Claims Investigation Committee Multi-Input Testing Device

ECE-4820: Electrical and Computer Engineering Design II

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Auburn Hills, MI

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ZF

Who is ZF?

- Global technology company and Tier 1 automotive supplier
- Provides advanced safety systems and vehicle control solutions
- Partners with major OEMs: Daimler, Chrysler, Tesla, Waymo(Google), etc.
- A leading innovator in commercial vehicle technology

North American Headquarters

- Project based at ZF Group's North American headquarters in Auburn Hills, MI
- Specializes in commercial vehicle solutions
- This facility is also home to the Claims Investigation Center

Figure 1: Source: google.com
ZF Group Office in Auburn Hills, MI

Claims Investigation Committee

What is the Claims Investigation Center?

- Specialized team focused on testing and initial investigation of field failure parts for commercial vehicles
- Identifies new field failures and determine areas for product improvement
- Works closely with Technical Call Centers, Field Quality, and Warranty teams
- Ensures readiness to test and analyze new product field returns at launch

CIC’s Role in Our Project

- Requires enhanced testing capabilites for new products
- Our project aims to develop a device to streamline testing and data collection
- Helps the CIC efficiently validate warranty claims and analyze field returns
- Supports the CIC’s mission to improve product quality and customer satisfaction

Motivation for the Project

Challenges with Current Testing Methods

- Testing on current brake system platform (mBSP) was built and industrialized specifically for that platform
- Long lead time and significant cost to release and document
- New platform components are not compatible with the current tester
- Current tester is not capable of testing in prototype phase

Need for Improvement

- The Brake Signal Transmitter's (BST) implementation in Daimler's new platform intensifies urgency
- High production volumes require efficient testing methods
- Expanding product line increases testing complexity

Figure 2: *Current brake component system tester*

Multi-Input Testing Device

Addressed Challenges

- Provides a unified testing platform for multiple devices
- Flexible and agile to adapt to new product lines
- Allows for prototype testing and validation
- Automates data collection and analysis to reduce time and errors
- Increases testing speed and accuracy
- Simplifies validation process for warranty claims
- Enhances capability to analyze field returns efficiently
- Cost-effective solution

Devices Our Solution Supports

Key Devices Under Test (DUTs)

1. **Brake Signal Transmitter (BST)**
   - Primary focus - critical new component for 2025 production
   - Acts as the brain that reads how hard a driver presses the brake.
2. **Continuous Wear Sensor (CWS)**
   - Works like a monitor for your brake pads and discs
   - Warns when brakes are wearing down using voltage
3. **Pressure Sensor**
   - Continuously measures relative pressure in vehicle control systems
4. **Electronic Stability Control Module (ESCM)**
   - Acts as a safety system that helps prevent skidding and rollovers
   - Monitors the vehicle’s movement and intervenes to keep it stable

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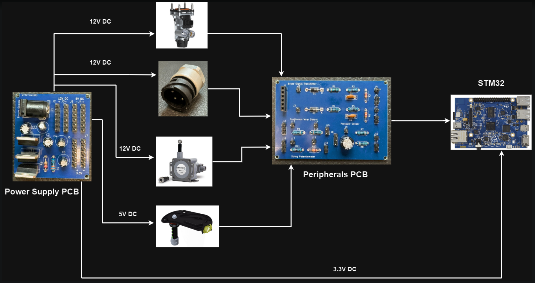
Project Solution



What this project aims to accomplish:

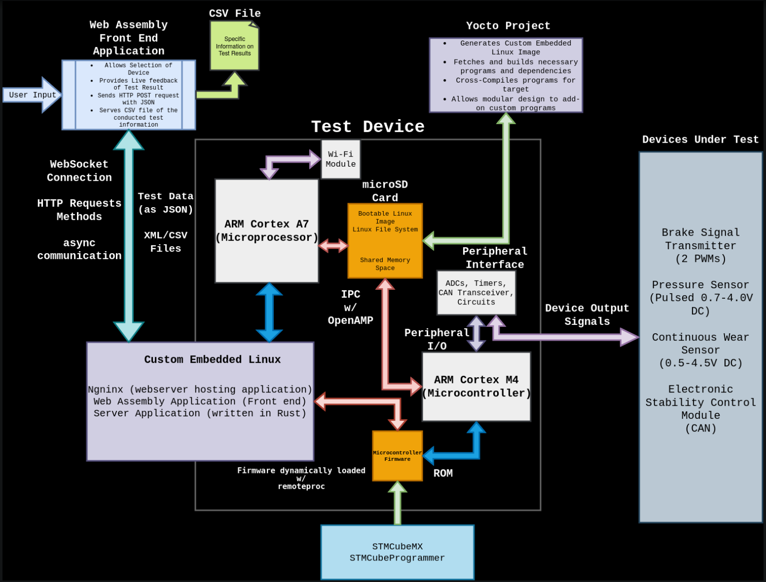
1. **Device Interfacing**
   1.1 Properly read Device Signals using the ARM Cortex-M4 on the onboard microcontroller on the **STM32MP157F-DK2**:
   - PWM duty cycle
   - Frequency
   - Voltages through an analog-to-digital converter (ADC)
   - CAN frames
2. **Physical Components and Hardware**
   2.1 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

Project Solution (cont.)

What this project aims to accomplish:

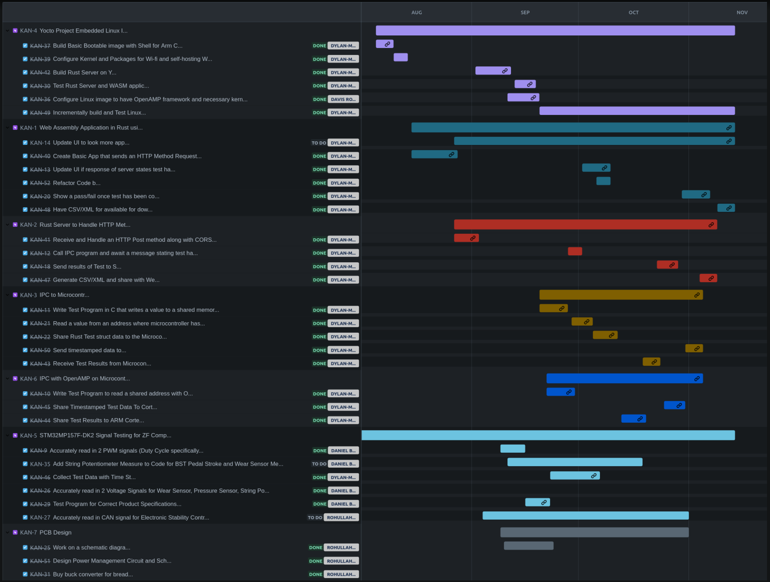
3. **Software**
   3.1 Custom embedded **Linux** distribution that will run on the onboard ARM Cortex-A7 microprocessor on the **STM32MP157F-DK2**
   3.2 Simple user interface on web-based application
   3.3 Custom Webserver to process information from web application to microcontroller
   3.4 Communicate 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

Comprehensive System Block Diagram



Project Solution and Overview

Gantt Chart



Project Solution and Overview

Budget Projection

Project Title	Multi-Signal Automotive Testing Device
Date	11/22/2024

Category	Item	Quantity	Estimated Under/Over	Unit Price	Shipping + Tax	Total Costs	Description
HARDWARE	STM32MP157-DK2	4	-	$109.00	$0.00	$436.00	ARM Cortex A7 & ARM Cortex M4
	String Potentiometer	1	-	$50.00	$0.00	$50.00	Detect and measure linear displacement
	Continuous Wear Sensor	2	-	$335.20	$0.00	$670.40	Monitors the wear of brake pads
	Continuous Wear Sensor Harness	2	-	$0.00	$0.00	$0.00	Wear Sensor Connector
	Linear Position Sensor	1	-	$50.00	$0.00	$50.00	Measures the position
	USB to CAN Cable	2	-	$47.99	$10.00	$105.98	Converts USB to CAN
	Pressure Sensor	2	-	$0.00	$0.00	$0.00	Sensor for measuring pressure data
	Electronic Stability Control Module	1	-	$0.00	$0.00	$0.00	Data for vehicle stability
	Brake Signal Transmitter	1	-	$0.00	$0.00	$0.00	Brake Pedal to receive signals
	Anti-static Wrist Band	1	-	$7.95	$0.00	$7.95	Grounding Wristband
	SD Card Reader	1	-	$20.00	$0.00	$20.00	SD Card Reader
	MINI360 Buck Converter	2	-	$6.99	$13.66	$27.64	Voltage Supply Regulator
	LM78xx Buck Converter	1	-	$13.99	$0.00	$13.99	Voltage Supply Regulator
	LM2596 Buck Converter	1	-	$12.89	$0.00	$12.89	Voltage Supply Regulator
	50 Values Resistor Kit	1	-	$12.99	$0.00	$12.99	Signal Conditioning Components
	24 Electrolytic Capacitors	1	-	$9.99	$0.00	$9.99	Signal Conditioning Components
	10 Values Rectifier Diodes	1	-	$9.99	$0.00	$9.99	Signal Conditioning Components
	Screw Terminals	1	-	$9.99	$0.00	$9.99	PCB Mount Terminals
	Male & Female Pin Holders	1	-	$12.99	$9.99	$22.98	Pin Holders on PCB
	Female DC Power Barrel Jacks	1	-	$5.99	$0.00	$5.99	PCB Mount
	PCB Board Kit	1	-	$13.99	$0.00	$13.99	Prototype Kit
	PCB Board Kit Copper	1	-	$7.99	$0.00	$7.99	Prototype Kit
	Custom PCB	10	-	$1.00	$19.99	$29.99	Custom designed circuit Board

Category	Total Costs
Hardware Costs	$1,518.75
Miscellaneous Costs	$0.00
Grand Total	$1,518.75

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Power Supply Schematic Design

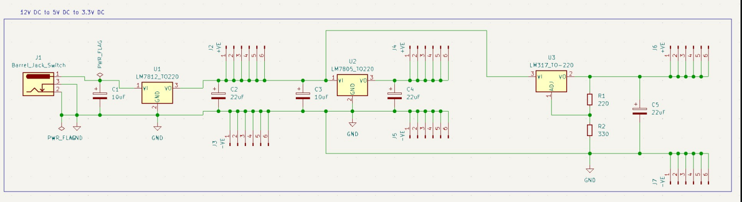

Figure 3: *power management system that converts 12V DC input into multiple usable voltage levels.*

Overview

- 12V DC stable voltage using LM7812 (1A)
- 12V to 5V DC using LM7805 (1A)
- 12V to 3.3V using LM317 adjustable regulator

Key Components

- LM7812, LM7805, LM317 voltage regulators for step-down conversion.
- Capacitors for noise filtration.
- Resistors to set voltages for LM317 as 3.146V DC (50uA).

Schematic Design - Brake Signal Transmitter

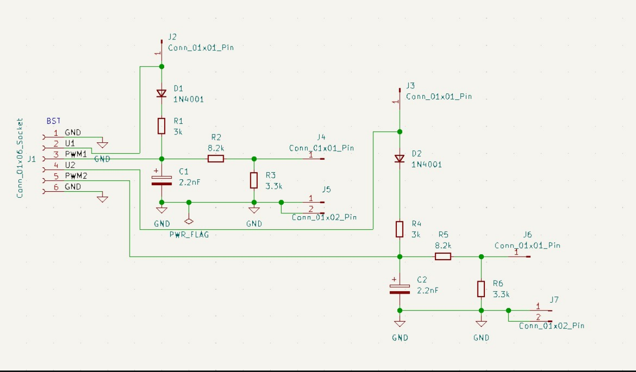

Figure 4: Circuit schematic of Brake Signal Transmitter (BST)

Key Points

- Captures the output of the Brake Signal Transmitter (BST) in the form of Pulse Width Modulation (PWM) signals.
- Includes resistors and capacitors for signal filtering.
- Diodes protect the circuit from voltage surges and reverse polarity.

Peripheral Interface Schematic Diagram

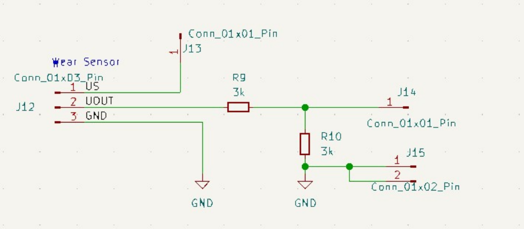

Figure 5: Continuous Wear Sensor Interface Schematic

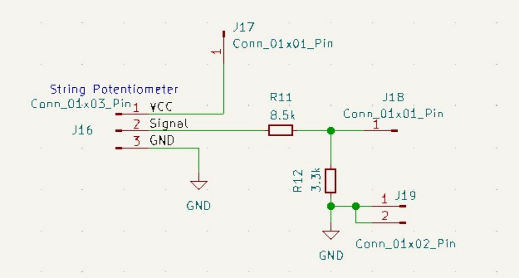

Figure 7: String Potentiometer Interface Schematic

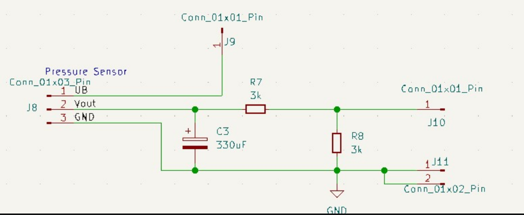

Figure 6: Pressure Sensor Interface Schematic

Key Points

- Captures analog voltage signals to monitor brake wear and pressure sensor and displacement on the string potentiometer.
- Uses voltage dividers for safe microcontroller input levels.
- Uses capacitors to stabilize the output.

Printed Circuit Board Design

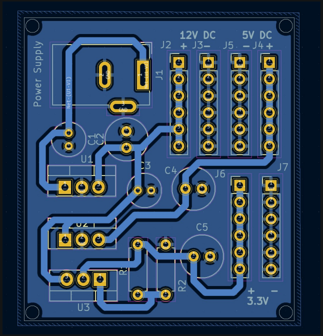

Figure 8: PCB for Power Management

Overview

- The power supply PCB converts the 12V DC input from the DC jack into regulated output voltages for the system.
  - 12V DC
  - 5V DC
  - 3.3V DC
- It is designed based on the schematic with components such as voltage regulators (LM7812, LM7805, LM317), capacitors, and resistors.

Key Components

- DC Jack (J1): Connects the input 12V DC power supply to the board.
- Output Pins:
  - J2/J3: Provides 12V DC output.
  - J4/J5: Provides 5V DC output.
  - J6/J7: Provides 3.3V DC output.
- Voltage Regulators
  - Step-down conversion for different voltage levels.
  - Smooth and stable output.
- Capacitors (C1-C5)
  - Ensure smooth voltage output by filtering noise and ripples.
- Ground connections: All components are referenced to a common ground for stable operation.

Peripherals Printed Circuit Board

Key Features

- Input/Power Pins:
  - Each DUT has a dedicated connector for input signals and a power signal.
  - J1: Inputs for BST (PWM1 and PWM2) | J2/J3: 12V Power Signals for BST (PWM1 and PWM2)
  - J8: Pressure sensor input | J9: 12V DC Power Signal
  - J12: Wear sensor input | J13: 5V DC Power Signal
  - J16: String Potentiometer input | J17: 12V DC Power signal
- Output Pins:
  - Processed signals are sent to the microcontroller through the output pins.
  - J4/J5/J6/J7: BST processed signals
  - J10/J11: Pressure sensor output
  - J14/J15: Wear sensor output
  - J18/J19: String potentiometer output.
- Signal Conditioning:
  - Resistors: Scale signals for safe microcontroller input.
  - Capacitors: Filter noise and stabilize signals.
  - Capacitors: Filter noise and stabilize signals.

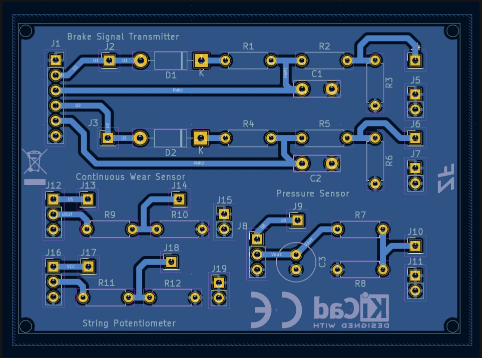

Figure 9: PCB for connecting to peripheral device

Hardware Design

Fabricated PCB

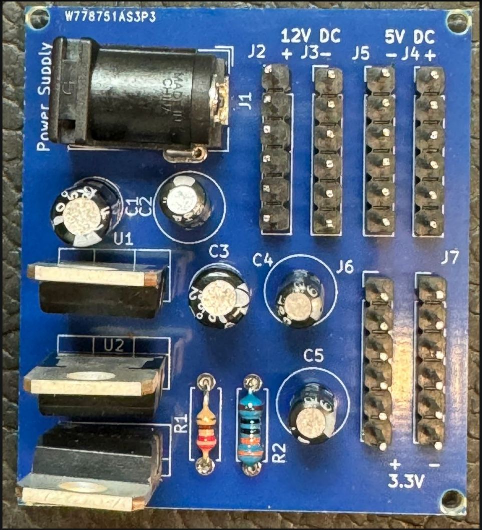

Figure 10: Power Management PCB

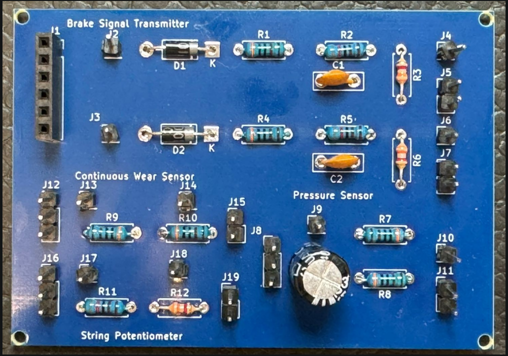

Figure 11: Peripheral Interface PCB

Enclosure Design

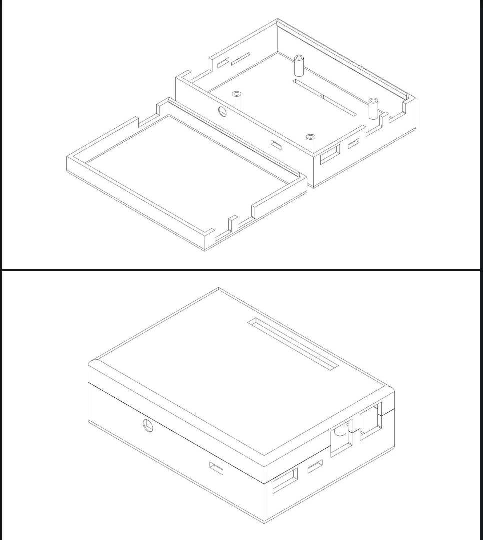

Figure 12: *Enclosure for STM32MP157F-DK2*

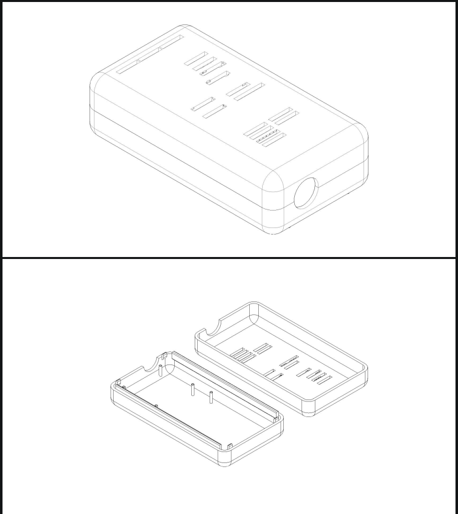

Figure 13: *Enclosure for PCBs*

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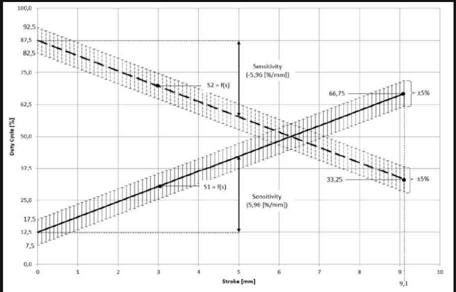
Firmware to Test Brake Signal Transmitter (BST)

Purpose

- Developed firmware on the onboard Cortex-M4 microcontroller to validate BST
- Ensures brake actuation is accurate to distance moved by brake pedal
- **Key Specifications:** Output range 1 mm to 9 mm, Sensitivity 5.96% DC/mm, Output signals PWM1 and PWM2 (S1 and S2)

Method

- **Input Capture:** Timers captures read two PWM signals from the BST
- **ADC Reading:**Optional string potentiometer for direct analog voltage measurements via ADC
- **Processing:** Calculates duty cycles, frequencies, and estimated stroke via timer interrupts
- **Validation:** Compare measurements against expected values according to product specifications to verify BST accuracy
- **Results:** Sends test results to the main processor for logging and user display



The nominal requirements, are fulfilled:

	S1 (PWM signal 1)	S2 (PWM signal 2)
Offset	12,5 % DC	87,5 % DC
Tolerance	± 5 % DC	
Sensitivity	5,96 % DC/mm	-5,96 % DC/mm
Frequency	200 ± 10 Hz	

Figure 14: *Product Specifications for BST*

Firmware to Test Continuous Wear Sensor (CWS)

Purpose

- Developed firmware on the onboard Cortex-M4 microcontroller to validate the Continuous Wear Sensor (CWS)
- Ensures accurate measurement of brake pad wear levels to enhance vehicle safety
- **Key Specifications:** Output range 0.7V (18 mm or new pad) to 4.0 V (53 mm or worn pad), Sensitivity 0.08 V/mm, Voltage divider ratio 2:1

Method

1. **ADC Configuration:** Read direct analog voltage via ADC using DMA for efficiency and a timer trigger for consistency
2. **Wear Calculation:** Mapped the measured voltage to brake pad wear using a linear relationship and handled special conditions (e.g., new pad, worn-out pad) with specific tolerances
3. **Validation:** Compared wear values against expected values based on product specifications
4. **Results:** Error thresholds to determine pass/fail and send detailed test outcomes to the main processor for logging and user display

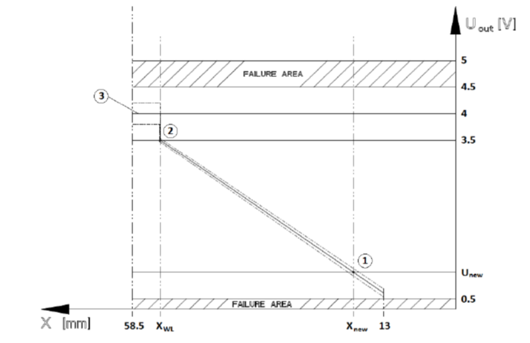


Figure 15: *Product Specifications for CWS*

Firmware to Test Pressure Sensor

Purpose

- Developed firmware to validate Pressure Sensor readings on the Cortex-M4 microcontrooler
- Ensures accurate measurement of pressure when given for reliable vehicle control system purposes
- **Key Specifications:** Output range 0.5V (0 bar) to 4.5 V (10 bar), Sensitivity 0.4 V/Bar, Voltage divider ratio 2:1

Method

1. **ADC Configuration:** Configured the ADC to read analog voltage from the Pressure Sensor using DMA for efficient data transfer and utilized a timer to trigger ADC conversions periodically
2. **Pressure Calculation:** Mapped the measured voltage to pressure using a linear relationship given in the product specifications with the addition of converted pressure from bar to psi
3. **Validation:** Compared calculated pressure against expected values based on product specifications with voltage tolerances to determine pass/fail status
4. **Results:** Sent detailed test outcomes to the main processor for logging and user display

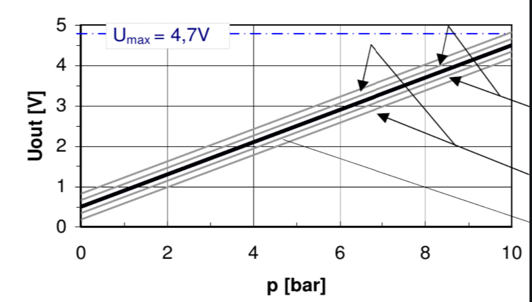


Figure 16: *Product Specifications for CWS*

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Embedded Linux and The Yocto Project

Embedded Linux

- Industry standard for embedded Operating system
- Rich ecosystem of open-source tools and software

The Yocto Project

- Collection of tools to build a custom embedded Linux distribution
- Fine-grain control of every aspect of deployed image

Embedded Linux

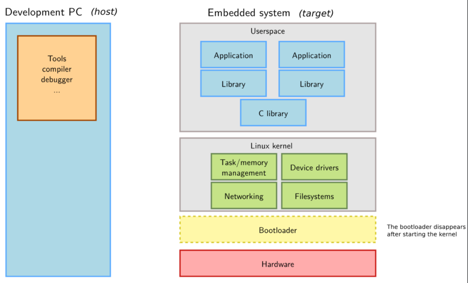

Figure 17: Source:https://bootlin.com/
Embedded Linux system architecture

Why use embedded Linux?

- Industry standard for any embedded operating system
- Access to open-source software (OSS) and tools
- Networking and connectivity made easy
- Easily save/access data with filesystem

Using The Yocto Project to Build a Custom Distribution

What is the Yocto Project and why?

- Most popular set of tools for embedded Linux Development
- Collection of OSS tools to make a custom Linux distribution
- Independent of target architecture
- **bitbake** build tool handles **metadata**
- **MetaData** can be in the form of
  - software build/patch instructions
  - configuration files for software
- **MetaData** organized in its **Layer Model**

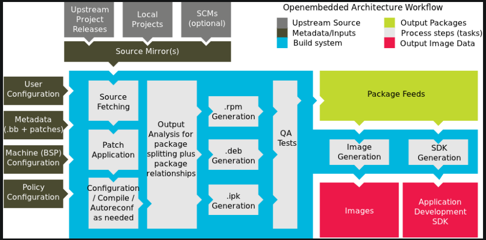

Figure 18: Source: https://docs.yoctoproject.org
High-level diagram representing how builds work using The Yocto Project

Custom Linux Image for the STM32MP1-DK2

What is used in the deployed image?

- ST's BSP (board support package) layer provides metadata
  - Hardware drivers
  - Kernel Configurations
  - Devicetree
- Custom layer **meta-zf-project**
  - **nginx** (webserver), **wpa_supplicant** (Wi-Fi access client/ IEEE 802.1X supplicant)
  - recipes for custom applications (Web application, Server, Cortex-M4 Firmware)
  - Kernel configurations and custom Devicetree

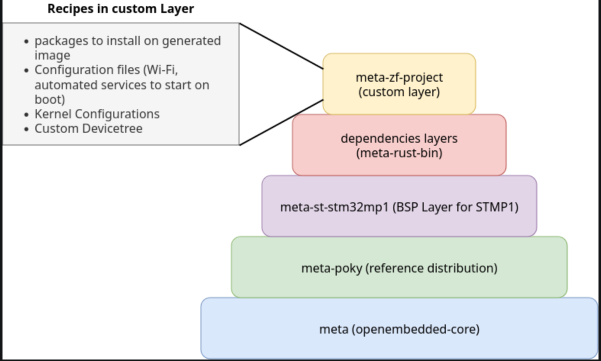

Figure 19: *Layer Model representation of this project for deploying onto a STM32MP1-DK2*

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Inter-Process Communication on a Heterogenous Architecture

With a heterogenous architecture (ARM Cortex-A7 and ARM Cortex-M4) how can information be shared?

Hetergenous multiprocessor SoCs cannot directly communicate

OpenAMP (Asymmetric Multi-Processing) Project

- Software framework that places standard protocol for shared memory
- Implemented on top of **virtio** framework
- STM provides **virt_uart** driver for recieving/transmitting messages over **RPMsg protocol**
- STMP1 layer automatically enables the **RPMSG tty driver** kernel module
  - creates file in Linux filesystem: **/dev/ttyRPMSG<X>**
  - can read and write to like a normal file
- **remoteproc** framework allows dynamic and remote loading of Cortex-M4 firmware
- **Resource Table** defined in firmware opens a trace in **/sys/kernel/debug/remoteproc/remoteproc0/trace0**
  - Used for logging measured data in CSV format

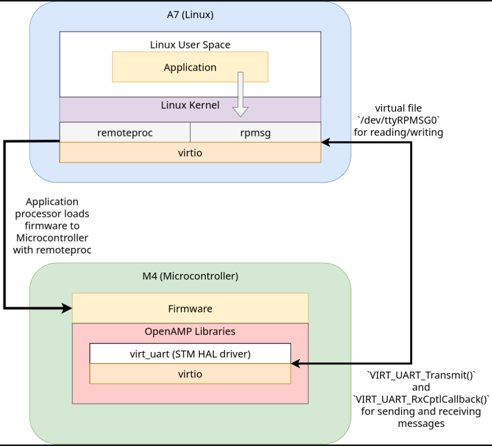

Figure 20: Inter-processor communication between Cortex-A7 (Linux) and Cortex-M4 (Microcontroller)

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Rust

The Rust programming language was used to write both major applications (web-based application and web server) for 2 main reasons.

Figure 21: *Ferris, universally accepted mascot of the Rust Programming language*

Memory Safety and Performance

- A set of rules called **Ownership** enforced by compiler to prevent memory leaks
- **Borrow checker** within the compiler prevents programs unsafe programs from compiling*
- Nearly as or just as performant as C with **Zero Cost Abstractions**
- Advocated by/used by several United States goverment agencies:
  - **National Security Agency (NSA)** and **Cybersecurity and Infrastructure Security Agency (CISA)**
  - **Defense Advance Research Projects Agency**
  - **The White House**

Web-Application for User Interface

Web Application in WebAssembly (WASM)

- WASM is a compiled, binary format executable
- Much faster than traditional Javascript programs
- Using the Yew framework, written in Rust

Web application Features

- Shows if application is connected to associated server
- Selection of different devices
- Shows progress and state of test
- Allows download to results in a CSV

Figure 22: *Web application with dropdown selection of different devices*

Custom API Web Server

Web Server features

- Handles **HTTP requests** from web application
- Dynamically loads M4 Firmware for selected device with **remoteproc**
- Polls for results by reading and writing to **/dev/ttyRPMSG0**
- Saves information from **/sys/kernel/debug/remoteproc/remoteproc0/trace0** as CSV for download

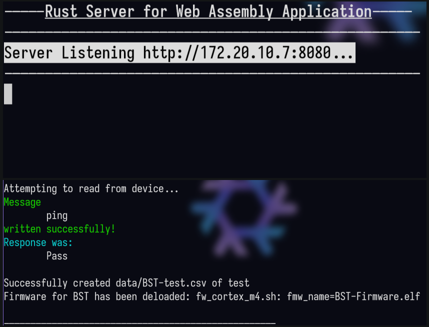
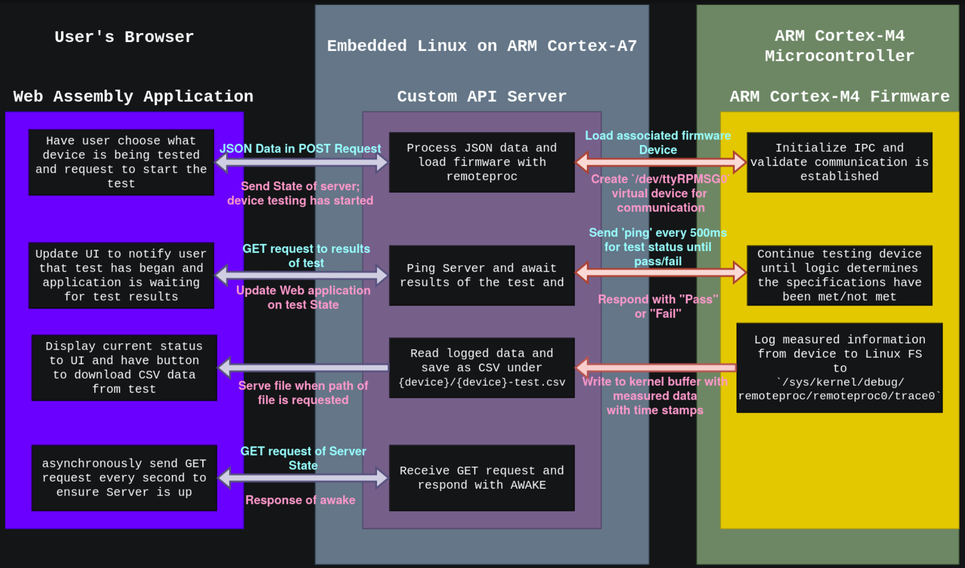


Figure 23: *Console logging of server application*

Software Architecture



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Link to video demonstration

https://dylxndy.xyz/senior-design-presentation/verification

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Challenges

- System Clock configuration with Devicetree
- Timer configuration for PWM signals
- Mini-360 Buck Converter
- PCB Creation

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Future Work

- Finish CAN implementation for ESCM
  - USB to CAN used currently
  - enabled **CAN_GS_USB** module in Linux Kernel
- Improve Web application appearance

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Special Thanks

- Dr. Grantner (faculty advisor)
- David Florida (lab technician)
- Patrick McNally (Head of Engineering at ZF Group - Auburn Hills, MI)
- Davis Roman (Senior Staff Software Engineer at Rivian - Palo Alto, CA)

Thank you

Any Questions?

Project Sources

- **Custom Yocto Project Layer:**
  - `https://github.com/DMGDy/meta-zf-project`
- **Custom Web Server in Rust**
  - `https://github.com/DMGDy/zf-webserver-app`
- **Web Application in WASM**
  - `https://github.com/DMGDy/zf-yew-app`
- **Microcontroller Firmware**
  - `https://github.com/danb127/Brake-System-Tester`
- **This Presentation**
  - `https://github.com/DMGDy/ECE4820-Presentation`