# Senior Design I

*Smartphone-integrated Heads Up Display for GPS Navigation in Automobiles*


Figure 1: The Heads Up Display of a Chevrolet Corvette, displaying a tachometer, speedometer, and g-meter.

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**60 Page Submission:**

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# 1.0 Summary

In today's world where mobile technology has become an essential part of our lives, it is often difficult to disconnect and put these mobile devices away for much longer than a few minutes. This becomes a major hazard when getting behind the wheel of a vehicle. There are a myriad of distractions to take into account when driving a vehicle. According to the National Highway Traffic Safety Administration, "distracted driving is dangerous, claiming 3,166 lives in 2017 alone". Distracted driving not only puts the driver's life in danger, but also the lives of the other drivers and passengers on the road, creating dangers such as speeding.

With our Senior Design project, we will design a device that provides a driver with enhanced situational awareness by displaying pertinent information in the driver's field of view. To accomplish this, we want to create our own device using knowledge of hardware and software gained throughout our college careers. This device will contain a bluetooth module for wireless connectivity, a display module, a power delivery system, an LED array, and a speaker. The device will read information sent by the phone and use a display module to project an image onto the windshield of the vehicle, containing information such as speed limit data or navigational aids. Apart from the display module, we have also discussed adding an LED array to turn on when certain conditions are met. For example, if a driver begins to drive over the speed limit, a red LED will turn on and a speeding announcement will be played over the speaker.

There are vehicle manufacturers that have special packages that contain integrated heads-up displays, but these packages are often associated with premium prices. Additionally, these heads-up displays are not always integrated with advanced navigational awareness features such as speed limit awareness. We want to create a low cost solution that contains advanced functionality beyond what is provided with pre-existing heads-up display systems. To differentiate our device from other products, our device will have low power consumption, with a reduced footprint on the dashboard, and an easily readable and functional display.

We believe that this project will push us to learn more about the advanced systems required to make this device a reality. As seniors in Computer Engineering, Electrical Engineering, and Optics and Photonics Engineering, we will combine our fields of study to effectively and efficiently produce a product that can be used to reduce the amount of distractions and increase situational awareness while driving a vehicle.

# 2.0 Project Description

## 2.1 Motivations

The motivation for this project is to demonstrate our knowledge of optics, electrical design, and programming that we have accumulated while studying at the University of Central Florida. Classes such as Electronics, Computer Sciences, Embedded Systems, and Optics have given us in depth knowledge about the processes of engineering in our respective fields of study. It's one thing to take classes that discuss these topics, but it's incredibly beneficial to actually synthesize a physical project using this knowledge.

Upon initial group formation, we set out to determine the best project for our interests and skills. With a team consisting of two computer engineering students, one electrical engineering student, and one optics and photonics engineering student, there were a plethora of options that we could choose from that would prove to be challenging and exciting. The idea of creating a Heads-Up Display for a vehicle stuck out as one that could be well designed and implemented in the timeline of Senior Design. There are programming and hardware design aspects for our computer engineering students to tackle. The device would require power and electrical design that are taken care of by our electrical engineering student. Creating a display that can shine light off of the windshield of a car is a task that can be taken on by our Optics and Photonics student. We believe that there is enough depth in each field to provide equal opportunities for all of us to learn and contribute to creating a great Senior Design Capstone project.

One of the great things about having a Senior Design lecture is that it exposes us to a lot of strategies to making a successful design team. Events such as the Senior Design Bootcamp allowed us to come together and determine how each member of the group can contribute to the project as a whole. Referenced further in this document is a list of project milestones that we have determined to be important to the success of this project. We are going to do our best to stick to these milestones to promote timely and efficient work.

Another goal for this project is to make it as cost efficient as possible. We have not obtained any sponsorships, and as such we will be self-funding everything. As college students, bearing the cost of additional materials can be a burden. We will be sourcing materials to make the most effective product at the lowest price possible, reducing the financial strain on each member of the team.

## 2.2 Design Constraints:

The following constraints are being placed on the HUD device due to the factors that exist when building a self-funded design in a collegiate setting. The team has to adjust our design to match what is consistent with our expected budget and restrictions set by the University of Central Florida College of Engineering and Computer Science.

| Constraint | The HUD Device shall: |
|---|---|
| **C.1** | Cost no more than $300 |
| **C.2** | Must include a custom Printed Circuit Board (PCB) |
| **C.3** | Must not include pre-built components such as Development Boards |
| **C.4** | Must be designed by December 10, 2019 |
| **C.5** | Be user friendly |
| **C.6** | Must be built by April 2020 |
| **C.7** | Maximize energy efficiency |
| **C.8** | Increase driver safety and awareness |
| **C.9** | Not interfere with the driver's view of the road |
| **C.10** | Not distract the driver in any way |
| **C.11** | Must be reasonably designed |
| **C.12** | Must be funded by the students or sponsorship where applicable |

Table 1: Design Constraints

### 2.2.1 Legal Constraints

As it stands, there are no federal laws that limit or control the use of a heads up display in a vehicle. Similarly, there are no laws in any of the 50 states that regulate the use of heads up displays. Because of this, there are many car manufacturers that integrate heads up displays into their vehicles, all of which are 50 state legal. Heads up displays are also not subject to laws in Canada [4]. In fact, heads up displays seem to really have no legal restrictions in North America or Europe. As this device is being designed with the United States market in mind, the GPS heads up display should face few to no legal issues.

## 2.3 Engineering Requirement Specifications:

The following requirements set a defined scope for how the project will be designed and built. Each of the requirements will give the team a guideline for the end goal. Referencing this table will become useful for staying within the bounds of what we are going to create.

| Requirement | The HUD Device shall: |
|---|---|
| **R.1** | Weigh no more than 1 lb. |
| **R.2** | Not exceed 5x3x2 in. in size |
| **R.3** | Run off a USB Port |
| **R.3.1** | From this port there must be a voltage step down to run about 5 Volts or lower for low power consumption |
| **R.4** | Interface with a mobile phone via a Bluetooth connection |
| **R.5** | This will be compatible with android devices |
| **R.6** | Be able to display GPS data onto a windshield or dedicated screen |
| **R.7** | Have good resolution for easy viewing |
| **R.8** | The integration of software will be done using APIs provided by Google Cloud Platform |
| **R.9** | If the data displayed, such as google maps, requires sound, there will be a speaker on the side of the device |
| **R.10** | Be able to operate within a temperature range of -20 C to 50 C |
| **R.11** | Be able to operate in and be stored in direct sunlight |
| **R.12** | Be capable of adjusting to be visible with different windshield designs |
| **R.13** | Produce an image that is visible when viewed through polarized sunglasses |
| **R.14** | Be able to automatically adjust its brightness level according to the amount of ambient light |

Table 2: Engineering Requirement Specifications

## 2.4 Related Standards

As with any quality engineering project, there are standards that have to be adhered to in order to ensure that a product is safe, reliable, and compatible with other systems. Such standards can involve communication, data storage, or even legal considerations. Here, we list relevant standards and laws and state how we will ensure that our heads-up display conforms to them.

### 2.4.1 IEEE 802.15.1: WPAN / Bluetooth:

The IEEE 802.15.1 standard applies to wireless personal area networks (WPAN) and the construction of them through the use of Bluetooth technology for small, low power devices [1]. The standard contains a wide variety of clauses, message types, data-formats, and structured formats. Within the clauses state specifications for how the physical layer as well as the Medium Access Control (MAC) must operate in order to meet this standard.

### 2.4.2 IEEE 802.15.4: LR-WPANs

The IEEE 802.15.4 is a technical standard which defines the operation of low-rate wireless personal area networks (LR-WPANs) used by our BLE module. It specifies the physical layer and media access control for LR-WPANs, and is maintained by the IEEE 802.15 working group, which defined the standard in 2003. The standard specifies the architecture and topology of the wireless protocol.

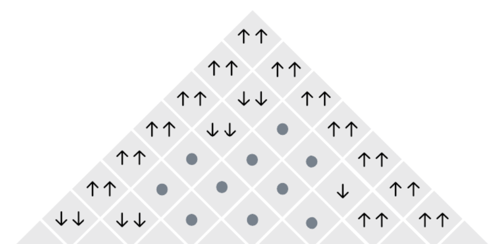
### 2.4.3 NMEA 0183: Data Sequencing

The NMEA 0183 standard is a technical standard governed by the National Marine Electronics Association, designed to standardize the format in which data is transmitted between transmitting and receiving devices. The data contains 8-bits synchronized to a 4800 Baud rate. There is one stop bit, and no parity or handshake bits.The NEO-6M GPS Module we could be using provides output data formatted to the NMEA 0183 Standard and need to be processed accordingly.

# 2.5 House of Quality:

There are many factors that need to be analyzed and discussed when designing our Heads-Up Display Device. Each of these factors has an impact on the implementation of our project. Below is a House of Quality chart to weigh the tradeoffs and effects of each factor on the outcome of our project.

| Legend | |
|---|---|
| + | Positive Polarity |
| - | Negative Polarity |
| ↑↑ | Strong Positive Correlation |
| ↑ | Positive Correlation |
| ↓ | Negative Correlation |
| ↓↓ | Strong Negative Correlation |
| ● | No Correlation |




| | | *Advanced Features* | *Low Power* | *High Resolution* | Thermal Procection | User Adjustable Mounting | High Brightness | Ambient Light Adjustment | Cost |
|---|---|---|---|---|---|---|---|---|---|
| | | - | - | + | + | + | + | + | - |
| *Durable* | - | ● | ● | ● | ↑↑ | ● | ● | ↑↑ | ↓↓ |
| *Low Cost* | + | ↓↓ | ↑ | ↓ | ↓ | ↓ | ↓↓ | ↓↓ | ↑↑ |
| *Easy to Use* | - | ↓ | ↓ | ↑↑ | ● | ↑↑ | ↑↑ | ↑↑ | ↓ |
| Advanced Functionality | + | ↑↑ | ● | ↑↑ | ● | ↑↑ | ↑↑ | ↑↑ | ↓↓ |
| Increased Situational Awareness | + | ↑↑ | ● | ↑↑ | ● | ↑↑ | ↑↑ | ↑↑ | ● |
| Compact | + | ↓↓ | ↑ | ↓ | ● | ↓↓ | ↓↓ | ● | ↑ |

Figure 2: House of Quality

## 2.6 Project Milestones:

The Senior Design Project spans across our final two semesters at the University of Central Florida. Projects of this scale do not happen without proper planning and time management. The following table displays our timeline for each stage throughout the design and implementation of the HUD Device:

| Task | Start Date | End Date | Status |
|---|---|---|---|
| **Senior Design I** | | | |
| Create Groups | 8/30/19 | 8/30/19 | Completed |
| Project Ideas | 8/31/19 | 9/6/19 | Completed |
| Role Designation | 9/7/19 | 9/8/19 | Completed |
| Initial Project Documentation - Divide and Conquer | 9/13/19 | 9/20/19 | Completed |
| Start Design Documentation | 9/23/19 | 9/23/19 | In Progress |
| Table of Contents | 9/23/19 | 12/2/19 | In Progress |
| Research Individual Parts | 9/23/19 | 12/2/19 | In Progress |
| Schematic Design | 9/23/19 | 12/2/19 | In Progress |
| 60 Page Rough Draft | 9/23/19 | 11/1/19 | In Progress |
| 100 Page Submission | 11/1/19 | 12/2/19 | In Progress |
| Parts Acquisition | 11/30/19 | 1/1/19 | In Progress |
| **Senior Design II** | | | |
| All Parts Must Have Arrived | 1/1/19 | 1/15/19 | In Progress |
| Schematic Implementation/ Prototyping | 1/16/19 | 2/28/19 | In Progress |
| Testing Design | 3/1/19 | 3/30/19 | In Progress |
| Final Prototype | 4/1/19 | 4/15/19 | In Progress |
| Miscellaneous Time for Further Troubleshooting | 4/15/19 | 4/20/19 | In Progress |

| | | | |
|---|---|---|---|
| Panel Presentation | TBA | TBA | In Progress |

Table 3: Project Milestones

# 3.0 Research Related to Project Description

## 3.1 Existing Projects and Products

Parallax-free sighting systems have been in use by the military since before World War II in fighter planes. Indeed, military aircraft have been the primary use case for a heads up display for much of the technology's life. More recently, heads up displays have made their way into consumer vehicles. What's more, there are available third-party heads up display options that read out car diagnostic data and can even hold a cell phone to act as a heads-up GPS.

### 3.1.1 Display Design

There are different approaches to creating a heads-up display. From these, we know that brightness is a common concern with third-party models. This section will cover existing variations of heads up displays.


Figure 3: An off-the-shelf GPS heads up display.

Figure 3 shows a third-party solution that utilizes a standard smartphone as a display. The phone is held in place via a mount that also attached to a small transparent screen. The image from the phone’s screen is reflected off the mount’s screen and is visible to the driver. The phone requires a special app to display GPS data and speed that can be seen by the driver i.e. the image is reversed so that the reflection is readable to the driver. Note that when in use the heads up display wholly monopolizes the phone. If the driver wishes to use the phone in any way, the phone must be removed from the mount and the app must be closed.


Figure 4: An off-the-shelf ODBII heads up display.

Another possible design for a car heads up display is shown in Figure 4. This design uses a module with a dedicated LED-lit instrument cluster. While this particular implementation is unable to display GPS data, it is able to read information from a vehicle’s OBDII port. This allows the device to display fuel efficiency, speed, and tachometer data read from the vehicle itself. Note how the device uses the vehicle’s windshield as the screen. This simplifies the use of the device, but introduces the problem of possibly having a display that is too dim to see in direct sunlight. This product tries to alleviate that by including a reflective film to place on the window.

Figure 5: An off-the-shelf GPS heads up display that features its own display screen.

One more example of an add-on heads up GPS is shown in Figure 5. The device is attached to the sun visor and displays its own image onto a screen. The phone is attached via USB and uses a specialized app for displaying the appropriate data. The phone can be used to play music while the GPS heads up display is used. The device is battery powered and therefore has a finite run time before it needs to be recharged. Also, the sun visor is unusable while the device is attached.

## 3.2 Attaching the HUD:

This is going to be a challenge because how the HUD is mounted has to be universal for any car. Some ideas that came to mind were mounting from the visor, but after thought this wouldn't work because of the distance to the windshield is too far, plus the dangling power cord is not very aesthetic. The next idea would be to use adjustable arms that are positioned onto the windshield via suction cups. After some deliberation this uses too much space on the windshield and could be a distraction/safety hazard with less viewing area. A promising idea would be to mount it, using clips or some mild sticky but removable adhesive, to the dashboard behind the steering wheel. This seems to be a tried and true method after researching other products and seeing how they mounted their devices.  The idea comes from the product below.

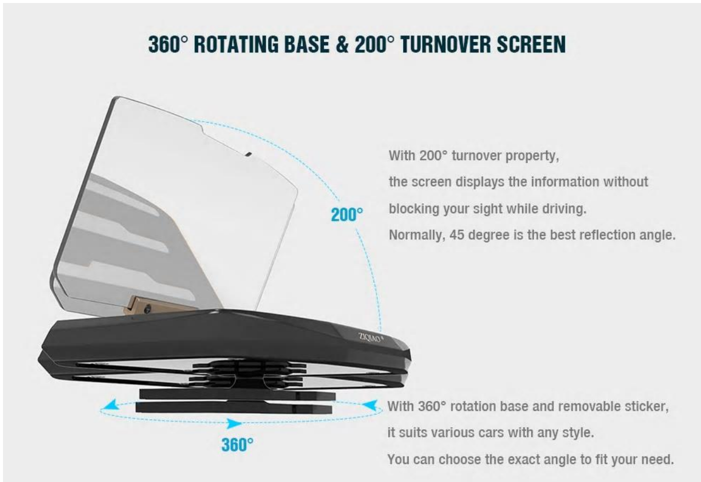



Figure 6: Idea for Mounting

This product also uses a swivel for horizontal movement whereas it would be better for our product to swivel horizontally and be able to move vertically to adjust the viewing angle.

In order to do this the first item would be the adhesive.  The only good fit would be a removable adhesive that will not damage a car's interior.  A candidate would be the tesa Powerstrip double sided tape.  It can hold up to 2 kg (4.4092 lbs) which would be strong enough to hold the HUD in place.  Another good thing about this product is if the tape is pulled it will release very easily, this way there is no damage to the interior and can be taken off if wanted.  This would be put on the bottom of the base platform of the HUD.  The next item would be the swivel.  It needs to be able to move vertically at the minimum.  This would be connected to the top of the base platform.

## 3.3 Display

The display is a challenge that requires a lot of thought and care. One of the primary challenges of the display will be one that can adequately show GPS and other information, all the while in bright sunlight. Consumer solutions involve a sort of reflective film that can be directly applied to a piece of glass, usually the windshield. Even if we choose to go with a separate glass screen that is attached to the device, it may be worthwhile to also include a reflective film. Because the device is to receive its power from a USB port, an otherwise adequate display may consume too much of the power budget. Another consideration is whether we want to use some sort of projector, a simple LCD screen, or a small LCD screen with a collimating lens. The advantages of a projector are that it can be collimated easily to show an image that focuses at an infinite distance. The downsides are its higher power consumption, larger size, and larger price tag. The advantages of using a small LCD with a collimating lens are lower power consumption, smaller footprint, and being able to be focused at infinity. The disadvantages are the difficulty of finding a smaller screen with adequate brightness, lower resolution, and issues with using a collimating lens, such as distortion. The advantages of using a larger LCD are the ability to simply reflect the screen without any extra lenses, high resolution, and ease of finding one with adequate brightness. The disadvantages are higher power consumption, inability to be focused at infinity, larger size, and possibly inadequate brightness within a reasonable financial and size budget.

### 3.3.1 Projector

The P1+ Mini Projector shown in Figure __ is very compact, which is extremely valuable in a space-constrained environment. However, the device itself is only capable of 30 lumens output. This isn’t very bright and would easily be washed out in bright sunlight. The unit itself can be found for roughly $100, which is more than we are willing to spend at this time. It is also a self-contained OEM solution and is therefore unsuitable for use in our project. In fact, upon further research it was found that there are few to no bare projectors to be had.

The P1+ Mini Projector was the only projector that was seriously considered. All other projectors that were reviewed were inadequate in multiple ways. Because projectors of suitable brightness and size are too expensive, too power-hungry, and too pre-built, it was decided that projectors would not work for our heads up display.


Figure 7: P1+ Mini Projector

# 3.4 Small LCD Screen to be Paired with Collimating Lens

## 3.4.1 Option 1: Adafruit ADA938 Screen

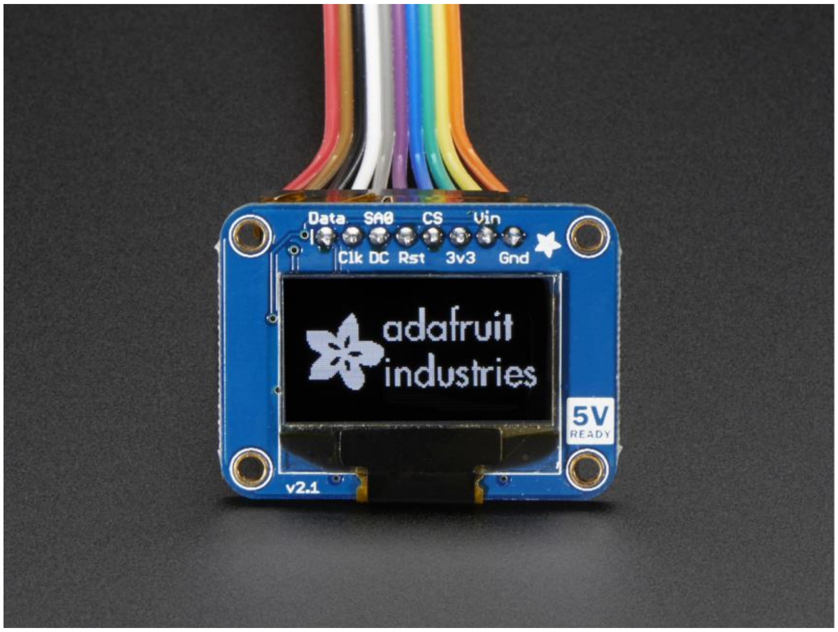



Figure 8: Adafruit ADA938 Screen

The Adafruit ADA938 is a 1.3” 128x64 black/white OLED screen. Because the screen itself is small, it is a candidate for use with a magnifying lens to be collimated and focused at infinity. On top of that, the screen uses OLED and is monochromatic black/white. Since OLED black is done by switching off individual pixels, the contrast of this screen is excellent. As a result, the only light that would be seen would be from the active pixels and the resulting reflected image would have no extra “black” in the background. The price is not too bad, as the screen can be found for $10 or less. However, the screen is only capable of 100 $cd/m^2$ and will not be bright enough for our purposes. What's more, the ADA938 uses OLED. OLED pixels have a finite lifespan, and so our screen can be subject to burn-in or general loss of brightness in as little as 1000 hours! While the thought of amazing contrast is tempting, the ADA938 is not likely to be considered. Of all the reasons not to use this screen, the major deciding factor is brightness.

### 3.4.2 Option 2: ENH-DG128064-66 Transparent LCD


Figure 9: ENH-DG128064-66 transparent LCD display

The ENH-DG128064-66 is another small screen. Unlike the ADA938, this screen uses standard LCD technology and is transparent. This gives us the benefit of a less expensive display that will not suffer from burn-in and also gives us the ability to use a separate LED back light of our choosing. This screen, like the ADA938, has a resolution of 128x64, which is not a high resolution but will be readable when used. The key feature is the ability to be paired with a high-intensity LED of our choosing. This gives us the ability to pick an LED that meets our brightness and power consumption requirements while fitting within our size and financial constraints. This screen can be found for as little as $3 online and can be ordered at that price from multiple sources. The low price gives us the option of ordering multiple screens to be combined in a 2x1 or 2x2 setup to achieve a higher resolution that can be used to create higher quality images for the driver. While that would involve extra cost and complexity, these screens are so inexpensive that it could be viable.

### 3.4.3 Option 3: TP241MC01G transparent OLED screen

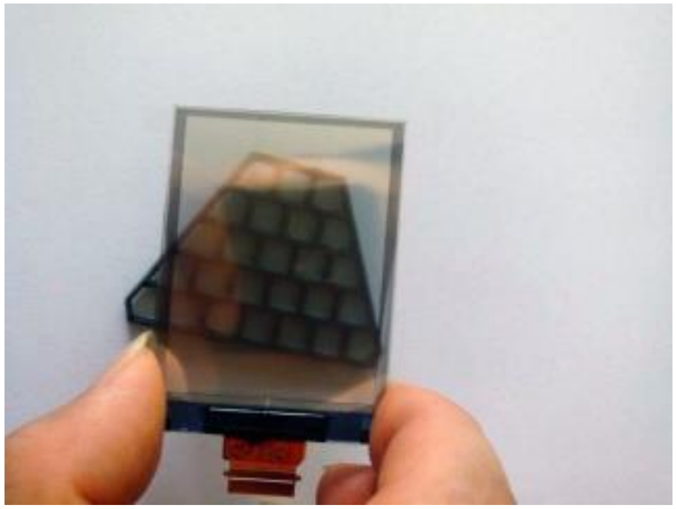


Figure 10: TP241MC01G transparent OLED

The TP241MC01G shown in Figure __ is another small screen that was considered. Unlike the previous two screens, this model has a higher resolution of 128x160. This would give us a much higher resolution that would allow for more detailed graphics to be displayed. This screen is also capable of showing color images, which would give us the ability to use multiple colors in our display. One massive benefit of this screen is that, like theENH-DG128064-66, this screen is transparent. This would allow us to choose an LED light source that would produce a satisfactory amount of screen brightness. This screen would be roughly twice as large as our other two options, at 2.4" across. The larger size would require the use of a larger positive collimator lens. This screen is also using OLED technology, which would result in a noticeably finite lifespan of our heads up display. The price of this display dwarfs that of the others we researched, as the TP241MC01G is difficult to find for less than $80. Because of its high price, larger size, and limited lifespan, this screen will likely be passed over in favor of a more compact and affordable option.

Because a heads up display works best with a collimated image that is focused at infinity, using a small screen with a magnifying lens will likely be the solution we choose for this project. Also, due to brightness considerations, we know that a transparent LCD-type screen will be ideal because we have the freedom to choose an adequately bright LED to illuminate the screen.

# 3.5 Large LED Screen

## 3.5.1 Option 1: W050P40PH01 LCD Screen


Figure 11: W050P40PH01 LCD screen.

The LCD screen shown in Fig. __ is a 5" diagonal LED backlit LCD display with RGB capability. The screen is affordable and, more importantly, bright. With a brightness of 1000 cd/m$^2$, the screen should be bright enough to be seen in daylight. However, this display brightness may be at the lower limits of what is actually visible on a bright sunny day. What's more, this arrangement does not allow for a collimating lens. Instead, the screen will simply reflect off of a glass surface and its reflection will be focused at a finite distance. While this is common for aftermarket heads up solutions, this does not allow the image to be in focus at all distances the driver may be looking.

## 3.6 Heads Up Display

The main feature of this device is that it is to display GPS information via a heads up display. Heads up displays have been in use, in some form or another, since World War II, where they found use in fighter planes. In 1942, the British Royal Air Force experimented with projecting information from the radar onto a flat screen that also displayed the plane's gyroscopic gunsight [6]. The inclusion of the radar readout onto the screen allowed pilots to more quickly engage targets while flying at night. The heads up display emerged again in the Royal Air Force, who coined the term "heads up display" in the late 1950's [7]. Heads up displays then went on to be included in different NATO and Warsaw Pact jet fighters. In more modern times, heads up displays can be found in commercial aircraft and even consumer cars and trucks.

Heads up displays work by using three main components. These components are the projector, the combiner, and the video generation computer [8]. The projector unit uses optical components to collimate the image. To collimate an image, a screen or other display is placed at the focal point of a positive lens or negative mirror. When an object is placed at the focal point of a positive lens or negative mirror, the resulting image is focused at infinity. Instead of the resulting rays converging at a single point somewhere past the optical component, the rays instead stay entirely parallel to each other to an infinite distance. The result of using a collimator in a heads up display is that the image is always in focus, whether the viewer is looking at an object 5 feet or 5 miles away.

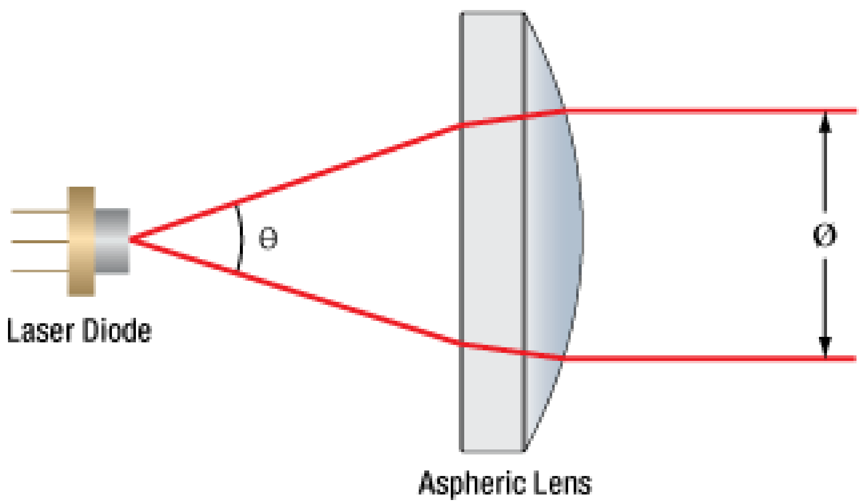



Figure 12: A laser diode and a collimating positive lens. Image

The combiner is simply the medium used to overlay the collimated image with some other image, usually to overlay the heads up display image onto a view of the outside world. For this, all that is needed is a piece of transparent glass. In many heads up display applications, the combiner is a vertical or near-vertical sheet of glass that is placed within a few feet of the user. In most jet fighter cockpits and in some commercial HUD solutions, the combiner is a vertical or near-vertical glass sheet. In some consumer cars that feature heads up displays, the windshield itself is used as the combiner.


Figure 13: A simple angled glass combiner. [Image]

The final component of a standard heads up display is the video generation computer. The video generation computer is all of the necessary hardware and software to process data as input and give data as output that can be transformed by the projector into an image. As computers have become more advanced, video generation computers have become faster and more powerful while also using less power and taking up less space. Because of this, video generation computers can be used the heads up displays of a wider variety of vehicles, and even in fields such as augmented reality. Modern-day systems such as Arduino or Raspberry Pi have enough power to be used as video generation computers and in many cases even have pinouts for display devices built into the board itself. Back before the transistor was in common use, such computers would use vacuum tubes that requires much more space and power. This limited the use of video generation computers to vehicles with enough space, like larger aircraft. Some of these systems are specified for different nations' militaries or corporate designs, so even otherwise modern aircraft may still be using vacuum-tube-based video generation computers.

# 4.0 Components Selection

## 4.1 Power Supply:

There are several USB types from the plug in side to the connector. The most prominent are the USB 2.0 type A and USB 3.0 type. These plug versions both provide 5 volts nominal. The difference between the USB 2.0 and USB 3.0 type A is that the USB 2.0 type A provides 500 mA compared to the USB 3.0 which can provide 1.5 to 3 A over the 5 volt bus. The other big difference was that the USB 2.0 has a throughput 480 Mb/s and the USB 3.0 has a throughput of up to 5 Gb/s. For power needs it is not as important. The next decision is whether to use a USB micro B or USB type C connection ends. The micro USB is more simplistic with only four pins, two for power and two for data transfer. The USB type C has an additional five pins, in terms of current three of those wires are for standard downstream port, a charging downstream port, and a dedicated charging port. The charging downstream port and dedicated downstream charging port supports up to 1.5 A.

To supply power to the HUD the USB 3.0 A to micro type B connector and cable will be used. The reason why is because the micro type B is cheaper and more readily available with breakout boards that allow for easy access to the two pins that are needed for power. They may have a lower rating but the good thing about USB is that you can plug any USB device into any USB cable and into any USB port. The initial idea was to use the cigarette port, but more and more cars are solely using the USB connectors in cars and doing away with the cigarette ports. If that is not an option, a typical car charger that has a USB connector will still work. Below are three choices that use a female connector USB board mount. The factors that go into this decision are cost, accountability, and time to ship.

### 4.1.1 Option 1: USB Micro-B Breakout Board Product ID: 1833

This first option comes from the online supplier Adafruit. They offer a breakout board with the female USB type B connector and 5 pins broken out to easily attach wires to supply power to a device. In addition to easy mounting and use they even supply a small stick of 0.1” header so it can be soldered on and plugged into a breadboard. It has through hole shielding pads for a strong connection. It costs $1.50 and can ship in less than a week. Also, there was a video demonstration that shows how robust this connector is. The datasheet also shows that this item can withstand temperatures from -30 to 80 degrees Celsius, which helps to comply with our need for higher temperature resistance.

### 4.1.2 Option 2: BOB-12035

This is another breakout board from DigiKey. It seemingly offers the same as the

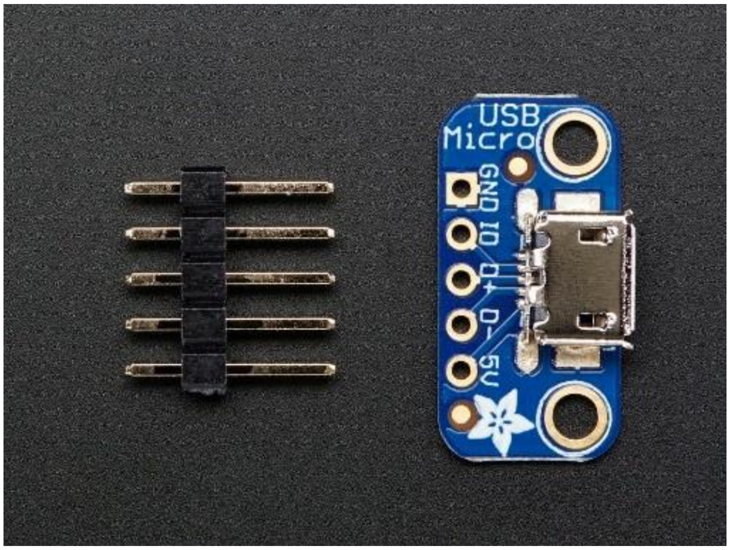



Figure 14: USB Micro-B Breakout Board Product ID: 1833

breakout board from Adafruit, with a female USB type B connector with 5 pins broken out for easy connection. Looking at the datasheet did not give as much information. It could be assumed that it can withstand higher temperatures of a car, but it is not known for sure. This board costs $2.50 and can also be shipped in a week. This board does not seem as robust, but it is still cheap and fits the functional requirements.


Figure 15: BOB-12035

### 4.1.3 Option 3: 2174507-2

This third option is a little less friendly but looks more professional. This USB type B female connector is just the connector part. It does not offer the easy access to the pins as the other two options provided. This part is more prone to come off as it does not have the reliable through hole mounts rather this would just be soldered onto the PCB and could prove a problem with repeated connects and disconnects. This part is $1.87 and can also ship within a week. Looking at the datasheet also gave less than desired information, still assuming it could resist temperatures in a car it is not explicitly given.


Figure 16: 2174507-2

# 4.2 Power Regulators:

The next item on the list is something that can convert the 5 volts to something smaller for the smaller components. The simplest item to use for this would be a linear regulator but that can only be tuned using the adjustment pin with resistors, if that would be adequate enough. Otherwise a buck converter might have to be used a tunable potentiometer for really precise voltage regulation.

## 4.2.1 Option 1: LM317T

This is a basic linear regulator which can take in 5 volts and make it into something smaller. The drawback of using linear regulators is that it produces a good amount of heat. That means getting a heat sink, which means more space taken up inside the unit. The LM317T can operate between 0 and 125 degrees Celsius. If in the event the part overheats it has over current and over temperature protection. The regulator can take in a maximum of 40 volts and have a minimum of 1.2 volts minimum with tuning on the output of the adjustment pin. The output current is up to 1.5 amps. But they're very cost effective, this particular part is only $0.64, and through digi-key can ship out on the day of purchase.

## 4.2.2 Option 2: LM2596 DC-DC Adjustable Buck Converter 3.2-46V to 1.25-35V Step Down Power Supply High Efficiency Voltage Regulator Module

The next option is a buck converter. The only downside to a buck converter is that they are marginally more expensive, this is a four pack so individually they would be about $2. With that being said, the buck converter can take in 3.2 volts to 46 volts, having an output of 1.25 volts to 35 volts with a maximum of 3 amps output. The trick here is that the input must be 1.5 volts higher than the output, so not that we would need it, but it cannot be used as a boost converter. To set this up, connect the input to the input terminals and output to the output terminals. Then tune the potentiometer to the desired voltage level. Another thing is that as long as this buck converter isn't used for very long periods of time, it's heat efficient and will not require a heat sink.

## 4.2.3 Option 3: TPS61222DCKR

This is a tiny boost converter that would take in 5 volts and convert it to anything between 1.8 to 6 volts. It has a high efficiency above 90 percent for 5 volt input to lower output, but with higher output current. This is a good choice because it operates at -40 to 85 degrees Celsius, and will not require a heatsink to dissipate power loss. In addition it has output overvoltage, overtemperature, and input undervoltage lockout protection. This comes with its own schematic and set of equations for making the output voltage adjustable. Ideally this will provide power to most of the HUD, except the screen display. This boost converter comes from Texas Instruments and sells for one dollar and ships in five days.

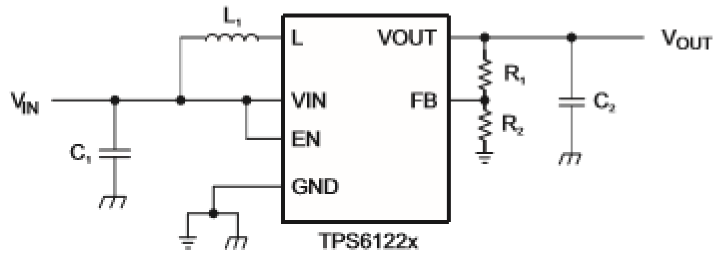



Figure 17: Schematic for TPS61222DCKR

The simple equation for determining output voltage is $R_1 = R_2((V_{out}/V_{FB})-1)$. VFB should be at 500 mV so choosing $R_1$ and $R_2$ becomes easy.

# 4.3 Boost Converters

Boost converters are an easy way to create higher voltage than the input voltage. The trade off is that the higher voltage reduces the amount of current provided from the input. The basic setup of a boost converter is an inductor in series with a voltage source, with a switch to ground and then a diode and capacitor in series which are in parallel to the switch. The way it works is when the inductor is connected to ground via the switch current flows through it for a very small amount of time that allows magnetic energy to be stored inside of it, and when the switch is opened the polarity of the inductor changes so current flows through the diode and two sources are now in series which charge the capacitor. The switch that allows this to happen has to cycle on and off fast enough to not ruin the inductor, usually performed by a switching device.

Initial estimates, ranging from 10 to 12 Watts, show that the power consumption of the device will be a little higher than what a single USB port alone can provide. So to combat this a boost converter will be used to generate a higher output voltage source primarily for the bright screen display that is required. Boost converters are cheap and can either be bought or made. The downside of using them is they take up room and generate heat.

## 4.3.1 Option 1: Super XL6009 DC-DC Adjustable Step-up Boost Power Converter

This step-up booster is on par with what is required. Being able to take in 5 volts as the input and being able to output about 12 volts at 0.8 amps, this provides 9.6 Watts of power. This is at the lower end of the estimate, but should be able to handle the power requirements  of the display.  In addition, the operating temperature of this device is between -40 to 85 degrees Celsius.  This has a very simple implementation design where the input voltage is connected to the input terminals and the output has output terminals.  A plus side too, it that the output can be tuned with the adjustable potentiometer on the boost converter for precise output conditions.  This product comes in a set of two for $6.93 from amazon.

Figure 18: Super XL6009 DC-DC Adjustable Step-up Boost Power Converter

### 4.3.2 Option 2: LT1613CS5#TRMPBF

This option is a build it yourself option.  The LT1613 is the integrated circuit only. To make it a boost converter the rest of the circuit is made with other elements attached to the LT1613. There is a schematic provided already to boost 5 volts to 12 volts at 130 milliamps. This gives a smaller power output of around 1.56 Watts, which is on the much lower end of the power requirement that was needed. The problem with this option is that there is a very long manufacturing lead time to get this particular piece, it would take about 8 weeks to ship.  The single component is cheaper at $4.28. Below the schematic for the 5 volt to 12 volt conversion.

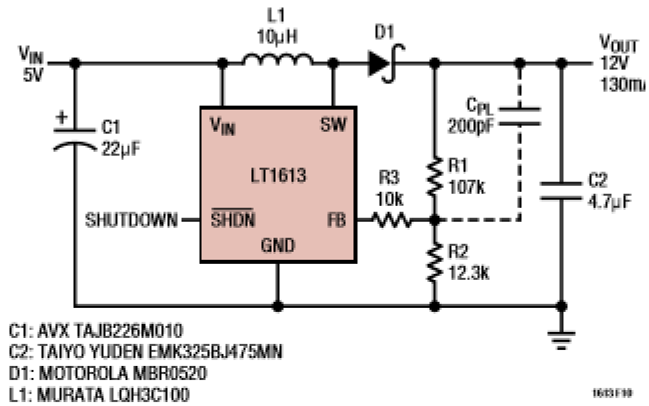



Figure 19: Schematic for 5 Volt to 12 Volt using LT1613

### 4.3.3 Option 3: LM2577-ADJ

The LM2577-ADJ is an adjustable boost DC-DC switching regulator. This is also a build it yourself option. This component has a wide input voltage range from 3.5 to 40 volts. With simple schematic design, the LM2577 can be made to boost 5 volts to 12 volts at 800 milliamps. This results in a power output of 9.6 Watts. This is still on the lower side of the anticipated power requirement, but should be enough to power the bright display. The LM2577 will operate at around 25 degrees Celsius when at 12 volts. In addition this part is readily available to be shipped with an asking price of $8.24**,** which is more expensive but worth the delivery time.

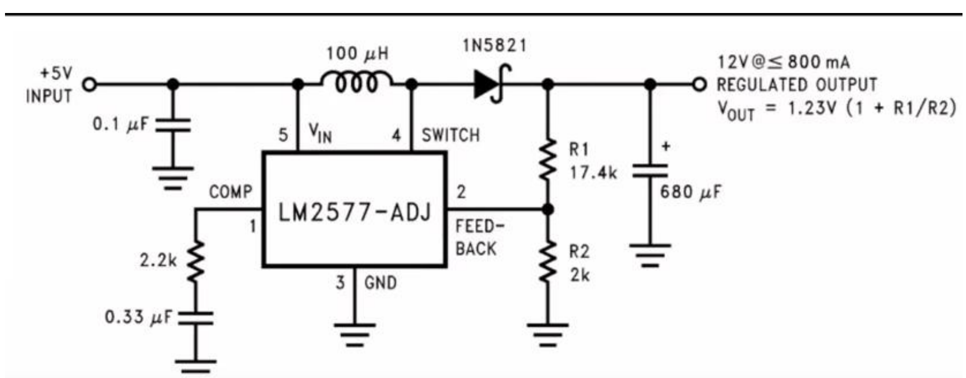



Figure 20: Schematic for the LM2577-ADJ for 5V to 12V

# 4.4 Heat Sinks:

Since the HUD is not going to be designed with a small fan, a heat sink will be needed for some of the components. Heat sinks are always an important part when thinking about heat dissipation in hardware since they easily get hot, especially during long periods of use. The most likely component that will need a heat sink in the processor that will be used and also the linear regulator. Cars can get up to 170 degrees on a hot day and that's not even having the HUD turned on. Unfortunately, space is always a key factor since the idea is to keep the HUD as small as possible.

The rate at which the heat sink transfers heat from the processor to the air is known as thermal resistance. To find the thermal resistance needed for the processor, you subtract the maximum inlet temperature from the maximum case temperature and divide that number by the maximum power dissipation of the processor. The thermal resistance is measured in degrees Celsius per Watt (C/W). The processor that is to be used has a maximum case temperature of 125 degrees Celsius, a maximum inlet temperature of , and the maximum power dissipation is 0.092 W. Below are some comparisons of heat sinks that could help our processor and linear regulator stay within operating temperatures.

## 4.4.1 Option 1: TO220 Bolt On Heatsink

When calculating for a thermal heat sink to be used with a linear regulator, subtract the output voltage from the input voltage and multiply by the load current. Ideally, the input voltage is 5 volts, the output voltage can range from 1 to 3.3 volts and the load current would not be greater than 0.1 amps. This gives a range of .4 watts to .27 watts which is just above its allowed 0.25 watt dissipation. This heatsink has a thermal resistance of 21 degrees Celsius per Watt power and is 9.5 x 19.1 x 19.1 mm in size. It may be mounted either horizontally or vertically.

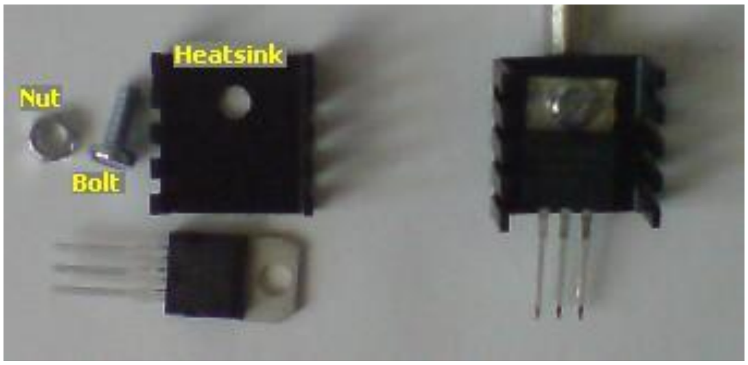



Figure 21: TO220 Bolt On Heatsink

### 4.4.2 Option 2: Extruded Aluminum Heatsink 7mm x 3.5mm Chip VGA RAM Graphics Card IC Radiator Cooler 7x7x3.5mm

The processor, TM320F2802x Piccolo Microcontrollers, is 7 mm x 7 mm and this particular heatsink is the perfect size for this processor. The processor can operate at high temperatures, about 125 degrees Celsius, but it will be in an already hot car and to combat this the aluminium heatsink can dissipate enough of the heat that would keep it in operating temperatures. This is very low cost at 5 dollars with ten of them in a lot, but the downside is that it takes almost 3 weeks to ship to its location.

## 4.5 Light Sensor:

The reason for a light sensor is so that when the HUD is in use it knows when to dim and brighten the display. This will be useful for the transition between day and night. This does not need to be a complex light sensor rather something that's close to the human eye.

### 4.5.1 Option 1: Adafruit ALS-PT19 Analog Light Sensor Breakout

This is another breakout board from Adafruit. It's very simple with a power need of around 2.5 – 5.5 volts and once its on the only thing to do is read the analog voltage on the OUT pin. As light increases the voltage increases. A bonus is that it's RoHS compliant. Due to the high rejection ratio of infrared radiation, the spectral response of the ambient light sensor is close to that of human eyes. This goes for about $2.50 and can be shipped out in less than a week. Also, it meets the temperature performance of being able to operate between -40 and 85 degrees Celsius according to the datasheet.

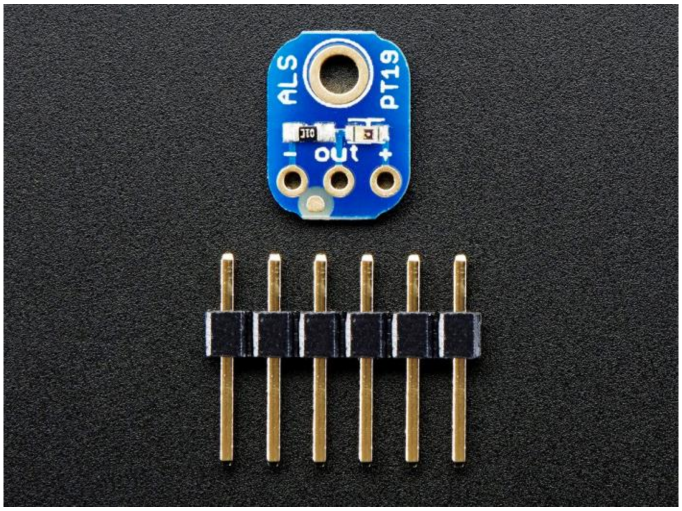



Figure 22: Adafruit ALS-PT19 Analog Light Sensor Breakout

### 4.5.2 Option 2: OPT3007YMFR

This product is made by Texas Instruments. This is a good fit because it's a super thin light-sensor with a fixed $I^2C$ address. This device matches the human eye with rejecting more than 99% of infrared light. It's able to measure between 0.01 to 83k Lux, this will allow for fine tuning when dimming the display. It has a very low operating current at 1.8 μA which is what we're looking for in terms of the limited power that is available. The dimension of this chip is 0.856-mm × 0.946-mm × 0.226-mm which is space efficient but will require a PCB since it's a surface mount device. The OPT3007 will operate between -40 to 85 degrees Celsius. One last upside is that this is a smaller version of the OPT3001 that was used in the embedded systems class, so this isn't a totally new component to figure out.

### 4.5.3 Option 3: Adafruit 161

The Adafruit 161 is a very simple photodiode. This CdS cell respond to light between 400nm and 600nm wavelengths, peaking at about 520nm. Basically, all they can detect is if there is light or if there isn't light. For this reason, they shouldn't be used to try to determine precise light levels in lux. So, the upside is that they are very cheap, this one is $0.95, and they are very robust so no worries of it giving out. To read this our main CPU will determine what the voltage off the photodiode is. The higher the voltage the brighter it is.

## 4.6 Mini Speakers:

The addition of speakers allows for visual cues as well as audio cues to be given. The idea is that if there is a turn to be taken, the user can hear that a turn will come up in so many feet, or if there is an alternative route to be taken that the option is there and can be selected when prompted. The goal in choosing a speaker is that it must use low power. With low power though, it must also be loud enough to be heard over normal traffic conditions.

### 4.6.1 Option 1: Breadboard-Friendly PCB Mount Mini Speaker - 8 Ohm 0.2W

This little speaker has it all. It's small and robust being only about 30 mm in diameter. The pins can fit perfectly into perfboard too. The speaker is an 8 Ohm and uses 0.2 W or less of power. The optimal temperature range is within -10 to 40 degrees Celsius. The frequency range is between 600 Hz to 11 kHz. There is a class D amplifier that will work with the speaker if that is something that is needed down the line. This speaker is $1.85 and can be delivered in about a week.

### 4.6.2 Option 2: Mini Metal Speaker w/ Wires - 8 ohm 0.5W

This tiny 1-inch diameter speaker cone has an 8 Ω impedance and will be using 0.5W or less of power. This particular speaker is very simple, and its metal body is extremely lightweight. The rated frequency range is similar to the speaker above, operating between 600 Hz to 10 kHz. Also, it has a good temperature resistance being able to operate between -20 to 55 degrees Celsius. Again, this speaker can work well with class D amplifier if it is something that is needed. This speaker is $1.95 and can be delivered in about a week.

# 5.0 Navigation

One of the main features we would like to implement into the heads-up display is displaying navigational information to the driver. Looking at a phone for navigation can be dangerous and distracting as it removes the driver's eyes from the road ahead. We can eliminate this risk by displaying pertinent navigational information right in the driver's field of view. For example, if a driver's desired route has a series of turns, a counter with how far the driver is from the turn will appear, along with street names and the direction in which the driver has to turn. This will increase the driver's awareness and reduce the possibility of making a wrong turn or getting lost. To achieve this, we would need to obtain the path the user will take from starting point to destination. There are a variety of ways we could create a path from beginning to end.

## 5.1 Predetermined Routing

Predetermining the route ahead of traveling means we could gather coordinates for each turn along the way. The waypoints could be determined by mapping out the user's desired route using an application such as Google Earth. The route will most likely contain a series of turns that the driver will have to make in order to reach the destination. At each turn, coordinates will be created to mark the waypoints that the driver must drive through to stay on the route. These waypoints could be entered into the device and stored for processing. Using a GPS chip, we would be able to keep track of where the driver is in relation to those stored waypoints. When the driver begins his or her route, a distance variable will keep track of how far the driver is from the first point. This information will be displayed to the driver on the Heads-Up display in the form of a visible distance counter. As the driver gets closer, the distance will be shown counting down accurately. Once the driver gets to specified distances from the next waypoint i.e. 1 mile, the system will announce a turn is ahead using the built in speaker and sound recorded onto the device. Additionally, the HUD will display an arrow in the direction of the next turn as well as the street name that the driver will be turning on to. This will allow the driver enough time to make note of his or her surroundings and prepare to make the turn. Once the driver reaches the waypoint, the system will move to the next waypoint and begin counting down the distance to it.

This process of predetermining the route the driver will take and inputting the turn coordinates manually has advantages and disadvantages alike. For advantages, it drastically reduces the amount of components needed to implement the device. The driver would predetermine the waypoints of each turn, enter and store them into the device as coordinates, and then have the GPS chip determine the distances between each of the coordinates as the driver is on the route. Being able to reduce the components required to implement the device means that the cost to both manufacturer and consumer can be minimized, as well as complexity to build would decrease. This decreased complexity would allow the device to require less power, making it more efficient electronically. As for disadvantages, predetermining and storing waypoints is an extremely rigid system. It does not allow the driver a quick way to modify the route once it has been programmed into the device and started. If the driver wishes to change the route from what is already active on the device, the driver would need to manually reprogram each waypoint for the GPS to track. We anticipate that this would be a time consuming process and would require the driver have access to a computer and the interface required to program the device. Due to the inflexibility of this approach, it is unlikely that we would implement our device in this fashion.

## 5.2 Google Cloud Platform API

As mentioned above, manually entering waypoints into the device is not the most efficient way to implement navigation for our HUD. A much more efficient implementation would leverage the power of pre-existing and well established navigational platforms to assist in obtaining route information.  Google Maps a mapping application for mobile devices that uses the device’s internal radios, sensors, and GPS to stream information about the user’s current location to Google’s infrastructure, determining the user’s exact location along a route down to great precision. Maps is extremely useful for determining the most efficient route between the starting point and destination. Engineers from Google have spent years developing algorithms that analyze real-time traffic data, road closures, and other variables to give the driver the safest and most reliable route. The application’s user has the ability to add custom filters to the route, such as avoiding tolls or prioritizing distance against time.

Leveraging information from Google Maps would be the ideal scenario for implementing a navigational system into our HUD device. In order to do this, we would need to create a custom mobile application that would implement API calls to the Google Maps platform and obtain the data for a given route. For example, the driver would enter his or her desired destination into our application. The Maps API would return the most efficient route to the driver’s destination at the time of computation. This information could be streamed from our mobile device to the HUD device over wireless standards like Bluetooth. The HUD device would then show the route information just as in the previous implementation.

The ability to use Google Maps API will enable us to build a deeper and more advanced implementation for navigation. It will allow us to provide real-time updates to the driver's route. This opens the door for advanced features to be implemented, such as speed limit monitoring. Google Maps has information regarding the speed limit for the road the driver is currently driving on. The speed limit is displayed on the application, notifying the driver and potentially preventing them from speeding. We would like to implement this feature into our HUD by accessing the API for the speed limit of the road the driver is currently on and displaying it in the driver's field of view. We can combine this information with the live speed read by the onboard OBD2 port of the vehicle. If the driver's current speed goes beyond the speed limit retrieved from Maps, we would like to advise the driver to slow down, ensuring the driver is within safe driving conditions. The use of APIs would make route modification much easier, as it would only require the driver to enter the new location into our application and recalculate the route. This process is much easier than having to remap every coordinate by hand like the previous implementation. Hazards along routes such as traffic jams and accidents are often spontaneous and unplannable. We could implement a function to ping the API every few minutes to check for any hazards along the current route. If the API returns that a hazard lies ahead, we could have the API recalculate the route to avoid the hazard and keep the driver on the most efficient route.

Ultimately, implementing a custom mobile application paired with Google Maps APIs and streaming the information to our HUD would provide us with the most flexibility and advanced feature set. This is the implementation we would like to strive for when building the device.

# 6.0 Application

To support advanced navigational features noted in the previous section, we will need to access the APIs provided from the Google Maps Cloud Platform. There are already applications that exist that can access information from the Google Maps API and the standalone Google Maps application, however we do not have access to the source code of these applications and cannot ensure that the data we need for this project will be available. Additionally, the data will need to be streamed over our Bluetooth module once the destination is chosen by the user.

## 6.1 Application Design

The best method for ensuring that all of the required data is being received is to build a mobile application from scratch. We will be creating an application for Android phones using the Android Studio, since the development kits are readily available and easily implemented. Cost to implement this application will be minimal as we already have access to Android devices. The application's design language is going to be simplistic and minimal, enabling the user to locate the desired destination and send it to the HUD with ease. The mobile device will communicate with the HUD by pairing the two devices over a Bluetooth connection.

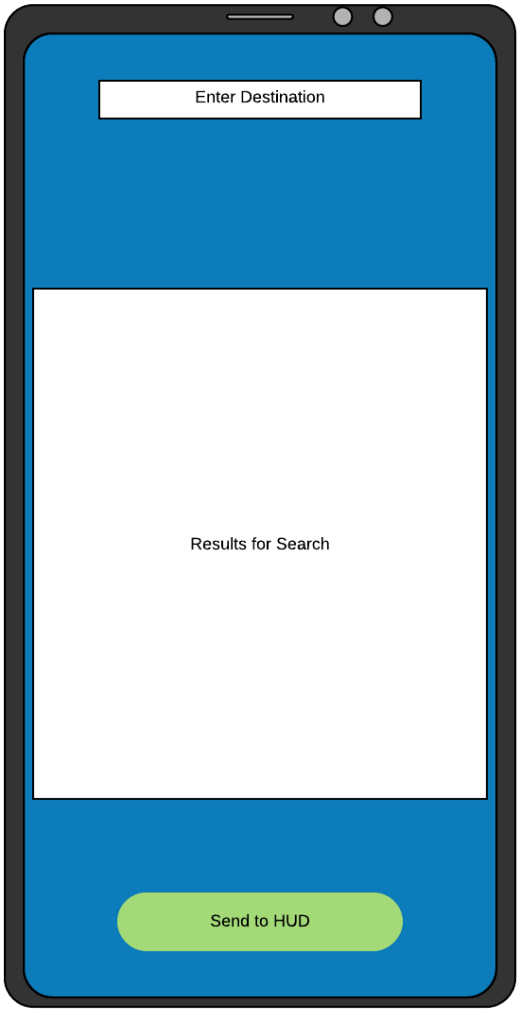



Figure 23: Application Design

The application design features a search bar at the top for the driver to enter his or her desired destination. As they are entering the destination, the Google Maps API will be suggesting destinations based on the text input from the driver. Once the desired destination appears, the driver will select it from the list. The Google Routes API will then be called to find the most efficient route from the mobile device's current location to the destination.

Once the route is returned, it will populate in an embedded map in the center of the screen. The driver will press the Send to HUD button when ready to proceed on the route. The Routes API will return each turn on the route as a coordinate, which can be used to create waypoints along the route. These waypoints will enable turn by turn navigation to be implemented in our HUD. Once the coordinates are obtained, the application will push them to the HUD from the Bluetooth connection. From this point, the responsibility for navigation is passed to the HUD device, where it will start comparing distances between the HUD's onboard GPS chip and the route's first turn coordinate. The application is not needed for navigation until a new route is desired.

The application will provide the driver with a convenient way to interface with the HUD. Since most people already own a smartphone, there will not be any additional cost to implementing this design.

# 7.0 GPS:

Implementing turn-by-turn navigation requires the device to determine its exact location to detect where the driver is located in relation to the designated route. There are a few methods that we could use to implement GPS tracking in the device.

## 7.1 Google Cloud Platform Location

The simplest and least complex method of tracking the device's location would be to use the information taken directly from the Google Maps API running in the application on the mobile device. Since the mobile application will already be reaching out to the Google API, it would be minimal to add in the ability for the application to read the device's current location and update this to the HUD. The GPS data could be stored in the HUD device to control the contextual information displayed on the HUD.

## 7.2 Mobile Device GPS Location

Our second option would be analyzing data provided by the onboard GPS of the paired mobile device. API Libraries provided in the Android Studio application would allow us to build GPS tracking directly into the application. This option as well as the Google API option would limit the need for extra components, lowering the overall cost and power required to implement the HUD. Once the data from the API has been received, it would be sent over to the HUD device via bluetooth, limiting the amount of computation needed to measure distances between waypoints along the route.

## 7.3 Standalone GPS Module

The third option for GPS capabilities would be to add a standalone GPS unit into the HUD's design. The GPS module works by detecting multiple satellites in geosynchronous orbit and using their relative positions to triangulate its exact position on Earth. As our HUD device will be mounted around the windshield of the vehicle, the GPS module should be able to sync with the satellites without interference. Implementing a standalone GPS chip would add power draw to the system and increase the cost of the overall design. However, it would allow us to gain experience coding for extra components that we do not have experience with, as well as add complexity to our final PCB. Standalone GPS modules are readily available on the market.

Ublox NEO-6M GPS Module: The NEO-6 module interfaces directly with the Arduino's UART over the TX/RX pins located on the module itself. The module is available for purchase on Amazon from DIYMall with an integrated GPS antenna to synchronize with the signal from the GPS satellites.

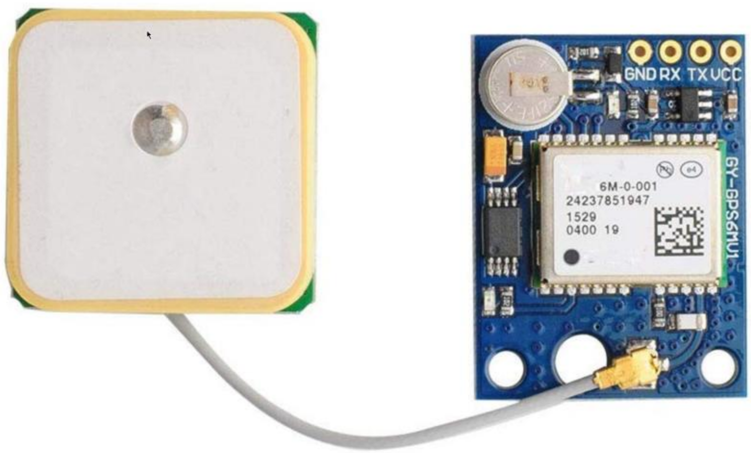



Figure 24: DIYmall GPS using u-blox NEO-6M GPS Module from Amazon

# 8.0 Communication:

The HUD must have a feasible way to communicate with a user's cell phone. This will allow crucial data to be transferred to and from the devices in order to maintain contact. Since the communication is to be with a user's cellphone, the protocol needs to be wireless. This means communication types such as serial and Ethernet are out of the picture. These methods, although very stable and well established in the tech development industry, will not work as running a wire through a car would be a safety hazard as well as unfeasible as most phones only have one port which is used for charging. If the device forced users to lose their one port to the HUD then it would not be a popular item in the slightest.

Fortunately, there are a lot of different types of wireless protocols available for different requirements. Popular protocols include Wi-Fi and Bluetooth, with lesser known ones such as ANT and ZigBee used for low power devices. The distance between master and slave, which is the user's phone and our device respectively, is going to be very small as it will be no larger than within a car. This allows us to choose a low power wireless protocol which fits our design best/

Based off of specifications listed below, this project will be optimal under the use of Bluetooth low energy.

## 8.1 Wireless Protocol Comparison

| Type | Voice | Data | Audio | Video | Low-Power |
|---|---|---|---|---|---|
| **Bluetooth ACL/HS** | X | Y | Y | X | X |
| **Bluetooth SCO/eSCO** | Y | X | X | X | X |
| **Bluetooth Low Energy** | X | X | X | X | Y |
| **Wi-Fi** | Y | Y | Y | Y | X |
| **Wi-Fi Direct** | Y | Y | Y | X | X |
| **ZigBee** | X | X | X | X | Y |
| **ANT** | X | X | X | X | Y |

Table 4: Wireless Protocol Comparison

Since the device will only need minimal communication between itself and the phone, characteristics such as audio and video streaming are not needed. The data column represents the ability to file transfer between one device and the other. Because the only real communication needed is packets to be sent over rather than whole multi megabyte files, the data column is not needed either.

ZigBee and ANT are good options with their own perks. ZigBee has a larger range than Bluetooth Low Energy (BLE), almost three times as much. ZigBee also supports multi node connections and is much more stable with multiple connections coming into it. Since this device only needs one node as a connection and distance is not an issue, BLE has 1/10 the power consumption and most importantly is compatible with Android and Apple operating systems which makes it perfect for device to smartphone connectivity.

ANT is ultra low power, so low that it can run off of a coin cell battery for years. The problem with ANT is that it is too low power with not enough features available for this project. ANT does not support operating systems ran on phones similarly to ZigBee and so the most logical choice is to use BLE. Below are some of the specifications for BLE.

## 8.2 Bluetooth Low Energy Specifications and Factsheet

| Technical specification | Bluetooth Low Energy technology |
|---|---|
| Distance/range (theoretical max.) | >100 m (>330 ft) |
| Over the air data rate | 125 kbit/s – 1 Mbit/s – 2 Mbit/s |
| Application throughput | 0.27-1.37 Mbit/s |
| Active slaves | Not defined; implementation dependent |
| Security | 128-bit AES in CCM mode and application layer user defined (2) |
| Robustness | Adaptive frequency hopping, Lazy Acknowledgement, 24-bit CRC, 32-bit Message Integrity Check |
| Connections | > 2 billion |
| Modulation | GFSK @ 2.4 GHz |

| | |
|---|---|
| Latency (from a non-connected state) | 6 ms |
| Minimum total time to send data (det. battery life) | 3 ms (3) |
| Voice capable | No |
| Network topology | Scatternet |
| Power consumption | 0.01–0.50 W (depending on use case) |
| Max current consumption | <15 mA |
| Service discovery | Yes |
| Profile concept | Yes |
| Modes | Broadcast, Connection, Event Data Models, Reads, Writes |
| Primary use cases | Mobile phones, gaming, smart homes, wearables, automotive, PCs, security, proximity, healthcare, sports & fitness, Industrial, etc. |

Table 5: BLE Specifications and Fact Sheet

## 8.3 Bluetooth Low Energy Architecture

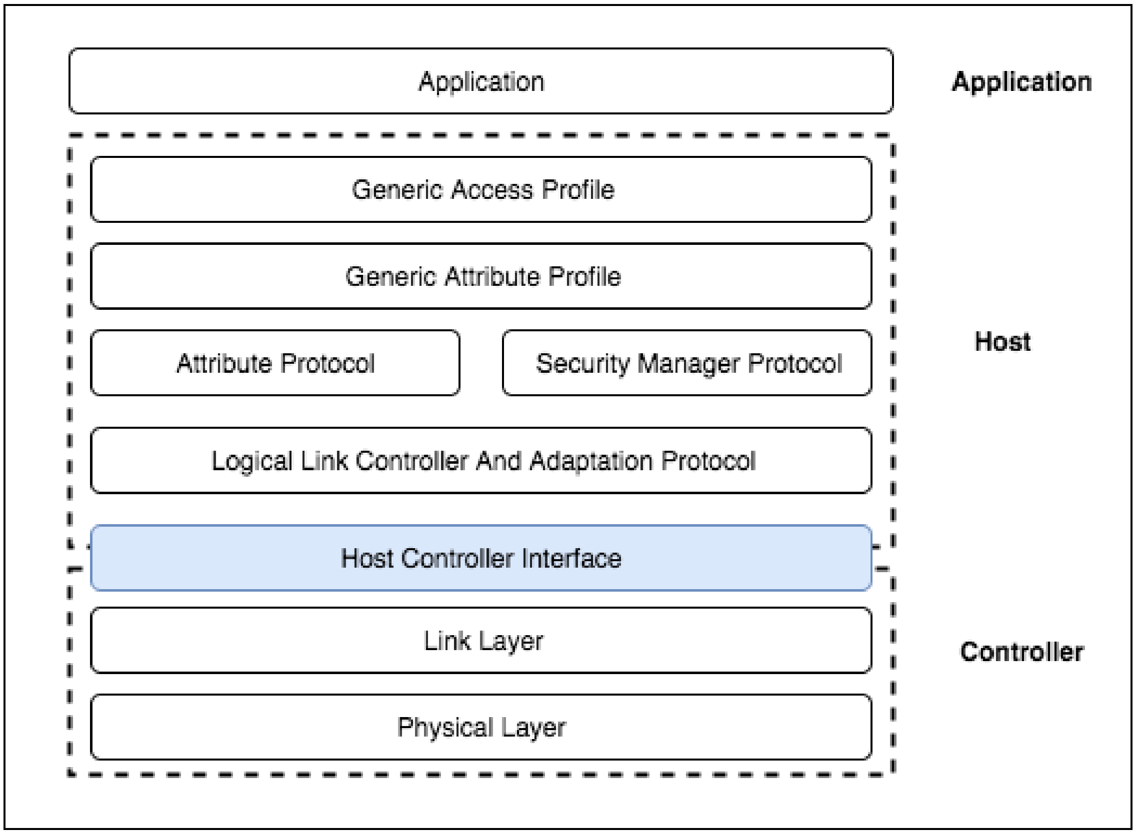



Figure 25: BLE Architecture

The physical layer (PHY) refers to the physical radio used for communication and for modulating/demodulating the data. It operates in the ISM band (2.4 GHz spectrum). This clock is standard for most wireless connectivity, even other protocols such as Wi-Fi use the 2.4 GHz spectrum.

The Link Layer is the layer that interfaces with the Physical Layer (Radio) and provides the higher levels an abstraction and a way to interact with the radio (through an intermediary level called the HCI layer which we'll discuss shortly). It is responsible for managing the state of the radio as well as the timing requirements for adhering to the Bluetooth Low Energy specification.

Direct Test Mode: the purpose of this mode is to test the operation of the radio at the physical level (such as transmission power, receiver sensitivity, etc.).

The Host Controller Interface (HCI) layer is a standard protocol defined by the Bluetooth specification that allows the Host layer to communicate with the Controller layer. These layers could exist on separate chips, or they could exist on the same chip.

The Logical Link Control and Adaptation Protocol (L2CAP) layer acts as a protocol multiplexing layer. It takes multiple protocols from the upper layers and places them in standard BLE packets that are passed down to the lower layers beneath it.

## 8.4 Bluetooth Packet Format

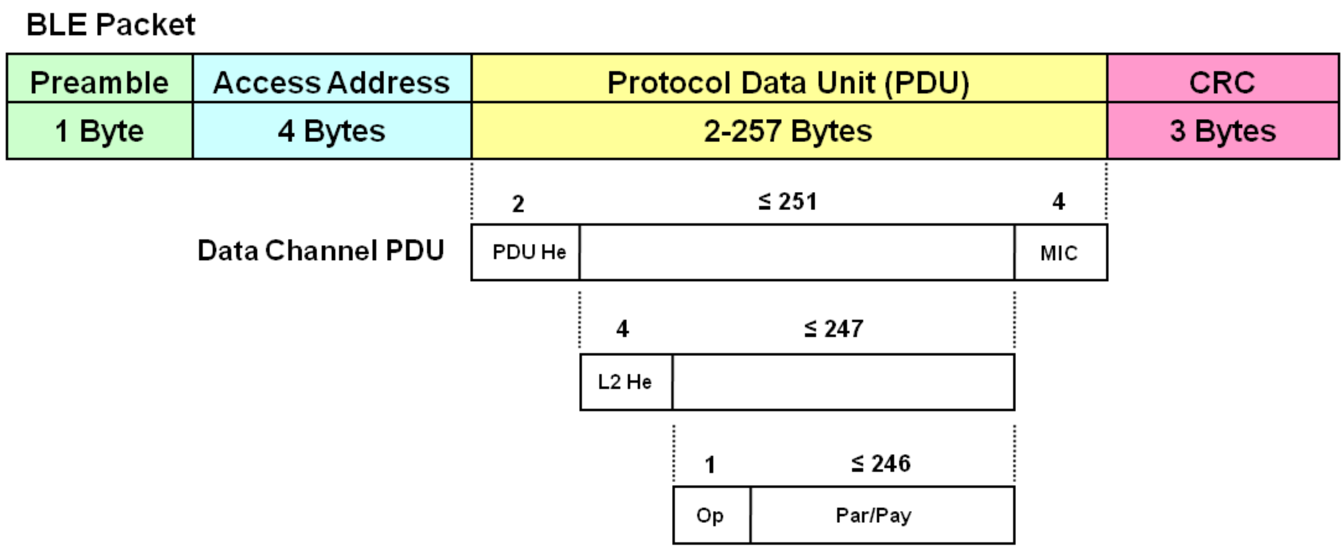



Figure 26: BLE Packet Format

Preamble: It is used by the BLE module for synchronization of time and frequency. The preamble also performs AGC (Automatic Gain Control). It is a predefined pattern of size 1 byte which is known to the receiver. Advertising packet use "10101010" in binary. Data packet use either "10101010" (if LSB of access address is 0) or "01010101" (if LSB of access address is 1) in binary form.

Access Address: For all advertising packet is uses fixed pattern "0x8E89BED6" in hexadecimal form with size of 4 octets. or 32 bits. This address is nicknamed “bed six” and is consistently the access address across every BLE module as part of a standard. For data packets it consists of a 32 bit random value generated by BLE device in "initiating state". The same value is used in a "connection request (CONNECT_REQ)" message.

PDU: It consists of either "advertising channel PDU" or "data channel PDU" as defined in the figure. The advertising channel 0000 (ADV_IND) will be the primary mode used for this project.

| PDU Type | Packet Name | Description |
|---|---|---|
| 0000 | ADV_IND | Connectable undirected advertising event |
| 0010 | ADV_NONCONN_IND | Non-connectable undirected advertising event |
| 0110 | ADV_SCAN_IND | Scannable undirected advertising event |

Table 6: PDU Packets

CRC: It is 24 bit in size. It is calculated over PDU. It is used for error detection of the packet. CRC is calculated using polynomial of the form $x^{24} + x^{10} + x^9 + x^6 + x^4 + x^3 + x + 1$.

This in total allows a packet to have a size of 265 bytes. The fastest a packet can be sent from a BLE module is 7.5 milliseconds. This allows an extremely fast transfer rate, however for consistency sake and for timing, we will send packets at a slower rate.

## 8.5 Bluetooth Module Specifications

32-bit ARM® Cortex™ M4F CPU
Supply: 1.7V – 5.5V
Flexible and configurable 48 GPIO
Bluetooth 5, IEEE 802.15.4, 2.4 GHz transceiver
• -95dBm sensitivity in 1Mbps Bluetooth low energy (BLE) mode
• -103dBm sensitivity in 125Kbps BLE mode (long range)
• +8 dBm TX power (down to -20 dBm in 4 dB steps)
• On-air compatible with nRF52, nRF51, nRF24L and nRF24AP Series
    • Programmable output power from +8dBm to -20dB
    • RSSI (1dB resolution)･Supported data rates:

Bluetooth 5: 2Mbps, 1 Mbps, 500 kbps, 125 kbps

IEEE 802.15.4-2006: 250 kbps
Proprietary 2.4 GHz: 2 Mbps, 1 Mbps
Advanced on-chip interfaces
• USB 2.0 full speed (12Mbps) controller
• QSPI 32MHz interface
• High speed 32MHz SPI
• Type 2 near field communication (NFC-A) tag with wake-on field▪Programmable peripheral interconnect (PPI)
• EasyDMA automated data transfer without CPU processing on peripherals▪12 bit, 200ksps ADC – 8 configurable channels with programmable gain
• 4 x 4 channel pulse width modulator (PWM)units with EasyDMA
• 5 X 32-bit timers with counter mode
• Up to 4 x SPI masters / 3 x SPI slaves with EasyDMA
• Up to 2 x I2C compatible 2-wire masters / slaves
• 2 x UART(CTS/RTS) with EasyDMA
• Quadrature decoder (QDEC)
• 3 x 24-bit real-time counters (RTC)
Operating Temp: -40°C to +85°C


Figure 27: nRF52840
Bluetooth Low Energy
module (9)

The voltage of this module fits within the requirement of our supply as we are using 5V. The USB serial allows easy debugging and configuration. The speed of the CPU and transceiver are both standard and fast enough to meet the requirements for the HUD.

## 8.6 Prototyping and Testing

The Bluetooth communication is tested using RSSI readings and serial monitor. Using a free smartphone application, we can determine RSSI commands that will verify an established Bluetooth connection.  A signal strength of -30dBm or more is considered according metageek documentation and will be used as a reference to determine the HUD’s  communication signal strength.

To check the validity of data, a serial monitor on Arduino IDE along with a Command Line prompt can be  used. The data bytes transmitted are ASCII characters and because

ASCII is a global standard, it makes deciphering the code easier. A good software test will be to run a loop that transmits packets continuously and the receiving end sends an acknowledgement in return to validate that the data has been received. A counter should be incremented every time a packet is received and sent to track the number of packets exchanged and test if any packets were lost during transmission. If a packet is lost, debugging begins to see if the issues are due to RF or digital portions.

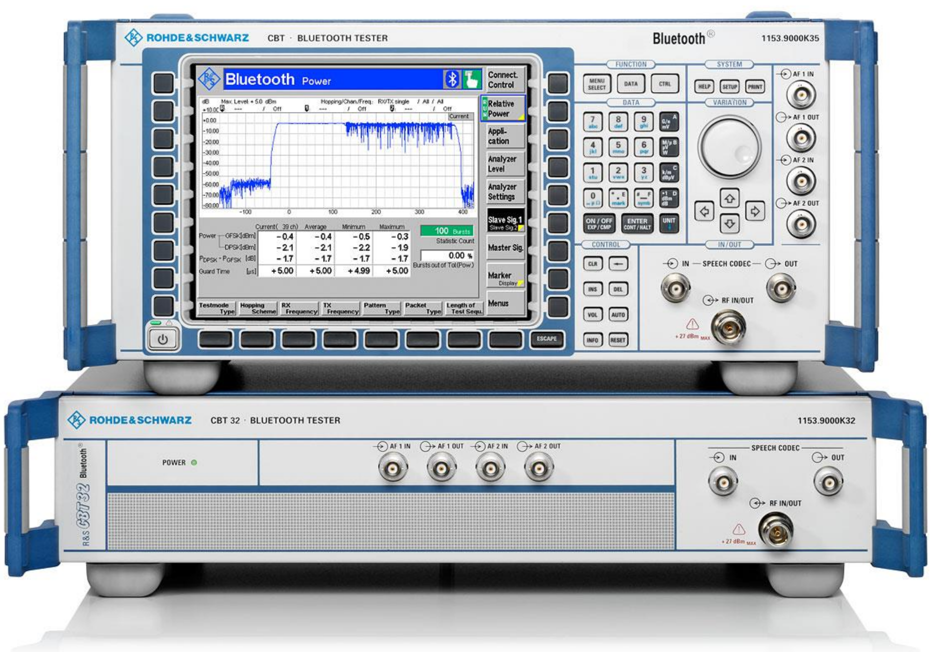



Figure 28: Oscilloscope

Above is an oscilloscope specialized for testing Bluetooth RF frequencies. Although this hardware is not available to us, a regular oscilloscope will be more than sufficient for testing as the specification sheet provides us all the expected values needed to be read.

## 8.7 Communication tests

When packets are sent over from the device to the phone and vice versa, we must confirm that the data being sent over are not garbage values and that packets do not overlap each other. This is done through multiple ways. First we confirm the validity through RSSI, or “Received Signal Strength Indicator,” which is one of two ways to confirm the packet. The second is through measurement of the RF signal. Because Bluetooth is a radio frequency based technology, an oscilloscope is used to measure the signal is dBm.

There exists free applications on the Apple AppStore that allows testing of Bluetooth devices in order to gain knowledge of what hex values are being sent. One of these applications is called LightBlue.

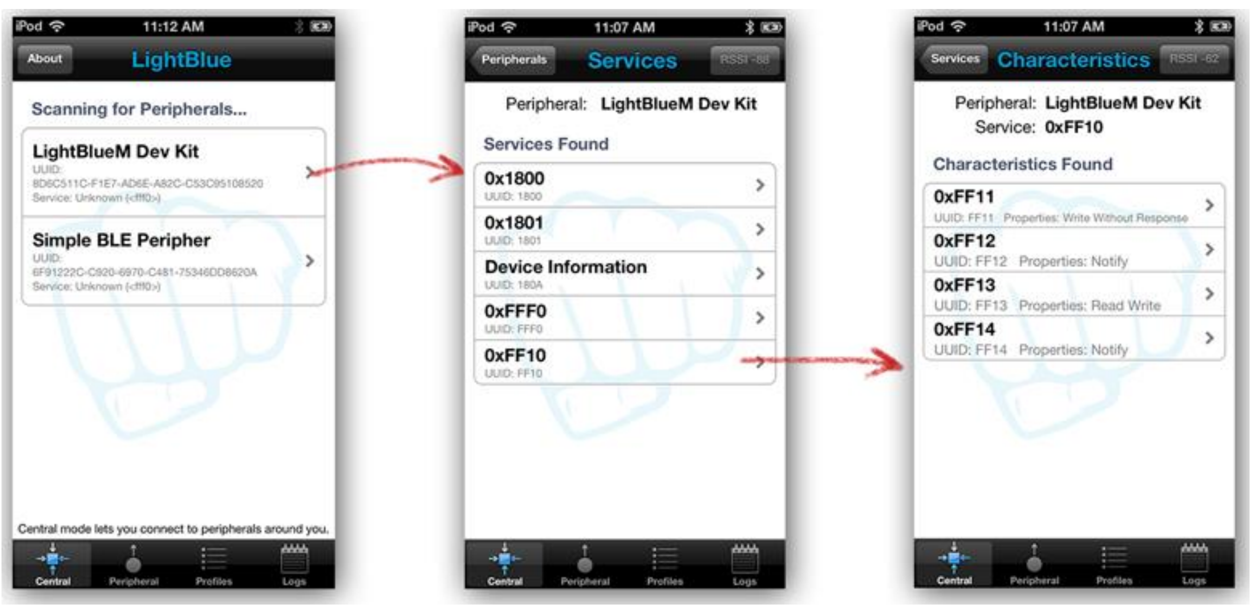


Figure 29: LightBlue App

The HUD’s BLE will be configured as a peripheral that has data the phone, the central, needs. With this application, we can send packets with a delay as low as 50 milliseconds and as long as 2 seconds. The data on Peripherals are organized according to their respective Profile. This profile contains a variety of services and characteristics. Characteristics are the holders of data, and can be accessed in 3 ways- Read, Write, and Notify. With these three types of data manipulation, we can fully test out the BLE module on a high level and make sure that distance is not a problem as well as any kind of interference.

Within the application we can find addresses to read and write to. In the figure above we can see their example has an address that starts at 0xFF10, and from there they can look at nearby addresses and determine what type of address it is. This way we can access data values such as RAM.

## 8.8 Packet Sniffing for Testing Both Nodes

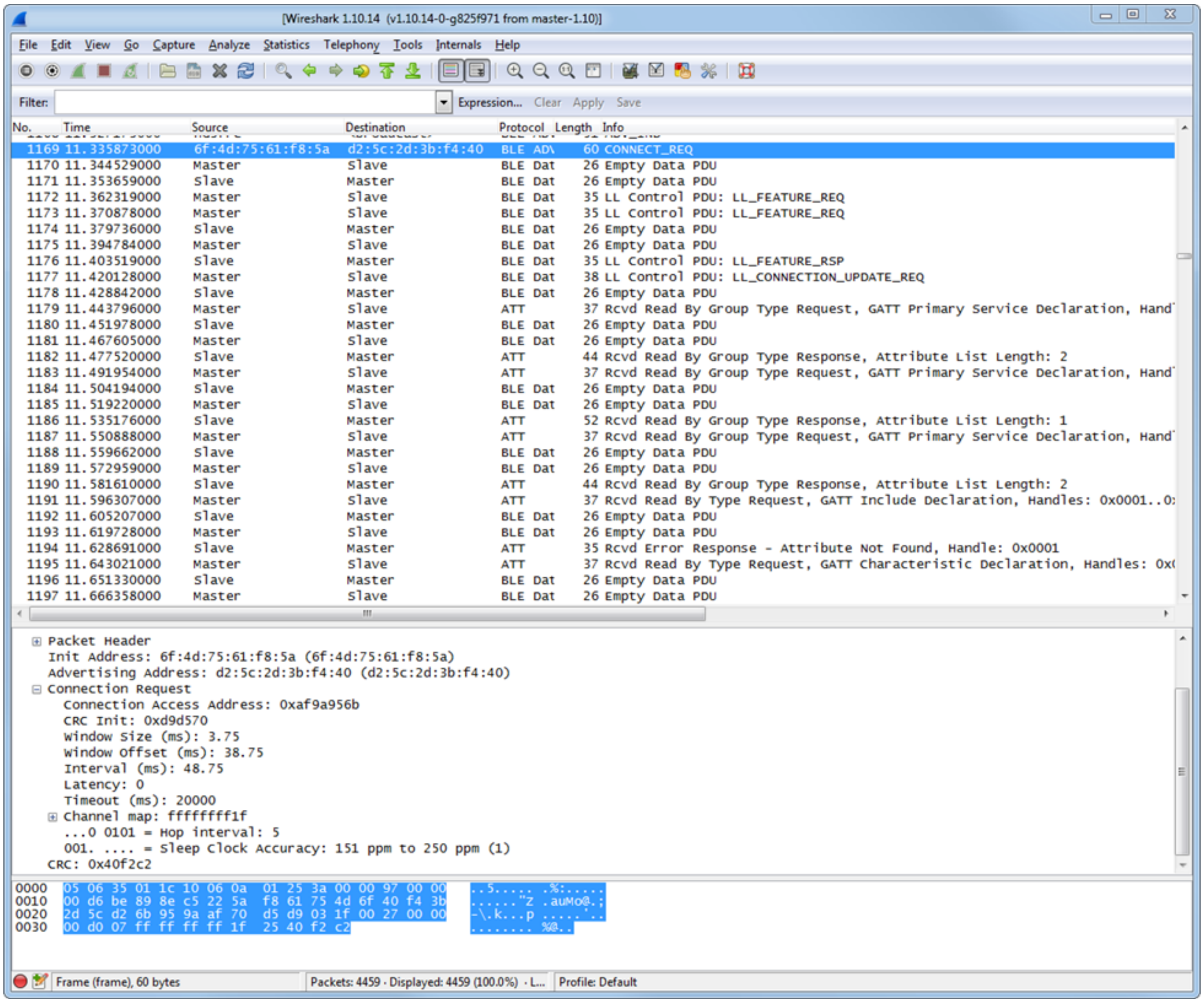



Figure 30: Wireshark [10]

This sniffer uses a Nordic evaluation board with special firmware programmed to the device. The nRF52840 captures the BLE packets, adds time, RSSI, and other metadata, and forwards them to Wireshark. The advantage here is that Wireshark is an industry standard tool that allows anyone to view your information. Wireshark is a free and open-source packet analyzer available for Android devices. Having software to check packets on both Android and iOS operating systems allows us to test on two of the most common smartphone operating systems on the market today. LightBlue and Wireshark will provide all the Bluetooth packet testing needed once the RF portions are confirmed to be operational and stable.

### 8.9.1 Packet Sniffing with WireShark

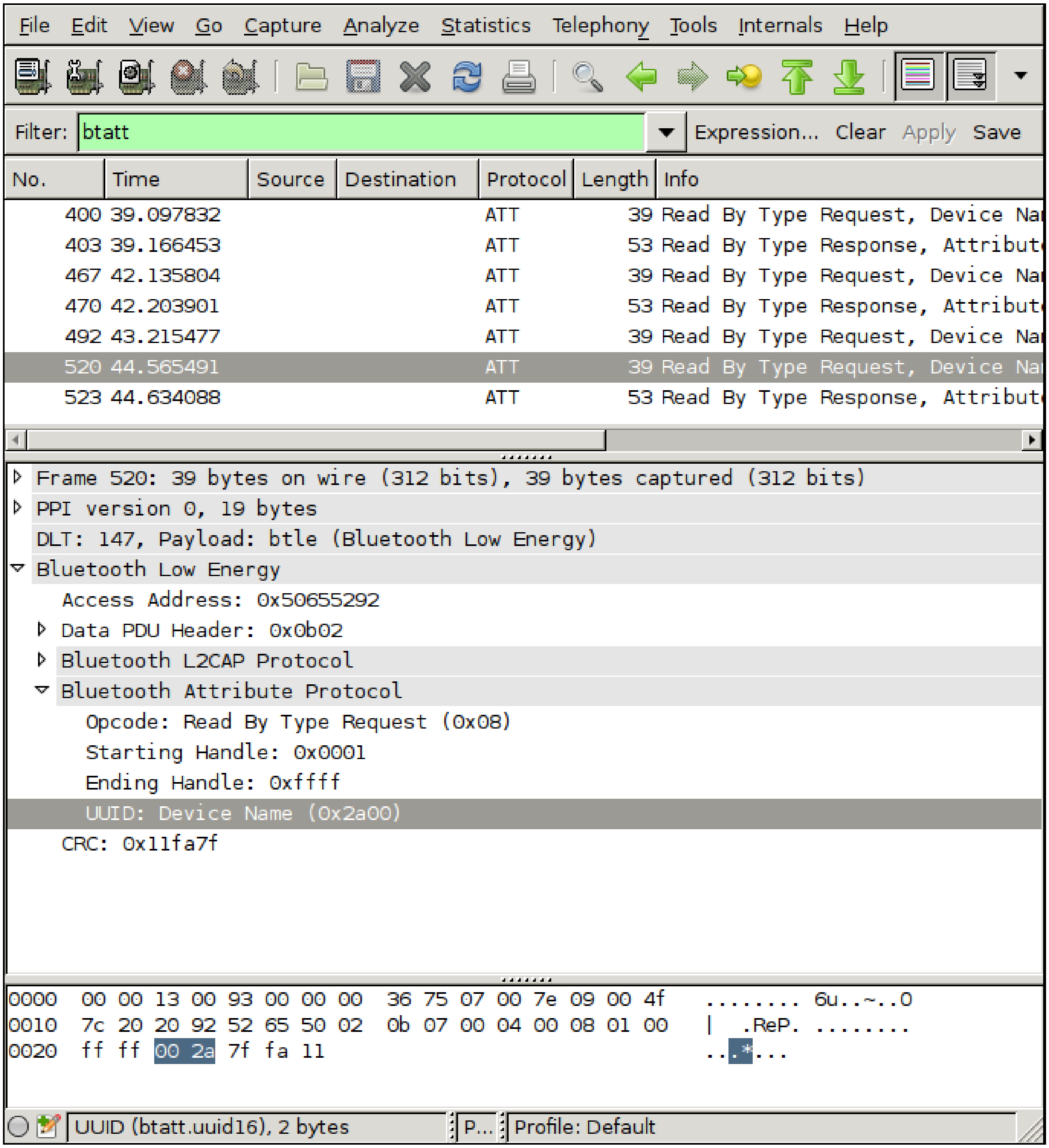



Figure 31: Wireshark Example 1 [12]

This is an example of what bluetooth traffic is formatted like when testing packets for sending and receiving. This excerpt is taken from the command prompt portion of

WireShark. Important information to take note of is the access address value, the attribute protocol that tells what the packet's characteristics are, as well as Opcode that says whether it is a packet being sent or received. The example above is a request from the computer to the BLE module asking for what the device name is. In the bottom where "00 2a" is highlighted, this is the portion that is being sent and specifically asks for the device name. When translated out of hex, it represents ".*" which does not mean anything to us but to the device, its recognized at requesting the name.

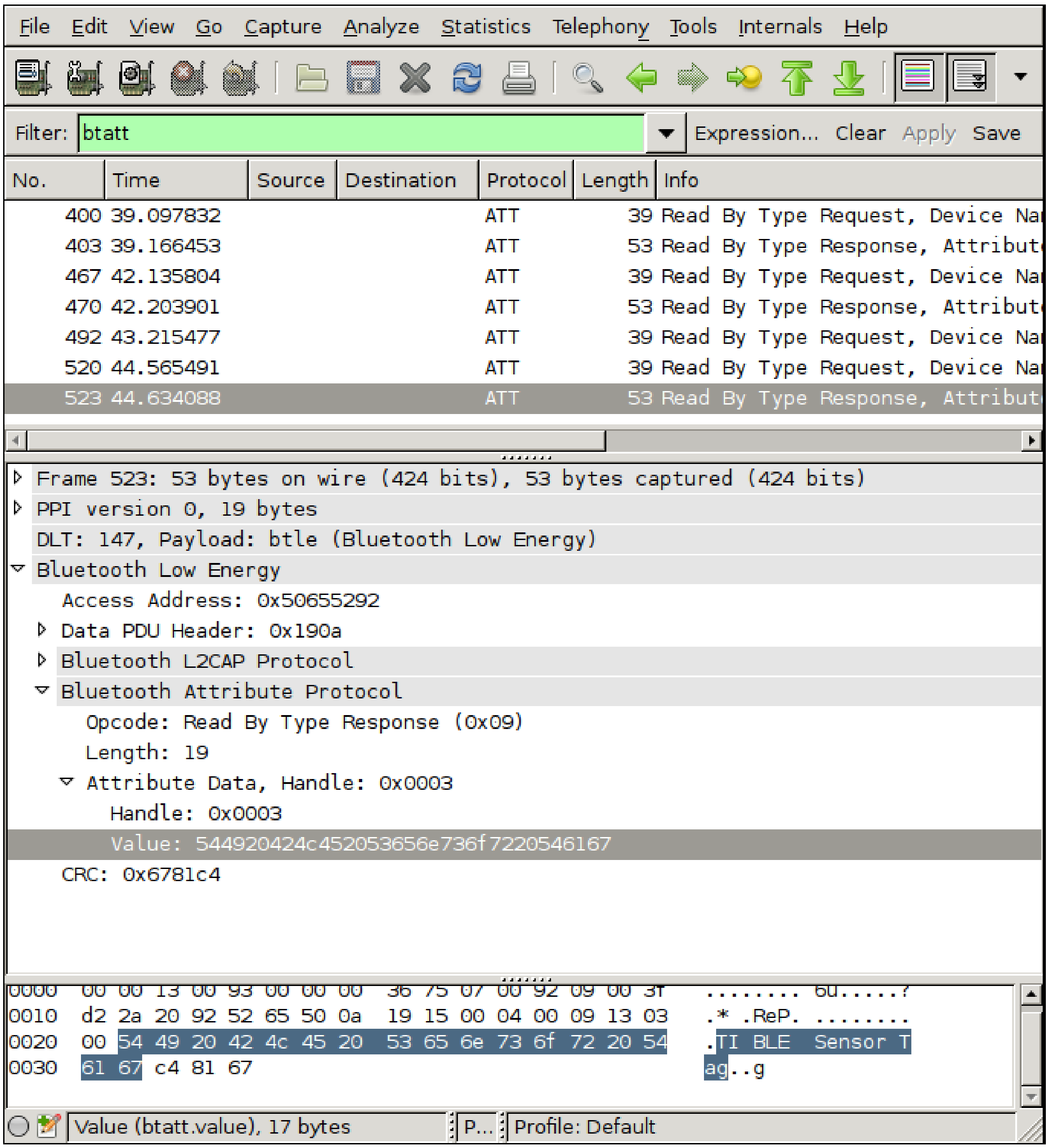



Figure 32: Wireshark Example 2 [12]

This next excerpt shows a packet received from the Bluetooth module in response to the packet sent above. The access address of the BLE is not surprisingly the same as all communication is based off that address. The response is in hexadecimal which is highlighted above. Wireshark lists that the total length of the packet as 19. When the hexadecimal string is translated, it reads “TI BLE Sensor Tag” which is the name of the TI CC2540 that is used in this example. These two screenshots show that Wireshark is very powerful, handy, and fits our needs perfectly.

# 9.0 Crash Detection:

This senior project was determined with increasing driver safety and awareness as a priority. The HUD will allow us to reduce distractions and prevent accidents caused by distracted driving. However, accidents can happen at any moment. In the event that an accident were to occur, response time is paramount to ensuring those involved are given the care they need. In addition to reduced distraction, we would like to add a crash detection system to our design.

## 9.1 Accelerometer

Vehicular crashes are often paired with impacts that produce strong and abrupt forces. These forces can be detected using an accelerometer to analyze the gravity relative to the position of the sensor. When a change in force occurs, the sensors on the accelerometer report the differences as data points and the microprocessor can determine if the impact is enough to constitute a crash.

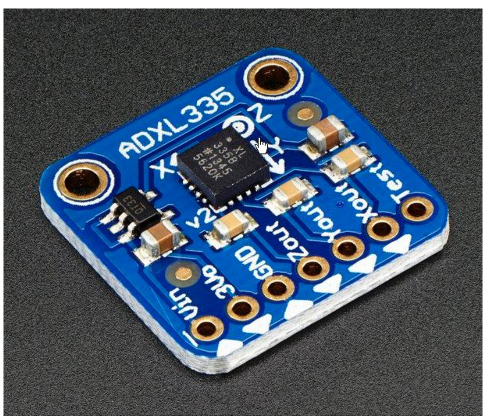



Figure 33Figure X: Adafruit ADXL335 Accelerometer

The Adafruit ADXL335 Accelerometer is a triple-axis accelerometer that comes with pinouts for x,y, and z axis measurements. It has an onboard voltage regulator that steps down 5V to the 3.3V required to power the accelerometer. The ADXL335's datasheet states that the chip can withstand forces up to 10,000g's, which is well within the impact forces we would expect from the typical car crash.

Once the accelerometer detects an impact, the HUD device will send a command to an SMS module located on the chip. The SMS chip will send a text message containing the device's current location and details about the crash to an emergency contact programmed by the user.

## 9.2 GPS Module

The SIM800L SMS module provides us with the ability to transmit and receive SMS text messages over a cellular network using a SIM card. The pinouts on the board can be attached to the HUD device to send out the GPS coordinates to the emergency contact following a detected crash.


Figure 34: SIM800L SMS GSM Module Board

# 10.0 Microcontroller:

The HUD device will need to receive data from the GPS module multiple times per second and calculate the distance between the received data and the waypoints along the route. This requires processing power and storage to manipulate and store the calculations. Once these calculations are complete, the display will need to be updated to reflect the most current information to the driver.

As we began to research microcontrollers needed to handle all the information from the GPS module, APIs, SMS module, and drive the display unit, it became apparent that a powerful microcontroller would be needed to provide the driver with the best user experience. The microcontroller has to have UART communication to interface with all of our modules. There is a common thread in projects that implement similar designs, a majority of them use Arduino or TI MSP based microprocessors. Upon researching Arduino and TI microprocessors, there are two that stood out. A comparison of these microcontrollers are listed in the following table.

| **Microcontroller** | MSP430F447 | Arduino ATmega 2560 |
|---|---|---|
| **Price ($)** | 8.50 | 38.50 |
| **Processor Speed** | 16 MHz | 16 MHz |
| **Data Bus Bandwidth** | 16-bit | 8-bit |
| **RAM** | 1 KB | 8 KB |
| **Flash Memory** | 32KB + 256B | 256 KB |
| **UART Channels** | 3 | 4 |
| **I/O Pins** | 48 | 54 |
| **Operating Temperature** | -45 C to 85 C | -40 C to 85 C |
| **Operating Voltage** | 1.8 V to 3.6 V | 5 V |
| **Special Features** | Integrated LCD Controller | Open Source |

Table 7: MSP430 and Arduino Comparison

## 10.1 Texas Instruments MSP430F447

The Texas Instruments MSP430F447 is unique as it has it's own integrated LCD controller. This would prove useful when driving the Heads-Up Display unit. A segment of the microprocessor would solely be devoted to this display, eliminating the need for the whole processor to calculate the updates to the display a few times per second. This would free up used memory, power, and allow the microprocessor to do calculations on other components and tasks.

## 10.2 Arduino ATMega 2560

The Arduino ATMega 2560 seems to be the most likely candidate for what we would implement into our project. The hardware for the Arduino Mega is open source, allowing us to create our own implementation of the microprocessor without infringing on copyrighted or patented designs. Additionally, Arduino's are well known for their flexibility and portability for projects containing embedded design similar to our project narrative. To abide by the regulations set by the College of Engineering and Computer Science, the development board for the Arduino Mega 2560 would only be used for design and testing. Our custom PCB will be designed to contain the Mega 2560 and all of it's components required to operate correctly and efficiently.

# 11.0 Budget:

To implement this project, we will need to research and obtain materials that will meet our specifications in order to produce an effective heads-up display device. We will need a PCB, a power delivery system, microprocessors, LEDs, soldering equipment, a bluetooth module, and a speaker. At this point, we have not obtained funding or sponsorships for anything involved with this project. As such, the group will be self-funded and will split the cost required to complete the device. To implement navigational aids, we may have to acquire a license to access the Google Maps APIs. This is something that will be researched to determine if this cost is realistic.
We have determined that a rough estimate of $300 will be enough to completely implement the project.

| Item | Description | Price($) |
|---|---|---|
| PCB | Implement all hardware needed onto PCB | 40 |
| Display Unit | Display information to driver on windshield | ~102 |

| | | |
|---|---|---|
| Power Delivery System | Provides power to system | ~45 |
| Microprocessor | Processes data and sends to display unit | 38.50 |
| LEDs | Show power states and pertinent information | ~5 |
| Soldering Equipment | Needed to implement electrical components | Free if borrowed from school |
| Bluetooth Module | Receive data from phone over bluetooth connection | 15 |
| Oscilloscope | Allows testing of RF portions as well as Voltage differences | Free if borrowed from school |
| Speaker | Play recorded sounds in specific situations | ~9.90 |
| Mobile Smartphone | Needed to host custom Application | N/A |
| GPS Module | Feed location data to system | 16.04 |

Table 8: Budget

# 12.0 Block Diagram:

The following is a block diagram for the Heads-Up Display Device, detailing each component required to implement its design, as well as each team member assigned to the implementation of the component.

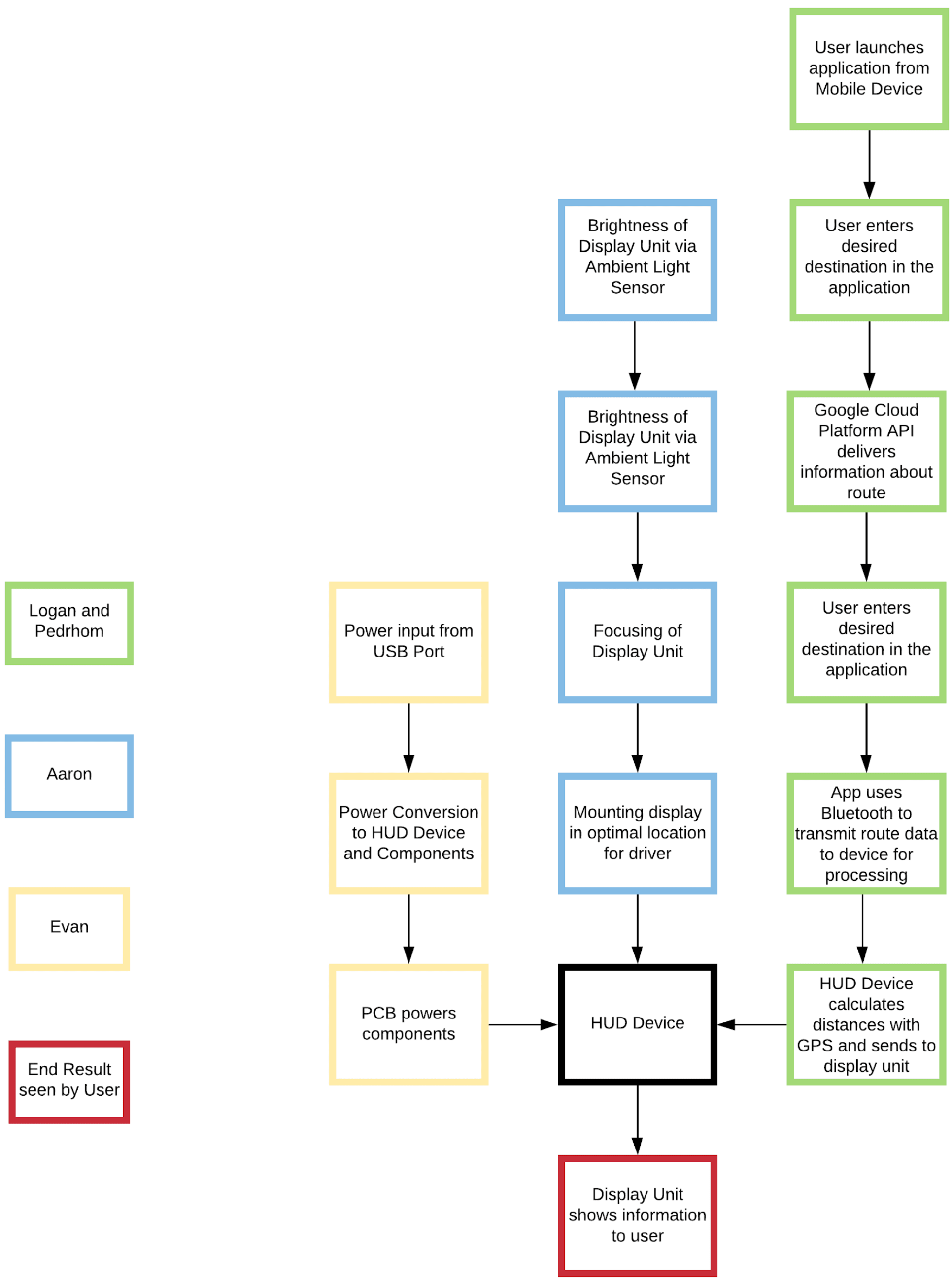



Figure 35: Block Diagram

The user will use an application to enter their desired destination. That destination will be uploaded and a route will be calculated. The application will send this data to the device to be processed. After the device receives the data, it will compare the user's GPS locaton with the route data. It will then display out to the user. This will be designed and implemented by Pedrhom Nafisi and Logan Glowth. The Electrical and PCB Design will be done by Evan Hall. The LCD Display and mounting system will be implemented by Aaron Majdali. Each member of the team has specialized knowledge for their given assignments, but will be available to help in other blocks as necessary.

# 13.0 Tools

Implementing a project of this scale becomes much easier and more efficient with the aid of tools at our disposal. The College of Engineering and Computer Science provides a myriad of resources to assist with the design and implementation of the Senior Design project. The following section is devoted to the tools our team will take advantage of throughout the course of Senior Design.

## 13.1 Communication

Clear channels of communication play a pivotal role in staying organized and maintaining the set schedule. The team will be utilizing a few different communication tools to ensure the project stays on track and is completed within the given timeline.

### 13.1.1 Discord:

Discord is a free VoIP application that provides the ability for users to talk, video call, chat, share files, screen share, and much more. Many of us already use Discord as a primary communication platform. Discord contains the functionality needed to archive group discussions in the event that referencing them is needed. This will be the preferred communication platform moving forward

### 13.1.2 Text Messaging:

Text messaging has been the group's initial form of communication since the beginning of Senior Design I. Sharing content across MMS is difficult as it compresses images and video to the point that it is not very usable. We will be shifting to utilize Discord moving forward.

## 13.2 File Preservation

Technology is not perfect and accidents happen. In an event where a computer crashes and data is lost, we want to ensure all of our hard work is backed up and protected. We will be utilizing Google Drive to store all of the documents and related materials to the project. Google Drive is free and provides us with enough storage to preserve all of our data.

## 13.3 Other Software

### 13.3.1 LucidChart:

LucidChart is a web-based application that allows users to collaborate in creating charts, diagrams, and other related tools. Some of the figures in this document were created using LucidChart. LucidChart is a paid service, but provides student licenses to users that apply with their University's domain email address.

## 14.0 Conclusion

Over the next two semesters, we will research, design, and build a Heads-Up display for a vehicle. The Heads-Up Display will be designed to increase driver awareness and safety when driving. Information will be displayed to the driver in a fashion that will not impede with the driver's view. The application we will create will allow the driver to choose a destination. The device will contact the Google Maps API and provide an efficient route to the destination. The device will then calculate the driver's current location using the attached GPS module and compare this location to waypoints along the route. The display unit will provide the user with a visual representation of the route and guide them to the destination with turn-by-turn directions.

The device is designed to reduce the likelihood for a driver to be distracted while driving. However, there is always the possibility for other drivers to be distracted. In the event that a crash occurs, we will have an impact detection system that will trigger when a strong or sudden impact is registered. This system will send an automated SMS text message to the user's designated emergency contact with information regarding the user's last reported location at the time of the impact. We hope to facilitate the ability for those impacted by the crash to get the help they need as soon as possible.

The device mentioned above will be designed and realized utilizing the knowledge that each member of the team has accumulated throughout their time at the University of Central Florida. We hope that this device will provide us with challenging and exciting design decisions, while promoting a positive effect on our community by producing a project focused on increased safety and awareness.

# 15.0 References:

*Note: Images used throughout this document are pending approval for use. They are the creations of their rightful owners and are subject to change to abide by the copyright regulations and the wishes of the image creators.*


[1] IEEE 802.15.1, IEEE, 2005.

[2] “Bluetooth 5 & BLE: Achieving maximum throughput”, 2017. [Online]. Available: https://www.novelbits.io/bluetooth-5-speed-maximum-throughput/ [Accessed 27/10/2019]

[3] “Bluetooth Low Energy Technology - Technical Information", 2014. [Online]. Available: https://web.archive.org/web/20140214120404/http://www.bluetooth.com/Pages/low-energy-tech-info.aspx

[4] https://californiaconsultants.org/wp-content/uploads/2014/05/CNSV-1205-Decuir.pdf

“Digital Micromirror Device.” *Wikipedia*, Wikimedia Foundation, 29 July 2019, https://en.wikipedia.org/wiki/Digital_micromirror_device

“DLP Products – Getting Started.” *DLP Getting Started* | *DLP Products* | *TI.com*, http://www.ti.com/dlp-chip/getting-started.html.

“U Drive. U Text. U Pay.” *NHTSA*, 8 May 2019, https://www.nhtsa.gov/risky-driving/distracted-driving.

[4] “Transport Canada Guidelines to Limit Distraction from Visual Displays in Vehicles.” *Transport Canada*, Government of Canada, 27 February 2019, https://www.tc.gc.ca/en/services/road/stay-safe-when-driving/guidelines-limit-distraction-visual-displays-vehicles.html

USB Micro-B Breakout Board Product ID: 1833. Digital image. https://www.adafruit.com/product/1833?gclid=Cj0KCQjw6eTtBRDdARIsANZWjYbPv2PNecbHn-w0ufd4guBG1Gbflosh96IIN8Usan008xAM-ppynC4aAiOUEALw_wcB

BOB-12035. Digital image. https://www.digikey.com/product-detail/en/sparkfun-electronics/BOB-12035/1568-1194-ND/5673780

2174507-2. Digital image. https://www.te.com/usa-en/product-2174507-2.html?te_bu=Cor&te_type=srch&te_campaign=ggl_usa_cor-ggl-usa-srch-selectmktg-fy20-genpl_sma-

1176_1&elqCampaignId=82989&mkwid=s%7Cpcrid%7C379682292390%7Cpkw%7C2174507-2%7Cpmt%7Ce%7Cpdv%7Cc%7Cslid%7C%7C%7C%7Cpgrid%7C77094862456%7Cptaid%7Caud-428581635047:kwd-303524422505%7C&gclid=Cj0KCQjw6eTtBRDdARIsANZWjYYUoTOlqH_kF4HvT1HfXuOvi64KU3XV9RP9IhCDD7UyvA6FJD83xxYaAkuaEALw_wcB

Texas Instruments. *TPS6122x Low Input Voltage, 0.7V Boost Converter With 5.5μA Quiescent Current.* PDF. October 12, 2019

Super XL6009 DC-DC Adjustable Step-up Boost Power Converter. Digital image. https://www.amazon.com/XL6009-Adjustable-Step-up-Converter-Module/dp/B01FDEWS7U/ref=asc_df_B01FDEWS7U/?tag=hyprod-20&linkCode=df0&hvadid=167146065113&hvpos=1o1&hvnetw=g&hvrand=13668942640763954150&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9057291&hvtargid=aud-798931705416:pla-304542141486&psc=1

Linear Technologies. *LT1613 1.4MHz, Single Cell DC/DC Converter in 5-Lead SOT-23.* PDF. October 15, 2019

Texas Instruments. *LM1577/LM2577 SIMPLE SWITCHER® Step-Up Voltage Regulator.* PDF. October 15, 2019

TO220 Bolt On Heatsink. Digital image. http://www.reuk.co.uk/wordpress/electronics-and-electricity/buy-to220-bolt-on-heatsink/

Adafruit ALS-PT19 Analog Light Sensor Breakout. Digital image. https://www.adafruit.com/product/2748?gclid=Cj0KCQjw6eTtBRDdARIsANZWjYbF6W_jP3p3-3inJj6vZAhEjTdL001FtJpAdnoUMf2bSY44IGcK_ykaAgJkEALw_wcB

Idea for Mounting. Digital Image. https://www.skrten.com/products/skrten-navigation-hud-display

[6] White, Ian. *The History of Air Intercept Radar & the British Nightfighter.* Pen & Sword, 2007.

[7] Kim, John. *Rupture of the Virtual*. DeWitt Wallace Library, Macalester College, 2016.

[8] Previc, Fred and Ercoline, William. *Spatial Disorientation in Aviation*. AIAA, 2004.

ublox. *NEO-6: u-blox 6 GPS Modules Data Sheet.* PDF. October 30, 2019.

[9] https://www.adafruit.com/product/4078

[10] https://www.argenox.com/library/bluetooth-low-energy/ultimate-guide-to-debugging-bluetooth-smart-ble-products/

[11] https://www.extremetech.com/computing/115251-how-usb-charging-works-or-how-to-avoid-blowing-up-your-smartphone