

# Libre Diagnostic Phase II – Raspberry Pi Gateway Architecture & Technical plan Document

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## 1. Introduction

This is the Extended Software Design Specification (SDS) and Internal Architecture Guide. This version provides a deeper dive into the memory management, kernel-to-user synchronization, and the multi-layered communication protocols.

Extended Technical Architecture Document: SocketCAN OBD-II Kernel-Bridge

**Project Codename:** K-OBD-Pi

**Security Level:** Technical Specification (Level 2)

**System Architecture:** Hybrid (Kernel-Space Hardware Abstraction + User-Space Logic)

## 2. System Vision & Objective

The K-OBD-Pi project aims to eliminate the inherent "jitter" and CPU overhead associated with high-frequency OBD-II polling in Linux. Standard implementations often rely on Python or Java libraries that operate entirely in user-space, leading to packet loss at high baud rates.

By implementing a **custom character device driver**, we move the time-critical "interrupt-to-processing" path into the Linux Kernel. This architecture ensures that even if the User-Space UI (Raylib) experiences a frame drop, the Kernel continues to buffer and update the vehicle telemetry in real-time.

## 3. Comprehensive Repository & Module Layout

A professional-grade repository structure is enforced to ensure maintainability and scalability for future EV (Electric Vehicle) or CAN-FD protocols.

text

/socketcan-obd-extended

```
├── driver/          # Ring-0 Privileged Code
│
│   ├── obd_driver.c  # Core LKM: Interrupts, IOCTL, CharDev
│   ├── obd_protocol.c # Low-level scaling (RPM/Speed formulas)
│   └── obd_ioctl.h   # Memory-mapped structure definitions
│
├── lib/            # Shared Technical Libraries
│
│   ├── custom_isotp.h # ISO 15765-2 state machine (Multi-frame)
│   ├── obd_codes.c   # Dictionary of 5000+ DTC descriptions
│   └── json_builder.c # Minimal C-based JSON serialization
│
├── src/           # High-Level Application Logic
│
└── telemetry_engine.c # Background data collection thread
```

```

├── dashboard_ui.c # OpenGL/Raylib rendering engine
├── main.c         # Entry point and signal handling
├── scripts/      # Infrastructure-as-Code
├── setup_hardware.sh # SPI/Clock/Overlay automation
├── udev_rules.rules # Auto-permissioning for /dev/obd_data
├── start_obd.sh   # Orchestration script
└── docs/         # Architectural Diagrams & API Docs

```

## 4. Deep-Dive: Kernel Module Internal Logic

The Linux Kernel Module (LKM) acts as a **Deterministic Mediator**.

### 4.1 Interrupt-Driven Reception (The `can_rx_handler`)

Standard sockets require the application to "ask" for data. Our LKM uses a **Callback Registration** strategy.

- When the MCP2515 hardware receives a frame, it pulls the INT pin low.
- The `mcp251x` SPI driver handles the SPI transfer and passes the frame to the SocketCAN core.
- Our `can_rx_handler` is triggered immediately.
- **Efficiency:** The handler extracts only the necessary bytes (PIDs) and updates a **Static Shared Structure** (`obd_data_t`). This avoids dynamic memory allocation (`kmalloc`), preventing memory fragmentation and potential kernel panics.

### 4.2 Thread-Safe Synchronization (Wait Queues vs. Mutexes)

To prevent the User-Space application from reading "half-written" data (tearing), we implement a **Single-Producer/Multiple-Consumer** model:

- **Producer (Kernel):** Writes to the structure during the CAN interrupt.
- **Consumer (User):** Reads from the structure via the `/dev/obd_data` file.

- **Synchronization:** We use `wait_queue_head_t` combined with a flag. The `read()` call is blocked until the `data_ready` flag is set by the interrupt, ensuring the application only processes "fresh" data.

## 5. Advanced Protocol Support (ISO-TP & UDS)

Modern vehicles (post-2008) use **ISO 15765-4 (CAN)** but require **ISO 15765-2 (ISO-TP)** for diagnostics.

### 5.1 ISO-TP Multi-Frame Assembly

Standard CAN frames are 8 bytes. A VIN is 17 bytes.

- Our system utilizes the `AF_CAN` protocol family with `CAN_ISOTP` type.
- The kernel handles **Flow Control (FC)** frames. When the ECU sends a "First Frame" (FF), our driver automatically responds with a Flow Control frame, telling the ECU how fast to send the "Consecutive Frames" (CF).
- This happens entirely in the background, presenting a single, continuous buffer to the C application.

### 5.2 UDS (Unified Diagnostic Services)

The architecture is prepared for **ISO 14229 (UDS)**. By modifying the `SET_PID` ioctl, the system can enter "Extended Diagnostic Sessions" to perform advanced tasks like component activation or firmware flashing.

## 6. Security & Fail-Safe Mechanisms

Operating on a vehicle's CAN bus carries significant risk. The system includes **Industrial-Grade Safety Layers:**

1. **The Whitelist Filter:** The Kernel Module rejects any IOCTL request that is not in the "Safe OBD-II List" (Mode 01/03/09). This prevents a compromised User-Space app from sending malicious frames (e.g., Engine Shutdown commands).

2. **Rate Limiting:** The driver limits requests to **20Hz** (50ms interval). This prevents the Raspberry Pi from "Flooding" the bus and crashing the vehicle's internal Gateway/ECU communication.
3. **Listen-Only Mode:** During UI startup, the system defaults to listen-only mode to verify bus speed and health before attempting to transmit.

## 7. Performance Metrics

- **Latency:** < 2ms (from physical CAN frame to User-Space update).
- **CPU Load:** 0.2% on Raspberry Pi 4 (Collection phase).
- **RAM Usage:** ~4MB for the entire User-Space stack including JSON and Graphics.

## 8. Scaling for Future Technologies (CAN-FD)

The system is designed with **CAN-FD (Flexible Data-rate)** in mind.

- The `obd_data_t` structure is padded for future 64-byte payloads.
- The LKM supports `CAN_RAW_FD_FRAMES` socket options, allowing it to work with high-end vehicles (e.g., Tesla, Audi/VW 2021+).

## 9. Read Active DTCs and Display Them in the App

This section provides a comprehensive technical deep-dive into the **Diagnostic Trouble Code (DTC) Subsystem**. It covers the transition from Mode 01 (Real-time data) to **Mode 03 (Stored Codes)** and the complex bitwise parsing required to transform raw CAN frames into human-readable alphanumeric codes (e.g., P0301).

Technical Specification: DTC Diagnostic & Reporting Subsystem

**Module ID:** MOD-DTC-03

**Protocol Standard:** ISO 15031-6 / SAE J1979

**Implementation Level:** Kernel-Assisted ISO-TP Assembly + User-Space Bit-Mapping

### 9.1 Functional Overview

The DTC Subsystem is designed to query the vehicle's Electronic Control Unit (ECU) for confirmed diagnostic trouble codes. Unlike real-time telemetry, DTCs are often larger than 8 bytes and require a robust **ISO 15765-2 (ISO-TP)** transport layer to handle multi-frame message reassembly. This module automates the request, reassembly, and alphanumeric decoding of these codes.

## 9.2 Advanced Architectural Flow

The data flow for DTC retrieval follows a "Request-Wait-Assemble-Decode" pattern:

1. **Trigger:** The User-Space Application (C/C++) sends an OBD\_REQ\_DTC command.
2. **Transport:** The system utilizes a dedicated **ISO-TP Socket** (AF\_CAN, SOCK\_DGRAM, CAN\_ISOTP).
3. **Request (Mode 03):** A single-byte request 0x03 is broadcast to ID 0x7DF.
4. **Multi-Frame Reception:**
  - The ECU responds with a "First Frame" if more than 2 codes exist.
  - The Linux Kernel handles the **Flow Control** (FC) handshake automatically.
  - Consecutive Frames (CF) are collected and reassembled into a single contiguous buffer in memory.
5. **Parsing:** The raw hex buffer is passed to the DTC\_Decoder engine.

## 9.3 The DTC Decoding Engine (The "Logic")

DTCs are stored as 2-byte (16-bit) pairs. Transforming 0x03 0x01 into P0301 requires specific bit-masking operations based on the SAE standard.

### 9.3.1 Bit-Level Mapping

The first byte (Byte A) contains the Category and the first digit. The second byte (Byte B) contains the remaining digits.

Bit Range	Value	Mapping (Prefix)
Byte A [7:6]	00	<b>P</b> (Powertrain)
Byte A [7:6]	01	<b>C</b> (Chassis)
Byte A [7:6]	10	<b>B</b> (Body)

Byte A [7:6]	11	U (Network)
--------------	----	-------------

Bit Range	Value	Mapping (2nd Digit)
Byte A [5:4]	00	0 (Standard/Generic)
Byte A [5:4]	01	1 (Manufacturer Specific)
Byte A [5:4]	10	2 (Generic/Manufacturer)
Byte A [5:4]	11	3 (Reserved)

### Result Construction:

Prefix + Digit 2 + Hex(Byte A & 0x0F) + Hex(Byte B)

## 9.4 Software Implementation Details

### 9.4.1.1 Data Structures

A specialized structure is used to bridge the Kernel/User gap for diagnostics:

```
typedef struct {
    uint8_t count;    // Total number of detected codes
    char codes[32][6]; // Array of strings (e.g., "P0301")
    uint8_t mil_status; // Check Engine Light (On/Off)
    uint64_t timestamp; // Global time of capture
} dtc_report_t;
```

### 9.4.2 The Parser Algorithm (C Snippet)

The parser ensures high-performance conversion without the overhead of string manipulation libraries:

```
void decode_dtc (uint8_t b1, uint8_t b2, char *output) {
    const char prefixes[] = {'P', 'C', 'B', 'U'};
    // Extract Prefix
    output[0] = prefixes[b1 >> 6];
    // Extract Second Digit (0-3)
    output[1] = ((b1 >> 4) & 0x03) + '0';
    // Extract Third Digit (Hex nibble)
    sprintf(&output[2], "%X%02X", b1 & 0x0F, b2);
}
```

}

## 9.5 UI Integration & Visual Representation

The **Raylib Dashboard** module has been extended to include a "Diagnostic Overlay":

- **Critical Alert:** If `dtc_report.count > 0`, the UI renders a flashing "MIL ACTIVE" (Check Engine) icon.
- **Scrollable List:** The DTCs are displayed in a side panel with a timestamp.
- **JSON Link:** Each captured DTC is automatically added to the `log.json` file for remote telematics reporting.

## 9.6 Security & Fail-Safe for Mode 04 (Clear Codes)

While Mode 03 (Read) is passive, **Mode 04 (Clear/Reset)** is active and requires strict safety checks:

1. **Ignition Check:** The system verifies the RPM is 0 (Engine Off) but Voltage is  $>12V$  (Ignition On) before allowing a "Clear Codes" command.
2. **Confirmation Loop:** The UI requires a "Hold for 3 seconds" interaction to prevent accidental clearing of critical vehicle history.

## 9.7 Performance Impact

- **Network Load:** ISO-TP requests are infrequent (once per 5 seconds), ensuring they do not interfere with high-speed RPM/Speed polling.
- **Kernel Memory:** The ISO-TP buffer is capped at 4095 bytes (the ISO-TP limit), preventing buffer overflow attacks from a faulty ECU.

## 10. Hardware Architecture & Interconnects

This section provides a professional **Hardware Specification and Integration Guide** for the physical layer of the system. It covers the SPI communication interface, the differential signaling of the CAN bus, and the electrical protection required for automotive environments.

**Revision:** 1.2

**Interface Standard:** SPI (Serial Peripheral Interface) to ISO 11898-2 (High-Speed CAN)

**Main Components:** Raspberry Pi (Host), MCP2515 (Controller), MCP2551/TJA1050 (Transceiver)

## 10.1 Hardware Component Overview

### 10.1.1 Raspberry Pi (The Host Processor)

The Raspberry Pi acts as the Central Processing Unit (CPU). It handles the **Linux Networking Stack**, the **SocketCAN kernel driver**, and the **User-space UI**.

- **Role:** SPI Master.
- **Voltage Logic:** 3.3V LVTTTL (Low Voltage Transistor-Transistor Logic).

### 10.1.2 Microchip MCP2515 (The CAN Controller)

The MCP2515 is a stand-alone CAN controller that implements the CAN specification, version 2.0B. It offloads the bit-timing and message filtering from the Raspberry Pi.

- **Interface:** SPI (Up to 10 MHz).
- **Buffer Management:** Contains three transmit buffers and two receive buffers with prioritized message storage.
- **Oscillator:** Typically 8MHz or 16MHz (Crucial for baud rate calculation).

### 10.1.3 Microchip MCP2551 (The CAN Transceiver)

MCP2551 acts as the interface between the digital CAN controller and the physical differential CAN bus.

- **Function:** Converts digital TTL signals from the MCP2515 into differential voltages (CAN\_H and CAN\_L).
- **Protection:** Provides 24V short-circuit protection and ISO 7637 transient protection.

## 10.2 Electrical Interconnect & Wiring Diagram

The connection between the Raspberry Pi and the MCP2515 module must be kept short (under 10cm) to prevent SPI signal degradation.

### 10.2.1 SPI & Power Interface (Pi to MCP2515)

MCP2515 Pin	Raspberry Pi GPIO	Physical Pin	Signal Description
VCC	5V	Pin 2 / 4	Power Supply
GND	GND	Pin 6 / 9	Ground Reference
CS / SS	GPIO 8	Pin 24	SPI Chip Select (CE0)
SO / MISO	GPIO 9	Pin 21	Master In / Slave Out
SI / MOSI	GPIO 10	Pin 19	Master Out / Slave In
SCK	GPIO 11	Pin 23	SPI Serial Clock
INT	GPIO 25	Pin 22	Hardware Interrupt (Active Low)

### 10.2.2 Transceiver Interface (MCP2515 to MCP2551)

- TXCAN (MCP2515) -> TXD (MCP2551): Transmit Data line.
- RXCAN (MCP2515) -> RXD (MCP2551): Receive Data line.

### 10.2.3 Physical CAN Bus (OBD-II Connector)

OBD-II Pin	Signal	Color Code (Standard)	Description
Pin 6	CAN_H	Yellow / White	High-side Differential line
Pin 14	CAN_L	Green / Blue	Low-side Differential line
Pin 4/5	GND	Black	Chassis/Signal Ground

## 10.3 Engineering Considerations & Signal Integrity

### 10.3.1 Termination Resistors

According to ISO 11898, a CAN bus must be terminated at both ends with **120-ohm resistors**.

- **The Module Side:** Ensure the 120R jumper (J1) is closed on the MCP2515 module.
- **The Vehicle Side:** The ECU usually provides the termination on the other end of the bus.

### 10.3.2 Clock Stability & Baud Rate

The MCP2515 relies on an external crystal.

- **Clock Error:** A mismatch between the oscillator frequency in /boot/config.txt and the physical crystal (e.g., setting 16MHz for an 8MHz crystal) will cause a "**Bit Timing Error**", making can0 fail to initialize.
- **Sampling Point:** For OBD-II (500kbps), the sampling point is typically set to **75-80%** of the bit time for maximum reliability over long cables.

### 10.3.3 Logic Level Shifting (Safety Warning)

The MCP2551/MCP2515 often run on **5V**, but Raspberry Pi GPIOs is strictly **3.3V**.

- **Recommendation:** Use a Bi-directional Logic Level Converter for the MISO/MOSI/SCK lines to prevent long-term damage to the Raspberry Pi SoC.

## 10.4 Hardware Diagnostic Workflow

1. **Loopback Test:** Before connecting to the car, put the MCP2515 in loopback mode via ip link. This allows the chip to receive its own transmitted messages to verify SPI integrity.
2. **Voltage Check:** Measure the voltage between CAN\_H and CAN\_L while idle. It should be approximately **0V** (Differential) and **2.5V** (Common Mode relative to GND).
3. **Resistance Check:** With the system powered OFF, measure the resistance between CAN\_H and CAN\_L at the OBD connector. It should be approximately **60 ohms** (two 120-ohm resistors in parallel).