of which are constrained to the capabilities of the PCB manufacturers.

4.2.7 Sustainability Constraints

The final constraint driving the design of this product is sustainability. Sustainability relates to the ability for our product to adapt over time and not become fully irrelevant. The goal of this product is to allow it to be easily installed by the user. This allows it to be more cost efficient and appeal to a wider audience of customers. Another goal of this project in the topic of sustainability is how long it will be able to last on a vehicle. Of course, the budget constraints are driving this ability, but all components are incorporated such that they could be upgraded individually without requiring a replacement of the whole system. Finally, the sustainability of our product is related to the prevalence of older vehicles without these safety features built in. As technology progresses, more vehicles can be bought with the safety features provided by our product already incorporated. For now, and the near future, there will still be enough vehicles on the road without these features to justify a need for this product. However, once the “older” vehicles have these safety features, our product could become

obsolete. However, since this phenomenon is not projected to occur for a while, the need for our product is still justified for this project.

4.2.8 Solar Constraints

Besides weather conditions being a constraint to the solar panels there are additional constraints like size of the solar panel, connectors, durability, and cost. All these are important when considering using a solar panel as a power supply, given that we will be mounting the solar panel on the top of a vehicle we want to consider factors that can limit the performance of the solar panels .

Since there is a limited amount of surface area on the top of the vehicle, selecting an appropriately sized solar panel that can fit on the majority of vehicles is important. With that in mind we also need to consider that selecting a smaller solar panel directly affects the amount of power output the solar panel can produce. The weight is also an important factor as we might need to use a stronger adhesive to safely secure the solar panel on the top of the vehicle, but this can also potentially damage the layer of paint from a vehicle.

As for the connectors, most solar panels use an MC4 connector, most companies implement this due to safety reasons. While they can be easy to plug in, they are difficult to unplug, the reason being to avoid any accidental disconnection under a loaded system. One of our goals is ease of installation, how we connect to the PCB is important. Whether it be from a DC jack or a terminal block, it is important that we convert the MC4 connector to any of the two making it easier to install.

Having the solar panel mounted on top of the vehicle, we should consider factors like vibration and dust accumulation. Having the wires exposed to vibration can lead to damage and affect the performance of the solar panel or terminate any power flow. In addition to dust accumulating quickly on the vehicle, bug splatter could be an issue as it covers the solar panel and blocks sunlight. Having the solar panel as the power source for the quarter panel PCB, we need to ensure that we mount and maintain the solar panel to provide the expected performance.

Certain solar panels provide features other than efficiency like coating for photovoltaic modules and a more durable frame for the solar panel. Having the solar panel on a moving vehicle we should expect unforeseen events like a rock hitting the top of your car. Providing a more durable solar panel would be ideal but the tradeoff is cost. In all, even though we want a more durable solar panel we still should stay within our budget.

Chapter 5:

Use of ChatGPT and 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.

As it will be talked about below, there are a plethora of both pros and cons that come associated with using AI in the scale of this project. An example could be asking a platform like ChatGPT any sort of question related to programming, where it can provide the user information that could possibly help them understand issues they have been facing, but at the same time provide blatantly wrong information that those who are looking to quickly get around doing the work necessary won't notice.

5.1 AI Benefits

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

5.1.1 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 forms such as Chegg's 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.

5.1.2 Research and Design Assistance

Chat GPT and Google's Gemini were also useful in designing the DC-DC amplifier which was a new task for the CPE that took it on. With chat GPTs 4o model it is able to search the web and search the data sheets. Where there was confusion about the datasheets specifications, chat GPT provided more clarity. These specifications were then verified in simulation and back calculation into the datasheet's provided equations. There was one discrepancy when calculating the high pass ac coupling capacitor for the op amp inverting input. With a frequency of 40 KHz and the formula $C = \frac{1}{2\pi f R_{in}}$ where $R_{in}=10\text{ K}\Omega$ should result in approximately 398 picoFarads however chat GPT returned with 398 microFarads and the signal was not properly filtered causing a bias in the amplified output. This was an easy mistake to recognize and fix especially at the SPICE simulation stage.

Chat GPT also made us aware of the bias caused by the non-ideal op amp currents and provided a link to a video on how to calculate bias resistors to negate the op amp current bias.

Chat GPT was able to aid us in the circuit design process, it was able to troubleshoot the design of the audio amplifier and make sure the code message/signal was correctly sent from the ESP32 board to the amplifier and then to the speaker in our speaker demo.

Chat GPT was also able to troubleshoot issues in the Eagle PCB and schematic design process. It helped solve library issues regarding overlap and footprint layout. It even was able to help solve issues with the library not correctly being updated and used in the schematic design, which was keeping us from creating the layout and footprint of crucial components.

One of the largest helps was the ability Chat GPT had to go back and forth with us on design of the internal cab PCB questions we had regarding the Head Up Display setup and laser diode power options. We had issues with finding a simple and efficient way to provide the necessary current to the laser diode from the ESP32 board. Chat GPT was able to suggest several options that we explored to find a solution to our issue by using an N-channel MOSFET transistor and a small resistor to establish our required current for laser operation. This was a huge help in staying on schedule and being able to adjust and explore options much faster than individual research regarding our design problem.

5.1.3 Coding Help

With the emergence of generative AI, it has resulted in plenty of cases where someone could struggle with trying to figure out how to properly implement code that they have been working on, allowing for them to get proper guidance on how to bring the code to what you desire for it to properly become. Something like this can be extremely beneficial, as often times when you try to look something up

online and try to find a proper fix for the error that is occurring, it will result in links to websites that can contain very suspicious information, lead to a forum website that has a similar issue to what you are having but with no responses, to website that has a much more complicated question and an even more complicated solution, or something that has absolutely no correlation at all. In some instances, generative AI can really help to reduce a lot of these issues that occur, where if you give it a prompt it can lead to a direct solution to your answer without the extra information attached to it.

Examples of this helping, when related to this project, can be questions related on how to implement the WiFi library properly using the ESP32 that we selected for our project. If we wanted to, we would be able to look up a topic such as “how would you obtain the MAC address of an ESP32” and it would provide the code necessary, allowing for users to get a relatively quick answer to their solution without needing to sift through loads of unrelated information that tends to exist on websites.

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 are 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.

5.2.2 Incorrect Code

As discussed previously, generative AI has allowed for great ways to solve any issues that may arise while programming, solving plenty of issues that occur while trying to create a program that reaches your true goal. With this however, it has led to plenty of cases where the help provided from AI has its own errors that did not previously exist in the code. This can exist in many forms, such as attempting to rewrite most of the existing code that was provided and turning it into a program that is wildly overcomplicated, providing an updated program that didn't address most of the errors that were previously present, often times magnifying or creating its own errors along the way.

These types of issues are oftentimes created due to where these generative AI models are trained on, in most cases being already existing information that is present on the internet. Because of these training methods, it limits what capabilities of it's problem solving, as most of the information it is using is based on information from at least one year ago, most cases two years ago, a time period that may seem small, but vast considering how many solutions that can result from real human beings on a daily basis. On top of this, some of the information that these generative models are trained on may have some incorrect information, as not everything that exists on the internet is always true.

If you were to also ask ChatGPT a programming question, such as something related to embedded firmware design, it would give you an answer based off of exactly what you provided through the text prompt. While the information that is provided to you is correct or not, all you need to respond to ChatGPT in this scenario is "this is wrong" and it will, at most times, end up completely rewriting the code to something that may have no relevant purpose to what you were expecting. Changes like this in ChatGPT can cause it to be so volatile to use, that it will make using it in more complicated programming environments not worth it to use, since it can cause times where it will impede your progress rather than successfully advance it.

5.2.3 Plagiarism

Due to the rapid expansion of generative AI, it has led to reports of plagiarism to skyrocket, since people will oftentimes take the information that they received from ChatGPT and just submit the text as is, claiming the work as their own. Occurrences like this end up appearing, especially in school, much more often than it has previously when people would copy assignments off of each other. Within the Senior Design class, this can show up in all types of forms, mainly through either the report writing or through software implementation of the project.

As Senior Design is meant to be the final culminating event of your undergraduate degree and putting together the skills you have learned to get to this point, using plagiarism in this case can severely detriment the credibility of someone's knowledge that they have learned throughout their time getting their

degree, seeming as if this person didn't have the skills necessary to be able to this point on their own. To prevent this, the best way to find a use of generative AI in a design standpoint like this should be to just create starting points of where to research for a project like this or used for citation purposes of other texts, allowing for there to be minimal possibilities of infractions of plagiarism that may result.

Since generative AI models are trained off of other texts that are mostly available online, some cases where they originate from physical media, they can be seen as basing their information off of already existing texts without specifically citing this information until you ask for it from the chatbot itself. In appendix C, prompt and answer 14, it shows this exact scenario, with it telling you what type of technical documents it found this information from, along with starting a followup that it can perform a search to provide a list of links and references.

5.2.4 Incorrect Information

Chat GPT can be an incredible tool for accessing more information than thought possible in an impressive amount of time. However it is not perfect, and sometimes gives incorrect information that if not vetted and checked, could ruin many aspects of a project. This can even be represented on its own website, where it states in very small text on the bottom of the page that ChatGPT can make mistakes, something that most people will end up missing.

An example of this was when we were exploring a conceptual design for our internal cab circuit. When we asked Chat GPT about the ESP32 Wroom board and utilizing the five volt bus for constant power input into our circuit. Chat GPT responded by saying that there was no 5 volt bus on our board and that the ESP32 Wroom only was capable of 3.3 volt input signals. Thankfully due to our extensive research of the ESP32 Wroom board, we knew that was not correct info coming from Chat GPT, if the ESP32 Wroom is connected to a USB power source, that five volt bus is available for constant power input in our circuit. After explaining that to Chat GPT, it quickly corrected and acknowledged the information we presented.

Another example was when we were exploring the audio amplifier options and talking about power and output from specific amplifiers. Chat GPT responded to specific amplifiers mentioned and attempted to correct us on the specifications of these amplifiers. Claiming power output was actually 4.2 watts, when we knew the model amplifier we were talking about was in fact only capable of 3.2 watts max output power. Chat GPT also attempted to correct us on the voltage input range into the amplifier. For some reason it attempted to inform us that the input voltage range was 10 volts to 45 volts, which was nowhere near reality. The actual supply voltage input for the amplifier in question was 2.5 volts to 5.5 volts. After we corrected Chat GPT again, it was able to change the parameters in its "head" and work with us on conceptual questions we had.

Chapter 6: Hardware Design

6.1 Optical Component Design

This section is meant to give the details for the design of the optical components of this project, namely the head up display system and the stereovision imaging systems. The calculations used for product selection as well as the thought process behind major design decisions will be discussed.

6.1.1 Head Up Display Design

The main basis of the head up display design is based on the principles of the 4F system incorporating Fourier transform to produce an image at the output of the system. This design allows the system to incorporate significant optical design as well as produce a custom image at the output, which is the windshield of the vehicle for this system. The image chosen as the output is the caution symbol that looks like a triangle with an exclamation point in the center. This image will appear anytime a hazard is detected by any of the radar or imaging sensors. As discussed in the research section, a red color laser diode was chosen to produce this image, as red is the universal color used for caution and alerts. This color will also stand out from the majority of conditions on the roadway, so should be most easily visible to the driver.

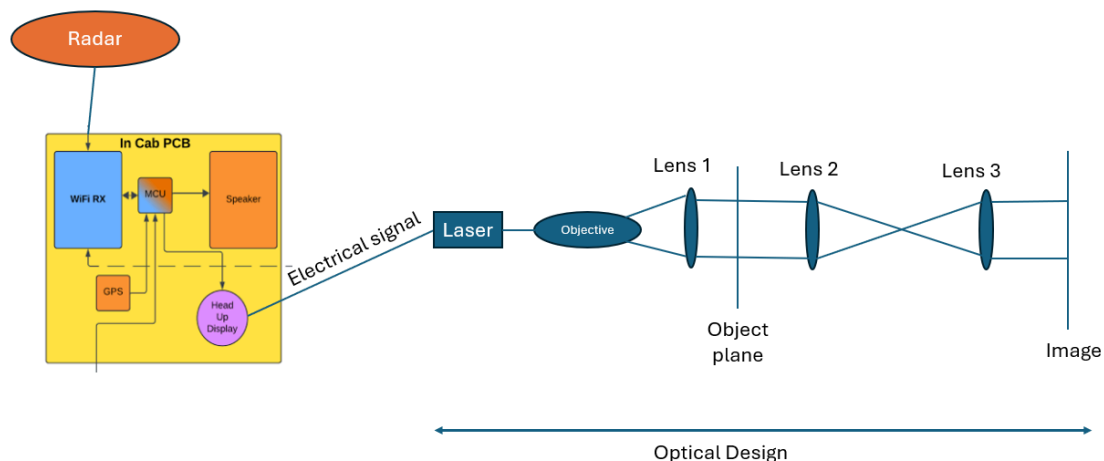


Figure 6.1.1a: Optical design layout of the Head Up Display

A large constraining factor of the optical design for the head up display is the depth of the dashboard. For the vehicle we are using to install and demonstrate this project with, the dashboard, or the distance from the steering wheel to the windshield was measured to be about 1 foot. This is chosen as the length constraint of the head up display, so that the system could rest on the dashboard

without interfering with the driver. A potential placement of the head up display system on the ceiling of the vehicle was considered, but was decided against for two reasons. The first reason is that the vehicle being used for this demonstration has a fairly low roof, and the driver is very tall. There was a larger safety hazard for the driver and the components if he were to accidentally hit his head on the system, so it was determined that the dashboard placement was more ideal.



Figure 6.1.1b: Anticipated output of the Head Up Display system

The second reason this placement was chosen as ideal is that the curvature of the windshield increases as it nears the roofline of the vehicles, at least in this particular model. To avoid distortion of the final image, using the lower half of the windshield as our output plane is more ideal. It also makes the system more accessible for a variety of drivers. If a driver that is shorter was to utilize our product, the top of the windshield is more likely to be outside of their normal field of view of the road, which negates one of the main purposes of our design. From the opposite point of view, someone that is taller and wanting to utilize our system, the lower half of the windshield is still within their regular field of view, because it is important to view the portion of the road in front of your vehicle while driving. The versatility of accessibility for our product is aided by the placement of the head up display system on the dashboard, and therefore this was chosen as the ideal placement for our final design.

When considering all of the component sizes, focal lengths, and working distances, it was determined that using lenses with a focal length of 25.4mm

each would be most ideal for incorporation into this design, while remaining within the spacing constraint of the dashboard.

After the components were selected, a housing was fabricated to align and contain the optical components. Because of the specificity of the measurements and needs of the system, 3D printing was chosen as the most ideal fabrication method. More specifications for this process will be discussed in the prototype fabrication and demonstration sections of this paper.

6.1.2 Stereovision Imaging System Design

The front bumper imaging systems are designed on the basis of stereopsis. Stereopsis is the principle by which the human eyes perceive depth. Depth perception is based on the disparity of the images received by each eye, related to the distance between each eye. These distances work together to allow the brain to calculate the distance from the eye to the object being viewed.

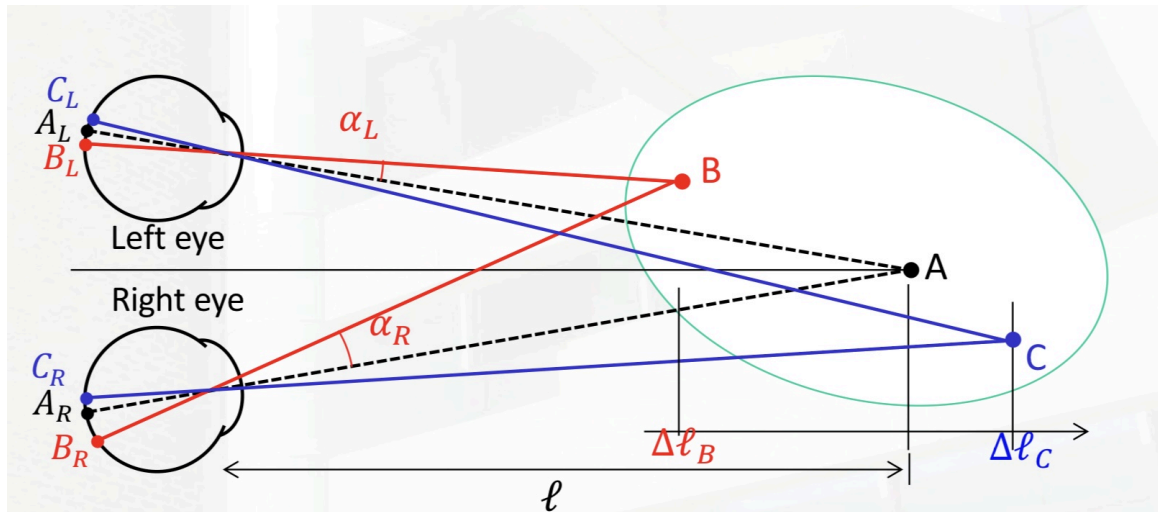


Figure 6.1.2a: Diagram depicting how the brain perceives depth via stereopsis

For the imaging system in our project, there will be two cameras mounted on the front bumper of the vehicle, acting as the two “eyes” of the system. They will be mounted a fixed distance apart, so that depth can be accurately calculated. The software is responsible for the image processing aspect of this task, acting as the “brain” of the system. The software will take the two images from the two cameras, overlay the images, and calculate the pixel disparity between the largest object to calculate the distance to the object in front of it.

6.1.3 Lane detection imaging system

The same cameras being used for stereovision on the front bumper will also be used for lane detection. The field of view of the system must be large enough to

image the lane lines while the vehicle is driving. Edge detection will be used to detect the lane in the image captured by the imaging system, which is discussed in further depth in the software portion of this paper. The imaging system will have to be calibrated once the cameras are installed onto the vehicle, to ensure that they can accurately determine whether the car is fully contained within the lane, drifting to one side, or outside of the lane lines at all. This will be different for each vehicle because each is unique in width, and mounting positions can vary, which is why calibration is necessary.

6.1.4 Calculations for component specifications

When designing our system, it is important to choose the optical components necessary to meet the optical parameters required to meet the overall system requirements. The overall system requirements related to the optical components of our project involve the head up display image size, and the field of view of the front stereovision cameras. From each of these system requirements, more specific derived requirements were created related to each major component that makes up the head up display and the stereovision imaging system.

Table 6.1.4a: Optical component specifications

Component	Parameter	Specification
Head Up Display	Image size	0.5 in ²
Head up display	Package size	12 x 5 x 3 in
Laser	Package size	1 in ²
	Wavelength	630 nm
	Output intensity	1 mW
	Drive current	100 mA
HUD lenses	Focal length	2 in
	Diameter	2 in
Combiner Screen	Size	1 in ²
Front Cameras	FOV	45°
Camera lenses	Focal length	6 mm

Once these specifications have been determined, calculations must be done to ensure that the components we have selected will meet these specifications.

The first calculation done is involving the overall package size of the head up display. The length of the system can be calculated by adding up the component length of the laser diode, the length of the microscope objective, the working distance of the objective, and the four times the focal length of the lenses selected. Because we are confined to the depth of the dashboard, which was determined to be 12 inches, we can set this equation equal to that length to determine the maximum allowable focal length of the lenses to be utilized in this system. This formula, as well as the calculations, are shown below.

$\text{Laser} + \text{Microscope Objective} + \text{Working distance} + 4f = \text{Total length}$
$18.4\text{mm} + 160\text{mm} + 0.66\text{mm} + 4f = 304.8\text{mm}$

From this equation, it can be calculated that $f \leq 31.435 \text{ mm}$. In order to allow for some error, and based on the lens selection available to us, lenses with a focal length of 1 inch, or 25.4 mm were selected. This focal length can be plugged into the formula above to show that we will have an expected system length of about 11 inches.

In order to remain within the package size height and width requirements of 3 and 5 inches respectively, the lenses chosen have a diameter of 1 inch as well. This will help to ensure that the head up display system can sit on top of the dashboard without interfering with the driver's view of the road ahead of them.

The next component specification calculated to be done is to determine the field of view of the front stereovision imaging systems. We will use the camera sensor format along with the field of view formula to determine the focal length necessary to achieve our goal of a 45° field of view. The field of view formula is shown below.

$FOV = \arctan\left(\frac{d}{2f}\right)$
--

In this formula, FOV is the full angle field of view of the imaging system, d is the sensor size, either diagonal, horizontal, or vertical, and f is the focal length of the lens system being used to direct light towards the sensor.

As seen from the data sheet of the camera selected for our project, the sensor integrated into this system is the OmniVision OV5647. This sensor has 5Mpixels, and has a sensor size of 0.25 inches, or 6.35 mm. After rearranging the formula and solving for f, using $d = 6.35\text{mm}$ and $FOV = 45^\circ$, it was calculated that the ideal focal length should be 7.66mm. And to increase the field of view, a smaller focal length must be used.

After calculating all of the necessary specifications, and comparing to the data sheets of the components selected for use in this project, the calculated values

were compared to the original derived requirements, to determine if each parameter was achieved or improved. This information is all tabulated below.

Component	Parameter	Specification	Calculations	Comparison
Head Up Display	Image size	0.5 in ²	0.75 in ²	Improved
Head up display	Package size	12 x 5 x 3 in	11 x 2 x 1.5 in	Improved
Laser	Package size	1 in ²	10.4mm x 18.4 mm	Improved
	Wavelength	630 nm	655 nm	Achieved
	Output intensity	1 mW	1 mW	Achieved
	Drive current	100 mA	35 mA	Improved
HUD lenses	Focal length	2 in	1 in	Improved
	Diameter	2 in	1 in	Improved
Combiner Screen	Size	1 in ²	5.1 in x 5.9 in	Improved
Front Cameras	FOV	45°	45°	Improved
Camera lenses	Focal length	6 mm	7.66 mm	Achieved

Table 6.1.4b: Optical component comparisons

6.2 Power Delivery

This system will use both the solar panel and the electrical system from the vehicle as a power supply for our design. The 4-quarter panel PCB will be connected to a singular solar panel providing a maximum power of 25 W, the front bumper will be tied into the fuse box utilizing the vehicle 12-volt battery, and the in-cab PCB will be pulling power from a 12-volt cigarette lighter socket or a 5-volt USB port.

6.2.1 Quarter Panel Design

The power delivery for the quarter panel PCB will involve a stand-alone charge controller ensuring that the battery doesn't overcharge and a voltage regulator providing the needed voltage rail. The quarter panel will need 3.3V rail to power the MCU and ESP32, but the ultrasonic sensor we will be using will use an operating voltage of 60 Volt peak to peak at 40kHz. An additional regulator will be implemented using 5 volts provided by the MCU, from there a sub circuit will be designed to obtain the needed frequency for the ultrasonic sensor.

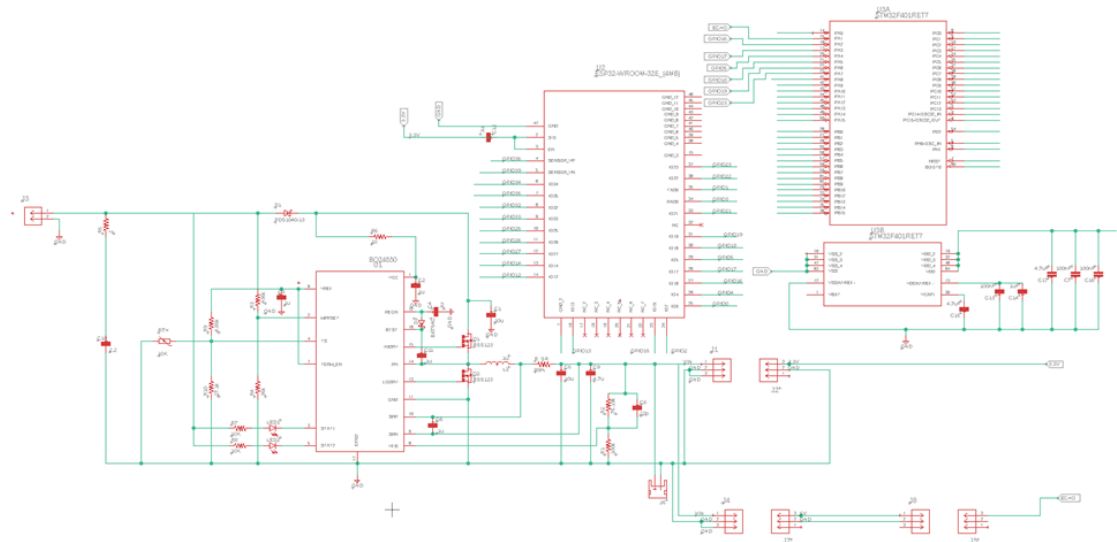


Figure 6.2.1a: Quarter Panel Schematic



Figure 6.2.1b: a power distribution of the quarter panel

The 20-volt solar panel will start sending power to our PCB through a PCB terminal block. A Schottky rectifier is used here as protection to ensure that no current is flowing back to the solar panel. To utilize the maximum power point tracking the charge controller offers we first need to know what the maximum power point of our solar panel is. The voltage maximum power point typically ranges from 70% to 80% of the open circuit voltage.

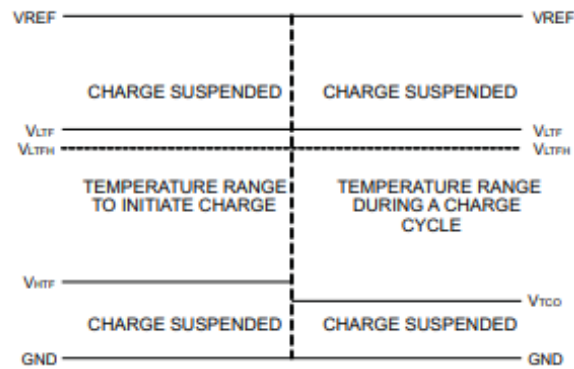


Figure 6.2.1c: Thermistor Sense Thresholds

Since the battery we are using doesn't have any temperature sensing features, we will have to use a thermistor. The purpose of the thermistor is to manage the temperature of the battery and if the temperature is out of the set range then charging will be suspended. The type of thermistor we choose is dependent on the battery chemistry we choose. Initially we had decided to use lithium polymer giving us an average charging temperature between 0 and 45 degrees Celsius, but due to LiPo cells not being allowed in the senior design lab we had to pivot and choose a different type of battery. Fortunately, the lithium-ion average charging temperature is the same as the lithium polymer.

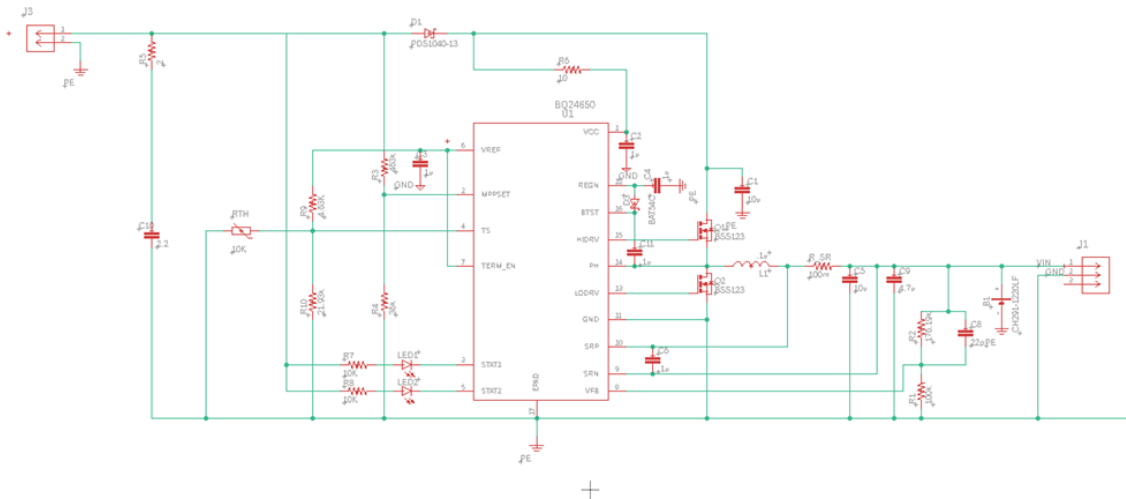


Figure 6.2.1d: Charge Controller Schematic

MAX25302A is one out of the three voltage regulators being used in the quarter panel. This regulator takes the 3.7 V from the battery and drops it down to 3.3 V

providing a voltage rail for most of the electronics on the PCB. To achieve a 3.3V rail we had to tie SELA to ground and leave SELB unconnected to achieve Hi – Z. we have decided to put all regulators on a breakout board and attach it to the main PCB allowing us to easily replace it without interacting with the main PCB. The second regulator TPS61022 will take the 3.7V and step it up to 5v to provide power to the signal amplifying circuit.

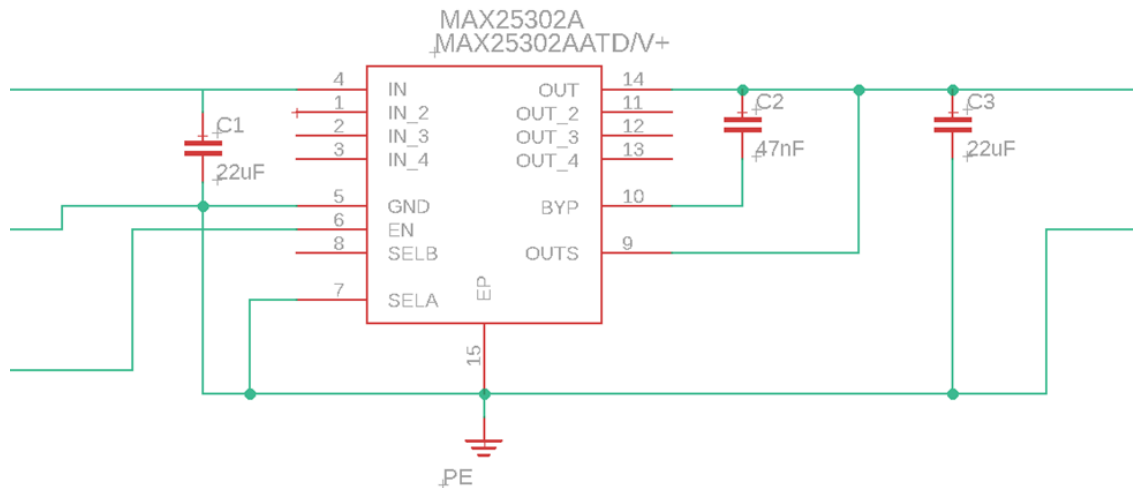


Figure 6.2.1d: MAX25302A Breakout Board Schematic

To provide the required power to the ultrasonic sensor we need to build a sub circuit that uses two op amps to produce the necessary gain for the signal provided to the op amps. The signal will come from the DAC incorporated into the STM32. There will be an extra voltage regulator to provide a DC voltage rail of 5V for the two regulators in the sub circuit. The purpose for these two regulators is to provide enough voltage range to obtain the necessary signal.

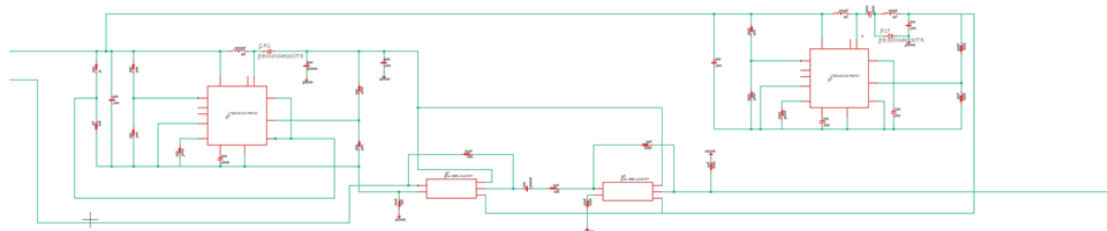


Figure 6.2.1e: Sub Circuit Schematic

The first regulator shown in figure 6.2.1f uses equations provided in the data sheet to obtain the appropriate resistor values to get a positive output value of 30 V . The 30 V output will then provide a positive power supply to the two op-amps. The second regulator shown in figure 6.2.1g will be using a similar but different equation to get a new set of resistor values to get a negative power supply of 30V. The -30 V output will then be the negative power supply of the two op-amps. With the two LT8331 we can get a voltage swing of -30v to 30v allowing us to get a 60-volt peak to peak.

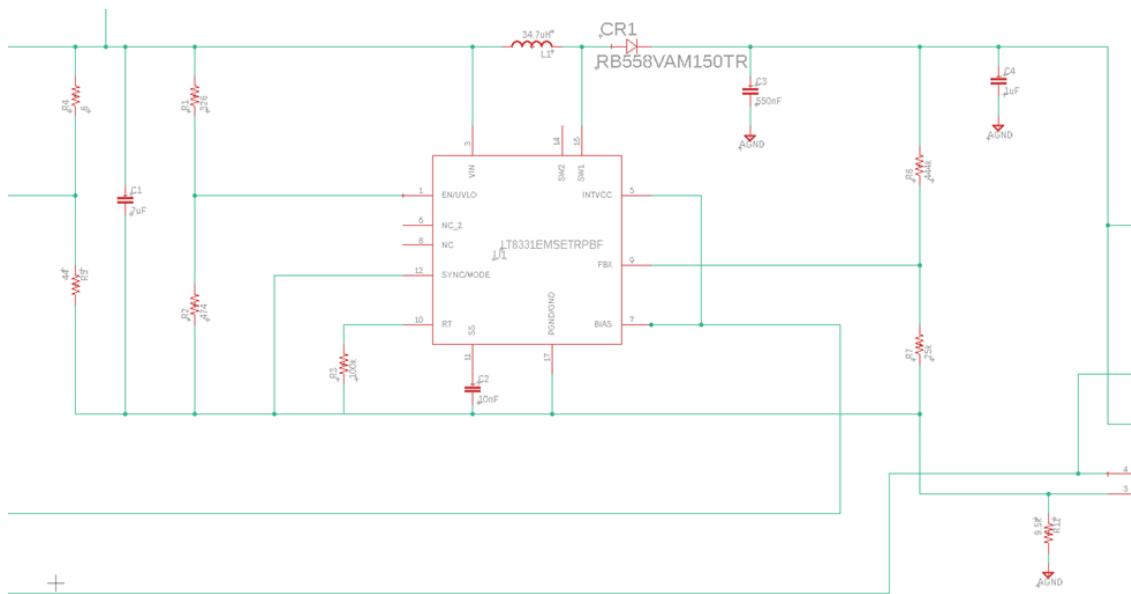


Figure 6.2.1f: 1st LT8331 Schematic (Left section of the sub circuit)

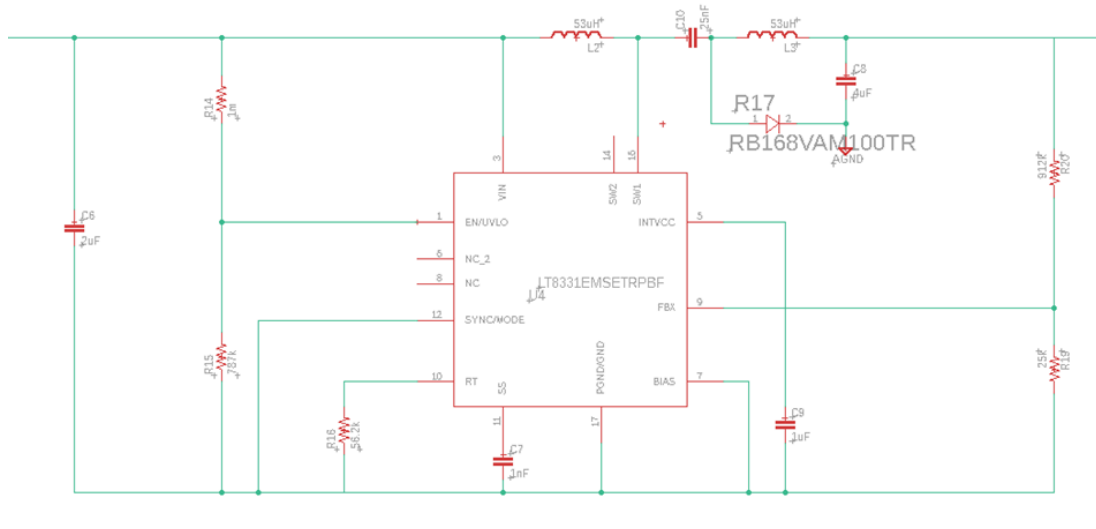


Figure 6.2.1g: 2nd LT8331 Schematic (Right section of the sub circuit)

After the two linear regulators have provided the necessary voltage supply for the two-stage op-amps, we are able to take the signal and amplify it to the needed voltage.

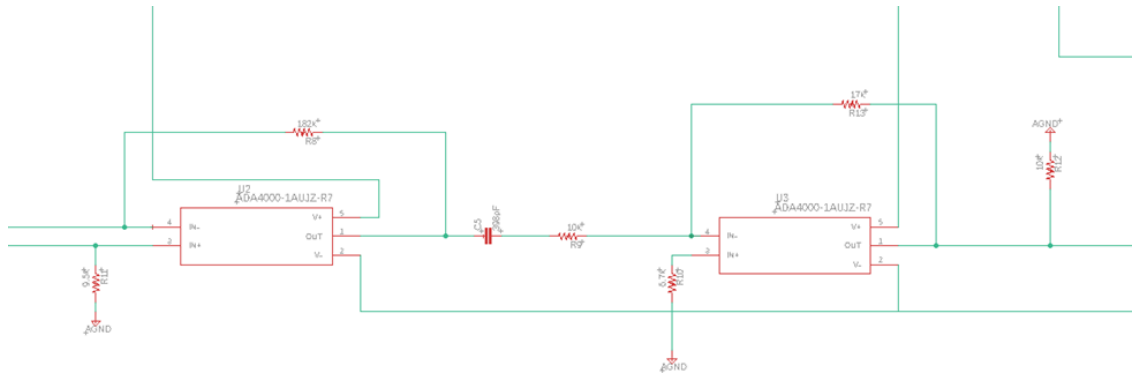


Figure 6.2.1h: Two Stage Op-Amp Schematic

6.2.2 Front Bumper Design

The power delivery for the front PCB will be connected to the appropriate fuse slot using a fuse tap adapter to use the 12-volt battery. From there the 12V battery would be stepped down to 5v and 3.3V to power the front bumper electronics. Below is the power distribution and the schematics.

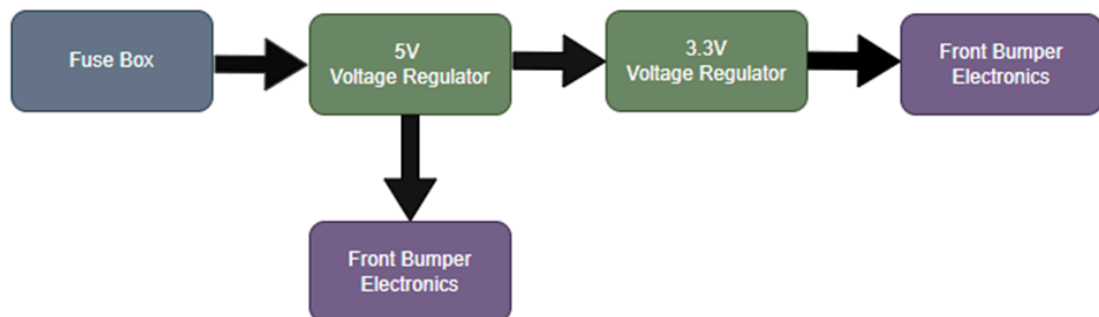


Figure 6.2.2a: Power Distribution for the Front Bumper PCB

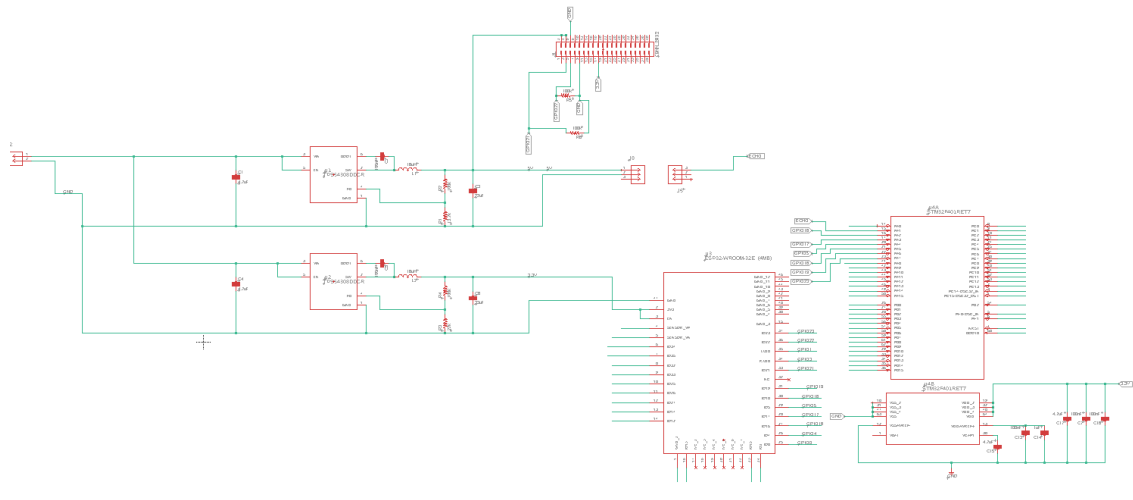


Figure 6.2.2b: Front Bumper Schematics

6.2.3 In Cab Design

The power delivery for the internal cab portion of the design is straightforward. The ESP32 will receive a usb input power of 5 volts and the ESP32 will provide 3.3 volts via GPIO pins to the audio amplifier and speaker. The ESP32 will also provide another 3.3 volts to a breakout board via a terminal block that will continue power distribution for the internal cab design.

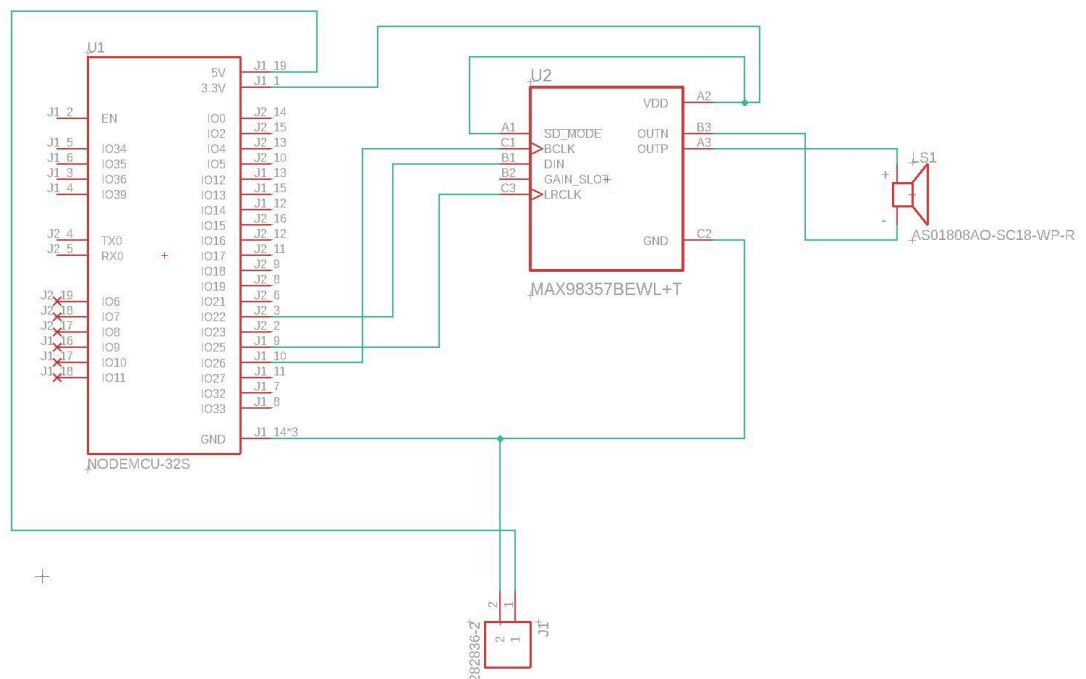


Figure 6.2.3a: Internal Cab PCB Wiring Schematic

The internal cab design continues from the main PCB to a breakout board that contains several circuits, first is the step up voltage regulator that will take the 3.3 volt signal from the ESP32 GPIO and step up to a 5 volt output with up to 200 milliamps of current. The next stage of the circuit involves another boost regulator that takes that 5 volt and 200 milliamp output and converts it to a 12 volt output. That 12 volts is then fed into a linear regulator that provides a constant current circuit of 30 milliamps that will regulate voltage between 4.8 volts and 5.2 volts, the operating voltage range of our laser diode. Along with the proper voltage range is the required current at a stable output of 30 milliamps to provide steady and safe current to the laser diode that will be connected via the terminal blocks at the end of the board.

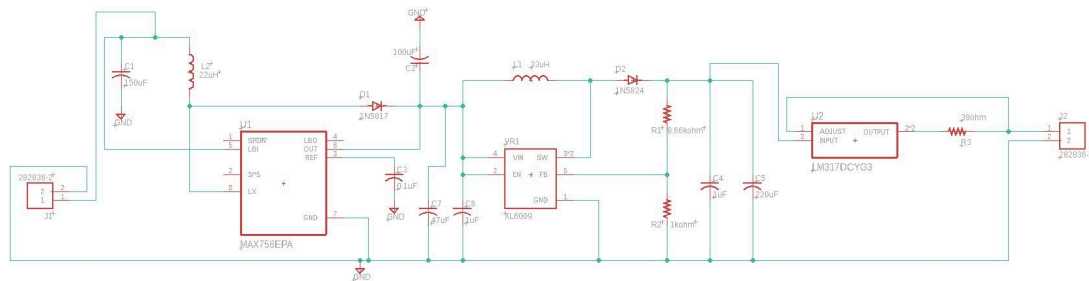


Figure 6.2.3b: Internal Cab Breakout Board Wiring Schematic

Chapter 7: Software Design

Software design plays a critical role in the success of any project by providing a structured approach to developing a robust and well-functioning system. It ensures that the system's components work together seamlessly, aligning with the project's objectives and constraints. Effective software design not only facilitates smoother integration and scalability but also reduces the likelihood of costly errors during implementation. By establishing a clear design foundation, teams can better manage complexities, improve efficiency, and enhance the overall quality of the final product.

7.1 Design Methodologies

Selecting the appropriate software design methodology is essential, as it directly influences the project's workflow, coherence, and adaptability. Each methodology has unique attributes, including its level of structure, flexibility, and ease of application, which must be weighed against the project's specific requirements. For the Proximity-Based Hazard Detection for Older Vehicles project, methodologies are analyzed to determine their suitability, aiming to strike a balance between adherence to a structured design process and the need for localized adjustments to achieve optimal outcomes. Below, these methodologies are discussed and compared to guide the decision-making process effectively.

7.1.1 Agile

Agile, arguably the most popular methodology —and the 2010s buzzword of the year in the project management world, is a cyclic design process framework that, as asana puts it– “breaks projects down into several dynamic phases, commonly known as sprints.”[42] A sprint is made up of 6 steps: plan, design, develop, test, deploy, and review. Agile’s strongest suit is it allows for the exploration of new features when the criteria may not be fully developed or understood. Agile also prioritizes customer communication, consistent and frequent interim deliverables over scrupulous and or tedious documentation. While it is not outright stated that documentation should not be taken, it is asserted by the second pillar of Agile that a function system is more important than a documented one.

Due to its iterative nature or sprint cycle, agile is able to live up to its name to quickly pivot or adjust to feedback form the customer, tests or other feedback on that sprint. Agile also provides the iterative review step where the team is to assess how and what worked, what worked well, not so well or maybe not at all. This review period allows for a more well strategized next iteration that plans around the last iterations mishaps and capitalizes on the strong points.

Agile is a great methodology for rapid development however it does come with some tradeoffs, most notably the lack of documentation. Too often users of the methodology take the prioritization of function over documentation that little to no documentation is ever taken. While this may lead to a more quickly delivered project in version one, it leads to several setbacks when adjustments need to be made. Worse it leads to nightmares if future developers need to revisit the project but have nothing to go on except to reverse engineer the functionality. Similarly the ability to pivot may be beneficial to meeting a customers dynamic demands, however, rapidly changing development parameters reduce confidence in project projections and deadline projections of large scale goals.

These setbacks have been recognized by several members in the industry and thus refinements weare made in variations such as Crystal Method, Dynamic Systems Development Model (DSDM), and Scrum. Since our project goals and expectations are well understood, and documentation is vital to production of this document, Agiles principles are not greatly suited for our development.

7.1.2 Waterfall

Waterfall is a linear project development methodology that follows a structured sequence of phases: gather requirements and plan, design, implementation, verification, and maintenance. As one of the oldest and most widely recognized project management methodologies, Waterfall has a clearly defined framework that ensures methodical progression through each stage.

The biggest advantage of Waterfall is its clarity and structured nature. Its five-phase approach provides a clear roadmap for teams to follow, helping ensure all requirements and needs are identified and allocated early in the

project. This approach also keeps the end goal in focus from the start, leading to more cohesive planning. Furthermore, the highly structured nature of Waterfall allows for easier communication within the team, as all members are aligned to the same plan. By prioritizing accessible information and consistency, Waterfall minimizes deviations from the expected project trajectory, which can be particularly useful for projects with well-defined requirements.

However, Waterfall's primary drawback is its inflexibility. This methodology assumes that all requirements are fully understood at the beginning, leaving little room for changes or iterations. If issues arise during an earlier phase, it is challenging or impossible to revisit and make corrections. Similarly, testing is deferred until the very end of the project, as no deliverables are available for evaluation beforehand. This can lead to costly and time-consuming fixes late in the process.

Another major limitation is the communication gap between the developer and the customer. Because there are no interim deliverables to review or refine during the project, customers are left without a tangible sense of progress. The result is a higher likelihood that the final product may not meet their expectations, leading to last-minute adjustments, missed deadlines, and strained trust. Furthermore, if initial requirements are incomplete or inaccurate, the project may suffer from poor resource allocation, understaffing, and underestimated budgets. This again can result in significant delays and last-minute strategy shifts that are difficult to manage under the rigid structure of Waterfall.

Due to these constraints, Waterfall is generally not well-suited for high-risk projects where information evolves over time or for projects requiring flexibility to adapt to unforeseen circumstances. For our senior design project, we have decided against using Waterfall as our primary methodology. However, certain aspects of Waterfall, particularly its emphasis on documentation, consistency, and linear planning, will still be leveraged for specific, self-contained subsections of our project.

For example, the semester one device demo will adopt a Waterfall-like approach. In this linear phase, we plan for the optics students to assemble the Head-Up Display (Head Up Display) and 3D print the housing, the electrical engineering students to construct the system on a breadboard for a demonstration, and the computer engineering students to implement the necessary controls using the IDE and program the ESP32-S development board. This straightforward, sequential process is well-suited for this portion of the project and will also allow us to document our approach thoroughly as it is executed.

By selectively incorporating the structured principles of Waterfall, we aim to achieve efficiency and clarity in areas that benefit from its methodology, while avoiding the rigidity that could hinder progress in more dynamic or uncertain aspects of the project.

7.1.3 Selection

For our selection, we will be going with a blend of these two methodologies, Agile and Waterfall. We make this selection to align with the needs of our project. Our project is relatively small, but a lot of the implementation is new to us. This high rate of learning while implementing aligns more closely with the Agile method as modifications will likely be needed as we learn of intricacies along the way. One such example is with our hazard sensing technology. Based on our device research we had landed on radar technology that seemed to fit all our design specifications and met all accessibility requirements of the lab facilities available. Unfortunately conversations with Dr. Weeks and a PH.D. Graduate student Kristen Ling, we were fairly last minute steered away from RF technologies due to the complexity induced by the high frequency technology. With Agiles iterative and flexible nature we were easily able to pivot to another more easily implemented technology. With a pure Waterfall method, we would implement the design and fail or make it to the end before we realized the design failed. We will also be using Waterfall as mentioned earlier.

7.2 Embedded IDE Selection

The programming of much of this project takes place at the register levels, that is, register store values used to determine the functionality of pins and components of the MCU and how it interacts with the sensors and devices used in the project. This requires the use of an IDE (Integrated Development Environment) to do in any timely manner. The IDE provides a space to write and compile the code as well as flash it to the MCU. The IDE also tends to have tools and libraries to ease the process when developing on the development board that accelerates the process.

In our project we have a selection of 2 different MCU the ESP32-s and the STM32F401RET7. First for the low power Wifi needs and low cost and the latter for its reasonable cost and 84MHz DAC. For the ESP32-S, a higher level of programming is used by the Arduinos wrapper classes in C++. Because the pins and registers are already known by a selection of platform, board and framework, coding is simplified to expressions such as send some signal to some pin n. For this programming we will be using platform IO, an extension in the VS code environment. It provides easy interfacing with the ESP32 MCU especially for tasks such as uploading audio files for the audio alert system. Arduino IDE was also considered, but it is relatively bare bones and achieving similar functionality required piecemealing expansions together that exacerbated complexity not beneficial to the project's outcome. Both IDEs are open source so there was no monetary decision point on their selection, only functionality and GUI based.

The STM32 works best with STM's own IDE STM32CubeIDE. STM32Cube is based on Eclipse IDE but expanded for the use of C++ and with support for Eclipse® add-ons, GNU C/C++ for Arm® toolchain and GDB debugger. This is the register level programming mentioned earlier. This will make the

programming here slightly more complex than the ESP32, however the required functionality is also reduced to programming the ultrasonic sensor easing the implementation of the system despite the more complex code.

7.3 System Design

The System is designed to interface the hazard detection technology with the driver. When the system boots up, it synchronizes the ultrasound modules so as not to cause interference. The GPS module is constantly monitoring speed via communication with the satellite network. The CV system monitors lane following, and distance to the next car ahead.

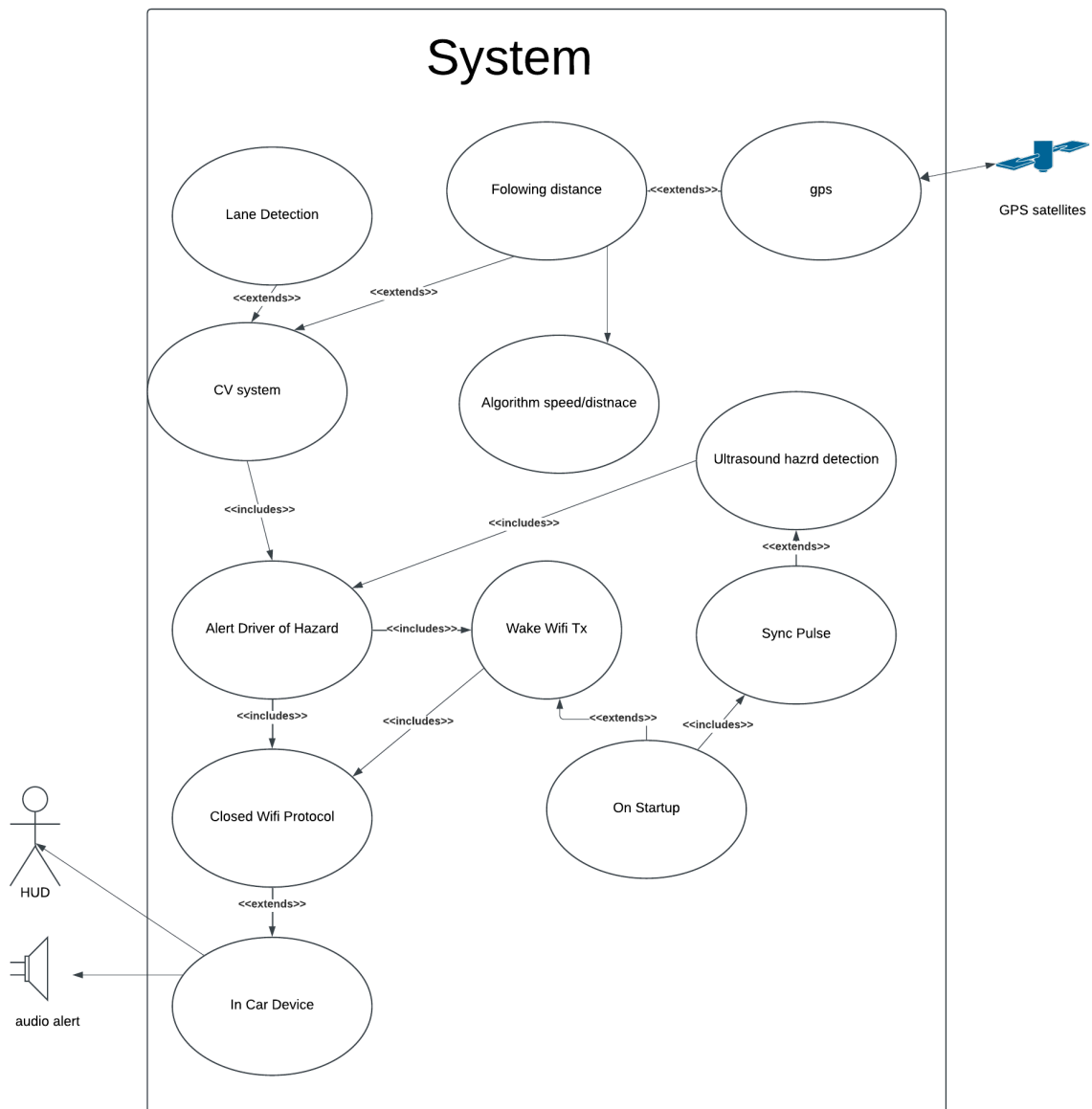


Figure 7.3a Software Use Case Diagram by Authors

Straying from safe parameters sends alerts to the command module which controls the human interfacing devices, the Head Up Display (Head Up Display) and speaker alarm. This system should keep the driver always aware of hazards; physical obstacles in proximity of the car, or hazardous driving such as lane straying or tailgating.

Our system will be incorporating computer vision for a lane detection and a stereovision distance calculator. Computer vision was a new scope for both CE students, so we started with the easier of the two tasks, lane detection. We discovered that images stored in the computer when in RGB format, are 3X8bit per pixel a byte per color channel. This information can then be read linearly or interpreted as needed using modulo techniques. There were several options to choose from of various API and libraries as well as OpenCV, Scikit-Image, SciPy, Pillow, NumPy and NanoDet. We also considered processing the image data through an FPGA to accelerate the CV process. This would require custom HDL code as well as specialized hardware for data storage during the process. For the more complicated application, we would lean more heavily on one of the libraries to implement our design.

7.4 Image Processing and Lane Detection

As mentioned, lane detection and stereo vision are factors of our design. These are both computationally and memory expensive. We investigated many ways to implement such algorithms from libraries that simplify computer vision tasks such as openCV to pre-trained deep learning model such as nanoDet. Below we will discuss the method that we chose for our system and how we plan to implement them in the coming semester.

7.4.1 Lane Detection

The lane stray detection system is programmed as diagrammed, the lane detection algorithm is programmed high level in python on the Raspberry Pi zero W2 using the openCV library. The camera is interfaced with the Pi using Mobile Industry Processor Interface (MIPI) via Camera Serial Interface 2 CSI-2, a high speed interface for communicating image data developed for high speed image data transfer on cellular devices. The data is taken from the camera and loaded in the 512 MB memory on the PI in RGB format in grayscale taking about 900KB of the space with a 720 x 1280 image aspect ratio. In the RGB data format the pixel data is stored in an array and can be easily and linearly accessed for processing.

First the image is checked to be in grayscale. Firstly the image is one third the size of a colored image, and secondly it is easier to process as pixel intensity is now represented by a value for 0 (black) to 255 (white). The filter set includes gaussian blur, which is performed to soften any finer details as not to overcrowd the edge detection algorithm. Then the Sobel algorithm is used to detect edges by comparing the intensity of neighboring pixels on a 2 x 3 kernel. A threshold is

used as a comparator for whether or not to mark a pixel as an edge. An edge is represented by a sudden change in intensity. A marked pixel is promoted to 255 intensity and all others are demoted to 0. This results in an image of just object edges. This image now overwrites the original to save space.

After the Sobel filter, the edge detection image is sent through a Hough transform which is an algorithm that takes pixel data of the edges, converts it into polar coordinates and votes on that line in the 2d space.

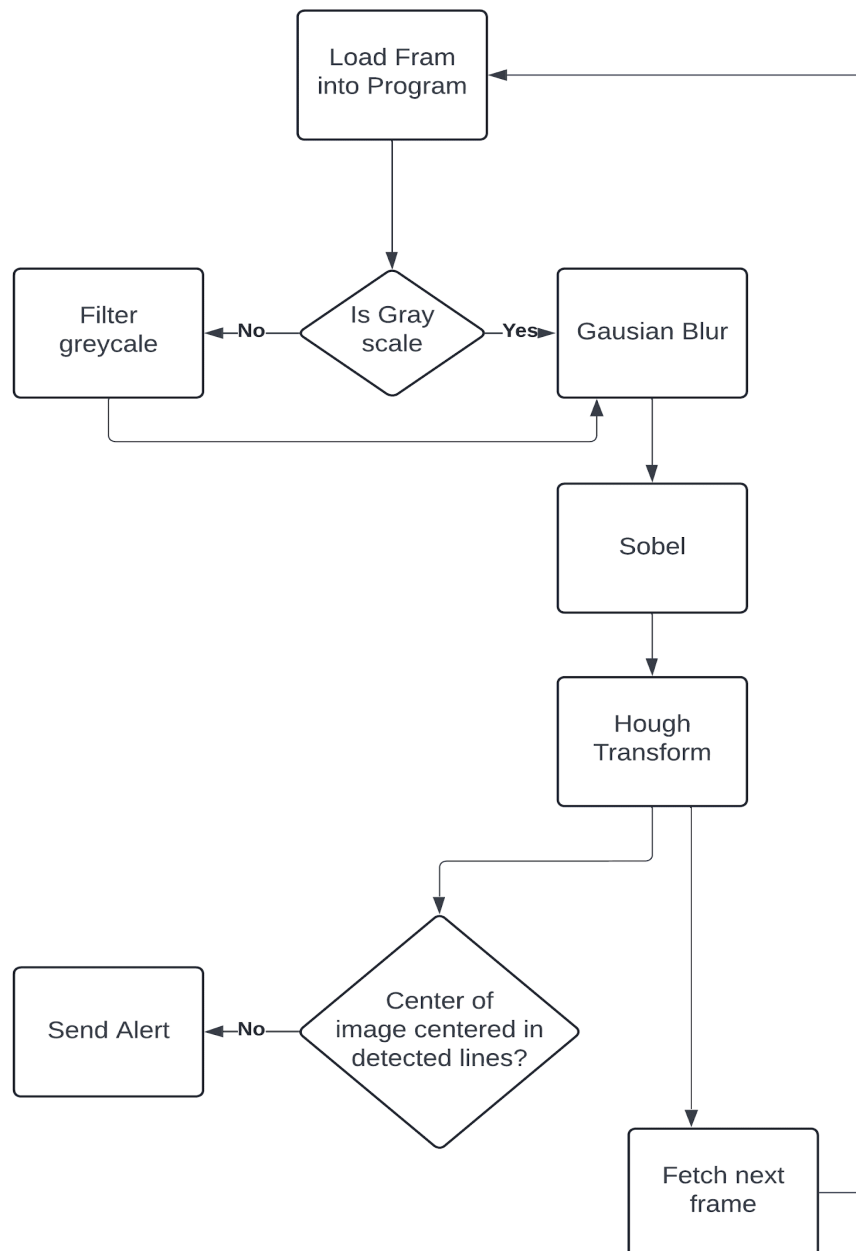


Figure 7.4.1a Lane Detection Flow Diagram by Authors

The Polar coordinate system in Hough space excels at this type of analysis as the line is represented by the same data no matter what point of that line you are observing. That is to say on the Cartesian coordinate system a point on a line $y = x$ would need an infinite set of pairs to represent each point on the line $(-\infty, +\infty)$ whereas the Hough space only stores the the angle of the shortest line (rho) ρ that is perpendicular to the desired line and the angle from the x axis to ρ . When each edge pixel of the image is assessed by the transform, it adds a vote for every line that could pass through this pixel at some coarseness of angle from 0 to 180 degrees. Since other pixels on the line will share the same ρ, Θ , actual lines will have many votes. Later, these lines can be identified by looking for the (ρ, Θ) coordinates above some threshold of votes. Further parameters are used to limit the angle of the lines that will be accepted as lanes. Since lanes should be relatively parallel to the left and right side of the image frame, we only want to consider lines from $0 \leq \Theta \leq 15$. Since the Camera is on the center of the car, we can then assert that the center of the image frame should be near the center of the two detected lanes $\pm 5\%$. If the camera falls outside this limit, then an alert will be sent to the diver for lane straying.

7.4.2 Safe Following Distance Subsystem

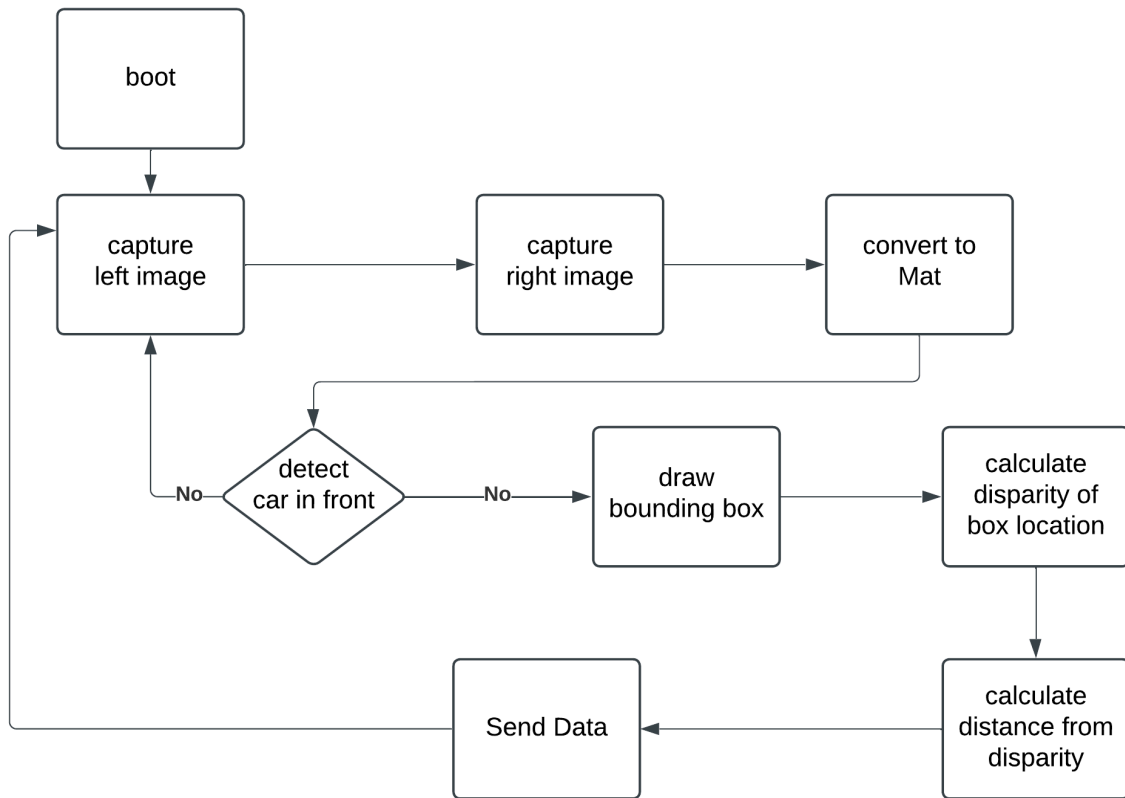


Figure 7.4.2a Follow Distance Stereo Vision

The Safe distance CV is more complex than the lane detection algorithm relying on machine learning to identify human vehicles, bikes, and other objects on camera. Since we don't have a supply of training data available, and we need a light weight system, we went with nanoDet, a light weight object detection system used in embedded devices. nanoDet also come with the advantage of being a pre-trained model with open source libraries. This means it is ready to identify target objects out of the box. We are only interested in identifying roadway vehicles directly in front of our diver in this scenario so we configure nanoDet to do so. We wrap the detected car in a bounding box and take note of the pixels at the corners of the bounding box.

Our camera system has two time Time-division multiplexed cameras using stereovision to calculate distance from the cameras and consequently the front bumper. There is a known disparity between the camera called the baseline, and we also know the size of each pixel in the camera sensor, as well as the focal length and field of view. We use these parameters and the location disparity of the bounding box corner pixels relative to each camera's image to calculate the distance. This distance is then compared to this speed calculated by the GPS system. We aim to follow the 2 and three second rule to alert the driver when they are following too close. This is above 60 MPH 3 second follow, and below is 2 seconds.

7.4.3 GPS Speed Calculation

Using the GPS data we can easily calculate the speed of the car by comparing the new location to the time elapsed. Even if the accuracy of the GPS is low, the precision is high so time based comparisons will be accurate. This calculation is then fed to the following distance algorithm to alert the driver if they are too close to the car in front of them.

7.5 Wireless Data Transmission and Reception

When designing our system we knew that a vital part of it would be the ability for the detection of hazards in the blind spot region. We also knew it was impractical to have many wires running about the exterior body of a moving vehicle. To navigate this we needed a wireless communication protocol. As discussed in the research section we considered many methods but decided on Wifi, specifically the ESP-NOW adaptation of it, due to its quick response time, relatively low power consumption, and stability it provides between our wireless transmitters and receivers, being the ESP32.

7.5.1 ESP-NOW Functionality

To implement wireless data transfer for our system, we would take advantage of the ESP32's wireless capabilities with the use of the ESP-NOW functionality, a communication protocol that is designed by Espressif, the manufacturers of ESP devices, that is designed to send short packet transmissions between ESP devices. ESP-NOW establishes either a one-way or two-way connection between

the ESP32 devices, allowing for a network to be formed between either at most 10 encrypted devices or no more than 20 unencrypted devices, all while maintaining a low power and low latency wireless connection. With ESP-NOW, it enables the ability for the user to design networks of ESP32 systems in an easier way than it has previously been seen before, such as creating a scenario where we can create multiple transmitter devices that go into a single receiver device, something that resonates heavily to what our system looks like.

In order for ESP-NOW to create a low power and low latency connection, it takes the standard Open Systems Interconnection (OSI) model and reduces the application, presentation, session, transport, and network layer all into a singular layer, causing there to only be ESP-NOW, data link layer, and physical layer. Due to this reduction in the OSI model layers, it allows for there to be no packet headers and unheaders that take up a bulk of the latency, allowing for a much quicker response and a reduced delay from any possible packet loss that occurs. This reduction in layers provides more than just a reduction in the latency, but also a reduction in the resources and memory used up by the CPU, allowing for more functionality to be built into the ESP32 module.

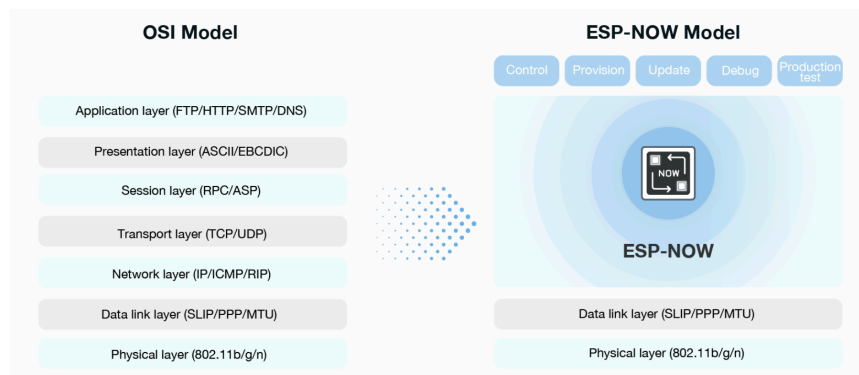


Figure 7.5.1a: OSI Model vs ESP-NOW Model

7.5.2 Receiver Design

With our receiver board, we would need to establish a connection between the receiver board and all of the transmitter boards by first obtaining the MAC address through the device. Once this MAC address is obtained, it will allow a secure connection between the receiver and all of the other transmitters, such that if the devices were to have an error and be forced to restart, as long as the MAC address is saved within the code of the transmitter, it will always connect to the receiver to get the information across.

Once the connection is established, the receiver will contain a callback function that will always be executed whenever it receives new data from one of the transmitters and then contain this value within the struct. After being stored, these values will be processed however it is deemed necessary by the receiver, due to the receiver being in the in-cab PCB as a part of our design. As the new information is received, the MCU, being the ESP32 for the in cab PCB, will take

note of what is being processed, have it send an audio alert to the user with the use of the built in speaker, and have it signal an alert through the heads-up display to inform the driver that there is some sort of obstacle within their vicinity. All of this information that is being received and processed will reside in the loop function in the ESP32, where all of the processing will take place regarding the audio alerts and Head Up Display as described.

7.5.3 Transmitter Design

With our transmitter board, it would be placed throughout the exterior PCB's of the vehicle, being the quarter panels and the front bumper, and take any of the objects detected using the sensors and transmit it back to the in-cab PCB. Within the ESP32 that is used for the transmitters, it will have the MAC address of the receiver ESP32 within the code, that way if the transmitter has an error that causes it to shut down or reset the device, it will always be able to reconnect to the receiver at a later point in time as necessary to maintain its data transmission.

Within the startup of the transmitter, it will make sure to register the device as a WiFi station, and from there go through the process of setting up the device through ESP-NOW to allow it to be apart of the network that we are creating for this system. Once it has been registered, it will check to see if a data packet can be sent to the receiver successfully, and once it can it will register the device as a part of the local ESP-NOW network that we are establishing for this design.

Once the setup has been completed, we will have a loop that will constantly monitor any input that comes from the sensors. Once an object has been detected within the vicinity by the sensor, the MCU will send this signal through to the ESP32, and have it sent to the receiver with the use of ESP-NOW, being a struct containing the data that is necessary. This loop of waiting for a signal to appear and sending it will run until a possible reset by the PCB, which will quickly reconnect to the receiver, or when the vehicle is shut off and powered down.

Chapter 8: System Fabrication and Prototype Construction

This chapter will show the layouts and construction processes for our project, representing the different aspects that we plan to develop in our system. With this in mind, we will show the PCB layouts for each one that is used, being the front bumper, quarter panels, and the internal cab. We will also talk about the devices that we demoed and the prototype that was constructed as apart of our design process.

8.1 PCB layout

This section will show our wiring schematics for every PCB that we designed, being the front bumper, quarter panels, and the internal cab. Software application used for all PCB design was done by eagle. When designing the layout, we had to consider the manufacturer's capabilities when we want to change things like

the size of via holes or trace width. Other things to consider when designing the layouts of the PCB was the proper placement of decoupling capacitors, keeping them as close as possible to the integrated circuit. This will reduce voltage drops if a large supply of current is needed.

For sensitive components like the ultrasonic sensor, we had to place any breakout board introducing noise far away from the sensor. The signal amplifying breakout board contains switching regulators and op-amps; both of these components have the capability to interfere with the sensor signals. To mitigate this when designing the signal amplifying breakout board is to minimize tracing where we can by keeping

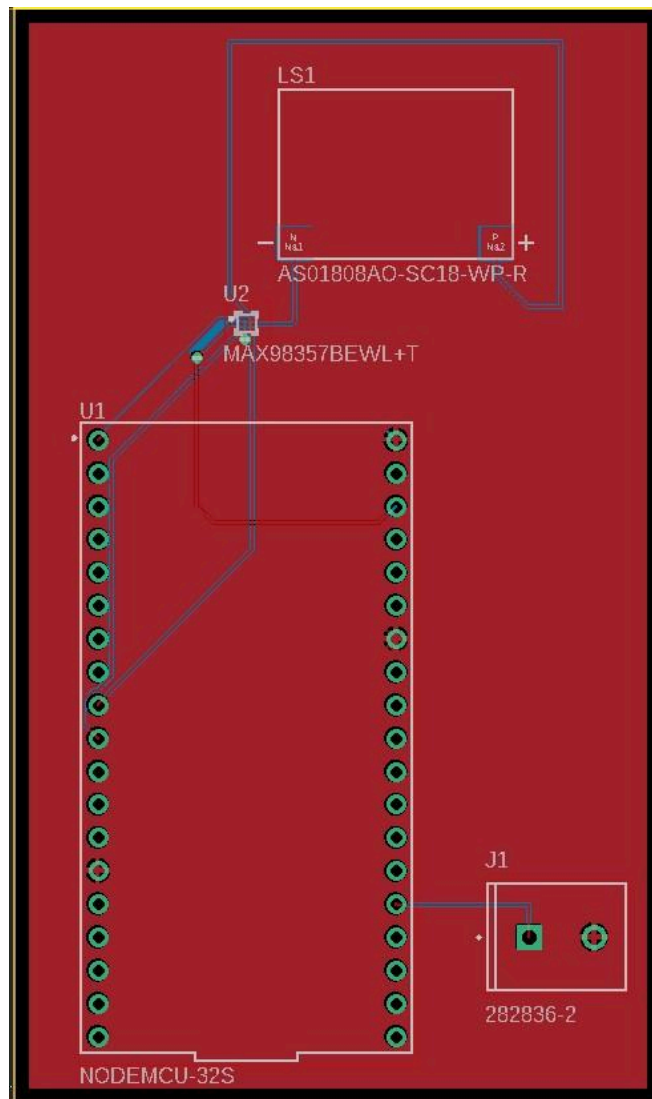


Figure 8.1a: Internal Cab PCB Board

the components close together. To further mitigate the noise produced by the breakout board is to manipulate the width of the tracing. For signal traces we want to use a smaller trace width, but for power traces we want to use a wider trace width. Before we can change the trace width we have to consider the manufacturer constraints.

This is the internal cab breakout board layout. A simple voltage regulator MAX756EPA is set up in a step up voltage circuit to transform 3.3 volts input into a 5 volt output with 200 milliamps of current to provide the XL6009 boost regulator that outputs 12 volts, Then the Lm317 is being utilized as a current

limiter circuit that can regulated the required range of 4.8-5.2 volts at 30 milliamps of current constant to power out laser diode for Head Up Display.

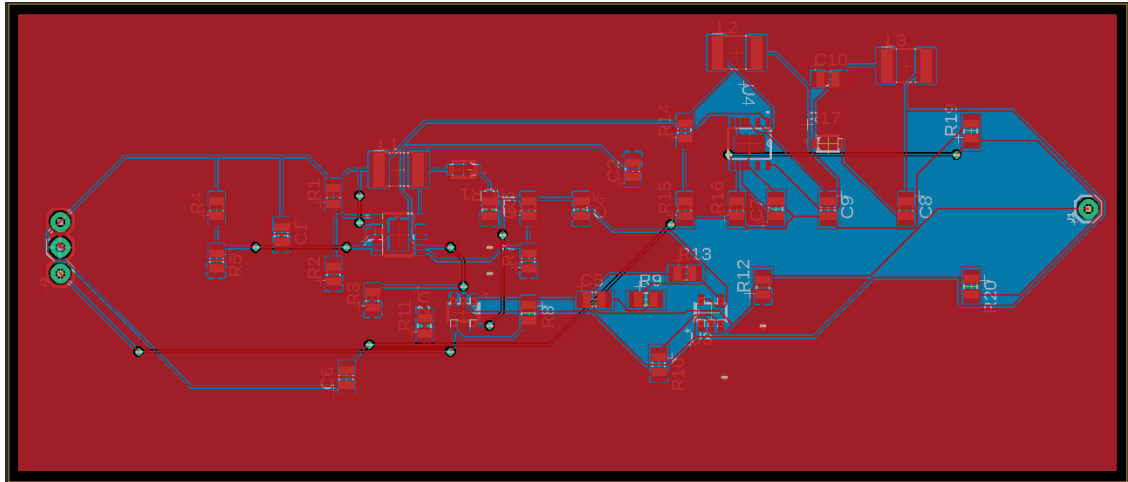


Figure 8.1d: Signal Amplifier Breakout Board PCB

8.2 Head Up Display Prototype Construction

A system housing for the head up display was 3D printed to hold the alignment of the optics of the head up display. Because of the need for precision when holding the lenses in place, standard fixed optic mounts were purchased from Thorlabs. The lenses selected have a diameter of 25.4mm, so the LMR1 mounts were purchased for use in this system. Then, 8-32 standard optical screws are being used to interface with the lens mounts and the 3D printed housing. The microscope objective that was purchased has a mounting diameter of 20 mm instead of the 25.4 mm that was purchased, so an adapted ring to aid in the mounting of this component was also 3D printed. The diameter of the laser diode casing was measured and will be held in place in the housing by a clip with a bore the size of the diameter. This allows the laser diode to be locked in place without being permanently affixed to the housing. The first iteration of the 3D printed housing, including the dimensions as calculated in the earlier chapter of this paper are shown below. The housing thus far includes the base assembly, and the clip being used to hold the laser diode in place. This iteration incorporates the full working distance of the microscope objective, as well as all four lenses from the proposed design.

Iteration 1:

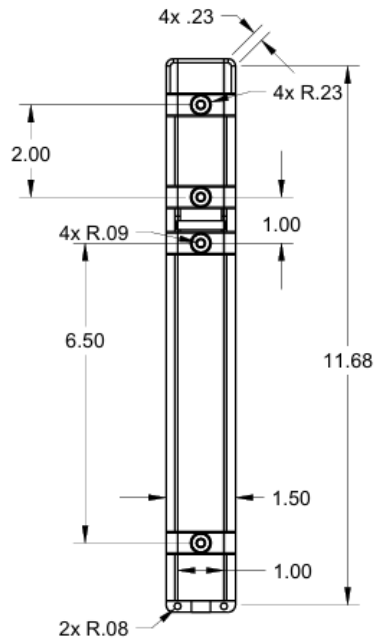


Figure 8.2a: Top-down view of the assembly base with dimensions, iteration 1

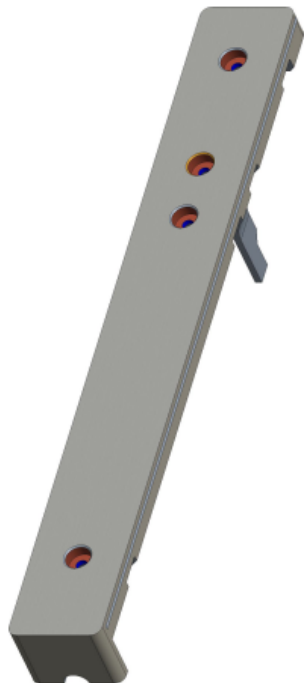


Figure 8.2b: Underneath view of the assembly base, iteration 1

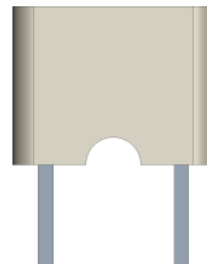


Figure 8.2c: Laser diode clip

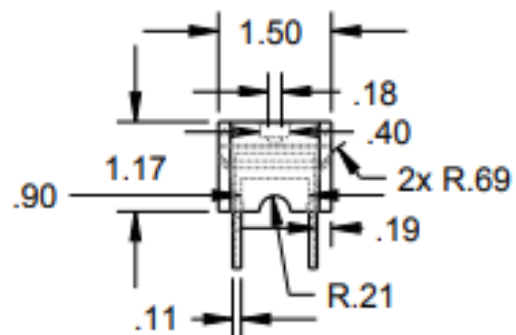


Figure 8.2d: Dimensioned view of the laser diode clip

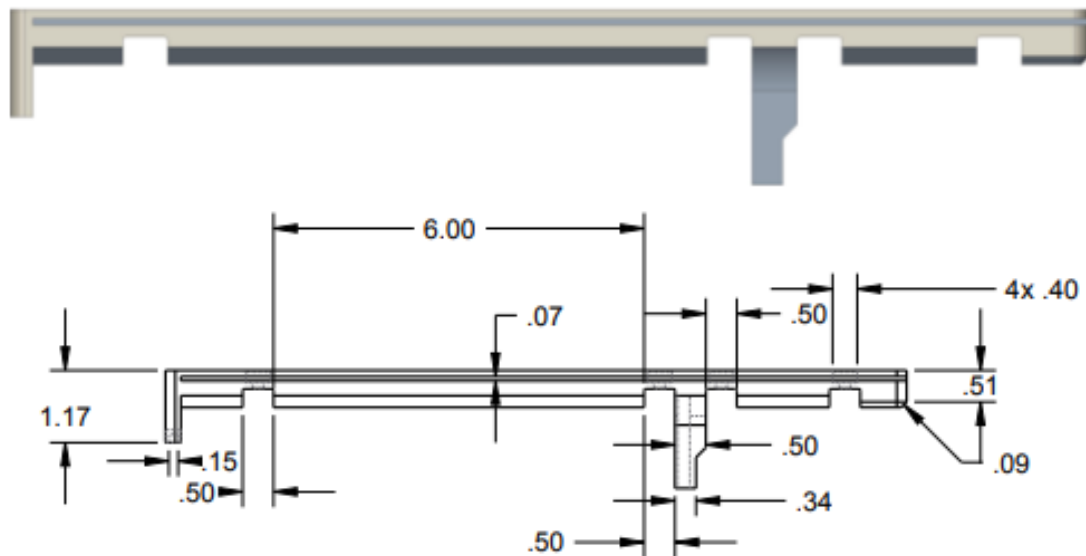


Figure 8.2e: Side view of the base assembly with dimensions, iteration 1

After testing the first iteration, a few issues needed to be resolved. The first issue encountered was that the full working distance of the microscope objective allowed the beam size to expand beyond the clear aperture of the 1 in diameter collimating lens. This was resolved in the second iteration by decreasing the length between the objective and the collimating lens from 6.5inches to 4.5inches. This helped significantly with the size constraints of the dashboard, so that our overall system will fit more easily in the space provided. The second problem that was encountered was one that had been anticipated after the initial proof of concept demonstration. This was the idea of removing the final lens from the system to allow for a larger output image to be projected onto the windshield. The second iteration reflects this difference by removing the last lens holder and therefore shortening the system length to 7.4 inches.

Iteration 2:

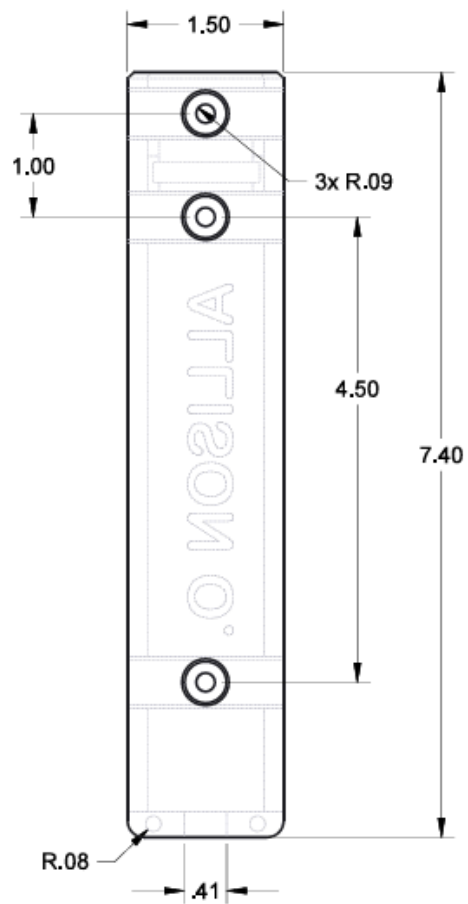


Figure 8.2f: Top-down view of the assembly base with dimensions, iteration 2



Figure 8.2g: Underneath view of the assembly base, iteration 2

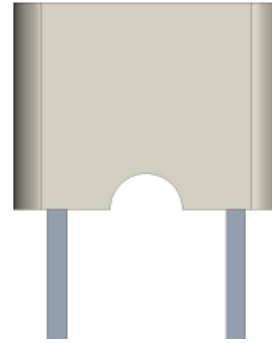


Figure 8.2h: Laser diode clip

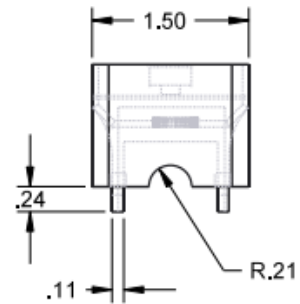


Figure 8.2i: Dimensioned view of the laser diode clip

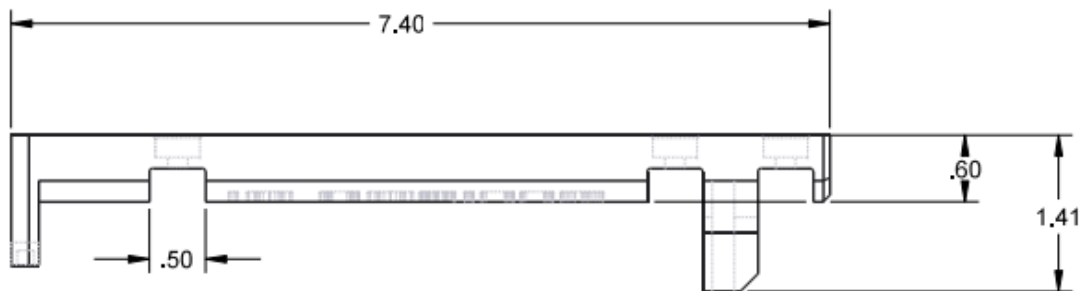


Figure 8.2j: Side view of the base assembly with dimensions, iteration 1

9.1.1 Speaker and Amplifier

The speaker and amplifier was used in tandem with the ESP32 Wroom board. The ESP32 Wroom generates a 440 Hz sine wave signal that is sent through the GPIO pins set up for a I2S audio interface.

The amplifier is set up to amplify the signal to power the speaker with up to 3 watts of power. Provoked by the signal from the amplifier, the speaker emits the amplified signal with a loud alert noise commonly known as concert A. This demo shows that we can trigger a signal with our MCU on command to alert the driver when needed in real time.

9.1.2 Head Up Display

Two major proof of concept demonstrations were conducted in the design of the head up display. The first demonstration was purely to demonstrate the concept of a 4F system. Standard optical lab tools were used, including a HeNe tube laser, mount and power supply, 6 posts and post holders, 3 150mm plano convex mounted lenses, a microscope objective lens and mount, a filter holder and a screen. These were all mounted on an optical breadboard, and aligned, as seen in the figure below.

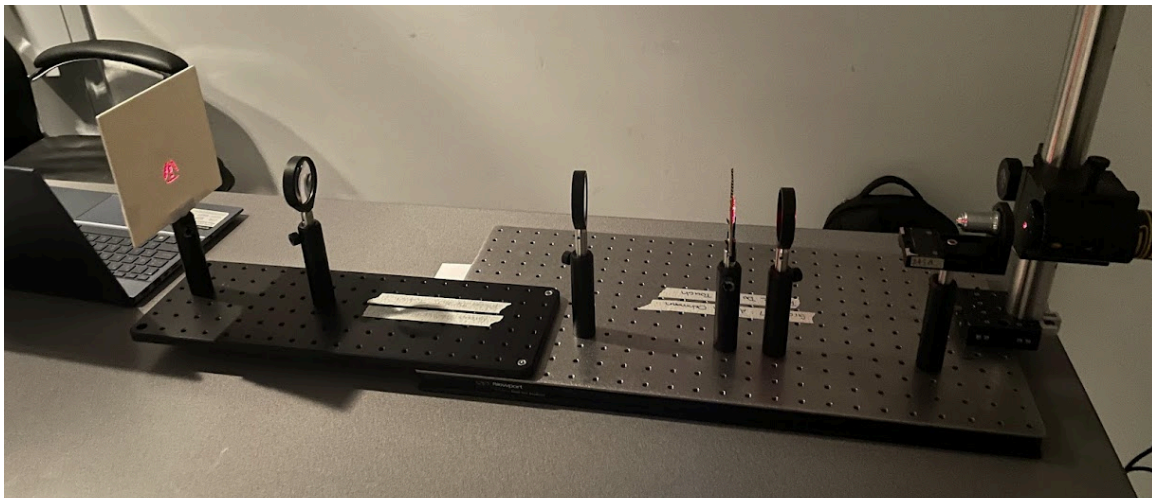


Figure 9.1.2a: Proof of concept initial demo of Head Up Display system

During this demonstration, a couple of lessons were learned. The first lesson was that the focal lengths of the lenses chosen for the final design must be significantly smaller than 150 mm, because of the size constraints on our project. The second lesson learned was related to the sizing of the output image. The concern with choosing lenses of a shorter focal length and therefore smaller diameter is that the output image will decrease in size. The output image size is a safety factor for this project, because the image must be large enough to be

visible to the driver. Further investigation was then conducted to analyze the effects of removing a last lens from the system, allowing the image to grow in size instead of becoming collimated at the output. The image produced at the output of the system grew once the last lens was removed. It was determined that this is likely the better course of action for the design, and will be considered in future design developments. The comparison of the output images from both the original system and then the system after the removal of the final lens is depicted below. As you can see, the image size increases significantly as a result of removing the last lens.

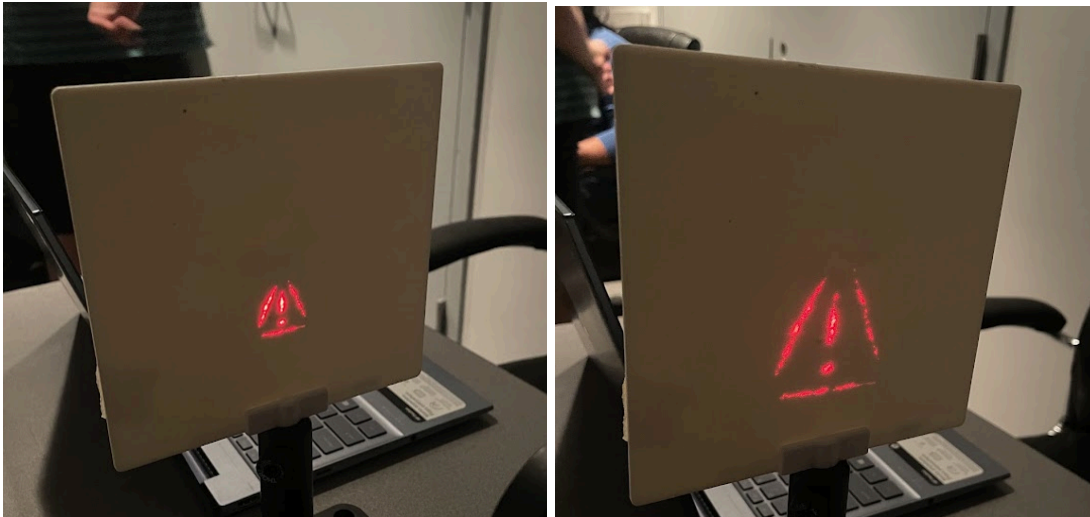


Figure 9.1.2b: Comparison of the output image size with and without the collimating lens, respectively.

The second proof of concept demonstration was a more in depth design, involving the 3D printed housing as discussed earlier, and incorporating the true components that will be used in the final system. This demonstration revealed a more true to size length of the system, as well as an idea about the true output image quality. A major lesson learned as a result of this demonstration is that there may be a need for a high output intensity laser, so that the image will be visible to the driver, even in high intensity light situations. Another lesson learned from this demonstration is that a more precise method for fabricating the template for the image at the object plane of the system will need to be used. Rudimentary methods were enough for the proof of concept phase of this design, but something more exact will be better for the design going forward. Finally, the last major lesson learned as a result of this demonstration is that more research into the combiner screen will be needed before implementation into the final design. A diffuse surface that can still be transparent from the viewing angle of the driver is necessary. The combiner screen purchased for use in this demonstration was not adequate. The screen reflected the image into another surface, but did not diffuse the laser light enough such that the output image could be viewed by the driver. Further trade studies on the surfaces that can be

used for this application will be conducted as this project progresses into the final stages of design. Potentials for utilizing a beamsplitter, or reorienting the location of the output face of the system are the main redesigns being considered, along with other potential options.

The figure below depicts the second demo of this system, utilizing the second iteration of the 3D printed housing, the current laser diode, the 20x microscope objective, and two 25.4mm focal length lenses. For the purposes of this demonstration, the laser was connected to an arduino board to provide the power to operate the diode. This power will be received from a different source in the final system, as well as incorporating an on/off signal received so that the output image is only being shown when a hazard is detected by one of the sensors integrated through the rest of the vehicle connected to this project.



Figure 9.1.2c: Secondary demo with actual components and housing

9.1.3 Stereovision

A demonstration of the concept of stereopsis applied to an imaging system was conducted. This was achieved by placing a few objects different distances away from a camera, and taking a picture. The same camera was then moved laterally by a recorded distance and a picture was taken again. It is important to note that this only worked because none of the objects moved in the time between the two images being captured. In our actual system, there will be two separate cameras, so that the images can be taken simultaneously.

Once the two images were taken, they were then overlaid onto each other so that the disparity between each object could be measured. The disparity was measured by taking the distance between the same point of the object in the two pictures and recording its displacement. Using the focal length of the imaging system, and the distance between the placement of the camera when taking the two images, the distance to each object can be calculated.

Camera 1 view:



Camera 2 view:



Figure 9.1.3a: Images obtained from cameras placed a set distance apart.

The formula used to calculate depth using the principles of stereopsis is shown below. The camera used to take the demonstration images has a focal length of 26 mm, and the distance between the cameras when capturing the two images was measured to be 10 cm. These values are crucial for the depth calculations.

$$Z = \frac{f \cdot B}{d}$$

Z : depth (distance from object)
 f : focal length of camera
 B : distance between cameras
 d : disparity (displacement)

Figure 9.1.3b: Depth calculation for stereopsis cameras

The figure below shows the overlaid images, and was used to measure the disparity, to be used in the depth calculations following. It should be noted that the objects closer to the imaging system have a larger disparity. This means that



Figure 9.1.3c: Overlay of the left and right camera images, being used to measure the disparity between objects in the image

in our project, the software will be searching for the objects with the largest disparity to calculate depth to the nearest object. This is important to prioritize so that the nearest hazard can be identified and the system can alert the driver as soon as possible to the incoming threat.

The figure below details the calculation done to determine the distance from the cameras to each object in the demonstration field. These depths were verified from real world measurement, and proven to be accurate. These will not be numbers known to the driver in our system, but will be important in the software in determining whether an object in front of the vehicle is close enough to be considered a hazard, relative to the detected speed of the vehicle.

<u>Object 1 (duck):</u>	<u>Object 2 (ball):</u>
Edge displacement: 3.1 cm	Edge displacement: 1.6 cm
Distance from viewer:	Distance from viewer:
$Z = \frac{26 \cdot 100}{31} = \underline{83.87 \text{ mm}}$	$Z = \frac{26 \cdot 100}{16} = \underline{162.5 \text{ mm}}$
<u>Object 3 (cup):</u>	<u>Object 4 (box):</u>
Edge displacement: 1.3 cm	Edge displacement: 1.1 cm
Distance from viewer:	Distance from viewer:
$Z = \frac{26 \cdot 100}{13} = \underline{200 \text{ mm}}$	$Z = \frac{26 \cdot 100}{11} = \underline{236.36 \text{ mm}}$

Figure 9.1.3d: Calculation of depth using the principles of stereopsis

9.1.4 ESP32 Wireless Data Transmission

A demonstration was made to show the aspect for the wireless transmission of data throughout our system, primarily from the outside modules to the interior modules to inform it on things such as objects that are within the vicinity of the vehicle, or if you are drifting out of the lane you are currently in. With this, there would be three programs that were created in order to achieve this proof of concept for our goal of wireless transmission.

To develop our wireless network, we would use it with the use of ESP-NOW, a wireless communication protocol that was designed by Espressif specifically for the ESP32, as discussed in section 7.5. This would come in with the header to use it, labeled as “esp_now.h”, along with the header for WiFi access, labeled as “WiFi.h”. Before we were able to start designing our program to allow for the wireless transmission, we first needed to find the MAC address of the receiver

device, which is represented in appendix D, program 1. In this, our setup function initializes our device with the ability to access WiFi with the help of the WiFi header. Once initialized, it will get the MAC address of the ESP32 device and output it through the terminal.

Once obtaining our MAC address of the receiver board, we would start the design of our transmitter code, as seen in appendix D, program 3. All transmitter boards would be designed to store the MAC address of the receiver board, allowing for stable reconnections in an instance that it would disconnect. In the setup, we would initiate the WiFi capabilities on the ESP32 and register it as a part of the ESP-NOW functionality, by checking if it is able to send data to begin with. Once it has been confirmed, we will add the device as a peer to the network, informing through the terminal if there is an issue that occur preventing it from being added. Once successfully added, we will declare the id of the board, along with random values that are used to further prove it. These values will be sent to only the receiver board using ESP-NOW functionality, and if it is successfully sent the terminal will print out the result. This data will then be received by the target device, and it will do with the information as it must, in this case being outputting the values to the terminal.



Figure 9.1.4a: ESP32 Boards all connected to different power sources

With the transmitter board designed, we would then design the program for the receiver board, as seen in appendix D, program 2. In this design, we would first initiate the board with the setup function for both WiFi capabilities and ESP-NOW capabilities to be a part of the network as necessary. Once setup is complete, a function would be existent that will wait for data to be sent through the network, only activating when the data is received from the master devices. In this function, it will process the data that is sent through ESP-NOW and have the results be processed by the program, which will be in this case outputting the data from one of the master devices to the terminal. While outputting, it will be sure to copy the data that is received and store it within a struct, being able to keep the storage for later uses.

With a vital part of the process of designing the program, we would need to ensure that if one of the devices were to reset or lose connection, it would be able to easily reconnect within the network without causing any possible issues for the driver. Thankfully, with ESP-NOW and the storage of the MAC address in the transmitter devices, the reconnection back to the network is fairly seamless, with all it needs is the slave device to be activated and it will easily connect with the system.

To ensure that the wireless transmission was effective as well, we would be sure to put all of the transmitters into different power sources as to not cause any possibilities of them being able to rely on a physical connection, with the receiver being connected to the computer as a power source, this way we have access to the terminal. This can also be represented from the results in the mini demo video, and the figure below.

Chapter 10: Administrative Content

As a vital part of the project design focus, we have a section dedicated to the administrative content involved in the Senior Design process. This will include information on several things, such as the milestones involved for the optical fabrication, project fabrication, and documentation, along with our planned bill of materials and budget, and finally the work distribution table between all of the members in the group.

10.1 Project 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, including the processes for the optical design, overall project design, and the documentation for the project that we plan to get completed over the course of our Senior Design project.

10.1.1 Optical Fabrication Milestones

The following table represents the tasks, start dates, anticipated end dates, and duration of the task for the optical fabrication side of our project.

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

Table 10.1.1a: Optical Fabrication Milestones

10.1.2 Project Fabrication Milestones

The following table represents the tasks, start dates, anticipated end dates, and duration of the tasks for the overall project fabrication. Some of these dates are listed as TBD, due to us waiting on the deadlines that are involved with Senior Design 2.

Task	Start Date	Anticipated End Date	Duration
Individual System Design	09/28/2024	10/26/2024	4 weeks
Individual System	10/27/2024	11/17/2024	3 weeks

Testing			
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

Table 10.1.2a: Project Fabrication Milestones

10.1.3 Project Documentation Milestones

The following table represents the tasks and planned time needed for the documentation side of the project that we are working on. For the 75 page and 150 page milestones, we have two dates, the first date being our planned date to finish the task, and the second date being the due date for the task that we have.

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

Table 10.1.3a: Project Documentation Milestones

10.2 Financing

Financing is a substantiation factor and constraint in the efforts of implementing this project. It is crucial that we understand the expenses required to meet our design goal with the devices we have chosen. The use of certain types of sensor come with some unknown costs such as special PCB design and RF circuits that can inflate costs not initially seen when researching parts and sensors. Below we will document the estimations and realized expenses of the project as we hurdle toward our drop dead due date.

10.2.1 Budget

The following table represents the planned budget that is attached to our project design. These are all cumulative estimates of what the rounded average price is per item that we need, along with the quantity that is needed to satisfy our goals.

Description	Quantity	Budget
Radar	4	70
Camera	1	35
MCU	6	70
LaneDetect FPGA	1	55
GPS Module	1	10

Head Up Display	1	200
WIFI Module	6	50
Speaker	1	5
PCB Board	6	195
Battery	4	80
Solar	4	60
Total		830

Table 10.2.1a: Estimated Budget

10.2.2 Proposed Bill of Material

The following table represents our bill of materials, where it lists the part type, the specific part model itself, the quantity of the part needed, and the exact price of the part, totaled up at the bottom for what we plan to spend over the course of this project design.

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
Head Up Display	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

Table 10.2.2a: Estimated Bill of Materials

10.3 Work Distribution Table

This section will show the work distribution between the group members for the project we are working on. In the table, it will group each member of the group by their major, being either electrical, computer, or optical, and list the task that they are dedicated to working on to envision the project that we have in our goals and objectives.

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 Wireless connections
Jonathan Joslin	Stereo Vision processing
	Lane Detection
	Audio Alert system

Optical Engineering	
Allison Oehmann	Head Up Display design
	Camera lens designs

Table 10.3a: Distribution of Work

Chapter 11: Conclusion

In conclusion, the Proximity-Based Hazard Detection System for Older Vehicles (P.B.H.D.S.O.V.) had the goal of developing an integral part of modern day vehicles and being able to apply it to aftermarket vehicles, with the primary goal being being able to greatly enhance the vehicle driver's safety from getting into an accident with their surroundings. This project represents the culmination of hard work by five students of the University of Central Florida, coming from three different areas of engineering, being electrical, computer, and optical, who all shared an interest in this idea of wanting to apply the modern safety features that the new vehicles have and make it accessible for all vehicles.

With the P.B.H.D.S.O.V., we wanted to focus on two major aspects, being the safety of the product and the accessibility for the consumer to use it. Regarding the safety of the product, we opted to prioritize this over any other factor that we came across in this project. To accomplish this, we chose to focus on what hardware, such as the sensors, MCU, and wireless transceiver/receiver modules we would incorporate into our design. In terms of focus on the software aspect, we would take into consideration the forms of wireless communication methodologies and the latency time to transmit the information from the quarter panels for front bumper to the in-cab module, as to alert the driver of any possible obstacles within their vicinity. While the time it takes for the data to travel across the vehicle was vital in our design, we wouldn't have been able to implement the focus of our latency of the overall system without the surrounding features of the entire product, being the heads-up display, speaker. With the heads-up display and the speaker, this was helped to maximize the ability to alert the driver of any obstacles that may occur around their vehicle to prevent accidents, grabbing both their visual and audio attention.

Instead of just ending the safety features at alerting you of obstacles in the vicinity of the vehicle, we went a step further with the implementation of our lane detection functionality, and stereo vision cameras. With the incorporation of these devices, it has brought a whole new aspect to our design, giving us the ability to alert the driver of them drifting out of their lane to get them to reposition themselves into a proper placement in the lane, as so they don't drift off of the road. While we could have ended with just the standard lane detection, we were

able to develop stereopsis cameras to work in tandem with the lane detection functionality in order to expand the field of view for our front bumper module, incorporating the entire lane in our possible range, plus the outside areas of the lane we are currently in to see the full length.

The second aspect we wanted to focus on with the P.B.H.D.S.O.V. is the accessibility for the consumers. The incorporation of this idea would be in part with the inclusion of our wireless modules and the incorporations of where our power sources originate from, being the car battery, solar powered aspects, and fuses that come from the inside of the car. The incorporation of the wireless modules has allowed us to avoid having wires run all around the car that might have been existent if we did not have it a part of our system. This has allowed us to create a wireless system of networks that are able to connect to one central unit that will process all of the information, with the use of WiFi and ESP-NOW. With the power aspects, we have been able to create the ability for minimal wires running around both the inside and the outside of the car, with them only running to where the power supplies are located for each specific PCB, with the quarter panels getting a wire ran up to the roof of the vehicle to access the solar panels, the front bumper getting power directly from the car battery due to how close it is and the intensity it requires, and the in-cab getting power from the cigarette lighter and fuses inside of the vehicle, allowing for it to be as close to the user as needed.

With this document, it serves as the main goal of providing an in depth record for the design for the Proximity-Based Hazard Detection System for Older Vehicles, representing the amount of work that has been attached to this project in all aspects of the design process, including research, design, testing, and implementation of the project. We hope that this will serve as its intended purpose for all future uses, whether it be for instructional purposes for future classes at the University of Central Florida, or by the off chance that this is picked up by a company for them to delve deeper into the possibilities of the product we have created.

With the final product, we hope to gain the ability to provide new safety measures to vehicles that do not have them, something that can be a life or death situation at times, allowing for more lives to be saved in the process. All of this work for the P.B.H.D.S.O.V. is brought on by their unyielding effort of the University of Central Florida students, professors, and faculty to always strive for excellence and reach for the stars. Hopefully, this project will reach its intended purpose of being able to enhance vehicle safety for not just the people who own modern vehicles, but for everyone that has access to vehicles, striving for a new era of vehicle safety.

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Appendix D – Software Code

```

1  #include <WiFi.h>
2  #include <esp_wifi.h>
3
4  void readMacAddress(){
5      uint8_t baseMac[6];
6      esp_err_t ret = esp_wifi_get_mac(WIFI_IF_STA, baseMac);
7      if (ret == ESP_OK) {
8          Serial.printf("%02x:%02x:%02x:%02x:%02x:%02x\n",
9              baseMac[0], baseMac[1], baseMac[2],
10             baseMac[3], baseMac[4], baseMac[5]);
11      } else {
12          Serial.println("Failed to read MAC address");
13      }
14  }
15
16  void setup(){
17      Serial.begin(115200);
18
19      WiFi.mode(WIFI_STA);
20      WiFi.STA.begin();
21
22      Serial.print("[DEFAULT] ESP32 Board MAC Address: ");
23      readMacAddress();
24  }
25
26  void loop(){
27
28  }

```

Program 1: Obtain MAC address for ESP32

```

1  #include <esp_now.h>
2  #include <WiFi.h>
3
4  typedef struct message {
5      int id;
6      int x;
7      int y;
8  } message;
9
10 message dataSend;
11
12 message board1;
13 message board2;
14
15 message boardsStruct[2] = {board1, board2};
16
17 void OnDataRecV(const uint8_t * mac_addr, const uint8_t *incomingData, int len) {
18     char macStr[18];
19     Serial.print("Packet recieved from: ");
20     snprintf(macStr, sizeof(macStr), "%02x:%02x:%02x:%02x:%02x:%02x",
21             mac_addr[0], mac_addr[1], mac_addr[2], mac_addr[3], mac_addr[4], mac_addr[5]);
22     Serial.println(macStr);
23     memcpy(&dataSend, incomingData, sizeof(dataSend));
24     Serial.printf("Board ID %u: %u bytes\n", dataSend.id, len);
25
26     boardsStruct[dataSend.id - 1].x = dataSend.x;
27     boardsStruct[dataSend.id - 1].y = dataSend.y;
28     Serial.printf("x value: %d \n", boardsStruct[dataSend.id - 1].x);
29     Serial.printf("y value: %d \n", boardsStruct[dataSend.id - 1].y);
30     Serial.println();
31 }
32
33 void setup() {
34     Serial.begin(115200);
35     WiFi.mode(WIFI_STA);
36
37     if(esp_now_init() != ESP_OK) {
38         Serial.println("Error loading ESP-NOW");
39         return;
40     }
41
42     esp_now_register_recv_cb(esp_now_recv_cb_t(OnDataRecV));
43
44 }
45
46 void loop() {
47     delay(1000);
48 }

```

Program 2: For receiver device to receive data from transmitters

```

1  #include <esp_now.h>
2  #include <WiFi.h>
3
4  uint8_t broadcastAddress[] = {0xE4, 0x65, 0xB8, 0x58, 0x5D, 0x10};
5
6  typedef struct message {
7      int id;
8      int x;
9      int y;
10 } message;
11
12 message dataSend;
13
14 esp_now_peer_info_t peerInfo;
15
16 void OnDataSent(const uint8_t *mac_addr, esp_now_send_status_t status) {
17     Serial.print("\r\nLast Packet Send Status:\t");
18     Serial.println(status == ESP_NOW_SEND_SUCCESS ? "Delivery Success" : "Delivery Fail");
19 }
20
21 void setup() {
22     Serial.begin(115200);
23
24     WiFi.mode(WIFI_STA);
25
26     if (esp_now_init() != ESP_OK) {
27         Serial.println("Error initializing ESP-NOW");
28         return;
29     }
30
31     esp_now_register_send_cb(OnDataSent);
32
33     memcpy(peerInfo.peer_addr, broadcastAddress, 6);
34     peerInfo.channel = 0;
35     peerInfo.encrypt = false;
36
37     if(esp_now_add_peer(&peerInfo) != ESP_OK) {
38         Serial.println("Failed to add peer");
39         return;
40     }
41 }
42
43 void loop() {
44     dataSend.id = 2; // change as necessary
45     dataSend.x = random(0,50);
46     dataSend.y = random(0,50);
47
48     esp_err_t result = esp_now_send(broadcastAddress, (uint8_t *) &dataSend, sizeof(dataSend));
49
50     if(result == ESP_OK) {
51         Serial.println("Sent successfully");
52     } else {
53         Serial.println("Error sending data");
54     }
55     delay(1000);
56 }

```

Program 3: For transmitter devices to send data to receiver

Appendix E – 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.

Prompt 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.

Prompt 4:

how do you create a local wifi network between a small scale device that will transmit it's data to a main unit where it will be processed

Answer 4:

Creating a local Wi-Fi network for communication between a small-scale device and a main unit involves several steps. Here's a basic guide:

1. Hardware Requirements

- **Main Unit (Host/Server):** A computer, Raspberry Pi, or a similar device.
- **Small-scale Device (Client):** Any device that can connect to Wi-Fi (e.g., microcontrollers like ESP8266, ESP32, or a Wi-Fi-enabled sensor).
- **Wi-Fi Router:** To create the Wi-Fi network (optional if using a direct connection).

2. Set Up the Main Unit

- **Option 1: Use an Existing Router**
 - Connect the main unit to the Wi-Fi router.
 - Assign a static IP address to the main unit to ensure it can always be reached by the small-scale device.
- **Option 2: Create an Ad-hoc Network**
 - If no router is available, configure the main unit to create a Wi-Fi hotspot (ad-hoc mode).
 - The small-scale device will connect directly to this network.

3. Configure the Small-Scale Device

- **Network Connection:**
 - Program the small-scale device to connect to the Wi-Fi network created by the main unit or router.
 - The device needs to know the SSID (network name) and password if security is enabled.
- **Data Transmission:**
 - Choose a communication protocol (e.g., HTTP, MQTT, WebSocket, etc.).
 - Program the small-scale device to transmit data to the main unit's IP address on a specific port.
 - Use libraries specific to the device (e.g., `WiFi.h` for ESP8266/ESP32 in Arduino IDE).

4. Set Up the Communication Protocol

- **On the Main Unit:**
 - Run a server (e.g., a web server or MQTT broker) to listen for incoming data from the small-scale device.
 - Process the received data (e.g., logging, processing, or real-time analysis).
- **On the Small-Scale Device:**

- Send data to the server running on the main unit at regular intervals or when specific events occur.

5. Testing and Debugging

- Test the connection by sending simple data (e.g., sensor readings) from the small-scale device to the main unit.
- Check for any network issues, such as poor signal strength or incorrect IP configurations.
- Use tools like Wireshark to monitor network traffic if needed.

6. Security Considerations

- Ensure the network is secure, especially if using a Wi-Fi router. Use WPA2 encryption.
- Implement authentication and data encryption protocols if the data is sensitive.

7. Power Management (Optional)

- If the small-scale device is battery-powered, implement sleep modes or optimize the code to reduce power consumption when the device is idle.

Example:

If using an ESP8266 to transmit temperature data to a Raspberry Pi:

- **ESP8266:** Connects to the Raspberry Pi's Wi-Fi network and sends temperature data via HTTP POST requests.
- **Raspberry Pi:** Runs a Flask server that listens for incoming data and stores it in a database.

This setup allows the small-scale device to transmit data to the main unit over a local Wi-Fi network, where it can be processed and used accordingly.

Prompt 5:

how to have 4 devices communicate the data received to a main unit wirelessly

Answer 5:

To set up a system where four devices communicate wirelessly with a main unit, you can follow these steps:

1. Select Communication Protocol:

- **Wi-Fi:** Suitable for high-speed data transfer over a local network.
- **Bluetooth:** Ideal for short-range, low-power applications.

- **Zigbee/Z-Wave:** Used in IoT applications with low power and long battery life.
- **LoRaWAN:** Good for long-range communication with low data rates.
- **RF Modules:** For custom wireless communication over specific frequencies.

2. Choose Hardware Components:

- **Transceivers/Modules:** Select modules based on the protocol (e.g., ESP8266/ESP32 for Wi-Fi, HC-05/HC-06 for Bluetooth).
- **Main Unit:** This could be a microcontroller (like Arduino, Raspberry Pi) or a dedicated receiver connected to a PC.

3. Set Up the Devices:

- **Device Configuration:**
 - Equip each device with a wireless module.
 - Assign unique identifiers (IDs) to each device.
 - Program the devices to collect and transmit data at specified intervals.
- **Main Unit Configuration:**
 - Program the main unit to receive data from all four devices.
 - Ensure it can differentiate data from each device using their unique IDs.
 - Implement error checking and data verification processes.

4. Establish a Communication Protocol:

- **Polling:** The main unit requests data from each device sequentially.
- **Broadcasting:** Devices send data to the main unit at regular intervals.
- **Mesh Network:** Devices communicate with each other and relay data to the main unit.

5. Data Handling and Processing:

- **Data Reception:** The main unit receives data packets and acknowledges receipt.
- **Data Processing:** Process the incoming data (e.g., filtering, aggregation).
- **Storage/Display:** Store the data in a database or display it on a dashboard.

6. Test and Optimize:

- **Range Testing:** Ensure all devices are within communication range of the main unit.
- **Interference Testing:** Check for potential interference from other wireless devices.

- **Power Management:** Optimize power consumption, especially for battery-operated devices.

Example Setup:

- **Wi-Fi-based system:** Using ESP32 modules for all devices, where they connect to a central router. The main unit (e.g., Raspberry Pi) listens to data on specific ports corresponding to each device.
- **Bluetooth-based system:** Devices use Bluetooth modules to pair with the main unit. The main unit listens to data from all paired devices.

This setup allows the main unit to gather and process data from all four devices efficiently.

Prompt 6:

what are the most common IEEE standards for Wi-Fi

Answer 6:

The most common IEEE standards for Wi-Fi are part of the IEEE 802.11 family of wireless networking protocols. Each version of the standard addresses different performance, range, and use case needs. Here are the key ones:

1. IEEE 802.11 (Legacy Wi-Fi)

- **Release Year:** 1997
- **Speed:** Up to 2 Mbps
- **Frequency Band:** 2.4 GHz
- This was the first Wi-Fi standard, but it is largely obsolete today.

2. IEEE 802.11a

- **Release Year:** 1999
- **Speed:** Up to 54 Mbps
- **Frequency Band:** 5 GHz
- Introduced better speed but had a shorter range compared to 802.11b due to higher frequency.

3. IEEE 802.11b

- **Release Year:** 1999
- **Speed:** Up to 11 Mbps
- **Frequency Band:** 2.4 GHz
- Widely adopted due to low cost and decent range but was slower than 802.11a.

4. IEEE 802.11g

- **Release Year:** 2003
- **Speed:** Up to 54 Mbps
- **Frequency Band:** 2.4 GHz
- Provided higher speed than 802.11b while maintaining backward compatibility with it.

5. IEEE 802.11n (Wi-Fi 4)

- **Release Year:** 2009
- **Speed:** Up to 600 Mbps (depending on the configuration)
- **Frequency Band:** 2.4 GHz and 5 GHz (dual-band)
- Introduced MIMO (Multiple Input Multiple Output), improving range and speed.

6. IEEE 802.11ac (Wi-Fi 5)

- **Release Year:** 2013
- **Speed:** Up to 3.5 Gbps (depending on the configuration)
- **Frequency Band:** 5 GHz
- Utilized wider channels, multiple spatial streams, and better MIMO technology for higher speeds.

7. IEEE 802.11ax (Wi-Fi 6)

- **Release Year:** 2019
- **Speed:** Up to 9.6 Gbps (theoretical)
- **Frequency Band:** 2.4 GHz and 5 GHz
- Improved efficiency in crowded environments, better battery life for devices (with features like TWT), and higher speeds.

8. IEEE 802.11be (Wi-Fi 7)

- **Expected Release:** 2024 (standard still in development as of 2023)
- **Speed:** Expected up to 46 Gbps
- **Frequency Band:** 2.4 GHz, 5 GHz, and 6 GHz (tri-band)
- Enhanced MIMO and increased channel width (up to 320 MHz) for ultra-high speed and reduced latency, designed for future high-density applications and low-latency streaming.

Additional Important Standards:

- **IEEE 802.11ad (WiGig):** Uses the 60 GHz band for ultra-fast, short-range communication, providing speeds up to 7 Gbps.
- **IEEE 802.11ah (HaLow):** Operates on sub-1 GHz frequencies for IoT and long-range, low-power communication.

These standards evolve to offer better speed, capacity, and efficiency based on user demands and technological advancements.

Prompt 7:

what is the typical power consumption of a wifi module for a PCB

Answer 7:

The power consumption of a Wi-Fi module for a PCB can vary widely depending on the specific module, its operating modes, and the use case. However, here are some typical power consumption figures for commonly used Wi-Fi modules:

1. **Low Power Modes (Deep Sleep):**
 - **Power consumption:** 10–100 μ A (microamps)
 - **Use case:** The module is in a deep sleep state, with only essential functions active to allow fast wake-up.
2. **Idle Mode (Wi-Fi connected but not actively transmitting):**
 - **Power consumption:** 10–200 mA (milliamps)
 - **Use case:** The Wi-Fi module is connected to a network but not actively transmitting data.
3. **Active Transmission (TX Mode):**
 - **Power consumption:** 100–500 mA
 - **Use case:** The module is actively transmitting data, which is the most power-consuming state.
4. **Active Reception (RX Mode):**
 - **Power consumption:** 50–300 mA
 - **Use case:** The module is actively receiving data.

Example Modules:

- **ESP8266/ESP32:**
 - **Deep Sleep:** ~20 μ A
 - **Idle (Wi-Fi on):** ~50–100 mA
 - **TX Peak:** ~200–400 mA
 - **RX Peak:** ~50–150 mA
- **Nordic nRF7002 (Low Power Wi-Fi):**
 - **Deep Sleep:** ~10 μ A
 - **TX Peak:** ~160 mA
 - **RX Peak:** ~60 mA

Power consumption can be optimized with proper management of sleep modes and reducing the duration of active transmission times.

Prompt 8:

what about power consumption for bluetooth modules for PCB

Answer 8:

The power consumption of Bluetooth modules for a PCB can vary depending on the Bluetooth version (e.g., Bluetooth Classic or Bluetooth Low Energy), the specific module, and its operating mode (idle, transmission, or reception). Here are the typical power consumption values for Bluetooth modules:

Bluetooth Low Energy (BLE) Modules:

- **Sleep Mode (Deep Sleep/Standby):**
 - **Power consumption:** 1–10 μA (microamps)
 - **Use case:** The module is in deep sleep, consuming very little power, ideal for battery-powered applications.
- **Advertising Mode:**
 - **Power consumption:** 10–500 μA
 - **Use case:** The module is broadcasting its availability to connect.
- **Connected Idle (No Data Transmission):**
 - **Power consumption:** 1–5 mA (milliamps)
 - **Use case:** The module is connected but not actively transmitting data.
- **Active Transmission (TX Mode):**
 - **Power consumption:** 3–15 mA
 - **Use case:** The module is actively transmitting data.
- **Active Reception (RX Mode):**
 - **Power consumption:** 3–15 mA
 - **Use case:** The module is actively receiving data.

Bluetooth Classic Modules:

- **Standby Mode:**
 - **Power consumption:** 1–10 mA
 - **Use case:** The module is ready to communicate but not actively doing so.
- **Active Transmission (TX Mode):**
 - **Power consumption:** 20–50 mA
 - **Use case:** The module is actively transmitting data.
- **Active Reception (RX Mode):**
 - **Power consumption:** 10–40 mA
 - **Use case:** The module is actively receiving data.

Example Modules:

- **Nordic nRF52840 (BLE):**
 - **Sleep Mode:** $\sim 0.4 \mu\text{A}$
 - **TX Mode:** $\sim 5\text{--}10 \text{ mA}$
 - **RX Mode:** $\sim 4.6 \text{ mA}$
- **TI CC2640R2F (BLE):**
 - **Sleep Mode:** $\sim 1 \mu\text{A}$
 - **TX Mode:** $\sim 7 \text{ mA}$ (at 0 dBm power)

- **RX Mode:** ~6.1 mA
- **BCM20732 (Bluetooth Classic and BLE):**
 - **Standby:** ~1 mA
 - **TX Mode:** ~24 mA
 - **RX Mode:** ~20 mA

Bluetooth Low Energy (BLE) is much more efficient than Bluetooth Classic in terms of power consumption, making it ideal for battery-operated devices like wearables and IoT sensors.

Proper use of sleep modes, efficient data transfer scheduling, and adjusting transmission power levels can greatly impact the overall power efficiency of a Bluetooth module.

Prompt 9:

what are the maximum amount of devices that can connect to one bluetooth module

Answer 9:

The maximum number of devices that can connect to a single Bluetooth module depends on several factors, including the Bluetooth version (Classic vs. Low Energy), the specific module, and how the connections are managed.

Bluetooth Classic:

- **Maximum Connections:** Typically, a Bluetooth Classic module can connect to up to **7 devices simultaneously** in a **piconet**.
 - A piconet consists of one **master** device (e.g., the Bluetooth module) and up to **7 slave** devices. The master manages communication with all the slaves, but only one slave can actively communicate with the master at any given time. Devices take turns, so communication is shared.
 - Some implementations allow for **scatternets**, where multiple piconets are interconnected. However, this is complex and less common in consumer products.

Bluetooth Low Energy (BLE):

- **Maximum Connections:** BLE is designed to handle many more connections compared to Bluetooth Classic. The typical maximum number of connections for BLE is much higher and depends on the specific hardware and software stack of the module.
 - **For most BLE modules**, the maximum number of connected devices can range from **4 to 20**. However, high-end modules or custom firmware can support **up to 50** or even **100 simultaneous connections**.

- BLE devices operate in **master-slave** architecture similar to Bluetooth Classic, but the master device (e.g., a central node or hub) can handle connections with multiple slave devices (peripherals) simultaneously. BLE is designed to maintain these connections with minimal power consumption.

Example Bluetooth Modules:

- **Nordic nRF52840 (BLE):**
 - Can support **up to 20 concurrent connections**.
- **Texas Instruments CC2640 (BLE):**
 - Typically supports **up to 8 simultaneous connections**, but this depends on the firmware.
- **CSR Bluetooth Classic Modules:**
 - Typically supports **7 connections** in a piconet.

Factors Affecting Maximum Connections:

1. **Firmware/Software Stack:** The firmware on the Bluetooth module can dictate how many devices can connect simultaneously. Some modules allow configuration to increase the number of connections at the cost of higher memory and CPU usage.
2. **Device Role:** In BLE, if a device acts as a **peripheral** (e.g., a fitness tracker), it usually connects to just one **central** device. But if the module is a **central device** (e.g., a hub), it can connect to multiple peripherals.
3. **Data Rate and Latency:** As more devices connect, the available bandwidth is shared among them, which can increase latency and reduce the effective data rate for each connection.
4. **Memory and Processing Power:** Modules with more memory and processing capability can manage more simultaneous connections.

Practical Limits:

While the theoretical limits might be high (50+ devices for BLE), in practice, maintaining stable connections and communication with many devices can depend on factors like data traffic, latency requirements, and interference in the environment.

Prompt 10:

what is the latency of a bluetooth conenction

Answer 10:

The latency of a Bluetooth connection varies depending on the Bluetooth version, the operating mode (Classic or Low Energy), and the specific use case. Here's a breakdown of the typical latency for different Bluetooth modes:

Bluetooth Classic (BR/EDR) Latency:

- **Typical Latency:** 30–100 ms
- **Use case:** Bluetooth Classic is used for applications like audio streaming (e.g., headphones, speakers) or file transfer. The latency is relatively low, but not sufficient for ultra-low-latency applications like gaming or real-time control.
 - **For audio applications (A2DP):** Latency can range from **100 ms to 200 ms**, depending on factors like audio buffering and compression.
 - **For HID (Human Interface Devices) like keyboards or mice:** Latency is typically **30–50 ms**, which is sufficient for user input.

Bluetooth Low Energy (BLE) Latency:

- **Typical Latency:** 6–30 ms (in connected mode), but this can vary significantly.
- **Use case:** BLE is designed for low-power, low-data-rate applications, so the latency is often lower than Bluetooth Classic, especially in well-optimized systems.

BLE Latency Factors:

1. **Connection Interval:**
 - BLE connections are event-driven, with a configurable connection interval that defines how often the central and peripheral devices communicate.
 - **Minimum interval:** ~7.5 ms
 - **Maximum interval:** ~4 seconds
 - A shorter connection interval reduces latency but increases power consumption.
2. **Slave Latency:**
 - BLE devices can skip connection events to save power, introducing **slave latency**. This is the number of consecutive connection events the peripheral device is allowed to skip before responding to the central device.
 - Increasing the slave latency increases battery life but adds more latency in data communication.
3. **Application Type:**
 - For **real-time applications** like fitness trackers or heart rate monitors, BLE latency is typically **6–30 ms**.
 - For applications where power savings are critical and latency isn't an issue, like temperature sensors, the latency might be much higher, depending on the connection interval.

Bluetooth Audio (Low Latency Profiles):

- **Bluetooth LE Audio (using LC3 codec):**
 - Expected latency: **20–30 ms** (for low-latency audio streaming)
 - The new LE Audio standard is designed to lower latency compared to traditional Bluetooth Classic audio (A2DP), with much more efficient data handling and better audio quality.
- **Bluetooth Classic with aptX Low Latency:**
 - Latency: **30–40 ms**
 - This codec is designed to reduce latency for audio streaming applications, making it suitable for scenarios like gaming or watching videos where synchronization is critical.

Practical Considerations:

- **Interference:** In real-world environments, interference from Wi-Fi or other wireless signals can increase latency. Bluetooth operates on the 2.4 GHz frequency, which is a crowded space, leading to occasional retransmissions and slightly higher latency.
- **Device Pairing:** The hardware and firmware of the Bluetooth module or chip can affect the performance, especially for handling latency-sensitive tasks like audio streaming or real-time sensor feedback.

Summary:

- **Bluetooth Classic:** 30–100 ms, depending on the application (lower for HID devices, higher for audio).
- **Bluetooth Low Energy (BLE):** 6–30 ms, depending on the connection interval and application.
- **Low Latency Audio (aptX or LE Audio):** 20–40 ms.

Prompt 11:

what is the latency of a wifi connection

Answer 11:

The latency of a Wi-Fi connection can vary widely based on several factors, including network congestion, signal strength, Wi-Fi standards, and environmental interference. Here's an overview of Wi-Fi latency for different use cases and factors affecting it:

Typical Wi-Fi Latency:

- **Home or Office Wi-Fi Networks:** 1–50 ms
In a well-optimized home or office network, latency typically ranges from **1 to 20 ms** when communicating with nearby devices or accessing local resources (LAN). For connections to the internet, latency can increase to **20–50 ms** or more, depending on your internet service provider (ISP) and external factors.

- **Wi-Fi in Congested Environments (e.g., public Wi-Fi):** 50–200 ms
Public Wi-Fi networks, like those in cafes, airports, or hotels, often experience higher latency due to network congestion, interference from other devices, and bandwidth limitations.

Factors Affecting Wi-Fi Latency:

1. **Wi-Fi Standards:**

- **Wi-Fi 6 (802.11ax):**
Latency is typically **1–10 ms** in optimal conditions for local network traffic, and it's designed to handle multiple devices more efficiently, reducing congestion-related delays. It supports lower latency through technologies like **OFDMA** (Orthogonal Frequency Division Multiple Access), which allows multiple devices to share channels without causing delays.
- **Wi-Fi 5 (802.11ac):**
Latency is generally in the **10–30 ms** range under typical conditions. Performance depends on the network load and signal quality.
- **Wi-Fi 4 (802.11n):**
Latency is generally higher, ranging from **20–50 ms**, especially in environments with multiple devices or network interference.

2. **Network Congestion:**

- In environments where multiple devices are sharing the same access point (AP), latency can increase due to packet collisions and retries. This is especially common in public spaces or homes with many connected devices.

3. **Distance from Router:**

- Latency increases as the distance between the device and the router grows. Wi-Fi signals weaken as they pass through walls or obstructions, which can result in higher latency.
- **Within 10 meters of the router:** Typically **1–20 ms** latency.
- **Beyond 30 meters or with obstructions:** Latency can exceed **50 ms**.

4. **Bandwidth and Speed:**

- High-speed connections (e.g., fiber) generally have lower latency than slower connections (e.g., DSL or satellite). For example, on a fiber connection, you may experience **1–10 ms** latency to the router, while on a DSL connection, it might be **20–50 ms**.

5. **Environmental Interference:**

- Wi-Fi operates in the 2.4 GHz and 5 GHz bands, which are also used by other devices like microwaves, Bluetooth devices, and neighboring Wi-Fi networks. Interference from these devices can increase latency.

6. **Internet Connection:**

- The latency to external servers (internet latency) depends on your ISP and the location of the server you're accessing. It's common to

see an additional **20–100 ms** latency for internet-based activities, depending on the distance to the server and the quality of your ISP's routing.

Specific Use Cases:

1. **Local Device Communication (LAN):**
 - Wi-Fi latency between devices on the same network (e.g., a phone to a smart TV) is generally **1–20 ms** under ideal conditions.
2. **Online Gaming:**
 - For online games, latency is crucial, and Wi-Fi connections typically introduce **20–100 ms** of latency depending on the network conditions, router quality, and internet connection. Gamers often prefer wired Ethernet connections for reduced latency, typically **<10 ms**.
3. **Video Streaming:**
 - Video streaming services like Netflix or YouTube are less sensitive to latency than gaming. Wi-Fi latency can range from **20–50 ms**, but most streaming applications can buffer content, making the impact of latency less noticeable unless it's extremely high.

Low-Latency Wi-Fi (Wi-Fi 6 and Future Wi-Fi 7):

- **Wi-Fi 6 (802.11ax):**
Wi-Fi 6 introduces significant improvements to reduce latency, especially in crowded environments. Technologies like OFDMA and **TWT (Target Wake Time)** help reduce the contention between devices, providing more consistent low-latency performance.
- **Wi-Fi 7 (802.11be):**
Expected to further reduce latency, aiming for **<1 ms** latency in ideal conditions for ultra-low-latency applications like virtual reality (VR) and real-time gaming.

Summary of Wi-Fi Latency:

- **Optimal Conditions (Wi-Fi 6):** 1–10 ms (local network), 20–50 ms (internet)
- **Typical Conditions (Wi-Fi 5):** 10–50 ms (local network), 50–100 ms (internet)
- **Congested/Public Networks:** 50–200+ ms

Wi-Fi latency is heavily influenced by network congestion, distance, and interference. For the best low-latency performance, especially in applications like gaming, wired Ethernet is still preferred.

Prompt 12:

if I were to have a pcb that uses three components, a radar module for detecting objects, an ESP32 for wirelessly transmitting the data, and an MCU to handle all other communications, would I want to use either I2C or SPI communication for between these devices

Answer 12:

For a setup with a radar module, an ESP32, and an MCU, you'd want to consider both I2C and SPI based on the specific requirements of each component:

1. **Radar Module:** Many radar modules use either I2C or SPI to communicate, but SPI is often preferred in radar applications for faster data transfer rates. If the radar module is collecting a large amount of data, SPI would be more efficient for transferring it quickly to the MCU.
2. **MCU to ESP32 Communication:** If the MCU is mainly handling data between the radar module and the ESP32 for wireless transmission, SPI would again be advantageous here due to its higher speed, especially if there's a lot of data to send or if low latency is a priority.
3. **Protocol Choice (I2C vs. SPI):**
 - **SPI** would be generally preferred for high-speed, low-latency communication. It's full-duplex, meaning data can be sent and received simultaneously, which can help with real-time radar data processing.
 - **I2C** could be an option if you want a simpler wiring setup (only two lines for data and clock) and can handle lower speeds. However, it's half-duplex and slower, which may limit its effectiveness in applications requiring quick data transfer, like radar.

Recommended Setup

- **Radar Module to MCU:** Use SPI for faster data transfer.
- **MCU to ESP32:** Also use SPI if speed is critical and you want to avoid latency, especially if the ESP32 will transmit radar data in real-time. If data size and latency aren't critical, I2C could work as well.

In summary, SPI would likely give you the best performance overall, especially for the radar module's data needs.

Prompt 13:

create an IEEE citation for this link:
<https://www.tek.com/en/documents/primer/wi-fi-overview-80211-physical-layer-and-d-transmitter-measurements>

Answer 13:

Here is an IEEE citation for the link you provided:

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].

Prompt 14:

where did you get this information from

Answer 14:

The information I provided comes from a combination of well-documented technical characteristics of Wi-Fi standards (like IEEE 802.11 specifications), industry best practices, and performance benchmarks commonly shared in technical articles, research papers, and Wi-Fi module datasheets. Specific latency values are derived from typical ranges observed in controlled environments and real-world scenarios.

If you'd like, I can perform a quick search for current, reliable sources to provide you with direct links or additional details. Let me know!

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	Moving and	Moving only

I hope this

detection	stationary	
Distance measurement	Yes	No
Velocity measurement	Yes	Yes
Direction measurement	Yes	Yes
Antenna pattern	Wide	Narrow

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 (Head Up Display) to notify when hazard is occurring and where the hazard is occurring.
- 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.