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**Claims-Investigation Committee (CIC)
Multi-Input Testing Device**

FINAL REPORT



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1 Abstract

This senior design project developed a comprehensive testing platform for ZF Group's automotive sensor validation, focusing on the Brake Signal Transmitter (BST) and related safety components. The system utilizes a dual-core STM32MP157F-DK2 microcontroller, combining an ARM Cortex-M4 for real-time signal processing with an ARM Cortex-A7 running a custom embedded Linux distribution for test management and user interaction.

The platform features a WebAssembly-based frontend interfacing with a Rust web server, enabling intuitive test configuration and real-time result monitoring. OpenAMP facilitates inter-processor communication between the Cortex-A7 and M4 cores, allowing seamless data transfer between the test execution and management layers. The system validates various automotive sensors against manufacturer specifications, providing automated test execution and detailed reporting capabilities through CSV export.

This solution significantly improves testing efficiency compared to existing methods, offering a scalable architecture that supports multiple device types including the BST, Continuous Wear Sensor, and Electronic Stability Control Module. Built with industry-standard technologies and professional engineering practices, the system demonstrates innovative integration of embedded systems, web technologies, and real-time processing for industrial testing applications.

2 Introduction

The Claims Investigation Committee Multi-Testing Input Device automates validation testing for ZF Group's automotive safety sensors. Built on the STM32MP157F-DK2 platform, it combines an ARM Cortex-M4 for real-time signal processing with a Cortex-A7 running custom embedded Linux for test management.

The system features a WebAssembly frontend with a Rust backend, using OpenAMP

for inter-processor communication. It processes PWM signals, analog inputs, and CAN communications to validate devices against manufacturer specifications. While primarily focused on Brake Signal Transmitter (BST) testing, the platform supports additional devices including Continuous Wear Sensors and Electronic Stability Control Modules.

This automated solution improves testing efficiency and consistency while maintaining automotive industry standards. Test results are available through CSV export, enabling detailed analysis and documentation of validation procedures.

3 Discussion

3.1 Background

ZF Group, a global Tier 1 automotive supplier specializing in advanced safety systems, identified a need to enhance their Claims Investigation Center's (CIC) testing capabilities. Based at their North American headquarters in Auburn Hills, MI, the CIC analyzes field failure parts and validates warranty claims for commercial vehicles.

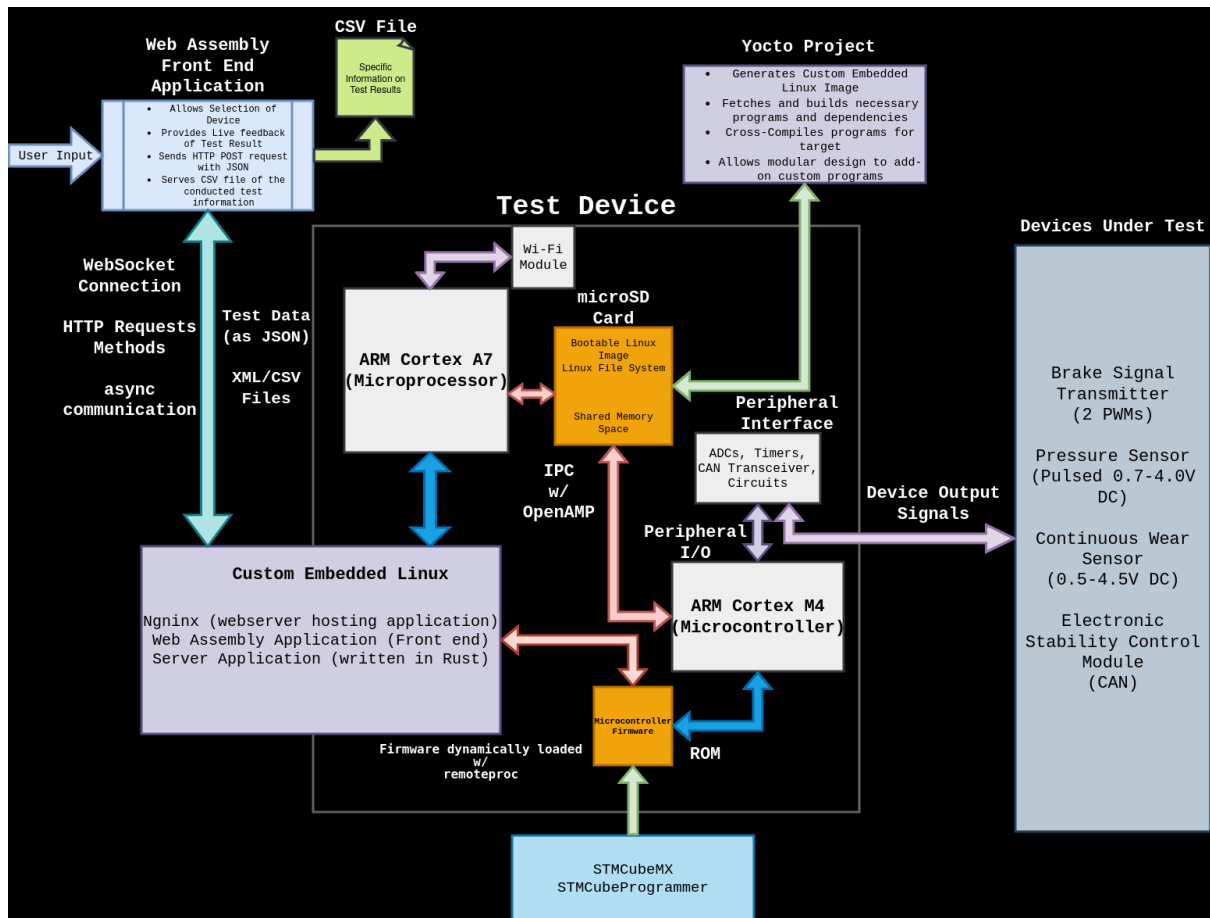
Our project addresses this need by developing an automated testing platform that streamlines the validation process for returned components. The system focuses particularly on safety-critical parts like the Brake Signal Transmitter, supporting the CIC's mission of efficient warranty claim processing and product quality improvement.

3.2 Need Statement

ZF Group urgently requires a modernized testing platform to address critical limitations in their current validation system. The existing mBSP tester is incompatible with new components, cannot support prototype testing, and creates significant delays in product validation. With Daimler's new platform implementation and increasing production volumes, ZF needs a flexible, unified testing solution that can efficiently validate multiple safety-critical com-

ponents while reducing testing time and costs. This system must support both current and future product lines while maintaining rigorous testing standards for warranty claim validation.

3.3 High-Level System Design



3.4 Specifications

1. Device Interfacing

1.1 Properly read Device Signals using the ARM Cortex-M4 on the onboard microcontroller on the STM32MP157F-DK2

- PWM duty cycle

- Frequency
- Voltages through an analog-to-digital converter (ADC)
- CAN frames

2. Physical Components and Hardware

2.1 Printed Circuit Board (PCB) for interfacing with DUT

2.2 PCB for scaling and managing power for the DUT and to the microcontroller

2.3 Enclosure for PCBs and STM32MP157F-DK2 board

3. Software

3.1 Custom embedded Linux distribution that will run on the onboard ARM Cortex-A7 microprocessor on the STM32MP157F-DK2

3.2 Simple user interface on web-based application

3.3 Custom Webserver to process information from web application to microcontroller

3.4 Communicate collected information from ARM Cortex-M4 to ARM Cortex-A7

3.5 Ability to download measured data, formatted as a CSV, through the web application

3.5 Deliverables

The hardware component centers around custom circuit designs, featuring **two specialized printed circuit boards**: a power management PCB that handles voltage conversion and regulation, and a peripheral interface PCB that manages signal routing and conditioning. Supporting these boards are **protective enclosures** designed to house both the PCBs and the STM32MP157F-DK2 development board, along with a comprehensive **wiring harness system** for reliable device connections.

The software architecture comprises multiple integrated components. At its foundation lies a **custom embedded Linux distribution** built using the Yocto Project, which provides the operating system environment. User interaction is handled through a **WebAssembly-based frontend interface** that enables device selection and test control. A **Rust-based web server** manages device communication and test execution. The system includes specialized **ARM Cortex-M4 firmware** modules for testing various devices: the Brake Signal Transmitter (BST) through PWM signal analysis, the Continuous Wear Sensor (CWS) via voltage measurements, pressure sensor validation, and Electronic Stability Control Module (ESCM) testing through CAN communication.

The testing and documentation deliverables ensure system validation and future maintainability. These include comprehensive **validation test results** demonstrating compliance with manufacturer specifications, a **CSV data export system** for maintaining test records, detailed **technical documentation** covering system operation procedures, and organized **source code repositories** with thorough documentation to support future maintenance and upgrades. Together, these components form a unified testing platform capable of handling multiple automotive sensor types while maintaining strict compliance with ZF Group's testing requirements.

4 Design and Implementation

4.1 Devices Under Test (DUT)

The Claims Investigation Committee's testing platform is designed to validate multiple critical automotive safety components from ZF's commercial vehicle braking systems. These devices represent key components in the braking system's safety chain, each serving specific functions that together, ensure reliable and safe vehicle operation.

The testing platform currently supports four devices: the Brake Signal Transmitter (BST),

Continuous Wear Sensor (CWS), Electronic Stability Control Module (ESCM), and a Pressure Sensor. Each device requires unique testing approaches due to their distinct communication protocols and operational parameters. Understanding these devices' functions and manufacturer specifications is crucial for implementing accurate testing procedures.

4.1.1 Brake Signal Transmitter (BST)

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4.1.2 Brake Signal Transmitter (BST)

The Brake Signal Transmitter (BST) is a critical component in ZF's commercial vehicle braking systems, providing real-time brake status information to the vehicle's Electronic Control Unit (ECU). The Brake Signal Transmitter generates the electrical and pneumatic signals that represent the braking demand of the driver within the modular Braking System 2.0 (mBSP 2.0) Electronic Brake System (EBS). The device has a single circuit pneumatic design and contains two redundant pedal stroke sensors and a switch that is only used in European design. To reduce the exhaust noise, the BST has a built-in silencer. The BST is actuated by a foot pedal which is provided by the vehicle manufacturer (In this case specifically Daimler Trucks North America). Two Pulse Width Modulation (PWM) signals are generated by the

BST, as long as both signals are powered.

The BST's electrical architecture is designed for robust operation in commercial vehicle environments. The BST uses a contact system of HDSCS by TYCO (AMP MCP 1.5/2.8 MIX 7 - pole linear bayonet) for electrical connections. Operating on a nominal 12V DC system, the device maintains functionality across an 8V to 16V DC voltage range with built-in protection against reverse polarity and overvoltage conditions. Each PWM channel draws no more than 50 mA current, with total load capacitance limited to 6.8nF per channel. The output signals are similarly protected, with maximum current limited to 15 mA per channel, incorporating short-circuit protection and reverse polarity protection to prevent damage to the device or the vehicle's electrical system.

The core functionality of the BST centers on its stroke sensor characteristics, which generate two complementary PWM signals (S1 and S2) that precisely indicate brake pedal position. These signals operate at $200\text{Hz} \pm 10\text{Hz}$ and follow specific duty cycle relationships:

- Signal S1 initiates at 12.5% duty cycle when the brake pedal is at rest (0mm stroke), increasing linearly at 5.96% per millimeter of pedal stroke.
- Signal S2 initiates at 87.5% duty cycle when the brake pedal is at rest (0mm stroke), decreasing linearly at 5.96% per millimeter of pedal stroke.
- Both signals maintain $\pm 5\%$ duty cycle tolerance throughout the stroke range.
- The signals intersect at approximately 6.3mm pedal stroke, with both signals at 50% duty cycle.

The PWM signals are defined by several key parameters:

- Amplitude varying between U_{max} (determined by CCU pull-up voltage) and U_{min} ($<1\text{V}$)
- Period $T = 1/f$, where f is the 200Hz carrier frequency

- Duty cycle calculated as $DC = T_{\text{high}}/T_{\text{total}}$

To ensure reliable signal integrity, the BST interface requires specific loading conditions:

- Pull-up resistors: $4k\Omega \pm 1\%$ and $3k\Omega \pm 1\%$ to 12V
- Filtering capacitors: $2.2nF \pm 10\%$

The BST's implementation in Daimler's 2025 platform underscores the importance of accurate validation testing. As the highest volume commercial vehicle platform in North America, ensuring consistent and reliable BST operation is crucial for vehicle safety and warranty claim processing. This testing platform's ability to precisely measure PWM characteristics, timing relationships, and stroke correlations provides essential validation capabilities for both production quality assurance and field return analysis.

4.1.3 Continuous Wear Sensor (CWS)

4.1.4 Electronic Stability Control Module (ESCM)

4.1.5 Pressure Sensor

4.2 Custom Printed Circuit Board for Device Interfacing and Power Management

This project involved the development of schematic designs and custom PCBs to manage power supply and interface with various devices under test (DUTs) using KiCad. The designs were implemented to ensure stable power distribution and accurate signal processing for the DUTs, with specific focus on hardware efficiency and durability.

4.2.1 Power Supply Schematic Design

The power supply schematic begins with a 16V DC input, connected via a power jack, which acts as the main source of power for the system. 10uF and 22uF Capacitors are placed before

and after each voltage regulator to ensure a stable voltage level and filter out any electrical noise. These capacitors also prevent voltage fluctuations, ensuring a stable supply to the components.

Voltage Regulation

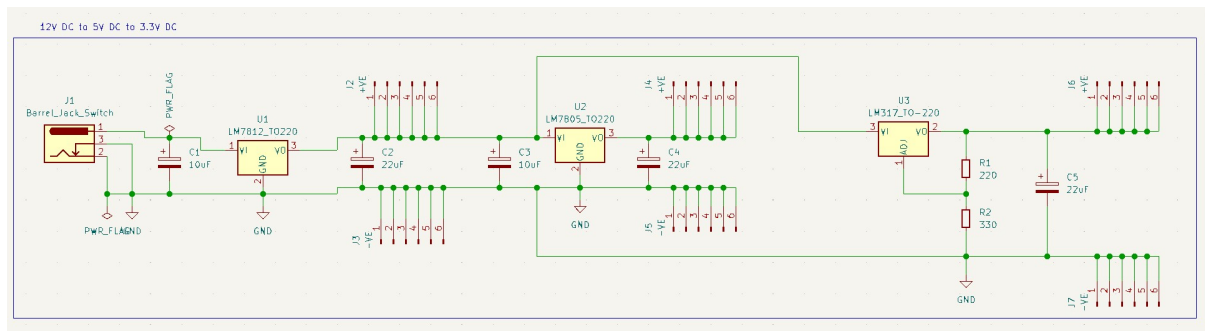


Figure 1: Schematic Design of the Power Supply Management System

- The LM7812 voltage regulator converts the 16V DC input to 12V DC.
 - The LM7805 voltage regulator further regulates the 12V DC to a 5V DC, suitable for devices that require low voltage.
 - The LM317 adjustable regulator is used to step down the voltage for the microcontroller, providing a stable 3.146V DC. This precise voltage is achieved by using a combination of 220-ohm and 330-ohm resistors, which set the voltage according to the parameters.
- This layered voltage regulation ensures that all peripherals and the microcontroller receive clean and safe power levels for proper operation.

4.2.2 Peripherals Schematic Design

The peripherals schematic shows the design and signal conditioning circuits for four Devices Under Test (DUT's): the Brake Signal Transmitter (BST), the Continuous Wear Sensor (CWS),

the Pressure Sensor, and the String Potentiometer. These circuits ensure accurate data acquisition and compatibility with the STM32 Board by conditioning, scaling and protecting the signals.

Brake Signal Transmitter

The Brake Signal Transmitter is designed to read the Pulse Width Modulation (PWM) signals, which represent the brake's operational state. The circuit includes resistors, such as 3k-ohms and 8.2k-ohms, to scale the PWM signals down to levels safe for the microcontroller. Additionally, a 2.2nF capacitor is used to filter out high-frequency noise, ensuring a clean and stable signal. 1N4001 diodes are included for overvoltage protection, safeguarding the microcontroller from potential voltage spikes.

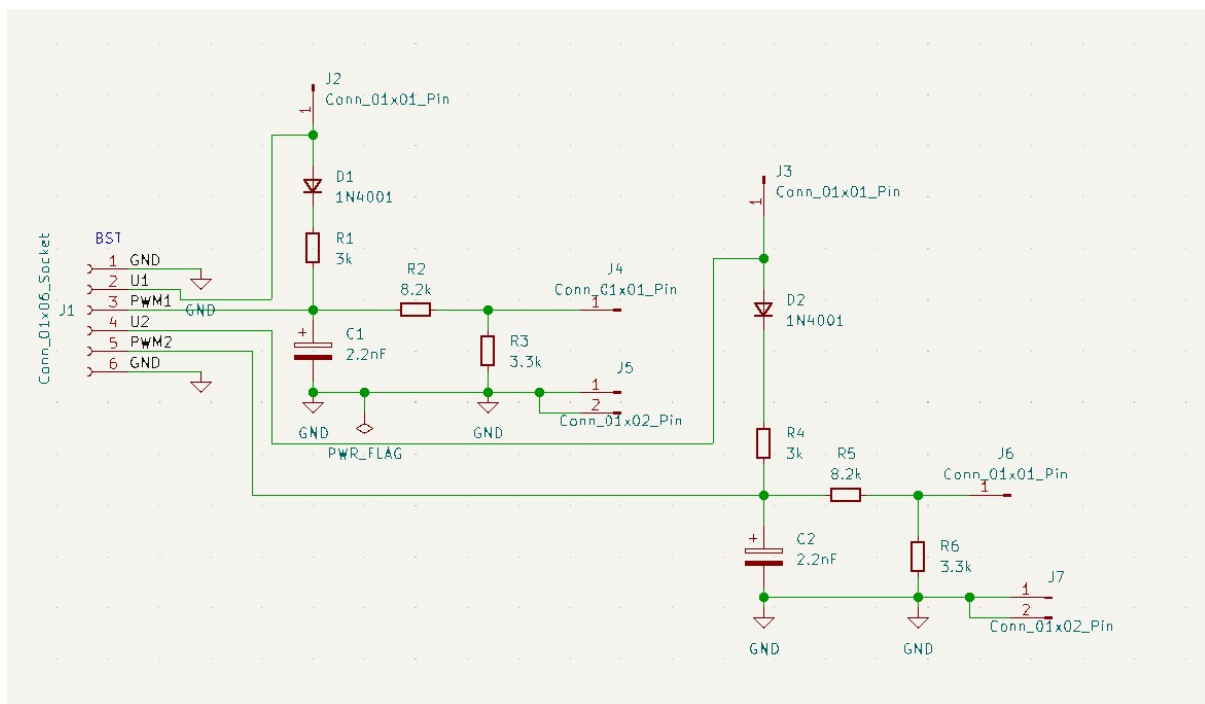


Figure 2: Schematic Design of the Brake Signal Transmitter

Continuous Wear Sensor

The Continuous Wear Sensor (CWS) captures analog voltage signals to monitor brake pad wear. This schematic is relatively simple but effective, using 3k-ohms resistors for signal scaling and stabilization. Proper grounding ensures that the integrity of the signal is minimized and maintain consistent readings.

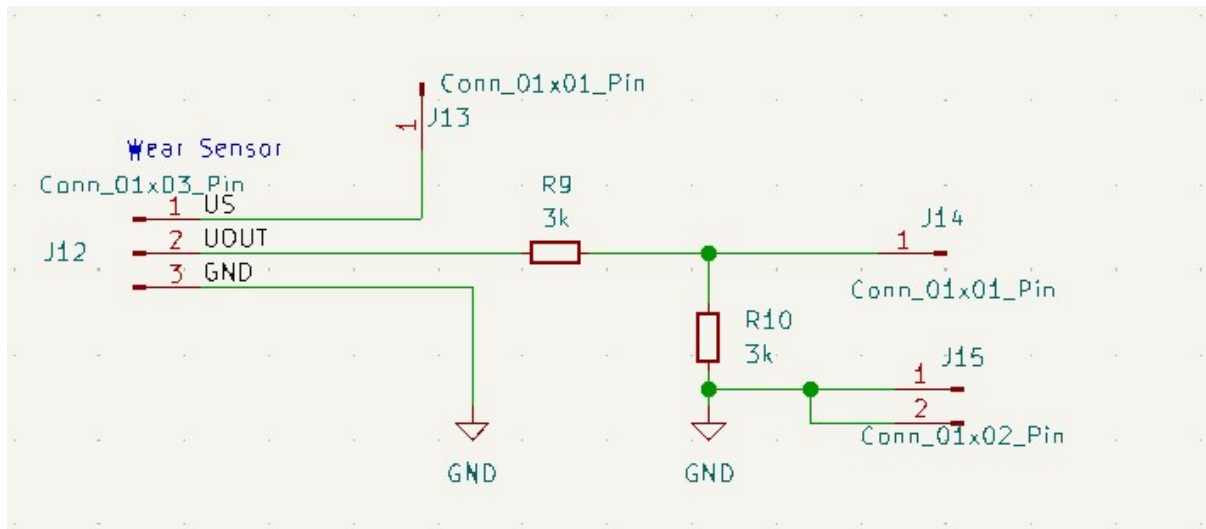


Figure 3: Schematic Design of the Continuous Wear Sensor

Pressure Sensor

The Pressure Sensor measures the pressure within the braking system. It outputs an analog voltage signal, which is conditioned using a 330uF capacitor to stabilize the output and eliminate fluctuations. Additionally, 3k-ohms resistors are used to scale and prepare the signal for processing by the microcontroller.

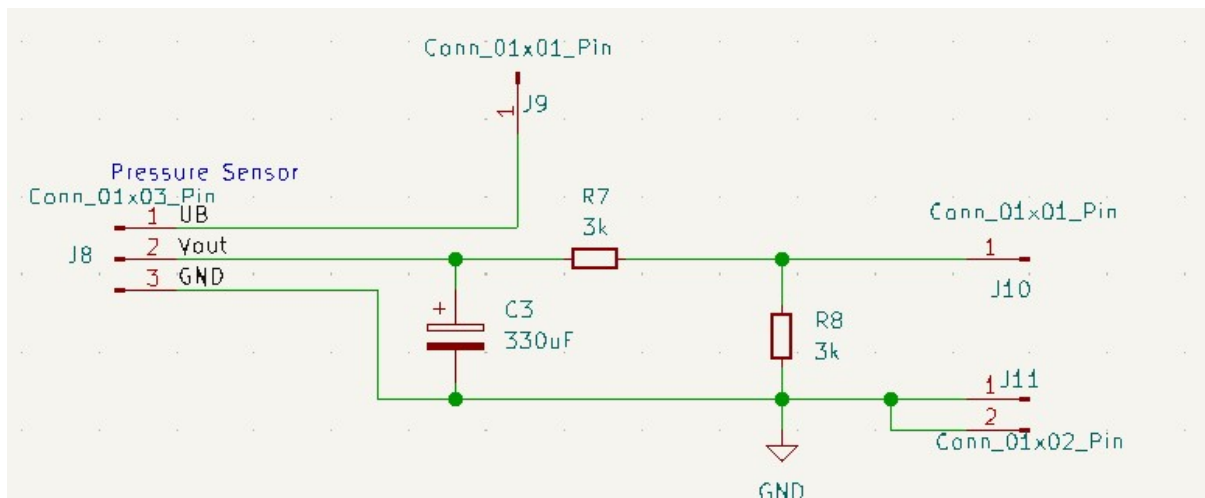


Figure 4: Schematic Design of the Pressure Sensor

String Potentiometer

The String Potentiometer is used to monitor the displacement, such as the movement of the brake pedal, and converts it into proportional voltage signal. This circuit uses resistors, including 8.5k-ohms and 3.3k-ohms, to scale the output signal to levels suitable for the microcontroller. As with the other peripherals, stable grounding and power inputs are implemented to maintain accurate and reliable signal transmission.

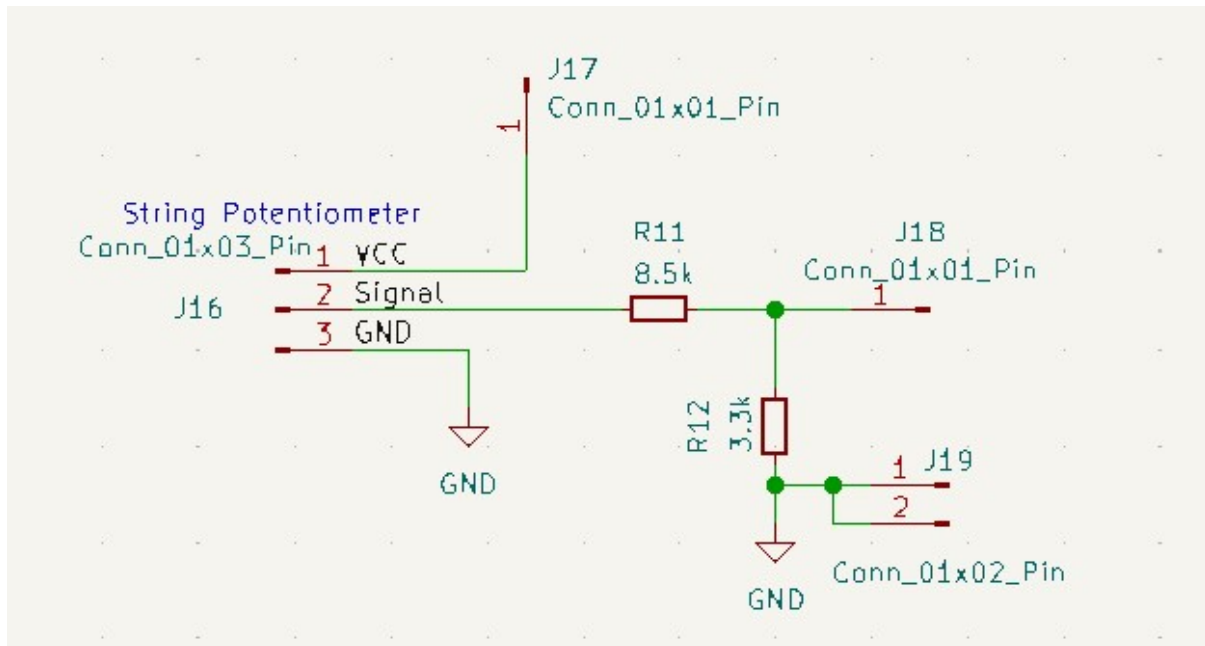


Figure 5: Schematic Design of the String Potentiometer

Overall, the peripherals schematics focuses on providing clean, conditioned, and scaled signals from each DUT's to the STM32 microcontroller while including corresponding components to prevent damage or errors. This ensures the entire system operates efficiently and reliably, with accurate data acquisition from all devices.

4.2.3 Printed Circuit Board (PCB's) Design

Power Supply PCB

The Power Supply PCB is a critical component designed to regulate and provide multiple voltage levels to the system. It starts at 16V DC input through a barrel jack connector. This 16V input is directed through a series of voltage regulators that step down the voltage to meet the requirements of the various components in the circuit.

The board utilizes capacitors of $10\mu\text{F}$ and $22\mu\text{F}$, which are strategically placed before and after each voltage regulator. These capacitors help to stabilize the voltage output by filtering out noise and ensuring smooth operation. The LM7812 regulator steps down the voltage to

12V DC, which is essential for certain peripherals. This 12V is then fed into another voltage regulator circuit comprising an LM317 adjustable voltage regulator along with two resistors, 220Ω and 330Ω , to further step it down to 3.146V DC. This precise voltage level is crucial for the operation of the microcontroller.

The design includes multiple output pins for 12V, 5V, and 3.3V voltages, ensuring compatibility with different devices and peripherals connected to the system. The layout of the PCB is compact yet efficient, allowing for adequate heat dissipation. The traces are kept wide enough to handle current flow effectively, and proper spacing is maintained to prevent any electrical shorts.

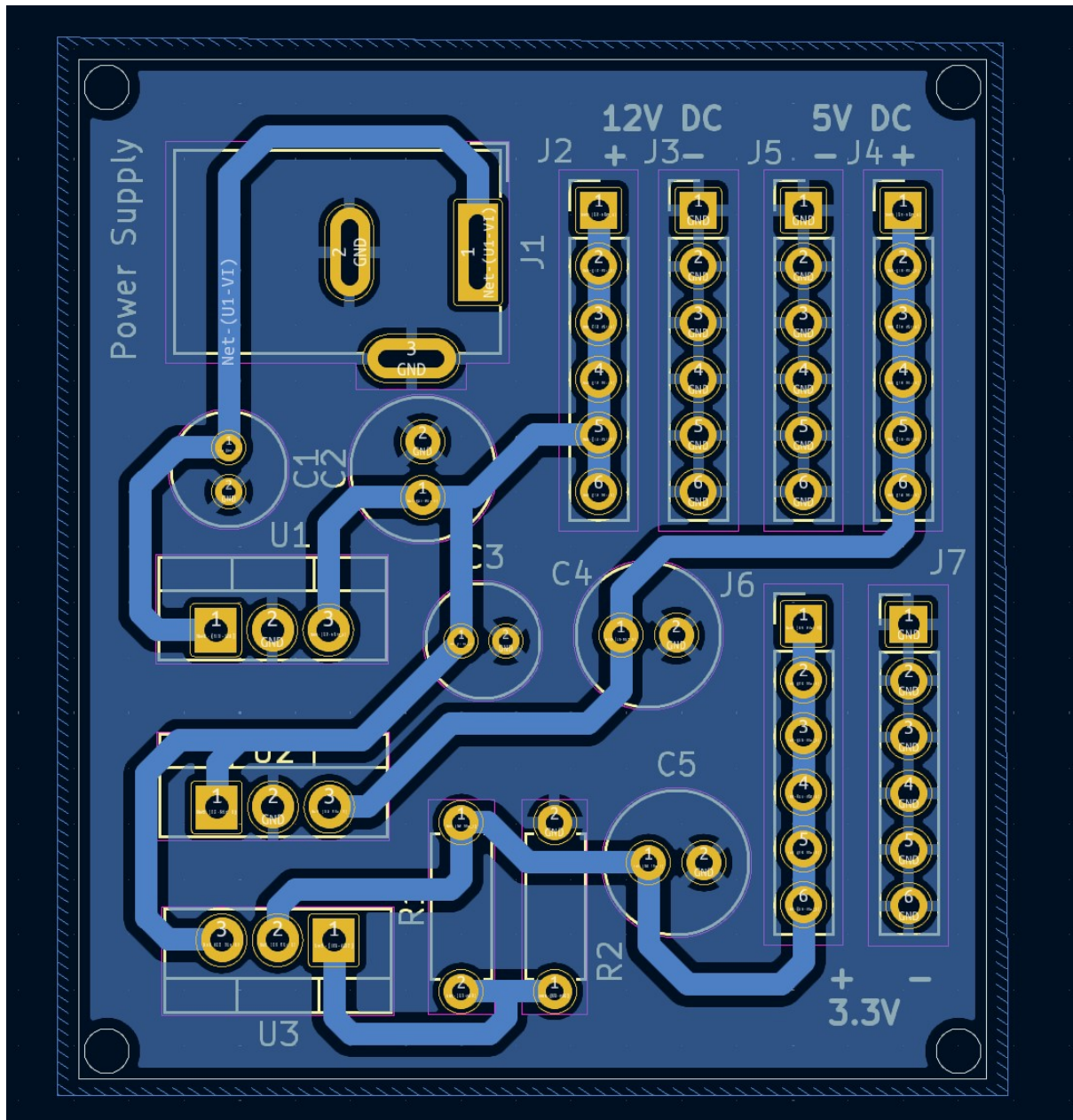


Figure 6: Printed Circuit Board Design of the Power Supply Management

Peripheral PCB Design

The Peripherals PCB is designed to accommodate all the connections and conditioning circuits required for the various devices under test (DUTs), including the Brake Signal Transmitter (BST), the Continuous Wear Sensor (CWS), the Pressure Sensor, and the String Poten-

tiometer. Each DUT is connected through dedicated input and output pins, clearly labeled on the board for ease of use.

The BST section includes diodes, resistors, and capacitors to read PWM signals reliably. The diodes provide protection against voltage spikes, while the resistors and capacitors condition the PWM signals for accurate processing. Similarly, the Pressure Sensor section features a capacitor to stabilize the signal and resistors to scale the output voltage for the microcontroller.

The Continuous Wear Sensor section captures analog voltage signals representing brake wear. This signal is scaled and filtered using resistors and capacitors to ensure accurate readings. The String Potentiometer section, on the other hand, converts displacement into a proportional voltage signal. Resistors in this section ensure the signal remains within the safe operating range for the microcontroller.

The PCB layout emphasizes clean and efficient routing, ensuring that signals are isolated to prevent interference. The components are arranged logically, with each DUT section clearly mentioned, making the board easy to debug and maintain.

Both the Power Supply and Peripherals PCBs were designed using KiCad, an open-source PCB design tool. KiCad's features allowed precise component placement and trace routing, ensuring reliable performance and manufacturability of the boards. These PCBs were custom designed to meet the specific requirements of the project, balancing functionality with simplicity.

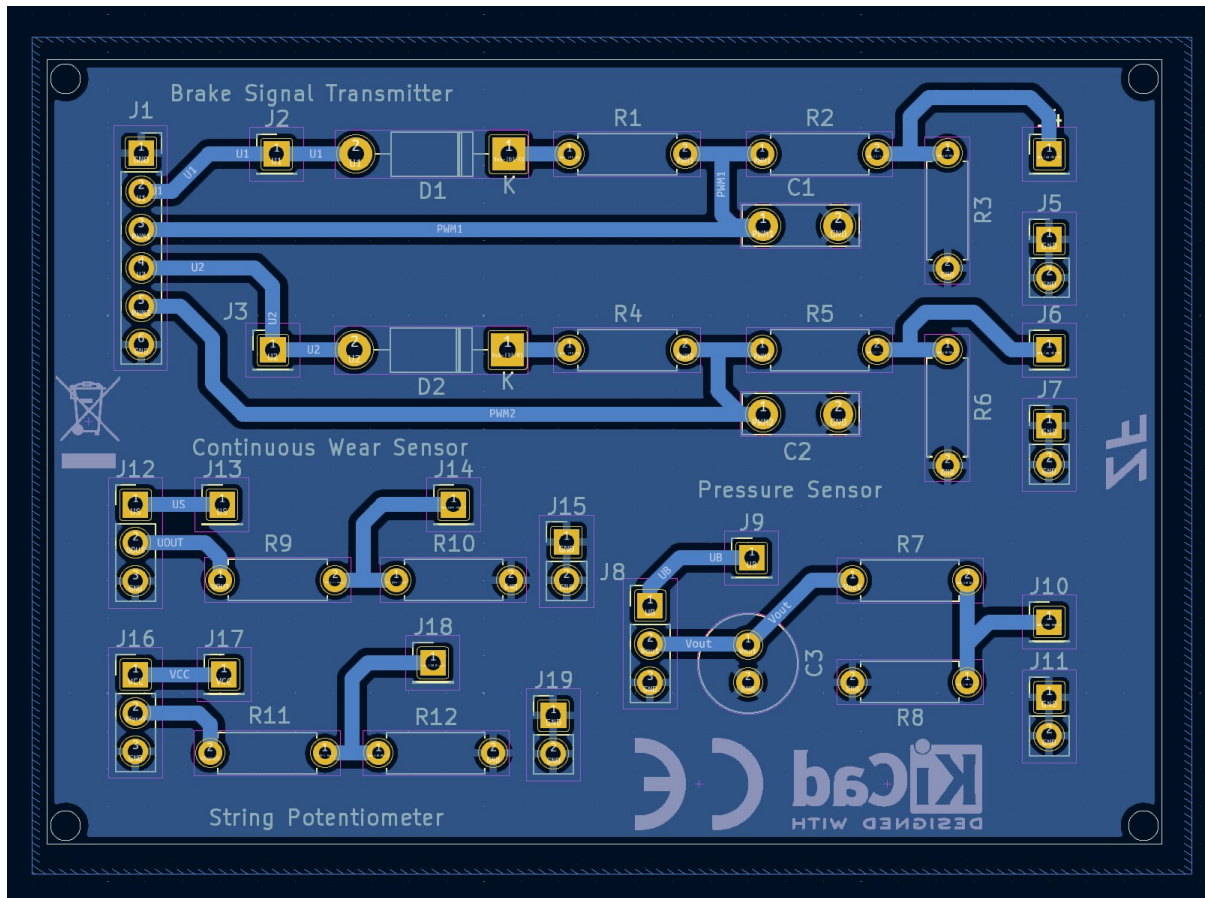


Figure 7: Printed Circuit Board Design of the Peripherals

4.2.4 Enclosure Design

The enclosures designed for the power supply and peripherals PCBs, as well as the STM32 microcontroller, were custom-built to meet the specific needs of the project. These enclosures were created using Autodesk's Fusion 360, allowing for precision in their design and ensuring they provided both functional and inventive advantages.

Power Supply and Peripherals Enclosure

The combined enclosure for the power supply and peripherals PCBs was designed with functionality as the primary focus. It ensures the protection of the internal PCBs while also providing easy access for connections and maintenance. Slots were strategically placed

for the DC jack and the input/output pins, which allowed efficient cable management and straightforward connectivity during operation. Additionally, ventilation slots were included to maintain stable temperatures and prevent overheating during extended usage.

The interior design included standoffs to securely mount the PCBs, preventing any physical movement that could damage connections. The two-part assembly of the enclosure made it user-friendly for repairs, upgrades, or debugging tasks. This modular design simplified the assembly and disassembly process while ensuring durability.

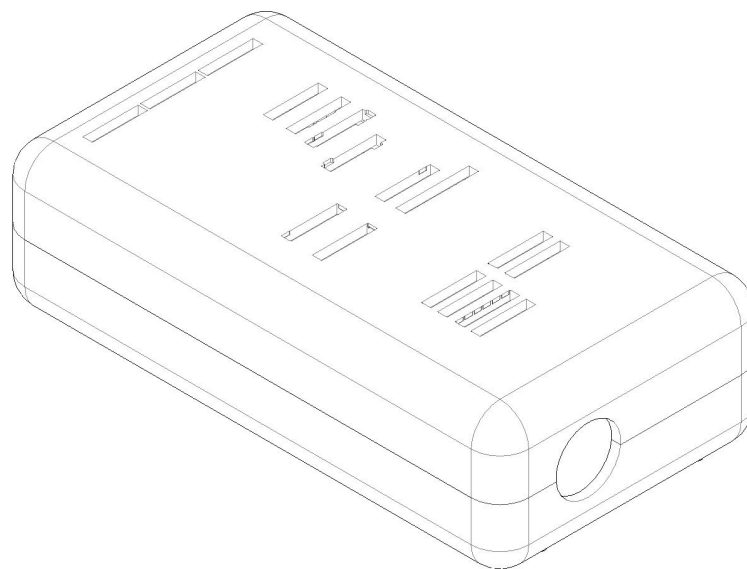


Figure 8: Enclosed Enclosure for Power Supply PCB and Peripherals PCB

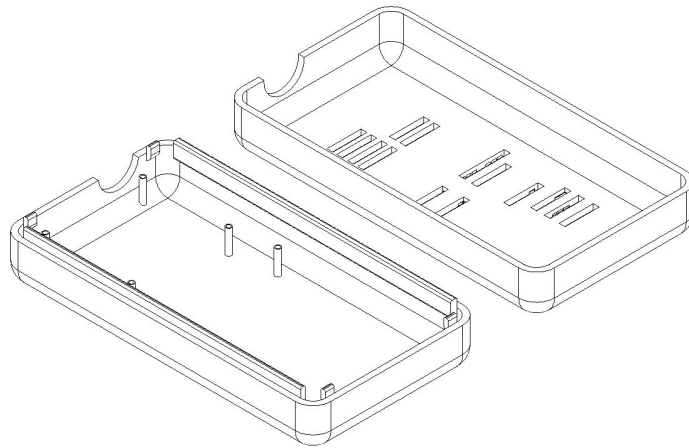


Figure 9: Open Enclosure for Power Supply PCB and Peripherals PCB

STM32 Microcontroller Enclosure

The STM32 enclosure was designed with the same principles of protection and accessibility but tailored specifically to house the microcontroller and its associated components. It featured openings for all essential ports, including USB, power, and communication ports, ensuring seamless integration with other devices and systems.

The enclosure's robust design protected the STM32 board from physical damage and environmental factors while maintaining airflow through ventilation slots to ensure thermal stability. Just like the power supply and peripherals enclosure, it was created as a two-part assembly, which facilitated quick access to the microcontroller during testing or maintenance.

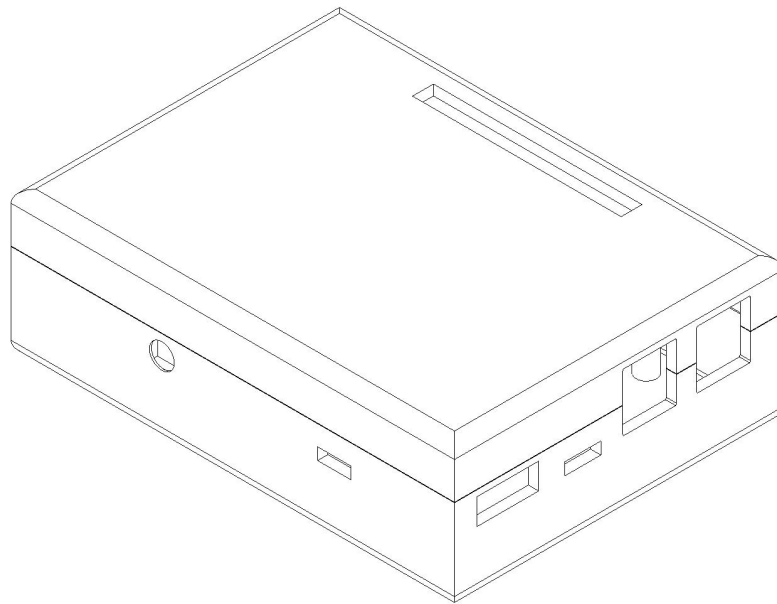


Figure 10: Enclosed Enclosure for the STM32 Board

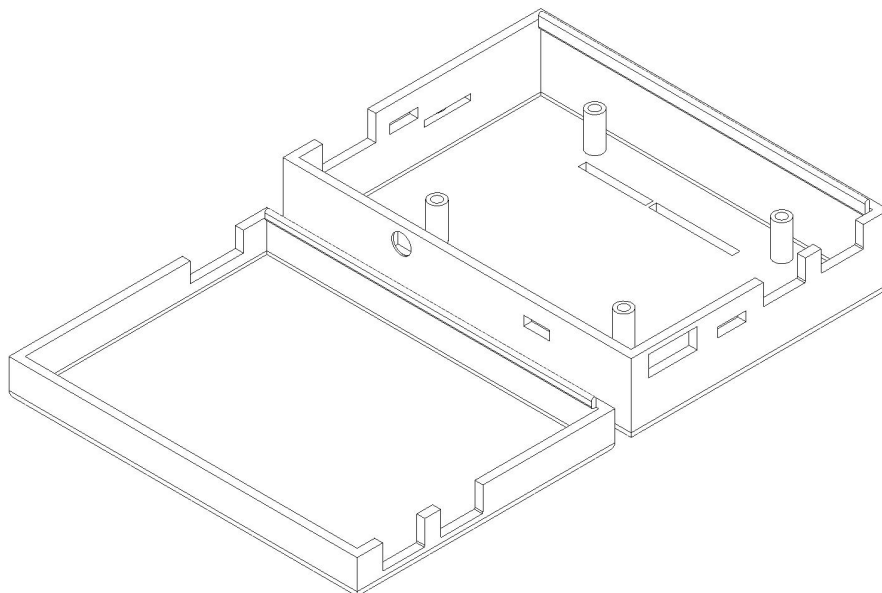


Figure 11: Open Enclosure for the STM32 Board

4.3 Arm Cortex-M4 Firmware

4.3.1 Brake Signal Transmitter (BST) Testing

4.3.2 Continuous Wear Sensor (CWS) Testing

4.3.3 Electronic Stability Control Module (ESCM) Testing

4.3.4 Pressure Sensor Testing

4.4 Embedded Linux with Yocto Project

The choice to use Embedded Linux for such an application was for various reasons: it provided access to a wide array of open-source software (OSS) and tools, it has a rich set of documentation accompanied by a big community of developers, and it is likely the easiest to develop on.

4.5 Interprocessor Communication with OpenAMP Project

4.6 Custom API Web Server in Rust

4.7 Web Assembly Application using the Yew framework

4.8 Design Considerations

When designing the Multi-Signal Automotive Testing Device, several factors were taken into consideration to ensure the project aligns with broader societal, environmental, and economic goals.

4.8.1 Public Health

This device ensures accurate testing of automotive components, contributing indirectly to public health by improving vehicle safety. For example, properly functioning brake signal

transmitters and stability control systems can reduce accidents, keeping roads safer for everyone.

4.8.2 Safety and Welfare

Safety was prioritized in the design process. The enclosures were crafted to protect the electronics from physical damage, and the use of standoffs and secure mounts minimizes risks of electrical short circuits. Additionally, the circuit design incorporated diodes to prevent reverse voltage damage, ensuring operational reliability.

4.8.3 Global Impact

The design supports the development of safer automotive systems globally. Since cars are used worldwide, this project contributes to the larger goal of enhancing vehicle reliability and reducing accidents, which has a ripple effect on public safety and environmental sustainability.

4.8.4 Cultural Impact

Automotive systems impact people differently based on their cultural priorities. In cultures where vehicle ownership represents progress and economic stability, this device indirectly supports technological advancement and trust in automotive technology.

4.8.5 Social Impact

Automotive systems impact people differently based on their cultural priorities. In cultures where vehicle ownership represents progress and economic stability, this device indirectly supports technological advancement and trust in automotive technology.

4.8.6 Environmental/Sustainability

The device was designed with energy efficiency in mind. For instance, voltage regulators and capacitors were used to ensure efficient power consumption. Furthermore, the focus on durability and modularity reduces electronic waste since individual components can be replaced rather than discarding the whole device.

4.8.7 Economic

Economically, this device helps lower testing costs for automotive systems by providing a reliable and reusable solution. The use of custom PCBs and locally designed enclosures ensured cost efficiency while maintaining functionality.

4.9 Design Impacts

The project had several direct and indirect impacts on a variety of domains, from the global stage to individual communities.

4.9.1 Global

On a global scale, this project aligns with the push for smarter, safer, and more reliable automotive systems. It enhances the tools available for testing automotive components, which is critical in the development of advanced driver-assistance systems (ADAS) and autonomous vehicles.

4.9.2 Economic

The device minimizes testing costs for automotive manufacturers, especially for smaller companies that may lack access to expensive testing equipment. Its modular design allows cost-effective upgrades, ensuring long-term usability.

4.9.3 Environmental

The environmental impact was reduced by selecting components that support energy efficiency and reducing waste through a modular design. Additionally, by enabling more reliable testing of components like brake and wear sensors, this project indirectly reduces environmental hazards caused by vehicle failures.

4.9.4 Societal

The societal impact of this project lies in its ability to enhance safety standards. Reliable testing leads to safer vehicles, which means fewer accidents, lower healthcare costs, and better public trust in transportation infrastructure.

4.10 Performance and Testing Analysis

5 Conclusion

The Claims Investigation Committee Multi-Testing Input Device project successfully delivered a comprehensive testing solution for ZF Group's automotive safety components. The system effectively automates validation testing across multiple devices including the Brake Signal Transmitter, Continuous Wear Sensor, and pressure sensors, addressing the key challenges faced by the Claims Investigation Center.

The implemented solution combines robust hardware design with modern software architecture. Custom PCBs manage power and signal routing, while the dual-core STM32MP157F-DK2 platform handles both real-time signal processing and test management. The WebAssembly frontend and Rust backend provide an intuitive user interface, with OpenAMP facilitating seamless inter-processor communication.

Test results demonstrate the system's capability to validate components against manufacturer specifications through automated data collection and analysis. The platform's modular design supports multiple device types and allows for future expansion. Notably, the system achieves significant improvements in testing efficiency compared to manual methods, while maintaining the rigorous standards required for automotive safety component validation.

Despite challenges in system clock configuration and PCB creation, the project fulfilled its primary objectives of streamlining the validation process and enhancing the CIC's testing capabilities. Future work will focus on completing CAN implementation for ESCM testing and further refinements to the web application interface.

6 Recommendations

For developing on this project further, potentially as another Senior Design Project, several recommendations can be made for improving current features, fully implementing features not finished, or extending functionality.

Improving the appearance of the web application is a very simple feature to begin improving. To extend on the web application, porting it from using the Yew Web Assembly framework to simple Web Assembly modules with calls to Javascript for Document-Object-Model manipulations would enhance the portability of this portion greatly for easier development.

A feature to finish implementation of is proper usage of the onboard CAN module by implementing pin-multiplexing on the Yocto device tree.

For a complete, comprehensive improvement, a completely custom PCB can be designed with all the different components of the STM32MP157F-DK2 properly connected and laid out, or completely different parts. This alone would be a giant project.