

Hardware Architecture and Component Selection for Automotive Driver Monitoring Systems

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Abstract - Driver Monitoring Systems (DMS) are safety-critical embedded vision platforms used to monitor driver attentiveness, drowsiness, and distraction. Automotive DMS hardware must support multi-gigabit video transmission, low latency processing, deterministic behaviour, EMI robustness, and compliance with automotive functional safety standards. This paper presents a comprehensive embedded hardware architecture for a DMS consisting of a camera module with FPD-Link or GMSL serializer, an ECU processing unit with deserializer and serializer, and a remote TFT display module. Detailed coverage includes MIPI CSI-2 and DSI protocols, FPD-Link and GMSL selection, connector and cable considerations, Insertion loss budgeting, Power over Coax (PoC) inductor and filter calculations.

Keywords - Driver Monitoring System, Embedded Vision, FPD-Link, GMSL, MIPI CSI-2, MIPI DSI, Power over Coax, Insertion Loss, Automotive Electronics, High-Speed Video Transmission.

I. INTRODUCTION

System Architecture

A Driver Monitoring System (DMS) is an in-vehicle safety technology that tracks a driver's attention, alertness, and behavior in real time to help prevent accidents caused by distraction, drowsiness, or impairment. The End to end connectivity for DMS system consist of three subsystems electronic control units (ECU's).

Camera Module ECU

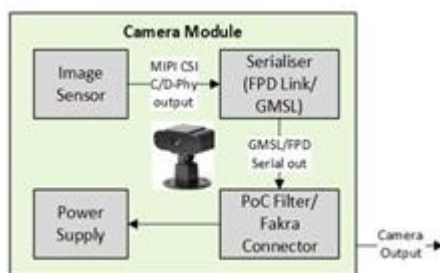


Figure 1: Camera Module ECU block diagram

As shown in the figure 1 camera module ECU consists of a CMOS image sensor that captures driver-facing video and outputs image data through a MIPI CSI-2 interface. A high-speed

serializer (FPD- Link or GMSL) converts the video into a multi-gigabit serial stream for long-distance transmission. A PoC bias network enables power and data over a single coax cable. Regulated power supplies ensure stable operation, and a 50Ω FAKRA connector provides robust automotive connectivity[1][3][4].

Central processing ECU

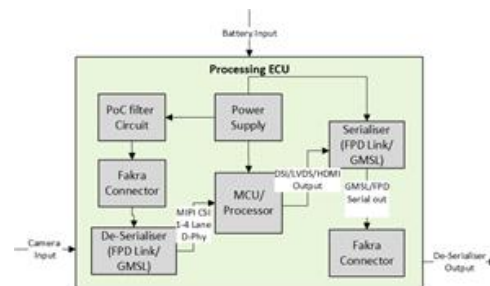


Figure 2: Central processing Unit ECU block diagram

The central processing ECU unit receives the serialized video via an FPD-Link or GMSL deserializer, recovering the original MIPI CSI-2 stream for the SoC. The MCU/SoC executes driver monitoring

algorithms and outputs processed video through MIPI DSI, LVDS, or HDMI interfaces. An optional serializer with FAKRA connector enables transmission to a remote display, supporting long harness lengths while maintaining signal integrity and automotive-grade reliability[1][3][4].

Display unit ECU

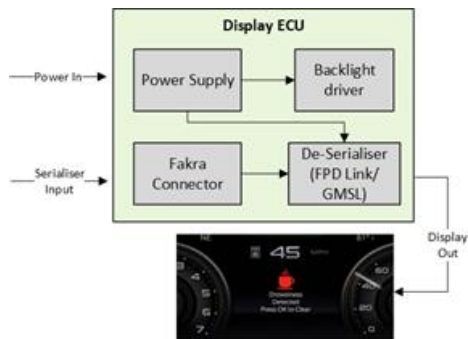


Figure 3: Display Unit ECU block diagram

The display module includes a deserializer that converts the high-speed serialized video back into a parallel or MIPI/DSI format for the TFT display. The TFT panel presents the processed driver monitoring visuals, while an integrated backlight driver controls brightness and uniform illumination, ensuring clear visibility under varying ambient lighting conditions. The module maintains robust automotive connectivity and signal integrity through controlled impedance and shielded interfaces.

The end-to-end data flow of a Driver Monitoring System (DMS) begins with the image sensor which captures video and outputs it via a MIPI CSI-2 interface. The serializer converts this parallel or MIPI stream into a high-speed serial link, which is transmitted over coaxial or STP cable. The deserializer at the ECU recovers the original CSI-2 data for the SoC, which processes driver monitoring algorithms. The processed video is then sent to the display via MIPI DSI or optionally re-serialized for remote display.

High-Speed Video Transport Technologies

High-speed camera and display communication in vehicle networking, SerDes technology is required for long distance communication to ensure reliable and smooth data transfer from one end of the

system to the other. SerDes (Serializer/Deserializer) converts parallel video data into a high-speed serial stream for transmission over automotive cables and then reconstructs it back to its original format at the receiving end. In this document, we explain the working principles and communication architecture of GMSL and FPD-Link technologies used for automotive camera and display connectivity. [3][4]

FPD-Link

FPD-Link, developed by Texas Instruments, is a high-speed serializer/deserializer technology for automotive video links. It features an embedded clock, adaptive equalization, a bidirectional control channel, Power over Coax (PoC) support, and spread-spectrum clocking. FPD-Link enables reliable multi-gigabit video transmission over long automotive harnesses while maintaining low latency and signal integrity. [3]

GMSL

GMSL, developed by Analog Devices, is a high-speed serializer/deserializer technology for automotive applications. Available in GMSL1 (~3 Gbps), GMSL2 (~6 Gbps), and GMSL3 (~12 Gbps) versions, it features adaptive cable equalization, supports coaxial and STP cables, includes built-in diagnostics, and employs spread-spectrum clocking. GMSL enables robust multi-gigabit video transmission over long automotive harnesses with high reliability. [4]

Selection Criteria

The selection between GMSL and FPD-Link depends on application requirements such as bandwidth, transmission distance, and low latency for real-time processing. Key considerations include functional safety compliance, EMI/EMC robustness, power-over-cable capability, support for multi-camera systems, bidirectional control channels, system scalability, ecosystem support, and overall cost to ensure reliable automotive camera and display communication.

MIPI Interfaces MIPI CSI-2

The MIPI CSI-2 interface is used between the image sensor and serializer, and between the deserializer and SoC. D-PHY uses a separate clock lane, supports 80 Mbps to >2.5 Gbps per lane, and employs differential signaling. C-PHY features an embedded clock with a 3-wire trio and offers higher bandwidth efficiency.

For 1920 × 1080 @ 60 fps, 12-bit RAW:
 DataRate = 1920 × 1080 × 60 × 12
 = 1.49Gbps

Including protocol overhead (~20%): means accounting for extra bits added by CSI-2 for packet headers, checksums, and control information, which increases the total transmitted data beyond the raw pixel data.
 ≈1.8Gbps Recommended configuration: 4-lane CSI-2 for margin. [1][2][7][8]

MIPI DSI

The MIPI DSI interface is used between the SoC and the TFT display, operating in Command Mode or Video Mode, and utilizes a PHY similar to CSI-2 for high-speed differential signaling. [1][2][7][8]

Cable and Connector Selection

FAKRA Connector

- 50Ω impedance
- Automotive locking mechanism
- High vibration tolerance
- Frequency support ≥ 6 GHz
- Minimum Insertion Loss

Used for camera-to-ECU link.[5]

Coaxial Cable

Advantages:

- Superior shielding
- Supports PoC
- Long-distance transmission
- Lower EMI radiation Typical attenuation:
- ~1 dB/m @ 3 GHz [6]

STP Cable

Advantages:

- Lower cost
- Flexible routing Requires:
- 100Ω differential impedance

- Careful EMC design [6]

Insertion loss budgeting

Insertion loss is defined as the attenuation of a signal caused by inserting a device into the transmission path.

To calculate the total insertion loss (IL) for a GMSL or FPD-Link link, the contributions from the FAKRA connector, coaxial cable, and PCB traces must be considered. [5][6]

The connector IL is obtained from the FAKRA datasheet, while cable IL per meter is provided by the vendor. PCB trace and via losses can be estimated based on trace length, width, and stack-up. The sum of these losses constitutes the total IL, which must remain within the limits specified in the serializer/deserializer datasheet to ensure proper adaptive equalization and reliable data transmission. [5][6]

Power over Coax (PoC) Inductor & Filter Selection Calculations

Power over Coaxial (PoC) is a technique that delivers both DC power and high-speed data over a single coaxial cable. It works by using a bias-T network, where an inductor passes DC power to the camera while blocking high-frequency signals, and a coupling capacitor allows the high-speed serialized video to pass while blocking DC, enabling simultaneous power and data transmission over the same cable.

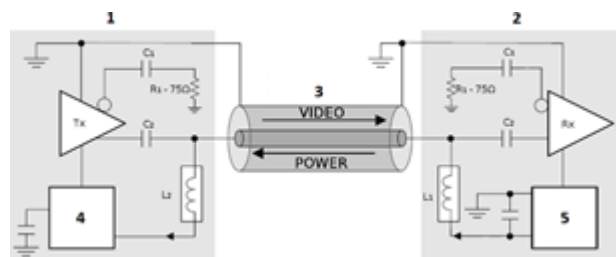


Figure 4: Power over Coax circuit

Inductor Selection

The inductor in the PoC bias-T network provides high impedance at the SERDES operating frequency, allowing DC power to pass while blocking high-speed signals. Its reactance is calculated as:

$$X_L = 2\pi fL$$

To ensure proper isolation of high-frequency data, the inductive reactance must satisfy:

$$X_L \geq 500 \Omega$$

This gives the minimum inductance:

$$L \geq 26.5 \text{ nH}$$

Typical automotive RF inductors in the range of 47–100 nH are selected to meet this requirement. To cover the entire operational frequency range of the SERDES, the inductor is added in series with the DC path, ensuring high impedance at all relevant frequencies and minimal signal attenuation.

Capacitor Selection

The AC coupling capacitor passes high-speed signals while blocking DC. Its reactance is given by:

$X_C = 1/2\pi fC$ To maintain low signal attenuation:

$$C \geq 10 \text{ pF}$$

This ensures proper transmission of the serialized video over the coaxial link.

Resonance Check

The series LC network must avoid resonating at the signal frequency. The resonant frequency is:

$$f_r = 1/2\pi\sqrt{LC}$$

Careful selection of 'L' and 'C' ensures 'Fr' lies outside the SERDES operating bandwidth.

II. CONCLUSION

This paper presents a comprehensive design approach for an automotive Driver Monitoring System, covering the complete embedded hardware chain from camera to display. Detailed analysis includes MIPI CSI-2 and DSI protocols, selection criteria for FPD-Link and GMSL serializers/deserializers, and automotive-grade connector and

cable considerations. Practical insertion loss budgeting, Power over Coax (PoC) design with inductor and filter calculations are discussed to ensure robust high-speed video transmission, signal integrity, and reliable operation over long harnesses.

Acknowledgements

We would like to acknowledge the contributions and foundational technologies that made this work possible. Special thanks to the developers and standards organizations behind GMSL and FPD-Link, whose high-speed serial link solutions enable reliable in-vehicle camera and display communication. We also recognize the MIPI Alliance for establishing the MIPI CSI-2 and DSI interface standards, which provide the essential framework for seamless sensor- to-SoC and SoC-to-display data transfer in modern automotive systems. Their innovations and standards continue to drive advancements in driver monitoring, ADAS, and in-vehicle infotainment technologies.

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