

Embedded Senior Project Report

Zak Rowland

Oregon Institute of Technology – Winter 2021



Author Notes:

Submitted in partial fulfillment of the requirements of Embedded Senior Project

(CST 472)

© 2021 Zak Rowland

Revision History			
<u>Revision</u>	<u>Date</u>	<u>Reason</u>	<u>Name</u>
1.0	November 19 th , 2020	Published draft	Zak Rowland
1.1	December 6 th , 2020	Revised draft and published Fall term report	Zak Rowland
2.0	January 31 st , 2021	Revised Fall term report and published draft	Zak Rowland
2.1	February 1 st , 2021	Revised Winter term report and published draft	Zak Rowland
2.2	February 16 th , 2021	Revised Winter term report and published draft	Zak Rowland

Abstract

The project is a Bluetooth diagnostic tool that interfaces with the OBD-II port in a modern vehicle. This system will consist of two major modules: the Bluetooth transceiver module that interfaces with the port, and the handheld module that includes a computer, Bluetooth transceiver, touchscreen, and rechargeable battery. Features of the system will be limited to the essentials to keep operation simple and costs low. The user will be able to read a list of diagnostic (trouble) codes and their descriptions as well as clear the codes. There will be another mode that will read sensor data and display it to the user including speed, oil pressure, and coolant temperature. A simple user interface will utilize touchscreen input for actions like selection, scrolling up and down, and changing modes or settings.

Table of Contents

Revision History.....	2
Abstract.....	3
Table of Contents	4
Project Management.....	6
Schedule.....	6
Estimated Non-Recurring Engineering Costs.....	7
Estimated Production Costs.....	8
Change Management Procedures	9
Status Reports	9
Skills and Knowledge Areas	9
Conceptual Overview.....	9
Introduction	9
Problem Statement.....	10
Intended Audience.....	10
Proposed Project	10
Relation of Proposed System to Existing Systems.....	11
Deliverables	14
System Description.....	15

System Block Diagram	15
System General Description	15
Major Subsystems	16
Hardware Platform Description	16
Software Platform Description	16
Component Comparison and Selection	17
Computer for Handheld Unit	17
OBD-II to UART Interpreter	19
Bluetooth Transceiver	20
Fall Term Progress, Problems, and Discussion	20
Winter Term Progress, Problems, and Discussion	30
Requirements	46
Glossary	49
Appendix A	50
Appendix B	51
References	52

Project Management

Schedule

Trello is the software used to schedule and manage progress on the project. The board is divided into five sections: Fall, Winter, Spring, In Progress, and Done, and each term has its own color to differentiate tasks in the In Progress and Done lists. If a task has multiple parts, a checklist can be added underneath the main task. The Trello board can be seen in Figure 1 below.



Figure 1. A screenshot of the [Trello](#) board used to track progress on the project [1].

Each task has a set due date to create a timeline and ensure progress is consistent. As seen in Figure 1 above, tasks marked complete turn green and tasks that are overdue turn red. Although simple, this makes it a bit more rewarding to finish a task and helps signify the urgency of completing overdue ones.

Estimated Non-Recurring Engineering Costs

<u>Description</u>	<u>Cost</u>	<u>Total</u>
Entry level computer engineer salary	\$70,000	9-months for \$52,500
(2) Breadboards	\$2.50 each	\$5.00
5V/3A+ USB-C power supply	\$10.00	\$10.00
Multimeter (Fluke 117)	\$180.00	\$180.00
Oscilloscope (Rigol DS1054Z)	\$349.00	\$349.00
Micro HDMI to HDMI cable	\$9.00	\$9.00
VSSOP-8 to DIP-8 adapter	\$3.19	\$3.19
SOT-223 to DIP-6 adapter	\$2.69	\$2.69
15V/1.5A wall power supply	\$1.99	\$1.99
		\$53,060.87

Table 1. Estimated non-recurring engineering costs.

Estimated Production Costs

<u>Description</u>	<u>Cost</u>	<u>Total</u>
Raspberry Pi 4 Model B 2GB	\$35.00	\$35.00
ELM Electronics ELM327 IC	\$16.00	\$16.00
OSOYOO 5" DSI display	\$43.88	\$43.88
Samsung 32GB MicroSD card	\$7.99	\$7.99
ESP32-DevKitC-32D microcontroller	\$9.99	\$9.99
MCP2551 CAN transceiver	\$1.09	\$1.09
4MHz crystal oscillator	\$0.50	\$0.50
L7805 regulator	\$0.50	\$0.50
317L regulator	\$1.00	\$1.00
TXB0102 logic level converter	\$0.71	\$0.71
Male J1962 Type A connector	\$2.00	\$2.00
MakerFocus Battery Pack/UPS for Pi	\$23.99	\$23.99
Momentary switch with LED	\$1.95	\$1.95
MCP3002 ADC	\$1.79	\$1.79
Assorted resistors	\$3.00	\$3.00
Assorted capacitors	\$3.00	\$3.00
Assorted diodes	\$2.00	\$2.00
Assorted transistors	\$4.00	\$4.00
		\$158.39

Table 2. Estimated production costs.

Change Management Procedures

If a change must happen in the requirements or design of the system, engineering change requests will be submitted to the project supervisor as well as a memo including information on why the change is needed, what the change is, and what the alternatives are.

Status Reports

The status of the project will be updated to management or the customer with memos, demonstrations, or meetings.

Skills and Knowledge Areas

This project will require knowledge of many hardware components and protocols. Information about the OBD-II port and the CAN Bus protocol is necessary for communicating with the vehicle. Bluetooth will be used to send and receive data to and from the OBD-II port, so knowledge of the protocol is needed. The handheld module utilizes a touchscreen user interface which means GUI development is required as well. Finally, schematic capture experience is needed to develop schematics for the two modules, including power circuitry. PCB layout and 3D printing experience may also be required.

Conceptual Overview

Introduction

Cars and trucks have become so common and inexpensive that almost every licensed driver owns one. Many of these people prefer repairing, maintaining, or

upgrading vehicles on their own, so this project is an open source, handheld Bluetooth OBD-II diagnostic tool for diagnosing and repairing vehicles. The system consists of two primary modules: the OBD-II port module and the handheld touchscreen module, both of which contain Bluetooth transceivers for wireless communication. Costs will be kept low to make the project accessible to as many people as possible. A tool like this is great for enthusiasts, hobbyists, home mechanics, and even professional technicians.

Problem Statement

There is no standalone, Bluetooth, and handheld system with the required basic features commercially available at a reasonable cost (<\$250.) The existing projects that are similar do not utilize a handheld touchscreen device or a custom Bluetooth OBD-II transceiver circuit.

Intended Audience

This project is targeted primarily towards home mechanics who wish to perform their own automotive repairs. However, paid technicians at a professional shop, or even electronics hobbyists and engineers, could benefit from a low cost and open source tool to interface with a vehicle wirelessly.

Proposed Project

The project is a Bluetooth OBD-II diagnostic tool for diagnosing and repairing vehicles. The system consists of two primary modules: a Bluetooth transceiver that interfaces with the OBD-II port, and a handheld rechargeable unit that displays information on a touchscreen and receives input from the user. The

handheld unit's default mode will be scanning for and clearing diagnostic (trouble) codes. However, there will be an option to switch modes and read data such as speed, coolant, temperature, and oil pressure.

Relation of Proposed System to Existing Systems

While commercial products similar to this do already exist, there is no reasonably priced solution (<\$250) that provides the required features, such as having a rechargeable handheld unit. The solutions that do exist, like the one pictured in Figure 2 below, can easily cost over \$500, and are bloated with unnecessary features.



Figure 2. An example of an existing solution that is high cost from [Amazon](#) [2].

These products are targeted more towards professional mechanics and technicians who work on multiple vehicles a day, making the investment justified. The low-cost options, like the one pictured in Figure 3 below, connect to a proprietary phone app or Windows computer which does not meet the requirements of having a standalone handheld device.



Figure 3. An example of an existing solution that is low cost from [Amazon](#) [3].

Many people do not like installing apps on their phone from small, unknown companies. Phones may also be needed for other things while working on a vehicle such as making phone calls or texts, playing music, looking up information and manuals, or even using the flash for a flashlight. Another problem with these cheap products is the high probability that the OBD-II interpreter integrated circuit used is a clone of the real one. The cloned chips are prone to malfunctions and sometimes have a limited command set compared to the genuine chips. This project is different from these existing commercial solutions because it will have a dedicated touchscreen handheld device that is rechargeable, a genuine OBD-II interpreter integrated circuit from the manufacturer will be used, all documentation and code will be open source, and costs will be kept as low as possible while retaining the necessary functionality.

There are projects completed by other students and engineers that are similar to this one. One example, called “OBD-Pi,” was done in 2014. However, this

solution used a prebuilt OBD-II Bluetooth reader and an aftermarket stereo head unit to display the data. [4] The proposed project will include a custom OBD-II interfacing circuit and a handheld touchscreen device. Another example is a project made for a 1997 BMW. Like this first example, this solution uses a prebuilt OBD-II reader that also utilizes a different interpreter chip (STN1110) [5]. A Raspberry Pi is also used in this project, but the touchscreen interface and the Pi itself are embedded permanently into the dash of the car.

The proposed solution differs from the existing projects because the OBD-II circuit will be designed from scratch using a genuine ELM327 IC, the touchscreen interface is portable and rechargeable, and all documentation and code will be open source. A comparison of the different solutions can be seen in Table 3 below.

<u>Name</u>	Autel MaxiCOM MK808BT [2]	Friencity Bluetooth Car OBD ii 2 OBD2 Scanner Adapter [3]	M3 Pi [5]	This project
<u>Cost</u>	\$560.00	\$9.99	\$130.00	\$160.00
<u>Bluetooth</u>	Yes, Wi-Fi for setup	Yes	Yes	Yes
<u>Touchscreen Handheld</u>	Yes	No	No	Yes
<u>Features</u>	<ul style="list-style-type: none"> • Over 25 functions and services • Works with all OBD-II protocols • Includes a USB cable for optional wired mode 	<ul style="list-style-type: none"> • Reads and clears diagnostic codes • Displays real-time data including engine RPM, coolant temperature, etc. • Inexpensive 	<ul style="list-style-type: none"> • Displays data including airflow sensors, load percentage, throttle percentage, current gear, speed, and temperatures 	<ul style="list-style-type: none"> • Reads and clears diagnostic trouble codes • Displays data including speed, temperatures, and pressures
<u>Cons</u>	<ul style="list-style-type: none"> • Expensive • Wi-Fi setup • Bloated with features 	<ul style="list-style-type: none"> • Functionality is hit or miss • Likely uses a cheap clone of a real OBD-II interpreter • Connects to phone or PC application 	<ul style="list-style-type: none"> • Does not read or clear diagnostic codes • Specially designed for one vehicle • Pi and screen mounted in dash 	<ul style="list-style-type: none"> • Supports only one OBD-II protocol (CAN-BUS)

Table 3. A comparison table for some of the existing solutions.

Deliverables

All source code and documentation will be delivered to program director Kevin Pintong as well as made open source. The components used to build the project will remain in Zak Rowland's possession.

System Description

System Block Diagram

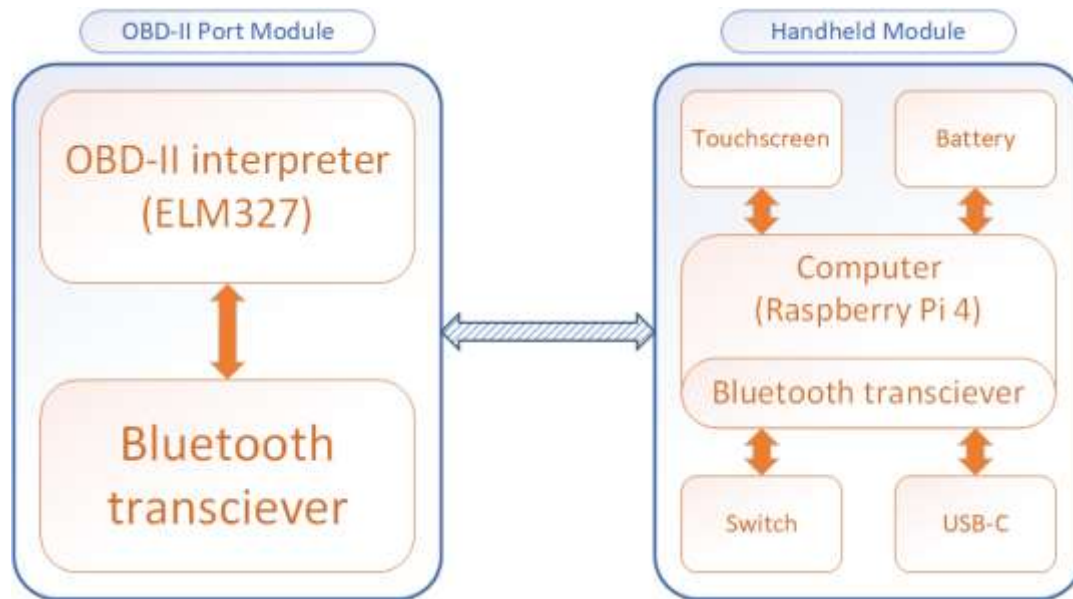


Figure 4. A block diagram of the system.

System General Description

Upon power up, the system's default mode is to scan diagnostic codes. To accomplish this, the circuit connected to the OBD-II must read all the trouble codes and send that information to the handheld unit through a Bluetooth connection. The computer inside the handheld device must process this information and drive a display for the user to see. Input from the user will occur through the touchscreen. A list of codes, or a message indicating the lack thereof, will be displayed to the user and they will be able to tap on a code to view the description and/or the possible cause. The user will have the option to clear all the diagnostic codes which involves sending a command over the Bluetooth connection so the OBD-II can respond accordingly. There will also be an alternate mode for viewing sensor information

live (at least 30 times per second,) and a settings menu to adjust various options like brightness or units.

Major Subsystems

The major subsystems of the project are the power circuitry for the OBD-II module, the Bluetooth circuitry for the OBD-II module, the rechargeable battery circuitry for the handheld module, and the user interface for the handheld module.

Hardware Platform Description

A Raspberry Pi 4 will be used as the computer inside the handheld unit. The Pi is a good choice for this project for several reasons. It can run popular operating systems which makes user interface development much easier. There is plenty of memory, storage, I/O, and even documentation, and the Pi 4 has a DSI connection that makes adding a touchscreen trivial. An ESP32 microcontroller will act as the Bluetooth transceiver for the OBD-II module. This microcontroller supports Bluetooth version 4.2, has several GPIO pins, and will make debugging the OBD-II module much easier.

Software Platform Description

For the Raspberry Pi, scripts will be written in Python and any other software, if necessary, will be written in C. The code for the ESP32 microcontroller will be written in C. Python scripts will be written in an IDE or text editor such as Spyder or Notepad++, and C code will be written in an IDE such as Visual Studio or Atmel Studio.

Component Comparison and Selection

This project was initially intended to be as low cost as possible. However, the COVID-19 pandemic has caused limited access to lab equipment. To keep the project achievable during such uncertain times, some parts may be chosen primarily due to their popularity and documentation. Table 4 below compares different single board computer options for the project. The Raspberry Pi 4 Model B was chosen due to its popularity, ease of use, and built in DSI connection for a display. However, the Raspberry Pi Zero W would be the ideal computer for the project due to its smaller size and lower power consumption.

Computer for Handheld Unit

Table 4 below compares different single board computer options for the project. The Raspberry Pi 4 Model B was chosen due to its popularity, ease of use, and built in DSI connection for a display. However, the Raspberry Pi Zero W would be the ideal computer for the project due to its smaller size and lower power consumption.

<u>Name</u>	Raspberry Pi 4 Model B	Raspberry Pi Zero W	BananaPi-M3
<u>Price</u>	\$35	\$10	\$43
<u>Processor</u>	Broadcom BCM2711 (Quad core Cortex-A72 ARM v8), 64-bit, 1.5GHz	Broadcom BCM2835 (Single core ARM1176JZFS), 1GHz	Realtek RTD1395 (Quad core Cortex- A53), 64-bit
<u>Storage</u>	MicroSD	MicroSD	8GB eMMC + MicroSD
<u>Memory</u>	2GB LPDDR4-3200 SDRAM	512MB	1GB DDR4
<u>Wireless</u>	Wi-Fi and Bluetooth 5.0	Wi-Fi and Bluetooth 4.1	Wi-Fi and Bluetooth 4.2
<u>I/O</u>	(2) USB 3.0, (2) USB 2.0, (2) Micro HDMI, DSI, CSI, 3.5mm A/V, Ethernet	Mini HDMI, USB OTG, CSI, Composite video	(4) USB 2.0, M.2, 3.5mm, HDMI, Ethernet
<u>GPIO</u>	40-pin	40-pin	28-pin
<u>USB/Power</u>	USB-C, 5V/3A+	Micro-USB, 5V/2A+	USB-C, 5V/2A+
<u>Other</u>	OpenGL ES 3.0 graphics		OpenGL ES 1.1/2.0 graphics

Table 4. A comparison table for single board computers.

Table 5 below compares two different OBD-II interpreter integrated circuits, the ELM327 and the STN1110. The ELM327 was chosen for the project. This chip is uncontestably the most popular when making OBD-II readers. The documentation is superb and there are many usage examples to reference, and it was chosen primarily for this reason. The STN1110 is almost an exact replica of the ELM327, it is even completely compatible with all commands used for the ELM chip. However, the STN1110 is half the price and includes an extended command set for even more

available features. Since the STN1110 is not documented as well as the ELM327 and access to lab equipment is restricted, it is more sensible to use the ELM chip.

OBD-II to UART Interpreter

<u>Name</u>	ELM327	STN1110
<u>Price</u>	\$21	\$10
<u>Operating voltage</u>	4.5 – 5.5VDC	3 – 3.6VDC
<u>Operating current</u>	12mA	63mA
<u>Power saver mode</u>	0.15mA	<2mA
<u>Operating power</u>	60mW at 5V	207.9mW at 3.3V
<u>Power saving power</u>	0.75mW at 5V	6.6mW at 3.3V
<u>Features</u>	<ul style="list-style-type: none"> • Power control with standby mode • Serial interface • Automatically searches for correct protocol • Fully configurable with AT commands • Low power CMOS design • Very popular and well documented 	<ul style="list-style-type: none"> • Fully compatible with the ELM327 (AT) command set • Extended (ST) command set • UART interface • Automatically searches for correct protocol • Large memory buffer (more RAM) • Voltage input for battery monitoring
<u>Cons</u>	<ul style="list-style-type: none"> • Expensive • Many buggy fakes/clones if not purchased from manufacturer 	<ul style="list-style-type: none"> • Less documentation and examples • Uses more power

Table 5. A comparison table for OBD-II interpreters.

Bluetooth Transceiver

Table 6 below compares different Bluetooth modules for potential use in the project. The HM-19 or HM-10 module was going to be used originally, however the ESP32 microcontroller will be used instead. The ESP32-DevKitC-32D uses Bluetooth version 4.2, costs about the same as the modules below, and provides more functionality for debugging.

<u>Name</u>	HC-05	HC-06	HM-19
<u>Price</u>	\$7.99	\$7.39	\$9.99
<u>Bluetooth version</u>	2.0	2.0	5.0
<u>Operating voltage</u>	3.6 – 6VDC	3.3VDC	3.6 – 6VDC
<u>Logic voltage</u>	3.3V	3.3V	3.3V
<u>Modes</u>	Master/slave	Slave only	Master/slave

Table 6. A comparison table for Bluetooth transceiver modules.

Fall Term Progress, Problems, and Discussion

Work completed so far has primarily been research and documentation. Notes, calculations, drawings, and time spent are all tracked in a spiral notebook as seen in Figure 5 below.

DATE	DESCRIPTION	TIME
9/27/20	Revising documents	3 hours
10/1/20	Researching parts	2 hours
10/2/20	Meeting 1 with Kevin	15 minutes
10/5/20	Building parts list	3 hours
10/3/20	Revising work deliverables	1 hour
10/9/20	Researching and ordering a screen, ELM327	2 hours

10/9/2020 continued:

I am going to wait until I start working on schematics before I decide on a Bluetooth module. This will be fine because I still need more parts (various circuit components.) Working on memo 1 now.

Figure 5. An example of the notes and time logs from the notebook.

The first difficult decision was choosing a Bluetooth module. The class was recommended to use the HC-05 module. However, that module uses Bluetooth 2.0, and the project requirements require at least 4.0. While deciding on a Bluetooth module, parts that were already chosen including the ELM327 chip, a 32GB MicroSD card, and a touchscreen were purchased.

Still undecided on Bluetooth parts, the Raspberry Pi was loaded with an operating system, Raspberry Pi OS, to test it. This operating system was chosen because it is the one recommended by the manufacturer, but it would be simple to change to a different one if necessary. An undervoltage warning appeared

intermittently while the Pi was in use, and it was discovered that the Pi prefers closer to 5.1V/3A instead of 5V/3A. The undervoltage will not be an issue because the rechargeable battery circuit will use a regulator that can supply 5.1V. After testing the various applications included with the operating system, a very simple Python GUI tutorial was completed. The tutorial was completed to get a feel for the process, and the result can be seen in Figure 6 below.

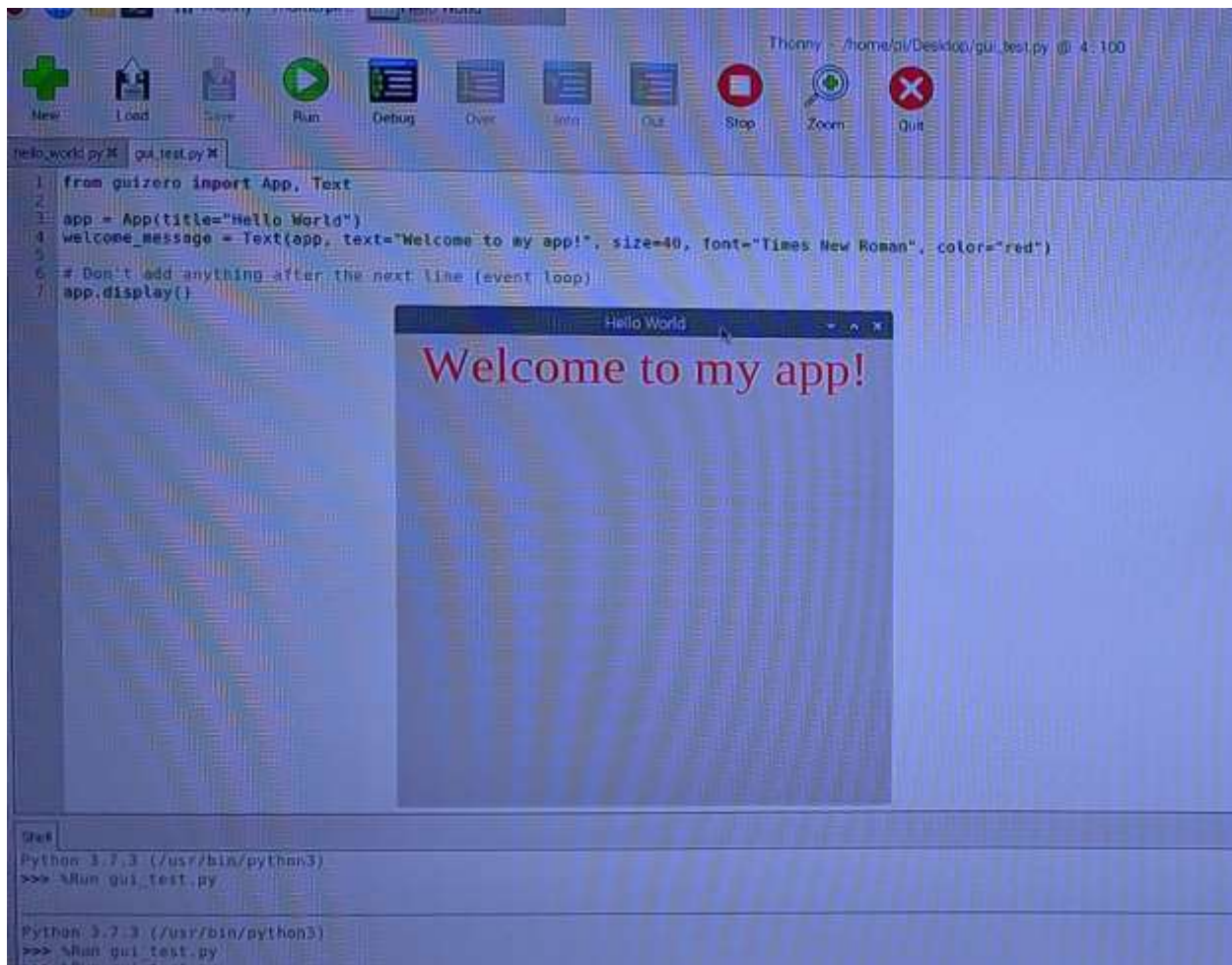


Figure 6. A picture of the basic GUI created with Python script.

While working on the documentation for the preliminary design review, more research was done on the components required for the OBD-II port module. Some

pins on the ELM327 are not required depending on the protocol used in the vehicle, so the pinout of the OBD-II port in a 2008 Nissan Altima had to be verified by inspecting the port to see which holes had metal contacts for pins. This pinout can be seen in Figure 7 below.

2008 Nissan Altima OBD-II Port (J1962 Type A)

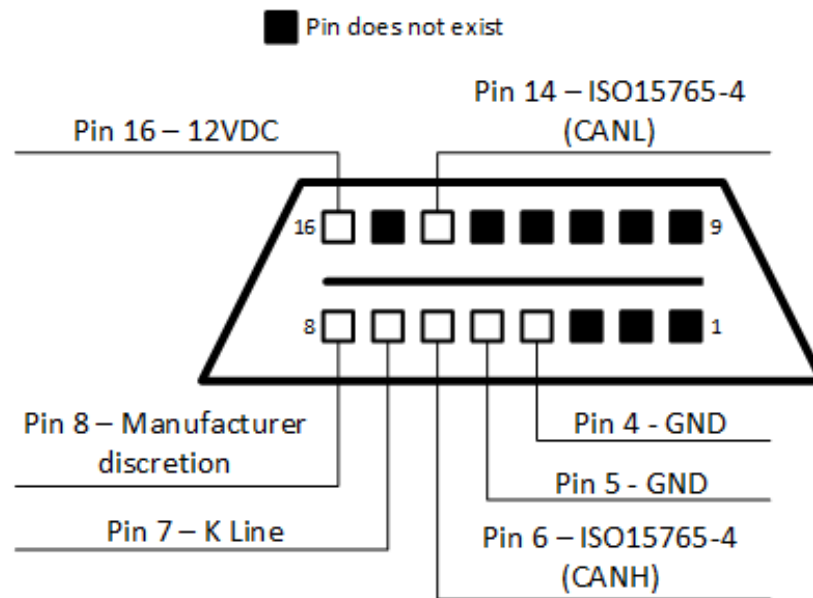


Figure 7. The pinout for the OBD-II port in a 2008 Nissan Altima.

Schematic capture with the KiCAD software began by creating a symbol library for the project, and the first symbol created was the ELM327 chip. An image of the symbol can be seen in Figure 8 below.

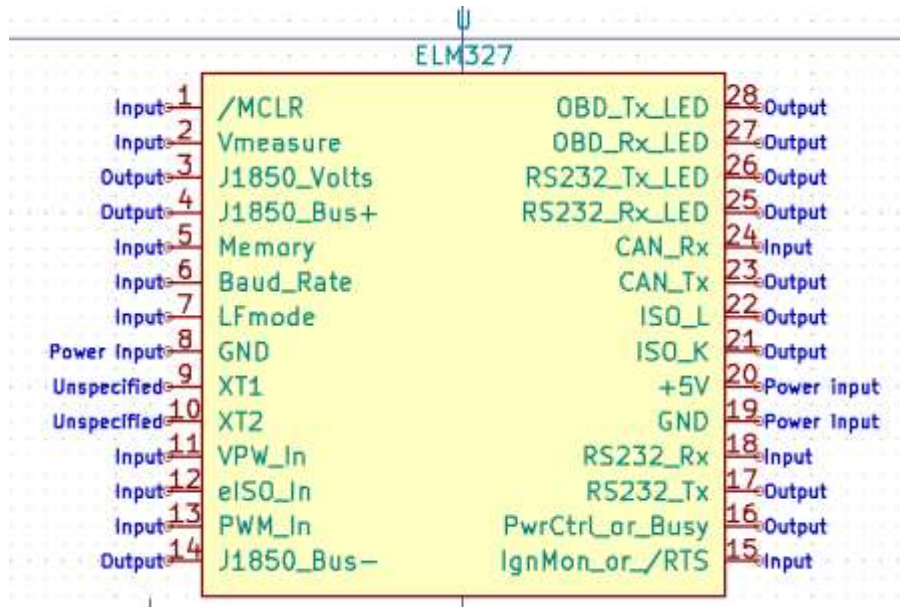


Figure 8. The ELM327 symbol created for use in schematics.

The official ELM327 datasheet includes a diagram for an example application circuit for the chip, so the schematic for the OBD-II port module will include pieces of the circuit recommended in said datasheet [6]. Since progress was being made on the schematic, a Bluetooth module had to be chosen. After more research, the ESP32 was chosen as the best fit for the project given the circumstances. This microcontroller uses Bluetooth version 4.2 so it meets requirements, includes TX and RX pins in the GPIO for serial communication, and will allow for much easier debugging.

While developing the schematic, a table of parts was made to make ordering and creating a bill of materials much faster. A screenshot of this Excel spreadsheet can be seen in Figure 9 below.

Figure 9. The Excel spreadsheet used to track parts and costs.

Development of the next schematic is currently underway and has involved researching rechargeable battery parts.

Progress on the handheld module's schematic was slow due to preparing documentation and a design review, however this is acceptable because this circuit is much less involved than the OBD-II port module. After the design review, all parts for the OBD-II module were ordered. Choosing resistors and capacitors proved to be more difficult than anticipated. When choosing resistors, there were many different options in composition (carbon film, metal film, etc.,) tolerance, power dissipation, size, and more. After some research, metal film resistors were chosen wherever possible due to the similar/equal prices and superior tolerances when compared to carbon film resistors.

The crystal in the circuit requires loading capacitors on each pin for a total load capacitance (C_L) of 20pF. The equation below was used to determine the value of the two loading capacitors.

$$Capacitance_{Load} = \frac{C_1 * C_2}{C_1 + C_2} + C_{Stray}$$

The capacitance load was known, 20pF, and C_{Stray} is stray capacitance from nearby wires and circuitry, typically 3-5pF. With this information, the values for the capacitors (30pF) can be determined.

$$20pF = \frac{C_1 * C_2}{C_1 + C_2} + 5pF \rightarrow 15pF = \frac{C_1 * C_2}{C_1 + C_2} \rightarrow C_1 = C_2 = 30pF$$

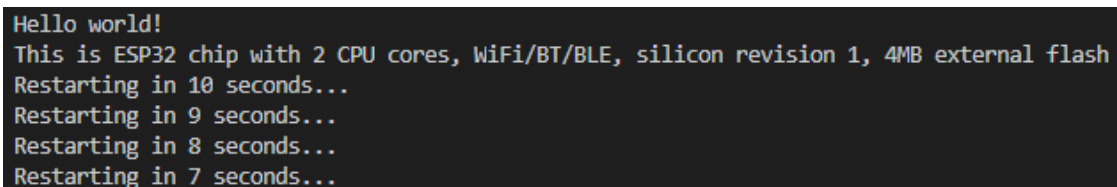
27pF capacitors were ordered instead as they were more common and are recommended for use in the ELM327 datasheet.

Once parts for the OBD-II port module were ordered, the parts table spreadsheet seen in Figure 9 above was updated accordingly. Following this began the difficult decision of choosing a rechargeable battery solution for the device. The Raspberry Pi 4 typically consumes about 600mA but can draw up to 1.2A [7]. The OSOYOO touchscreen consumes a maximum of 830mW (or 251.5mA) [8]. Since the maximum possible current draw is about 1.5A, it was determined that the battery would need to be at least 3Ah to power the system for a minimum of two hours as outlined in the requirements. The initial idea was to use a USB-C lithium-polymer battery charger from Adafruit and a compatible battery. However, this idea was scrapped because the battery voltage would need to be boosted to 5V/3A and it was

difficult finding Li-Po batteries with enough capacity and discharge current capable of doing so.

While still deciding on a battery configuration, the ESP32 was tested. After some research on programming environments for the ESP32, it was decided that Visual Studio Code with the official Espressif ESP32 extension (ESP-IDF) would be used. This environment was chosen because the extension is officially supported and provides build, flash, debug, terminal, and monitor functionality all in one place. Setting up this environment proved to be extremely time consuming. After waiting for downloads and installations, it was determined that the ESP-IDF installation path cannot have spaces in it, and the path did have spaces in it due to the username containing a space.

A new user was created to work around this problem, however the “hello world” program was still not building. After searching online and several more attempts uninstalling, downloading, and reinstalling, the issue was an incorrect path to the Python installation that had to be updated in the extensions’ settings. Once the path was updated, the example program compiled and successfully flashed to the ESP32 and the result can be seen in Figure 10 below.

A screenshot of a terminal window with a black background and light blue/green text. The text shows the output of a program: 'Hello world!', followed by chip information: 'This is ESP32 chip with 2 CPU cores, WiFi/BT/BLE, silicon revision 1, 4MB external flash'. Then it shows a series of 'Restarting in X seconds...' messages for 10, 9, 8, and 7 seconds.

```
Hello world!  
This is ESP32 chip with 2 CPU cores, WiFi/BT/BLE, silicon revision 1, 4MB external flash  
Restarting in 10 seconds...  
Restarting in 9 seconds...  
Restarting in 8 seconds...  
Restarting in 7 seconds...
```

Figure 10. The output of the “hello world” example program for the ESP32.

After this test program, the Bluetooth LE examples were browsed. All of the examples were relatively complex and a simple Bluetooth connection was all that

needed to be tested at the moment. The Arduino IDE was temporarily used as the Bluetooth examples included are much simpler. After some configuration, the ESP32 was creating a Bluetooth signal and an Android phone could successfully connect to it and read a characteristic as seen in Figure 11 below.

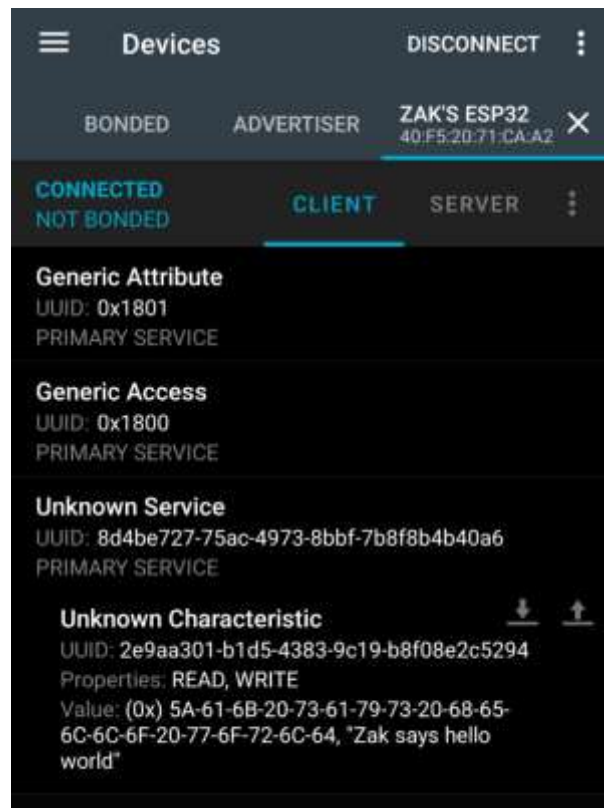


Figure 11. The ESP32 successfully connected to an Android phone app.

Once the ESP32's Bluetooth signal was confirmed to work with a phone, the Raspberry Pi 4 was tested next. Since the Pi does not include a Bluetooth stack by default, BlueZ was used as it is popular and open source (although a bit outdated.) After some configuration and troubleshooting on the Pi, the ESP32 was successfully connected to the Pi as seen in Figure 12 below. The same characteristic hex value read in the phone app was successfully read on the Pi.

```

[40:F5:20:71:CA:A2][LEI]> connect
Attempting to connect to 40:F5:20:71:CA:A2
Connection successful
[40:F5:20:71:CA:A2][LEI]> primary
attr handle: 0x0001, end grp handle: 0x0005 uuid: 00001801-0000-1000-8000-00805f9b34fb
attr handle: 0x0014, end grp handle: 0x001c uuid: 00001800-0000-1000-8000-00805f9b34fb
attr handle: 0x0028, end grp handle: 0xffff uuid: 8d4be727-75ac-4973-8bbf-7b8f8b4b40a6
[40:F5:20:71:CA:A2][LEI]> char-desc 0x0028 0xffff
handle: 0x0028, uuid: 00002800-0000-1000-8000-00805f9b34fb
handle: 0x0029, uuid: 00002803-0000-1000-8000-00805f9b34fb
handle: 0x002a, uuid: 2c9aa301-b1d5-4383-9c19-b8f08e2c5294
[40:F5:20:71:CA:A2][LEI]> char-read-hnd 0x002a
Characteristic value/descriptor: 5a 61 6b 20 73 61 79 73 20 68 65 6c 6c 6f 20 77 6f 72 6c 64
[40:F5:20:71:CA:A2][LEI]> _

```

Figure 12. The ESP32 successfully connected to the Raspberry Pi 4.

After these Bluetooth tests, the rechargeable battery solution had to be decided. As determined previously, the battery capacity needs to be at least 3Ah and must be capable of 3A output. Researching possible solutions led to battery “hats” for the Raspberry Pi. These hats are separate circuit boards that include a battery and all the charging and protection circuitry required. The MakerFocus Raspberry Pi 4 Battery Pack UPS was chosen because it includes a USB-C charging port, a 4000Ah battery, and it supplies a consistent 5V/3A to the Pi.

Once the battery solution was decided, the handheld module’s schematic was finished and can be seen in Appendix B. The parts spreadsheet was updated and the last of the required parts were ordered. Testing the various components including resistors, capacitors, and more, as well as building the OBD-II port module’s circuit are the next tasks that will begin next term. The state of the Trello board at the end of Fall term can be seen in Figure 13 below.

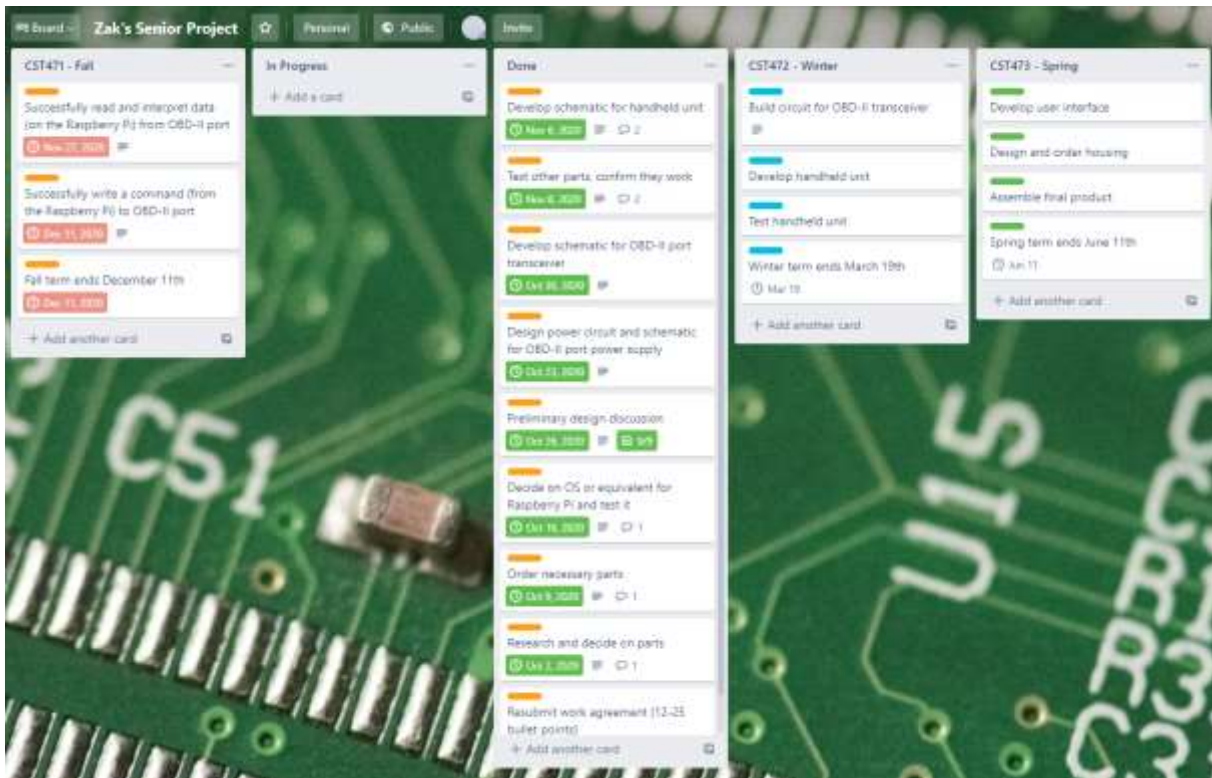


Figure 13. A screenshot of the [Trello](#) board at the end of Fall term.

The tasks to read and write data to/from the OBD-II port were not completed before the term reached an end because it requires the circuit to be complete; This was an oversight from the beginning of the term when trying to determine feasible deliverables.

Winter Term Progress, Problems, and Discussion

After a long winter break, progress had to be made on the circuit. The first task completed was measuring the resistors and capacitors using a multimeter to confirm they are the correct values. This turned out to be an unnecessary step, however being certain the values are correct does no harm. At the same time, the push button and LEDs were tested. The button also has an internal red LED that can be permanently powered or controlled by some device. An Arduino was used for

a 5V power source and the button was wired to power an LED while pressed. Figure 14 below shows the testing setup.

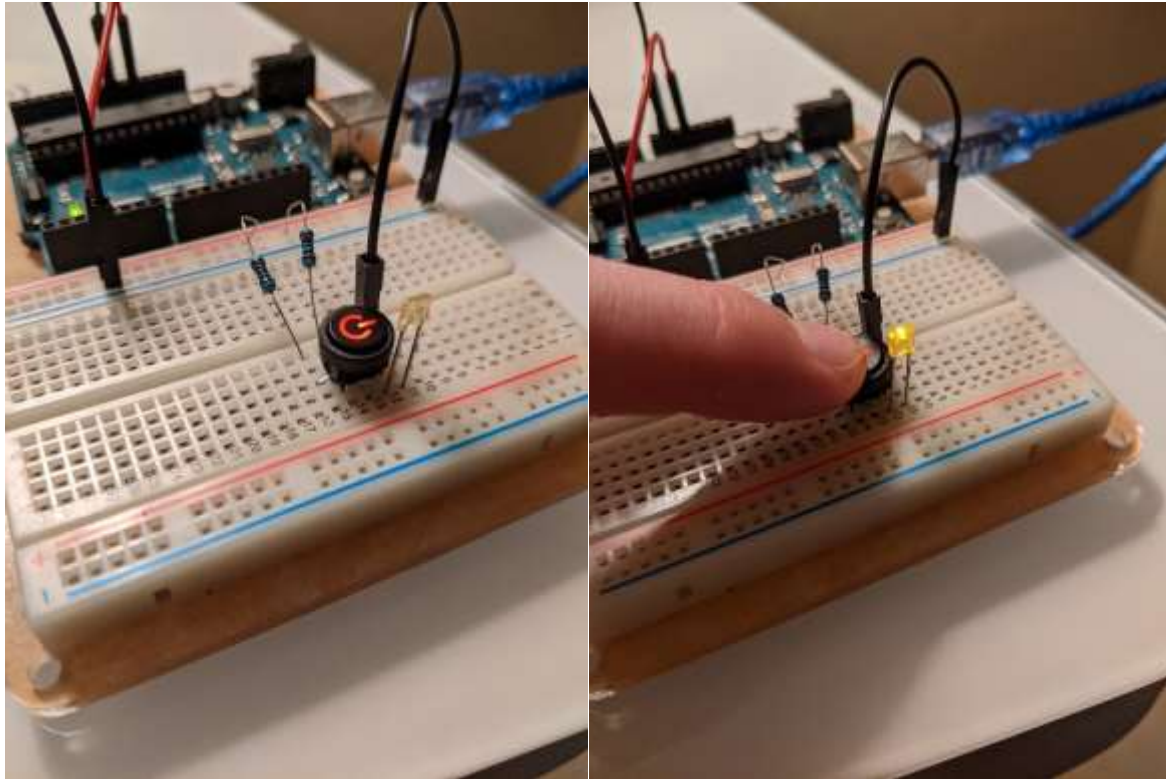


Figure 14. Testing the button and status LEDs.

Once these components were confirmed to be working, the circuit could be assembled. At this point, a VSSOP-8 to DIP-8 adapter and a SOT-223 to DIP-6 adapter were ordered to allow the small integrated circuits to be used on a breadboard.

After the first meeting with Kevin Pintong, the work agreement was revised to make the goals more feasible. The Trello board was updated with the term's tasks and due dates as seen in Figure 15 below.

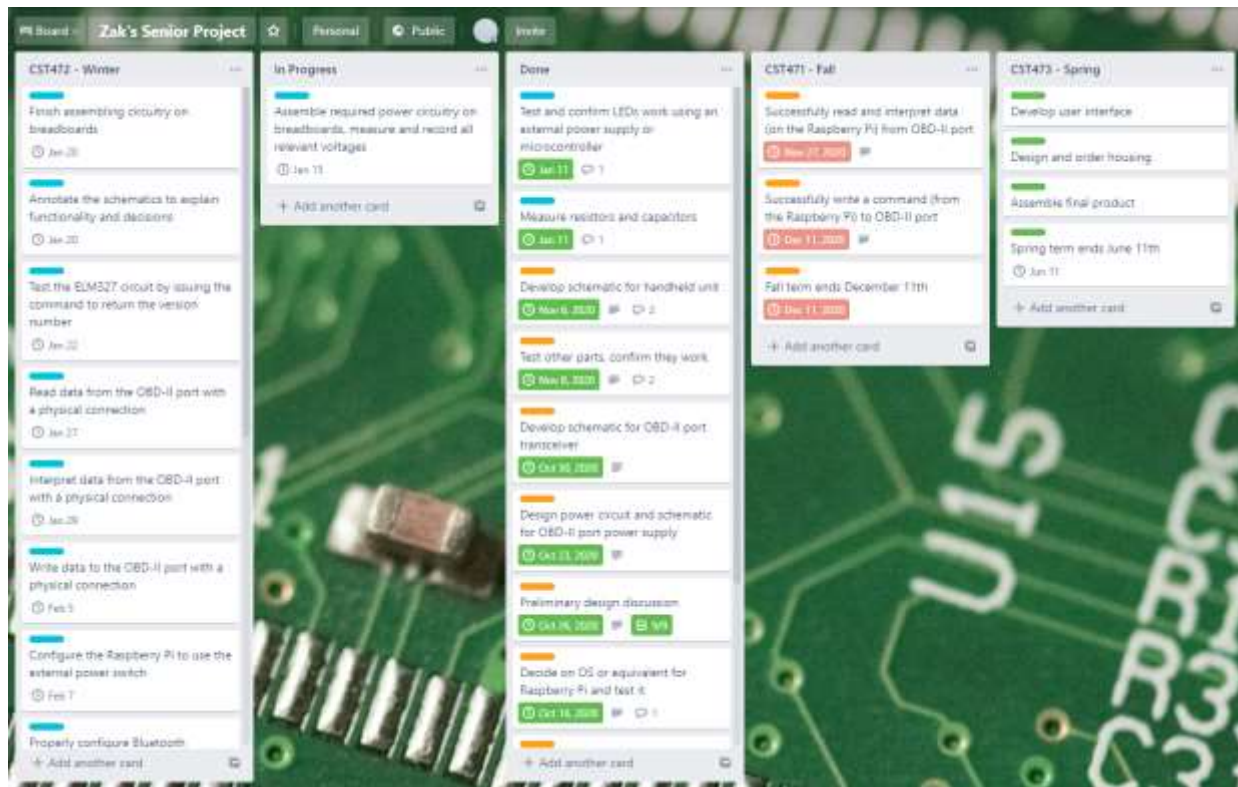


Figure 15. A screenshot of the [Trello](#) board at the beginning of Winter term.

The schematics for the project were also discussed during the first meeting. One of the filtering capacitors for the 5V regulator, C1, was originally a $0.1\mu\text{F}$ capacitor but after some insight was replaced with a $0.47\mu\text{F}$ capacitor for increased stability.

Before adding all the components to the breadboard, the power circuitry was assembled and tested first. The 5V portion was built first, and before connecting it the car's battery, the battery was measured at 11.98V. When finished, the regulator produced a consistent 5.05V and illuminated the power LED. Figure 16 below shows the voltage measurements and 5V circuitry.



Figure 16. Measuring and testing the 5V circuitry.

The 3.3V circuitry was assembled and tested in the same fashion and resulted in a steady 3.313V. Around this time, the DIP adapters arrived and were soldered together. The smaller IC, the TXB0102, was tricky to solder and one side got quite hot from the iron. After adding some flux, the pins soldered to the adapter nicely, however the possibility of heat damage cannot be completely ruled out. The assembled adapters can be seen in Figure 17 below.



Figure 17. The DIP adapters before and after assembly.

While building the circuit, a copy of the schematic was annotated at the same time to clarify the purpose of each portion. Examples of these annotations and the finished circuit can be seen below in Figures 18 and 19 respectively.

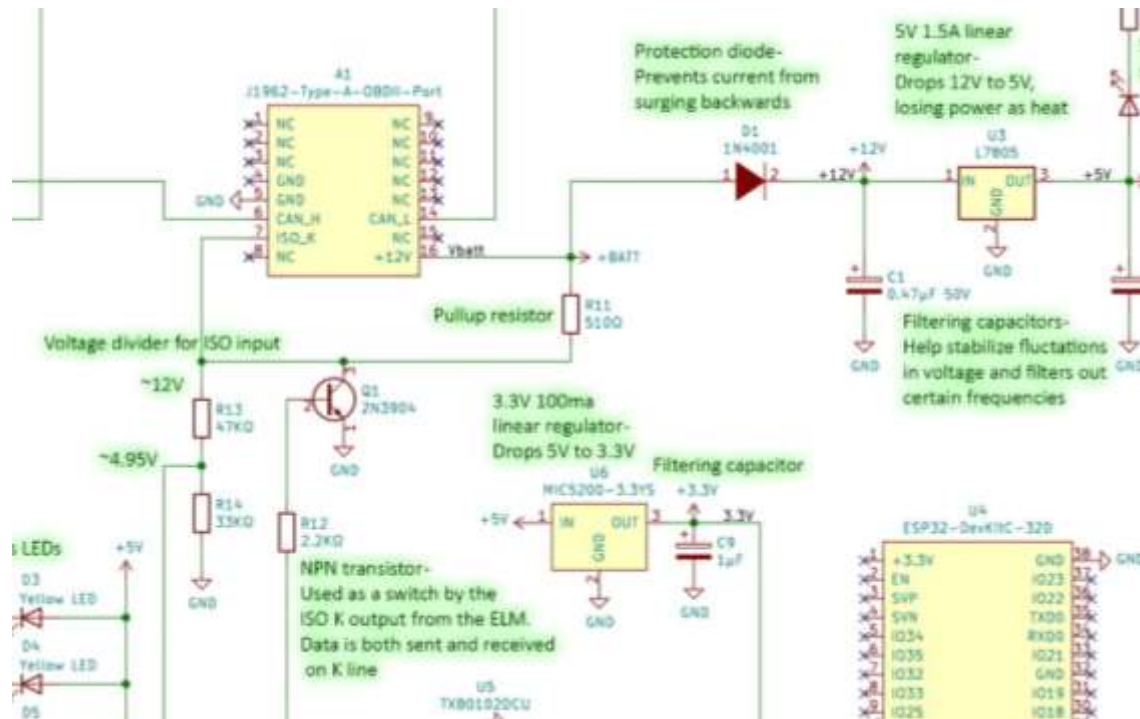


Figure 18. A section of the annotated schematic.

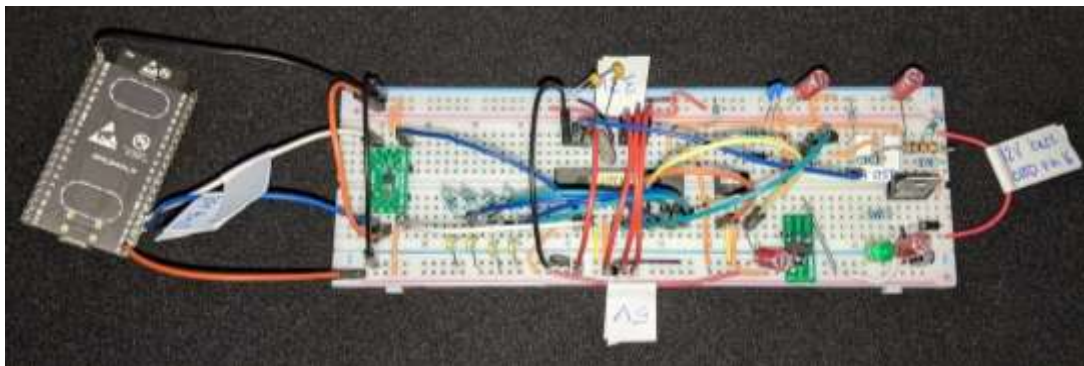


Figure 19. The finished OBD-II port circuit.

Once the circuit was assembled, it could be tested in the car. When connected, the status LEDs light in sequence which indicates the ELM327 is functioning at some capacity. However, with the ESP32's UART configured through Arduino IDE and the serial monitor open, the data read from the ELM327 was garbled.

The ELM327 was removed from the circuit and the voltages were measured once more since some components were moved around, but all voltages were still as expected, so the ELM was placed back into the circuit. In order to test if the ESP32 UART configuration or the logic level translator was the issue, a USB to serial adapter (UM232H-B) was used to communicate directly to the ELM327. Using this connection, the “AT Z” command to reset the chip and return the version number was issued successfully as seen in Figure 20 below.

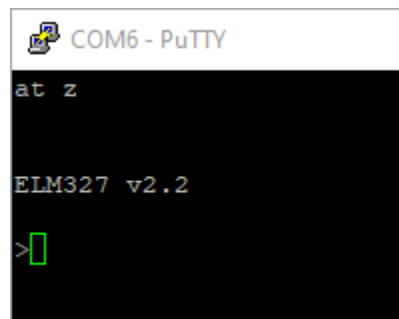


Figure 20. A command successfully issued to the ELM327 from a terminal.

The Espressif documentation includes some examples for configuring the UART for the ESP through the Visual Studio Code extension. After trying some of these examples, changing settings, and setting the baud rate in the ELM327 to 115.2K, the data was still garbled as seen in Figure 21 below.

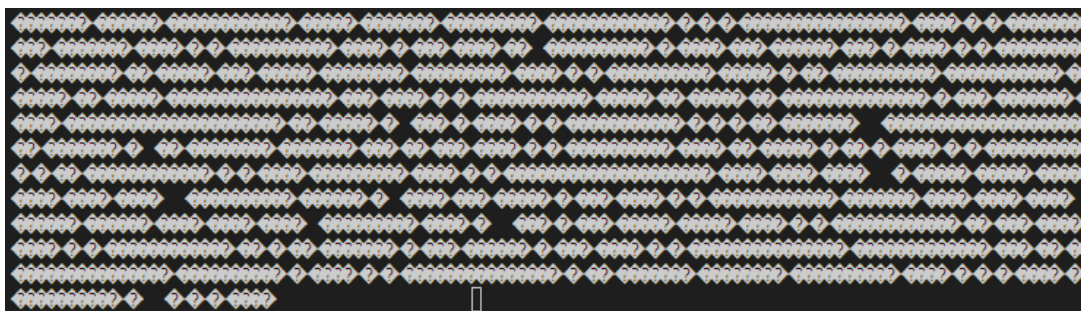
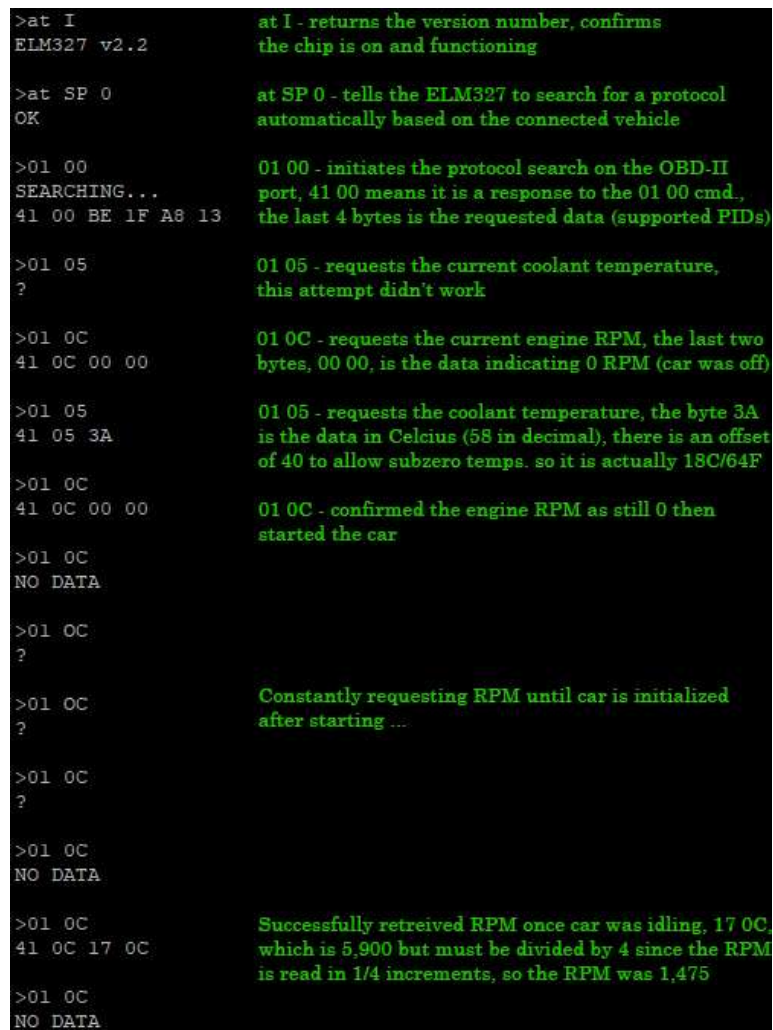


Figure 21. An example of the gibberish data read through the ESP32 UART.

This data was still present after commenting out any UART reads or writes, indicating it could be a software configuration issue. After failing to get the ESP32's UART to communicate correctly, the module was tested in the vehicle using the same USB to serial connection mentioned earlier. Using this method, the ELM327 successfully interfaced with the vehicle and was able to issue commands and read the response including checking coolant temperature, engine RPM, and more. The screenshots of the terminal session were saved and annotated to interpret all the different data retrieved and can be seen in Figures 22 and 23 below.



```
>at I
ELM327 v2.2

>at SP 0
OK

>01 00
SEARCHING...
41 00 BE 1F A8 13

>01 05
?

>01 0C
41 0C 00 00

>01 05
41 05 3A

>01 0C
41 0C 00 00

>01 0C
NO DATA

>01 0C
?

>01 0C
?

>01 0C
NO DATA

>01 0C
41 0C 17 0C

>01 0C
NO DATA
```

at I - returns the version number, confirms the chip is on and functioning

at SP 0 - tells the ELM327 to search for a protocol automatically based on the connected vehicle

01 00 - initiates the protocol search on the OBD-II port, 41 00 means it is a response to the 01 00 cmd., the last 4 bytes is the requested data (supported PIDs)

01 05 - requests the current coolant temperature, this attempt didn't work

01 0C - requests the current engine RPM, the last two bytes, 00 00, is the data indicating 0 RPM (car was off)

01 05 - requests the coolant temperature, the byte 3A is the data in Celcius (58 in decimal), there is an offset of 40 to allow subzero temps. so it is actually 18C/64F

01 0C - confirmed the engine RPM as still 0 then started the car

Constantly requesting RPM until car is initialized after starting ...

Successfully retrieved RPM once car was idling, 17 0C which is 5,900 but must be divided by 4 since the RPM is read in 1/4 increments, so the RPM was 1,475

Figure 22. Annotated screenshot of the first connection to the vehicle.


```

>
41 0C 15 4A
More RPM readings - 1,362.5 RPM

>
41 0C 14 82
1,312.5 RPM

>01 05
NO DATA
More temperature readings

>01 05
41 05 43
27C or 80.6F

>01 05
41 05 43
27C or 80.6F

>01 05
41 05 44
28C or 82.4F

>01 05
41 05 44
28C or 82.4F

>01 05
NO DATA

>01 05
41 05 45
29C or 84.2F, coolant is getting hotter

>09 02
014
09 02 - requests the Vehicle Id. Number (VIN), converted to
ASCII gives "1N4AL21E78N425026" which is the correct VIN
0: 49 02 01 31 4E 34
1: 41 4C 32 31 45 37 38
2: 4E 34 32 35 30 32 36

>04
44
04 - resets and clears all trouble codes and data, 44 in return
indicates success

?

0101
?

>0101
41 01 00 07 65 25
0101 - requests the current number of trouble codes, the third
byte, 00, is the data of interest indicating there are 0 codes

>03
?

>03
NO DATA

>03
43 00
03 - request the list of trouble codes, the 00 indicates there
are no codes

>

```

Figure 23. More data from the first connection to the vehicle.

With everything else working as intended, the next step is to debug the ESP32's UART configuration. It is also entirely possible that excess heat ruined the logic level translator when soldering, but an oscilloscope may be the only way to confirm the operation.

The state of the Trello board can be seen in Figure 24 below.



Figure 24. A screenshot of the [Trello](#) board.

Adding an external power button to the Raspberry Pi 4 turned out to be trivial. Following a tutorial from Embedded Computing Design [9], a line was added to the boot configuration file of the Pi to allow a switch connected to GPIO to shut it down using, power on is enabled by default. The internal LED was not connected yet, but it will be connected to a GPIO pin later to be controlled in a script. Figure 25 below shows the button connected to the Pi.



Figure 25. An external power switch connected to the Raspberry Pi 4.

The serial connection between the ESP32 and the ELM327 still required debugging, so a Hantek 2D72 handheld oscilloscope was borrowed from Oregon Tech for this purpose. While reading through the ESP32 documentation, it was discovered that the pins used for UART1 are reserved for SPI by default and are not recommended for other uses. After switching to UART0, a proper data signal was captured on the oscilloscope and can be seen in Figure 26 below.

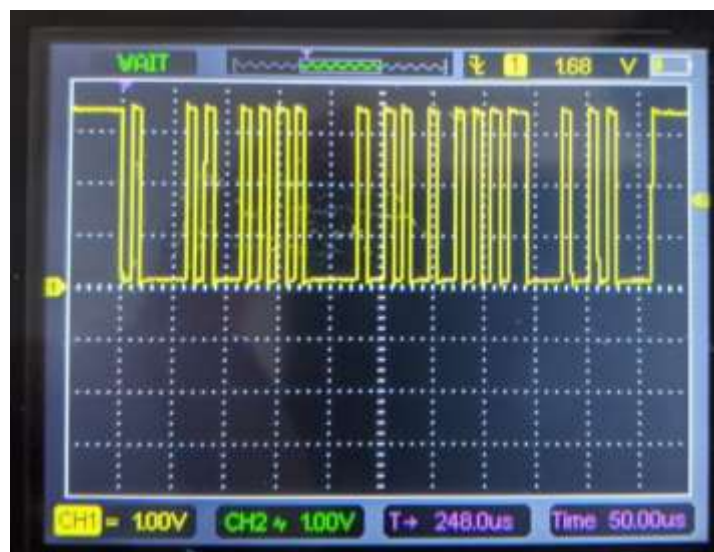


Figure 26. An image of the serial output from the ESP32.

The data was initially perceived to be incorrect since the decoded value was gibberish, however after a design discussion, it was realized that the data is sent least significant bit (LSB) first. To confirm this, the UART from an Arduino UNO was used to send the command “AT I”. The decoded oscilloscope reading from the UNO, which verifies the data, can be seen in Figure 27 below.

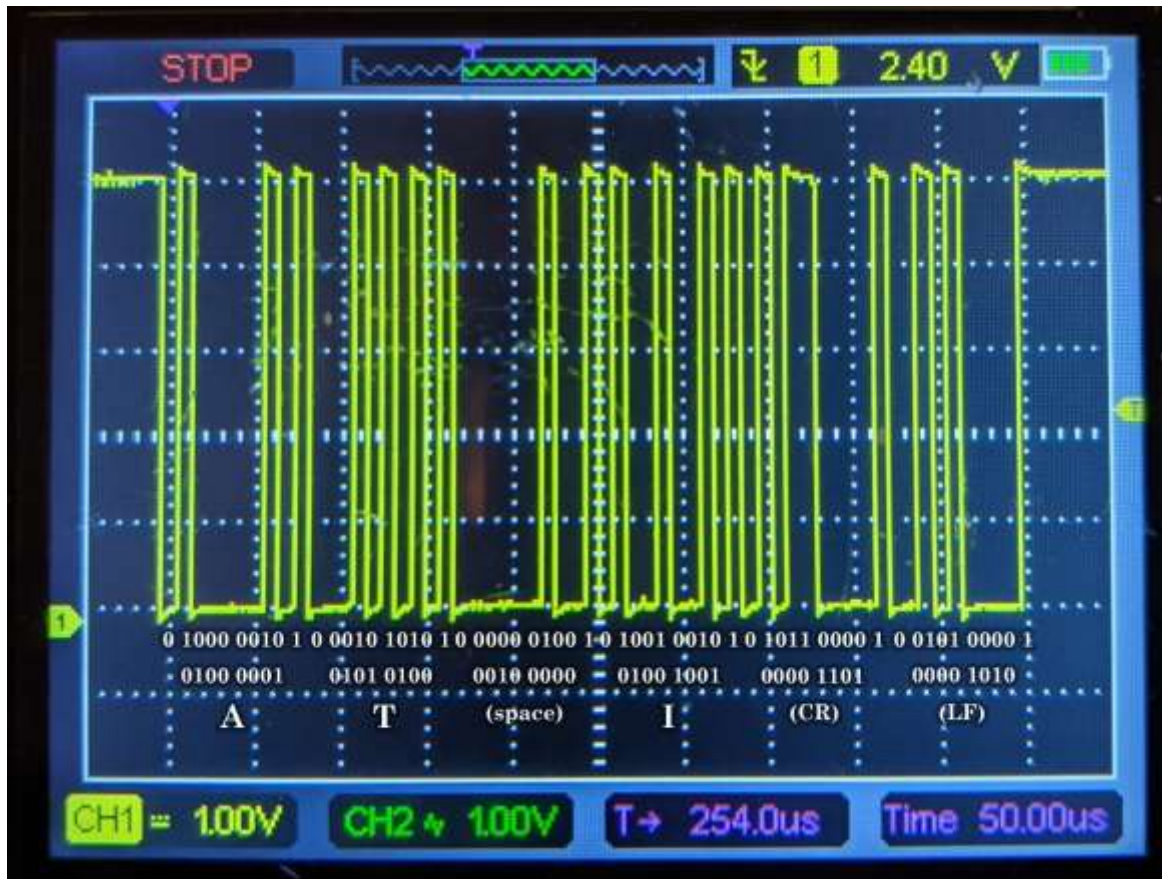


Figure 27. The decoded oscilloscope reading from the Arduino Uno.

Once the data was confirmed, the same test was performed on the ESP32 again. The signal produced by the ESP32, while at 3.3V instead of 5V, was identical to the signal produced by the Arduino Uno. This confirmed the ESP32 was producing the correct signal, and the oscilloscope reading can be seen in Figure 28 below.

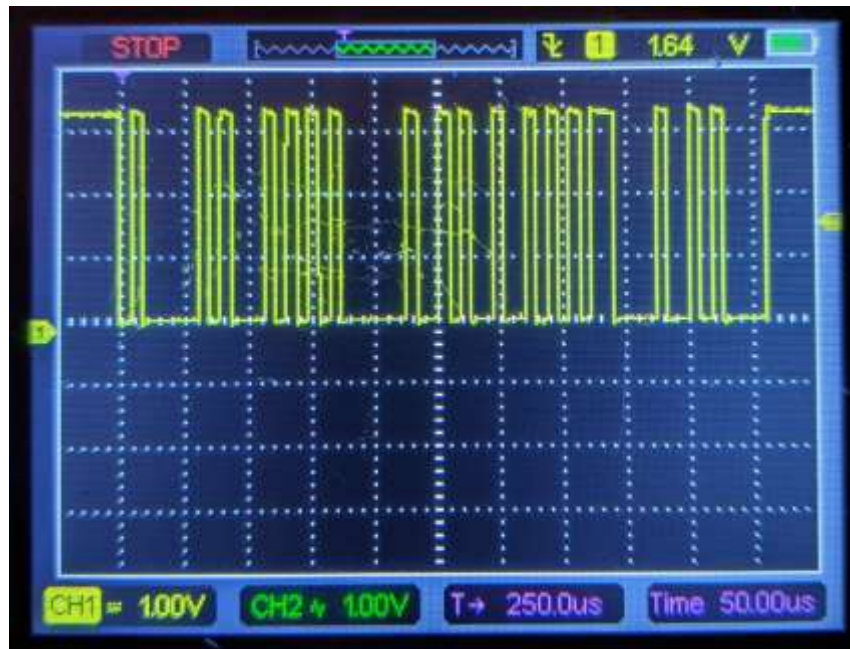


Figure 28. Another image of the serial output from the ESP32.

After confirming the ESP32's UART was functioning properly, the signal after 3.3V to 5V translation was tested with the oscilloscope. The signal quality was degraded, but the data appeared to be in tact as seen in Figure 29 below.

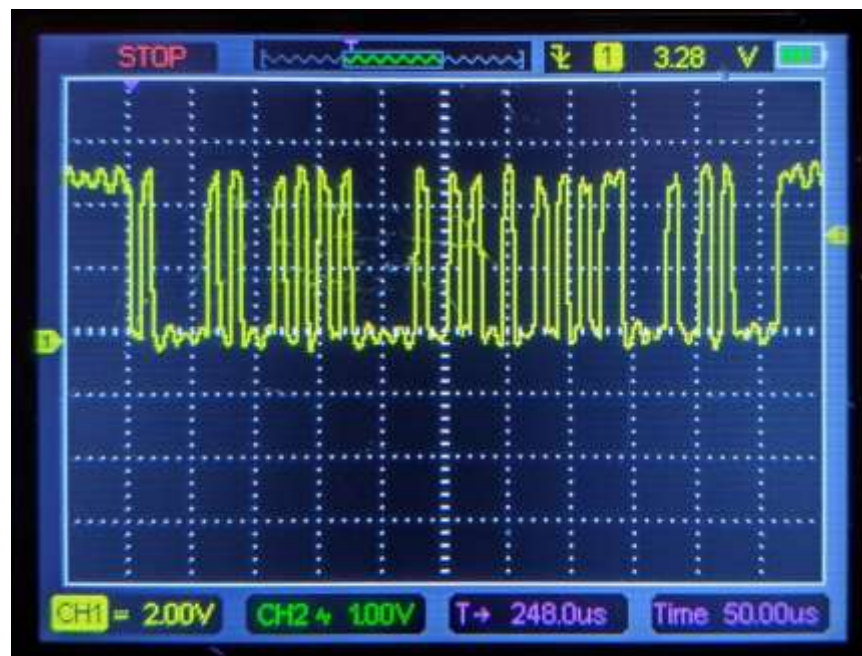


Figure 29. The serial output from the ESP32 after being translated to 5V.

Since the ELM327 was receiving the correct data from the ESP32, the ELM327's response was tested with the oscilloscope as seen below in Figure 30.

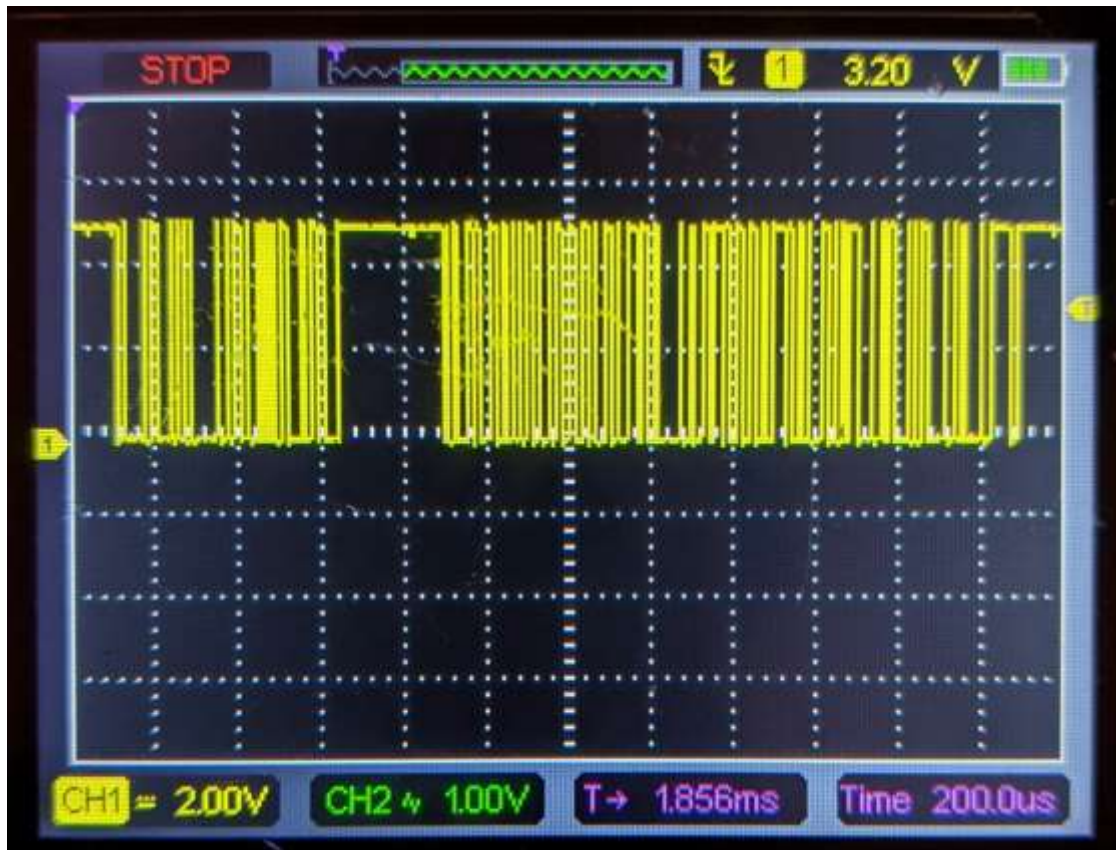


Figure 30. The ELM327's response to the "AT I" command.

This data was not decoded since the real point of interest was testing the functionality of the TXB0102 logic level translator. The signal from the ELM327 after translation from 5V to 3.3V appeared to be identical but with lost quality, similar to the 3.3V to 5V translation. The oscilloscope reading of the 5V to 3.3V conversion can be seen in Figure 31 below.

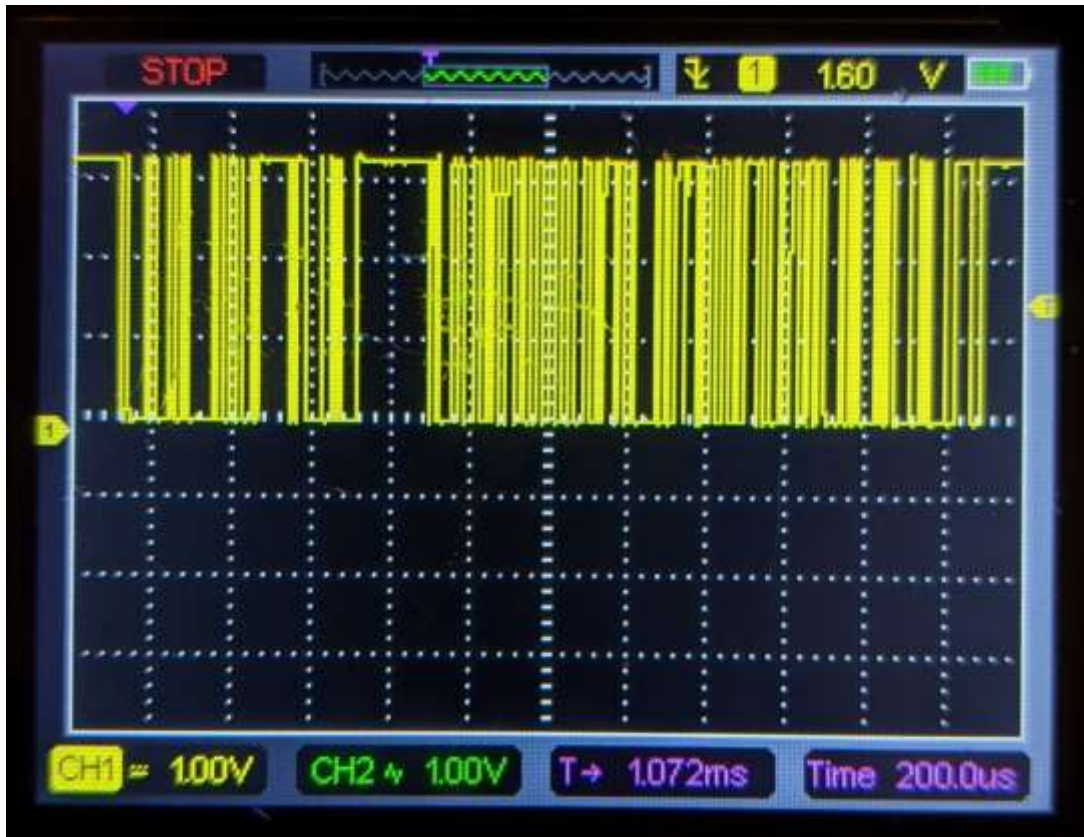


Figure 31. The ELM327's response after translation to 3.3V.

Since the logic level translator appears to be functioning correctly, the next task is configuring the Bluetooth connection between the ESP32 and the Raspberry Pi 4 so this data can be transferred wirelessly. The current state of the Trello board can be seen in Figure 32 below.



Figure 32. A screenshot of the current [Trello](#) board.

Requirements

1. The system shall work with the 2008 Nissan Altima OBD-II protocol, ISO15765-4 (CAN-BUS.)
 - a. Other vehicles that use the same protocol may work with the system, however it is not required.
2. The system shall be able to read and clear diagnostic (trouble) codes.
 - a. The user interface will display the diagnostic codes in list form with buttons to scroll up and down through the list.
 - i. The list will display the diagnostic codes (e.g. P0011) only.
 - ii. The user must touch one of the diagnostic codes to read the description or possible cause.
 - b. The user interface will provide a button to clear all diagnostic codes.
3. The system shall have the ability to read sensor data at minimum 30 times per second including speed, coolant temperature, and oil pressure.
 - a. The user interface will display the data in decimal format.
 - i. The option for digital gauges may be implemented.
 - b. The data will be displayed by default in units of miles per hour for speed, Fahrenheit for temperature, and pounds per square inch for pressure.
 - i. The option for metric units shall be implemented.
4. The system shall use Bluetooth 4.0 or greater for data transfer.

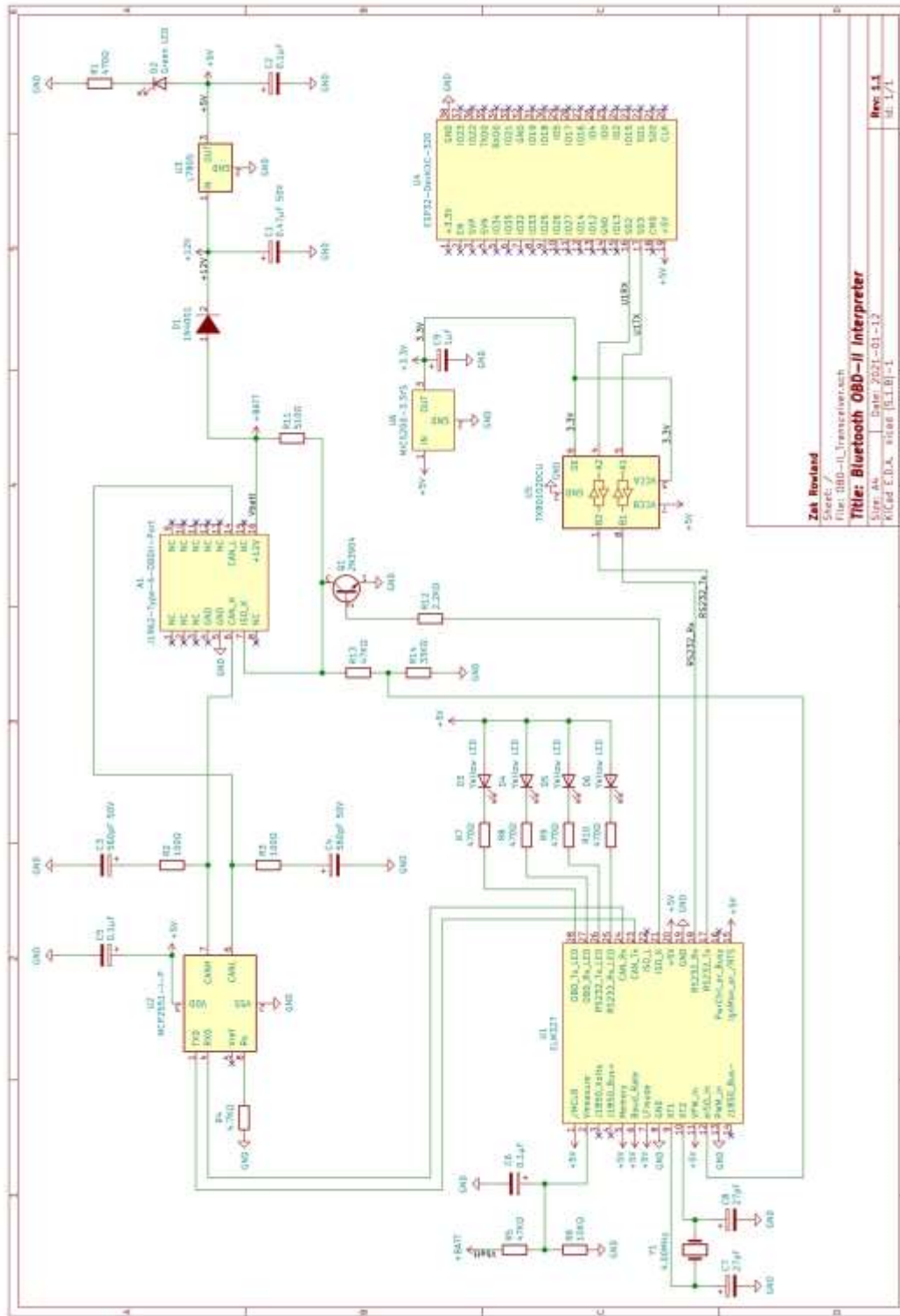
- a. The Bluetooth version shall be 4.0 or greater because previous versions do not support Bluetooth Low Energy (BLE.) The range of the connection is also improved with newer versions.
5. The Bluetooth transceiver circuit that interfaces with the OBD-II port shall be powered by the OBD-II port.
 - a. A power circuit will be designed to ensure power from the port is reliable.
6. The handheld unit shall use a touchscreen to display information and receive user input.
 - a. The touchscreen of the handheld unit shall be 3.5" or greater diagonally.
 - b. The touchscreen of the handheld unit shall operate at a resolution of at least 320 x 480 pixels.
7. The user interface shall not require multi-touch or swiping.
 - a. Operation with single presses simplifies the user interface and is more accessible to those with disabilities.
 - b. The option to scroll through a list by swiping up or down may be implemented.
8. The rechargeable battery shall be recharged via a USB-C port.
9. The rechargeable battery shall power for the handheld unit at full load for at least 2 hours.

- a. The rechargeable battery must include protection and charging circuitry.
10. The charge level of the rechargeable battery shall be displayed on the user interface.
- a. The charge level will be displayed as a percentage, 100% being fully charged.
11. The brightness level of the touchscreen shall be adjustable in the user interface in 10% increments, 100% being maximum brightness.
12. The housing of the handheld unit shall include a magnet.
- a. The magnet will allow users to easily mount the device on the various magnetic dash mounts available (or any other magnetic surface.)
13. The handheld unit shall include a physical ON/OFF power switch.
14. The system shall use a single board computer or microcontroller.
15. The code and documentation developed shall be open source.

Glossary

<u>Term</u>	<u>Definition</u>
OBD-II	OBD-II stands for On-Board Diagnostics (version 2) and is the interface used in all vehicles model year 1996 or newer.
CAN Bus	CAN stands for Controller Area Network and it is the bus protocol used in vehicles and other embedded systems to send and receive data to and from all the various devices (nodes) connected to it. The OBD-II port has connections to the CAN Bus.

Appendix A



[illegible]

References

- [1] Trello, Zak's Senior Project, <https://trello.com/b/57kp2fr0/zaks-senior-project>
- [2] Amazon, Autel MaxiCOM MK808BT Diagnostic Scan Tool,
<https://www.amazon.com/dp/B07MBSZH48/>
- [3] Amazon, Friencity Bluetooth Car OBD ii 2 OBD2 Scanner Adapter,
<https://www.amazon.com/dp/B082SMZTFL>
- [4] Instructables, OBD-Pi, <https://www.instructables.com/OBD-Pi/>
- [5] Raspberry Projects, M3 Pi: Raspberry Pi OBD-II Touchscreen Car Computer,
<https://projects-raspberry.com/m3-pi-raspberry-pi-obd-ii-touchscreen-car-computer/>
- [6] Elm Electronics, ELM327 OBD to RS232 Interpreter,
<https://www.elmelectronics.com/wp-content/uploads/2016/07/ELM327DS.pdf>
- [7] Raspberry Pi, Power Supply,
<https://www.raspberrypi.org/documentation/hardware/raspberrypi/power/README.md>
- [8] OSOYOO, Instruction for Raspberry Pi 5" DSI Touch Screen,
<https://osoyoo.com/2019/09/20/instruction-for-raspberry-pi-5-dsi-touch-screen/>
- [9] J. Cook, Raspberry Pi Power-Up and Shutdown with a Physical Button,
Embedded Computing Design,
<https://www.embeddedcomputing.com/technology/open-source/development-kits/raspberry-pi-power-up-and-shutdown-with-a-physical-button>