**Analysis and Design Document**

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# 1.0 - Needs Assessment

## 1.1 - Client/Customer Definition

In this context, the customers are deaf people riding the subway on the Toronto Transit Commission. Their attributes can be defined by the following criteria:

* Demographic: Deaf people.
* Geographic: Deaf people in Toronto.
* Behavioural: Deaf people in Toronto who take public transit.

Given that 18.9% of Ontarians are from Toronto, we can assume the target demographic is about 27,500 people [1] [2]. It is also assumed that these people will take public transit at least once in their lives. There also exist several complaints about this particular issue, such as Leona Zultek, a deaf woman, commenting on the TTC, saying, “I’m looking at people, they’re getting up and leaving, I have no idea why. I don’t know whether it’s an emergency, a medical emergency, whether it’s a technical problem… It’s completely frustrating” [3]. It should also be noted that the TTC’s audio announcements are also “totally incomprehensible,” as said by TTC user Khaleb Ibrahim [4], highlighting another problem for people who may use hearing aids or are partially deaf. Even someone like Liam O’Dell, a deaf individual from the UK, says

I assume there’s a tendency for rail staff to use megaphones or tannoy announcements to share information about delays because that’s far easier than figuring out how to display the information in several paragraphs on departure boards or train screens [5]

If an advanced transit system like the UK’s has issues like these, it further supports the claim to improve accessibility for the deaf in the TTC, as a way to come off as an exemplary transit model.

## 1.2 - Competitive Landscape

Technological System - Railway Stations Announcement System for Deaf

In India, a railway station announcement system was created by researchers with Python and Flask Framework, where announcement text was taken as input and produced Indian Sign Language as output [5].

Shortcomings: If a deaf person is not actively paying attention, they may miss an announcement happening at the moment, since they do not indicate that there is one happening. Additionally, it is not accessible to other deaf groups, who may not know a language like ISL.

LAMA - Public Phone Announcements

A system, developed by IBM research students, where people would be alerted by their mobile phones if there is an announcement [6]. The user would enter a place where LAMA is offered, and they can pick from a list of message delivery methods [6].

Shortcomings: Existing places had to have the LAMA system running, which may be challenging to do, especially in a subway system, where there is no cell service. People are expected to have the service ready and set up, which may be inconvenient for some people, as they may not want to or trust such a service. Also, the idea was not picked up by the general public.

Hearing Loop

A type of sound system for people with hearing aids that possess T-coils, where the audio input is directly transmitted into the hearing aid, through a magnetic field, which can amplify the sound [7].

Shortcomings: Assumes hearing aids have T-coils, but a lot of them do not, making it inaccessible for a good chunk of people. Subway platforms and trains are large, noisy, and often have irregular layouts, making it difficult to install a loop that covers the entire space effectively. Many people do not wear hearing aids, due to ineffectiveness or reliance on lip reading or sign language, so this system also becomes useless in that realm, as well.

## 1.3 - Requirement Specification

### 1.3.1 - Functional Requirements

Button Input: Each button press must accurately trigger a pre-loaded announcement stored in memory. The system must recognize a button press and send a corresponding UART signal to the second STM32 microcontroller within 1 second. The debounce mechanism will eliminate false signals due to mechanical noise, ensuring consistent behavior. This aligns with best practices in button-based digital systems for reliability in user input [10].

Preloaded Announcements: The STM32 microcontroller must store at least 10 pre-loaded announcements in memory, each uniquely associated with a button press. These announcements will display sequentially on the LCD screen without requiring external inputs. This design is efficient for pre-defined outputs in embedded systems, as documented in real-time button-triggered applications [11].

LED Indicator: An experimental study demonstrated that the illuminance that caught the maximum attention of participants was 1500 lux (99.75%), while the minimum was 500 lux catching 99.36%, [9]. Such high lux values may be feasible in the final product, but for the purposes of the project, the group will stick to a lower lux rating as it requires fewer LEDs and is less expensive. Also, the delta percentages were very insignificant, which does justify using fewer LEDs. Therefore, the group will aim for around 50 lux for the prototype; calculated by checking a datasheet, and squaring the area of a standard subway wagon, which is 3.13 meters [15]. The colour of the light indicator should be red, as it takes people to register the colour red at 2/100ths of a second, the fastest of any colour [11].

LCD Display Display Screen: The display must ensure that public transit announcements are clearly visible under various lighting conditions. Research indicates that for optimal readability, a display brightness of around 250-300 nits is sufficient for indoor environments [12]. Studies have also shown that a brightness level of 250-300 cd/m² is effective for readability in environments with varying light conditions [13]. To display the announcements, a 2004 I2C LCD will be used, which can handle up to 80 characters per line (more on it in technical requirements).

### 1.3.2 - Technical Requirement

Transmission of Data Between Microcontrollers: To transmit data between two microcontrollers, the group will be doing it through UART. Additionally, for both devices, the baud rate (rate at which information is transferred) must be equal [14]. To verify that the UART is working over the one-meter distance, an oscilloscope probe can be used to check when a unit transmits data, with one probe on the RX pin, and the group will verify if there is activity on the other pin [15]. For this project, a distance of greater than one meter may be needed based on the way the system is set up, but for the demo, it will be tested with one meter.

Power Consumption: To ensure that the project remains within the specified power limits, the total power consumption must not exceed 30 watts. This includes power used by both STM32 microcontrollers and all connected components such as the microphone, LCD, and LEDs. Power consumption will be verified using a multimeter to measure the current draw of the entire system under normal operating conditions [16]. The system must be designed and tested to confirm that it stays within this power limit to avoid overheating and ensure safe operation [16].

Button Debounce Mechanism

To prevent misreads caused by mechanical noise or accidental presses, the system must implement a debounce mechanism using hardware (RC circuit) or software (time delay). Each button press must generate a stable signal lasting at least 50 ms to ensure accurate recognition.

### 1.3.3 - Safety Requirements

Floating Voltage & Power Limit

It is recommended that the group ensures the pins drawing power have their pull-up resistors internally turned on, or it is at least implemented in the design, and every part of the project is grounded. If parts are not grounded, and a load fails, this could result in the group getting zapped by the circuit, so all parts must be grounded [35]. This means when testing the circuit or when the circuit is in use, all pins with voltage should be grounded for safety. Additionally, as stated in the project outline, the group should not be drawing more than 30 Watts of power.

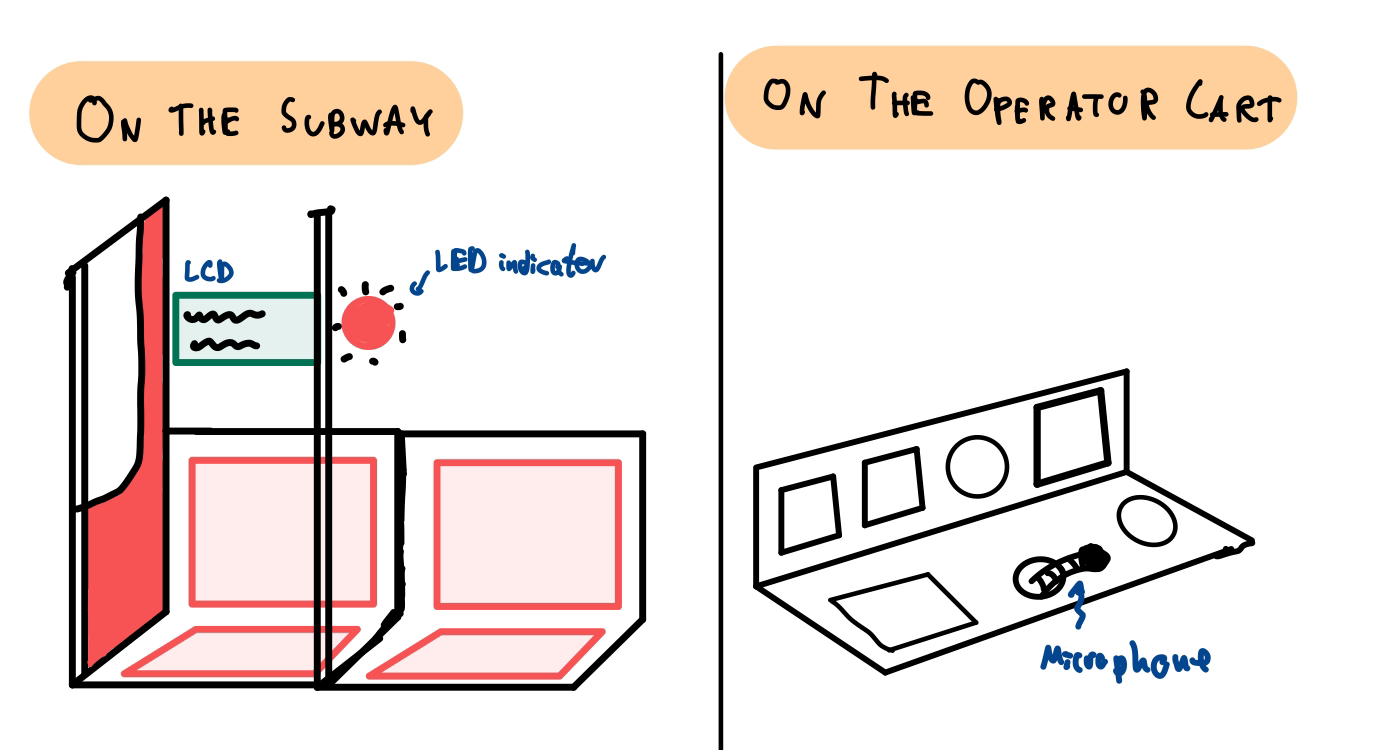
Temperature

When working with electronics, they should be stored at adequate temperatures. For example, the STM32 Nucleo board has an ambient temperature rating of –40 to +85 °C /–40 to +105 °C [36]. Therefore, it is very important to the project’s safety that the board is not being stored in such a way that these extreme temperatures can arise. Temperatures like these can cause components to malfunction and may cause certain components to heat up, creating fire and burn hazards.

# 2.0 - Analysis

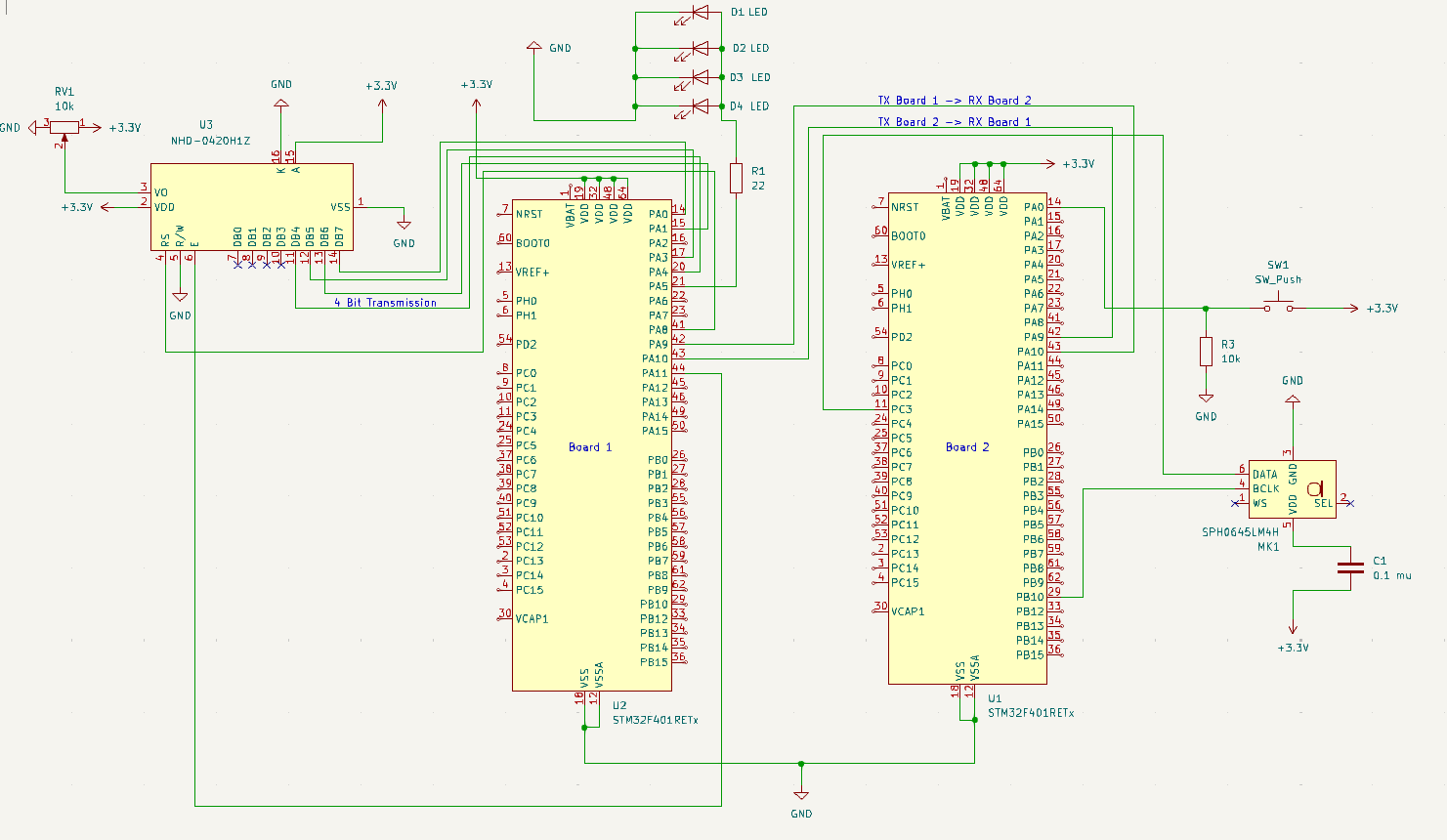
## 2.1 - Design

### 2.1.1 - Diagrams (High Level, Schematic, Wiring)



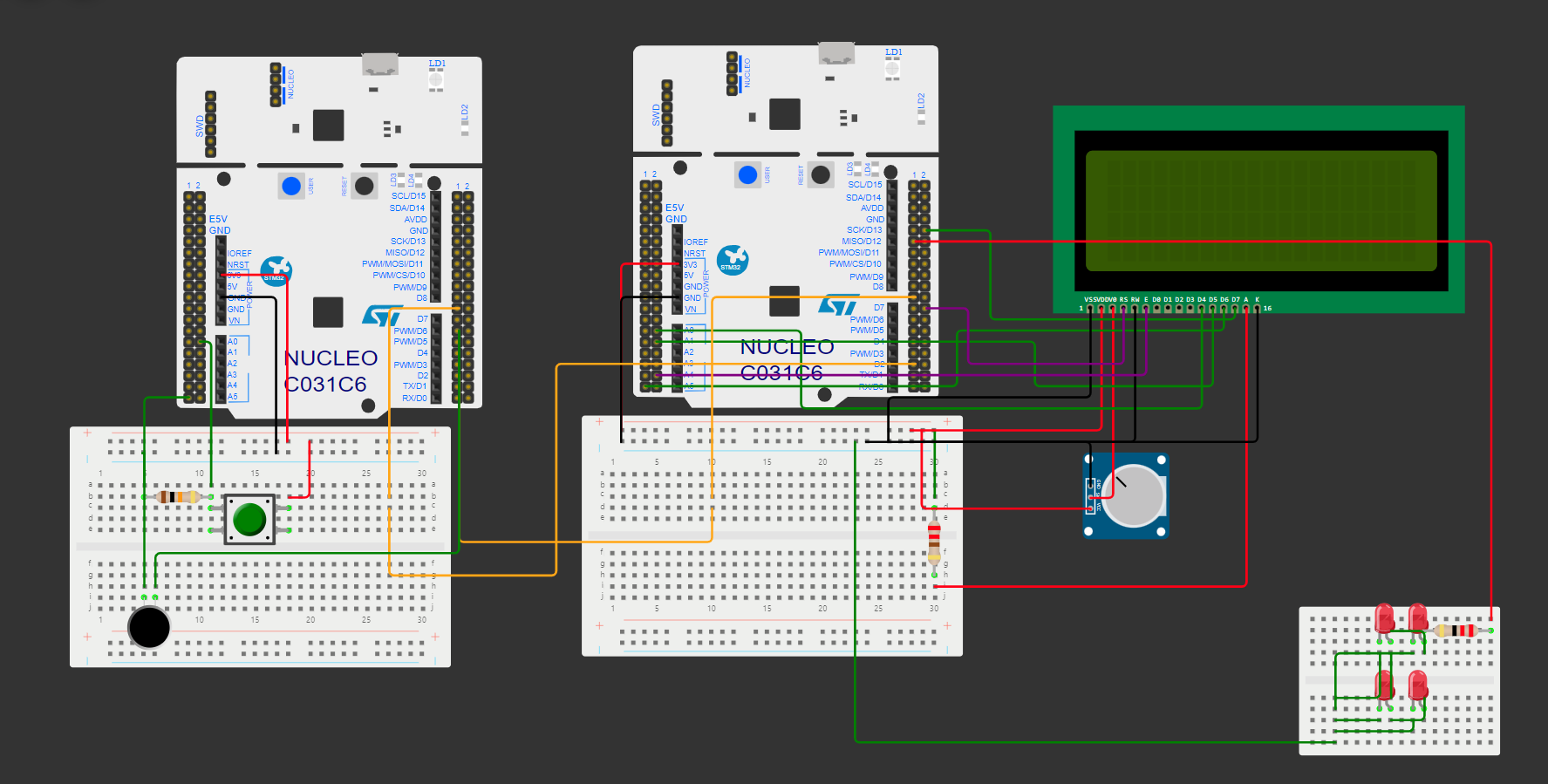
*Figure 2.1.1 - High diagram of the system in work*

This shows the placement of the LCD display and LED indicator in the subway car. The LED will alert passengers when a new announcement is posted on the LCD. This way if deaf passengers are distracted, they will be alerted by a pulsing LED.



*Figure 2.1.2 - Schematic of Setup*

The schematic lays out the connections for UART, microphone setup, button control, pull-down resistor for PA0, LED with resistor, and decoupling capacitor. For resistors, if the value is not stated, it is assumed to be in ohms, and for capacitors it is farads. Each connection is also clearly labeled to match the required GPIO pins on the STM32 boards. Note: The final wiring may look different, but this gives a low-level overview of the connections.



*Figure 2.1.3 - Wiring diagram of design*

This high-level diagram shows the components on breadboards, making it easy to see how each element—such as the two STM32 boards, LCD, button, and microphone—is connected in the final setup. Notice that the microphone used is wired differently, as the exact model being used was unavailable in the software in use. The component should comprise four more pins with GND, VDD, WS, and SEL with only the former two in use. In the final product, the wires would be hidden and soldered together (similar to Figure 2.1.1), but for the demo, the wiring will look similar to Figure 2.1.3.

### 2.1.2 - UART Transmission

The primary method of communication between the two STM32 boards is USART1. Here, PA9 (TX) from one board connects to PA10 (RX) on the other, and vice versa. This setup allows bidirectional communication, crucial for transferring audio data as well as control signals. As shown in the schematic diagram, the boards are effectively “listening” and “talking” to each other across this UART line, ensuring data is consistent on both ends.

Below is some pseudo code (UART algorithm):

If announcement to send:

Board 2: Prepare message (string)

Board 2: Send message (string) to board 1

Board 1: Receive message (string)

Else

Do nothing

### 2.1.3 - Microphone (Board 2 Only)

#### Button 1: Service Disruption Alert

* Message: "Attention: Service delay ahead. Please expect extended wait times."
* Purpose: Provides timely updates on unexpected service interruptions, ensuring passengers are informed of delays or changes.

#### Button 2: Emergency Announcement

* Message: "Emergency: Please evacuate the train at the next station calmly and follow instructions."
* Purpose: Addresses critical situations like fires, medical emergencies, or security threats, ensuring passenger safety.

#### Button 3: Route Adjustment Information

* Message: "This train will not stop at Broadview Station. Please plan your route accordingly."
* Purpose: Informs passengers of station-specific service adjustments (e.g., skipped stops) to help them plan their journey.

#### Button 4: Next Stop Information

* Message: "Next Stop: Greenwood Station. Prepare to disembark."
* Purpose: Keeps passengers updated about the train's location and next destination, aiding navigation and preventing confusion.

Coding this is pretty straight forward:

If PA pin associated with button is HIHG:

Transmit character array associated with button

### 2.1.5 - LED Indicator

The LED indicator is a simple but essential visual cue. Connected via a 220 ohm resistor to prevent burnout, the LED turns on when a message is being displayed. The schematic shows the LED setup on PA5, which is toggled HIGH or LOW depending on the button press. This LED signals to passengers that new information is being displayed on the LCD screen. Below is an expansion on the code from 2.1.2.

If LED pressed:

Board 2 signals board 1 to turn on LED (Run UART Transmission Code)

Pulsate LED in 3-second intervals

Else

Do nothing

### 2.1.6 - LCD Display (On Subway)

For the passenger area, an LCD (due to its price and functionality) will be used to show the transcribed announcements. However, for the demo, a smaller LCD will be used, a 2004 LCD. The display operates in 4-bit mode to conserve GPIO pins. Pins DB4 to DB7 are connected to PA4 to PA7, effectively transmitting data in smaller chunks. A potentiometer is connected to V0 to adjust the LCD’s contrast, as illustrated in the wiring diagram. This can be replaced with a resistor, depending on the manufacturer's preferences. The LCD receives the transcribed announcement data from UART and updates it in real time. Below is some pseudocode:

If new message from UART:

Wait 3 seconds

Clear screen

Set cursor to start of the next line

Print message

### 2.1.7 - Full Code Overview

This section will try creating a pseudocode outline for the actual code of the project.

Initialize system

Set Announcement to False

Loop:

If Button Pressed:

Identify which Button is Pressed

Map Button Press to Pre-loaded Announcement

Send Announcement to Board 1 via UART

Set Announcement to True

On Board 1:

Pulsate LED every 3 seconds

Display Announcement on LCD

Wait 10 seconds

Clear LCD

Set Announcement to False

End If

# 2.2 - Technical Analysis

## 2.2.1 - Ohm’s Law

When working with currents we must apply Ohm’s law which describes the relationship between current, voltage and resistance. The formula for Ohm’s law is Voltage = Current x Resistance [17].

By applying the correct amount of charge given the resistance in the circuit, Ohm’s law will be used to ensure functionality and safety when designing the electrical circuits used in our design so they can handle the expected current and voltage. It will also help us ensure that the system works under a certain voltage, as the parts used in the design have various voltages they operate in, such as the STM32 board which works on voltages of 1.8-3.6 V [18]. Therefore, the entire system will ideally operate at 3.3 Volts, with a power bank or some source powering the stm32 board via micro-USB. In the design, specifically Figure 2.1.2, Ohm’s law was applied multiple times:

* For the four LEDs, each LED has a rating of 20 mA, since there are 4, the sum of the currents is 0.08 A [19]. By Ohm’s Law, the resistance is 16.25 ohms ((3.3 V - 2 V)/(0.08)). The 2 V comes from the fact that LEDs have a forward voltage of 2 V, so the voltage drop will be 3.3 V - 2 V [19]. Other components had similar calculations done on them. The pull-down resistor (R3) has a value of 10k, as it is a common value for pull-down resistors for low voltages [20].

## 2.2.2 - P = IV

To ensure system efficiency, the total power consumption of all components is calculated. Power (P) is determined as the product of voltage (V) and current (I) [21].

STM32 microcontroller: V = 3.3 V, I = 50 mA → P = 3.3 × 0.05 = 0.165 W.

LED: V = 2.0 V, I = 5.91 mA → P = 2.0 × 0.00591 = 0.01182 W.

Adding up all components ensures that the system stays below the safety limit of 30 W.

## 2.2.3 - UART Communication

UART (Universal Asynchronous Receiver-Transmitter) is a widely used protocol for serial communication. Unlike synchronous methods (e.g., SPI, I2C), UART transmits data as individual bits over a single communication line without requiring a clock signal. The "asynchronous" nature simplifies wiring but demands precise timing. Key scientific concepts include:

Baud Rate Synchronization: Both transmitting and receiving devices must operate at the same baud rate (e.x., 9600 bps). Data integrity depends on accurate timing of each bit's start and stop.

Voltage Levels: UART typically operates at TTL (Transistor-Transistor Logic) levels (0 V for LOW, 3.3 V for HIGH). Signal stability is essential to avoid data corruption during transmission, verified via oscilloscopes.

Error Detection: UART uses stop bits and optional parity bits to detect transmission errors. These redundancies minimize data loss in noisy environments [45].

# 2.3 - Design Alternatives

## 2.3.1 - Morph Chart

| Function | Option 1 | Option 2 | Option 3 |
| --- | --- | --- | --- |
| Microcontroller Communication | UART | I2C | SPI |
| Display Tech | LCD | OLED | 7-Segment Display |
|  |  |  |  |
| LED Colour | Red | Orange | Yellow |

Displays:

OLED displays were initially considered for their greater visibility with high brightness and contrast. However, the reason they were not picked was due to their high power requirements, with the minimum voltage being 3 V, and the typical being 5 V {25]. Since the system is running at 3.3 V, the display was not picked. The 7-segment display is better at displaying words, rather than phrases or announcements, therefore it was not picked.

The overarching reason both displays were not picked was due to their high pricing, compared to LCD, and since the plan is to have multiple display systems in one subway cart, it makes sense to go for the cheaper version.

LED Colour

For reasons stated in section 1, the red LED was picked.

Microcontroller Communication

SPI requires more pins—four lines (MOSI, MISO, SCK, and SS)—which can be challenging in a setup where pin availability is limited. Each additional device also requires a dedicated chip select (CS) line, further increasing pin usage [27]. I2C uses two wires (SCL and SDA) for data and clock signals, allowing multiple devices to connect on the same bus. However, this requires each device to have a unique address and additional logic to manage multiple devices on the same line, adding unnecessary complexity if only two devices are communicating [27]. Therefore, UART was picked due to its simplicity, reliability and lower power needs.

# 3.0 - Costs

## 3.1 - Bill of Materials

DigiKey location[28]

Information about component identifier:

LED: [29]

Pushbutton:[30]

Potentiometer:[31]

220 ohm resistor [32]

10k ohm resistor[33]

Capacitor[34]

LCD[37]

Microphone[38]

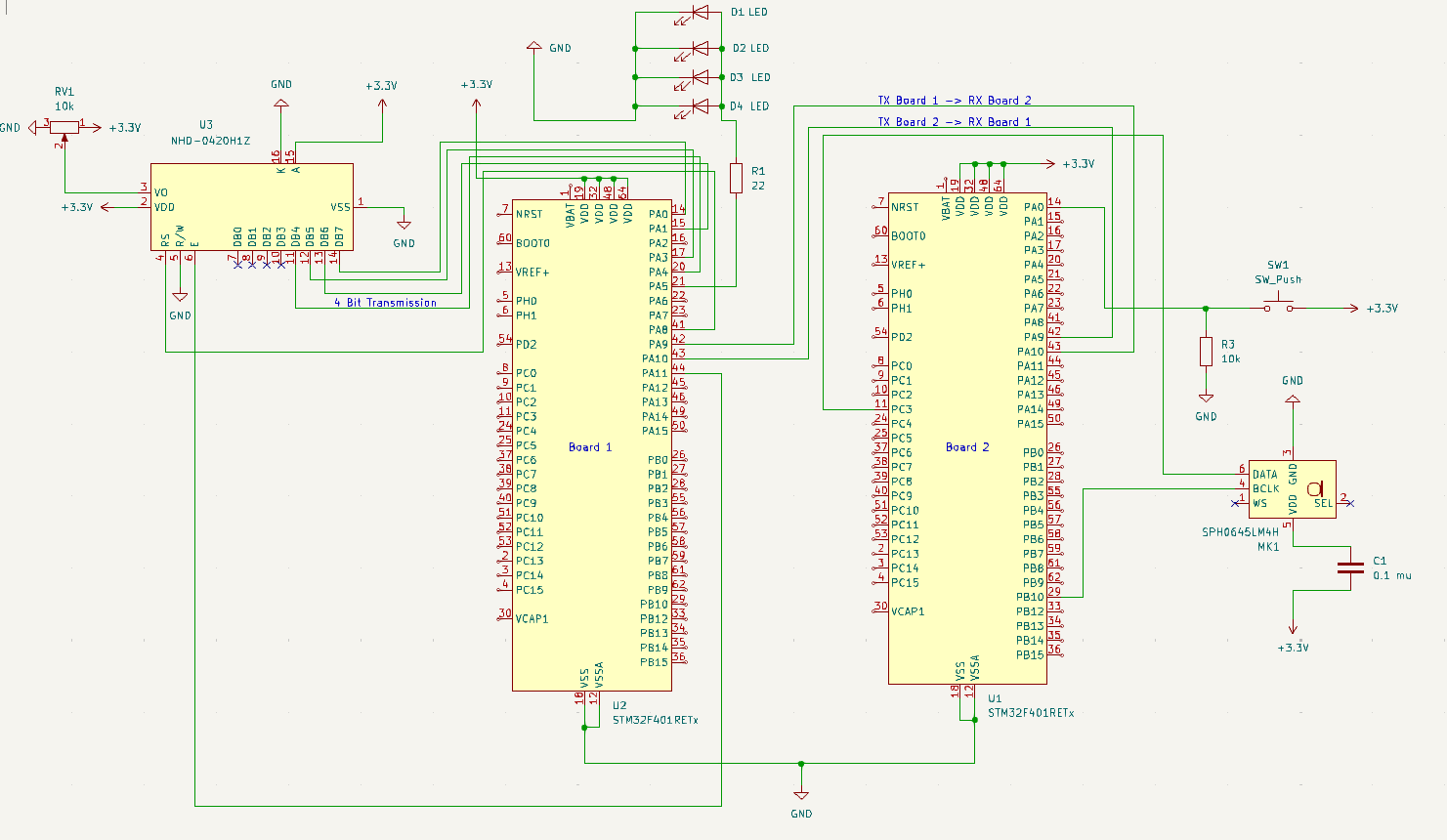
| Item No. | Quantity | Unit Cost | Manufacturer | distributor | Total Cost  (before tax) | Description |
| --- | --- | --- | --- | --- | --- | --- |
| RED LED | 4 | 0.28 | 121 Airport Drive 57201 Watertown United States( Würth Elektronik) | Thief River Falls, Minnesota, USA(digikey) | 1.12 | Round with Domed Top, 3.00mm Dia, 2.2V, 20mA, color is red |
| Push button | 1 | 1.49 | [6333 Dry Creek Parkway, Niwot, CO 80503](https://www.bing.com/ck/a?!&&p=6b22c6a6760d68c5a4fefaf78fa8117c0150cd34266f31671c8ccc23407e4793JmltdHM9MTczMDE2MDAwMA&ptn=3&ver=2&hsh=4&fclid=21ceedd7-7806-62a3-1185-ff947980632d&u=a1L21hcHM_Jm1lcGk9MTM0fn5Vbmtub3dufkFkZHJlc3NfTGluayZ0eT0xOCZxPVNwYXJrRnVuJTIwRWxlY3Ryb25pY3Mmc3M9eXBpZC5ZTjEzOXgxODk4MTYyODEmcHBvaXM9NDAuMDkwNjE0MzE4ODQ3NjU2Xy0xMDUuMTg0NzYxMDQ3MzYzMjhfU3BhcmtGdW4lMjBFbGVjdHJvbmljc19ZTjEzOXgxODk4MTYyODF-JmNwPTQwLjA5MDYxNH4tMTA1LjE4NDc2MSZ2PTImc1Y9MSZGT1JNPU1QU1JQTA&ntb=1) (SparkFun) | Thief River Falls, Minnesota, USA(Digikey) | 1.49 | SPST-NO, Off-Mom, 500mA, 250 V, Round, Button |
| 10k potentiometer | 1 | 8.9 | 2108 Century Way Boise, ID 83709(CTS Electrocomponents) | Thief River Falls, Minnesota, USA(Digikey) | 8.9 | Resistance:10k  Tolerance: ±20%, Power (Watts): 5W. |
| 220 ohm Resistors | 2 | 3.81 | 48 Lesmill Rd, North York ON M3B 2T5(Vishay) | 137 Glasgow Street, Unit 475 A, Kitchener ON N2G(Mouser Electronics) | 7.62 | Wirewound Resistors - Through Hole 10 watt 220 ohms |
| 10k Resistor | 1 | 0.16 | 3110 Edwards Mill Rd Ste 207, Raleigh, NC 27612(Stackpole Electronics Inc) | Thief River Falls, Minnesota, USA(Digikey) | 0.16 | Resistance  10 kOhms:  Tolerance:  ±5%  Power (Watts):  0.25W, 1/4W |
| 0.1 farad Capacitor | 1 | 0.3 | 6333 Dry Creek Parkway, Niwot, CO 80503 (SparkFun) | 6333 Dry Creek Parkway, Niwot, CO 80503 (SparkFun) | 0.3 | This is a very common 0.1uF capacitor. Used on all sorts of applications to decouple ICs from power supplies. 0.1" spaced leads make this a perfect candidate for breadboarding and perf boarding. Rated at 50V. |
| STM32 Nucleo Board | 2 | 46.1 | STMicroelectronics (110 Erb St W, Waterloo ON N2L 0C6) | W store(200 University Ave W, Waterloo ON N2L 3G1) | 92.3 | Development Boards & Kits - ARM Nucleo Board STM32F4 STM32F401RE 512K |
| LCD | 1 | 31.4 | 2661 Galvin Ct, Elgin, IL 60124(Newhaven Display Intl ) | Thief River Falls, Minnesota, USA(digikey) | 31.4 | Character Display Module Transflective 5 x 8 Dots STN - Super-Twisted Nematic LED - White Parallel 79.00mm x 36.00mm x 13.00mm |
|  |  |  |  |  |  |  |

Total cost = 165.17 (after tax)

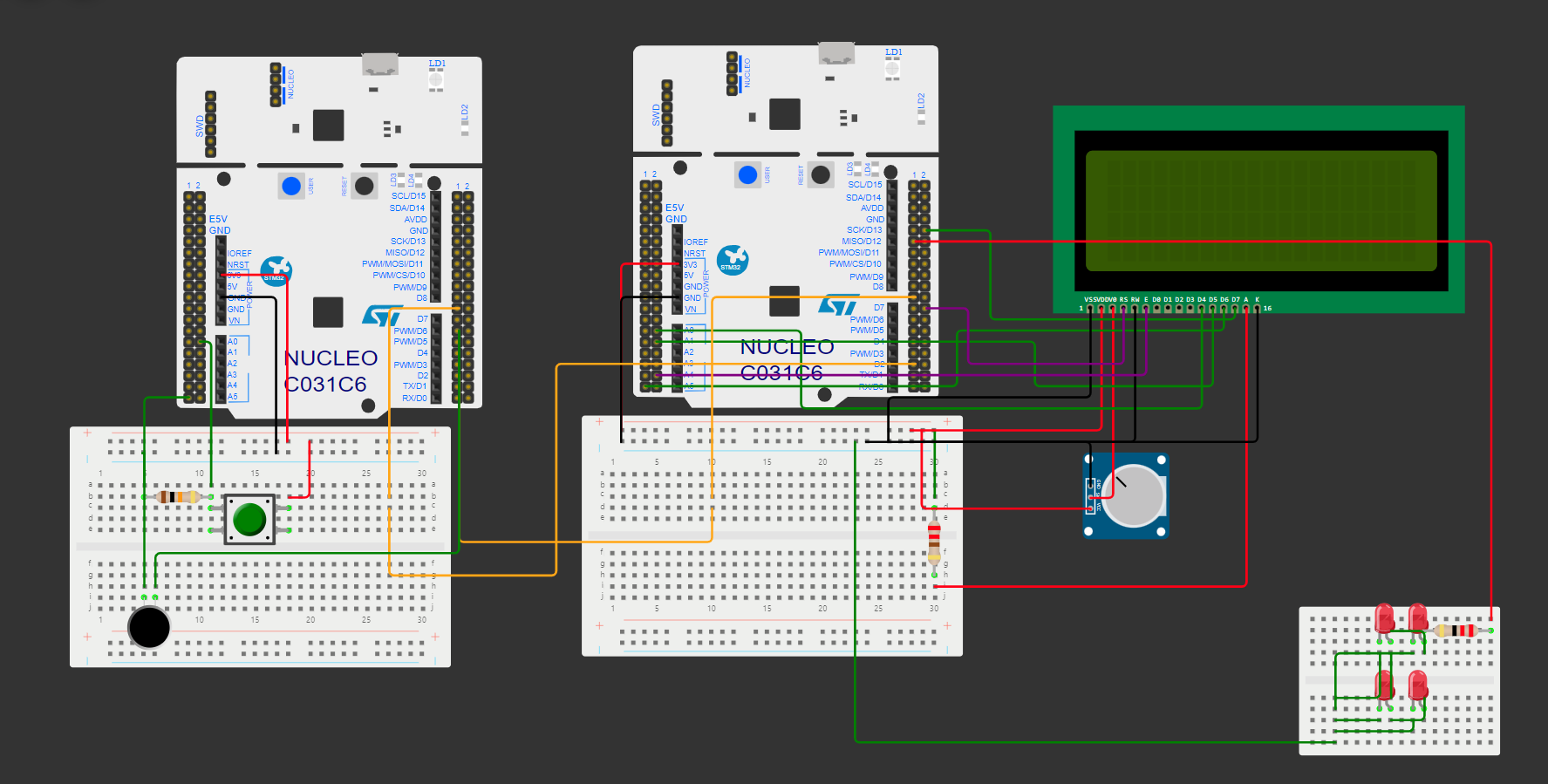
## 3.2 - Installation Manual and User Guide

## 3.2.1. Installation Instruction

1. Wire Connection: Use wire to connect our project with the microphone and place it on a smooth wall or surface (as shown in Figures 2.1.2 and 2.1.3.
2. Protect Device: Ensure the device is placed on a smooth surface and has been isolated from water sources by checking the surroundings.
3. Install Safely: Make sure to wear appropriate gear, safety gloves and eye protection.
4. Regular Inspection and Maintenance: Please inspect the device regulation so the danger can be overseen and accidents can be avoided.



*Figure 2.1.2 - Schematic Reestated*



*Figure 2.1.3 - Wiring diagram of design Restated*

## 3.2.2. Usage Instructions

1. Power up the system: Connect the STM32 Nucleo boards to a power source via USB (ex: power bank).
2. Press the button: This activates the microphone and begins the recording process.
3. Transcription process: The system captures audio, processes it, and sends the text to Board 1.
4. Display announcement: Board 1 updates the LCD with the announcement and lights up the LED indicator.

## 3.2.3. Troubleshooting

* No display on LCD: Check connections to the LCD and ensure power is supplied.
* LED not pulsating: Verify the connection and resistance value of the LED.
* Audio not captured: Ensure the push button is pressed to power the microphone.
* UART communication issues: Double-check the TX and RX connections between the two boards.

# 4.0 - Risks

## 4.1 - Energy Analysis

### 4.1.1 - Baseline Power Levels & Reference Standard:

The STM32 board will have power supplied directly to it by a power bank for the demo and some power source in practice. The board will output a baseline power level of 3.3 V [18]. While the system is idle, it produces a current around 6-10mA which results in 0.0198-0.0330W [18]. While the system is active, it produces a current around 25-50mA, which results in 0.0825-0.1650W [18]. At no point in time does the device consume, transfer, discharge, or expend more than 30W. The analysis uses the STM32 reference manual as its reference standard for this design.

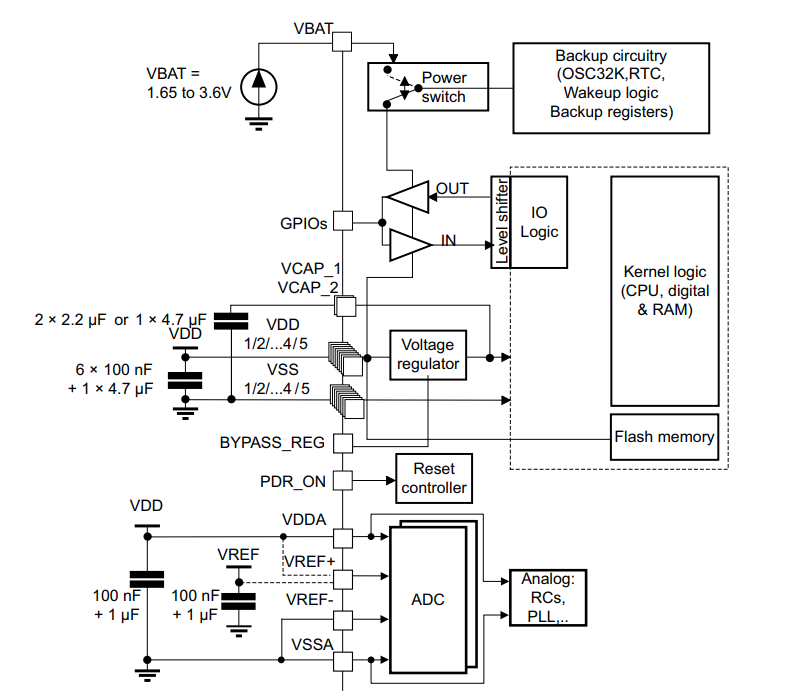
### 4.1.2 - Significant Energy Storage

Given the low voltage and current levels, energy buildup is not expected under normal operating conditions​. The only potential energy storage elements are the decoupling capacitors, such as the 0.1µF capacitor used with the MEMS microphone for noise reduction. However, the capacitance values are too small to store substantial energy that could pose a safety hazard. Using

We find that the energy from the capacitor would be 0.5445 microjoules, which would not be above the threshold set by the project (500 J).

### 4.1.3 - Total Energy Storage

Again, besides the one capacitor, there is not really any other energy storage happening, There may be some energy storage happening within the STM32 board itself, as an example Figure 4.1.3.1 shows the power supply scheme of the board:



*Figure 4.1.3.1 - Power supply scheme of the STM32 board*

Calculating the sum of the energies with the formula used above for the capacitors, we get 0.69 millijoules, which is still less than the required cap of 500. Therefore, the design meets all criteria.

## 4.2 - Risk Analysis

Possible negative consequences on safety or the environment from using the design as intended

* There are very few possible safety issues regarding the correct or incorrect use of the device because every component is stationary and implemented into the subway.
* Device operates at low voltages and is energy efficient, but scaled across multiple carts, the device may require more power, and so it might be worth being careful with wiring, since they will have more volts running through them.
* If the LED is pulsing at an unintended frequency it may affect passengers with past history of epilepsy or conditions of similar order.

Possible negative consequences on safety or the environment from using the design incorrectly?

* If improperly handled or tampered with, physical damage to components (e.g., removing or exposing internal wiring) could lead to minor electrical shocks, though the system operates at low voltage.
* Incorrect use may disrupt the LCD’s visibility or accuracy, leading to confusion among passengers due to inaccurate or missing transit info.

Possible negative consequences on safety or the environment from misusing the design or using it in a manner that was not intended:

* There may be a small case of a small shock if wires are tampered with.
* Certain small components may pollute the environment if the design was broken by passengers
* Possibility of theft of components, compromising deaf transit goers.

Possible ways that the design could malfunction

* If the device were to malfunction, it could overheat and cause damage to people nearby, the LCD could turn off or stop displaying the correct information which may lead to confusion. The red LED light or the LCD could flash rapidly, possibly causing issues for people with epilepsy, the push button could cause an electric shock for the operator or not respond.

The consequences on safety or the environment for each of the failure mechanisms specified

* If passengers miss important announcements, this may affect safety in navigation.
* The epilepsy issue could be severe, since the subway operates underground, and immediate medical assistance may not be available
* If the button is unresponsive, important announcements may not be displayed.
* Overheating of certain components may cause minor burns and if electrical components break off, may pollute the environment too.

# 5.0 - Testing and Validation

For every single test, the input voltage will be 3.3 V, and the test environment will be in typical indoor conditions, as it will be at the University of Waterloo. The power source will be a simple power bank. There are no significant environmental parameters for the test, as the device will be bolted onto a wall in actual practice.

## 5.1 - Button Input Test

Test Inputs: Press each button 5 times in quick succession (less than 1-second intervals).

Quantifiable Measurable Standard: Verify stability of button signal using an oscilloscope and check corresponding data transmission to Board 1.

Pass/Fail Criteria: Each button press must result in exactly one transmitted message corresponding to the correct announcement. No missed or extra signals allowed.

## 5.2 - LED Brightness Indicator Test

Test Input: Input will be a button press hold for 30 seconds with no audio being inputted, i.e. 3.3 V.

Quantifiable Measurable Standard: Lux (Luxmeter), forward voltage (Multimeter), pulse interval (Stopwatch)

Pass/Fail Criteria:

The LED of the device must have optimal visibility in a subway setting. To pass this test the LEDs must:

* Achieve 50 lux from a distance of one meter, measured using a lux meter
* Ensure the forward voltage is 2 volts
* Must pulse in 3-second intervals

## 5.3 - LCD Visibility Test

Test Input: The input speech will be “Train will not be making a stop at Woodbine station”

Quantifiable Measurable Standard: Block of text display time (Stopwatch), the brightness of the display (Luxmeter)

Pass /Fail Criteria:

* The LCD should present clear text from a distance of 2 meters.
* Each block of text should be displayed for 10 seconds
* The display should have a brightness of 250-300 nits, again to measure this a lux meter will be used

## 5.4 - Filter Test

Test Input: Play a pre-recorded audio sample containing subway announcements mixed with low-frequency background noise.

Quantifiable Measurable Standard: Frequency response and clarity. Use an oscilloscope to observe the output waveform before and after applying the high-pass filter. Look for reduced amplitude in the lower frequencies (below 500 Hz) and preservation in the speech range (500 Hz - 8 kHz).

Pass/Fail Criteria: The low-frequency noise (below 500 Hz) should be visibly attenuated by at least 50%, while the audio signal in the speech frequency range remains clear.

## 5.2 - Announcement Display Test

Test Inputs: Press each button to trigger announcements stored in memory.  
Quantifiable Measurable Standard: Compare displayed text with pre-loaded announcements.  
Pass/Fail Criteria: Announcements must match preloaded text 100%.

## 5.6 - UART Transmission Test

Test Input: Transfer an array of 150 chars from board 2 to board 1.

Quantifiable Measurable Standard: Transmission accuracy, Voltage Levels (Oscilloscope)

Pass/Fail Criteria:

* The accuracy of transmitted data must be above 90%
* Consistent voltage changes on TX and RX pins with expected 3.3V and levels throughout transmission, with data observed at both ends (TX waveform is mirrored in RX waveform).

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