MIPI Automotive SerDes Solutions (MASS™):
An Integrated Approach to Creating Functionally Safe Automotive Sensor Systems

Ariel Lasry
MIPI A-PHY® Working Group Vice Chair
Qualcomm CDMA Technologies GmbH
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Agenda

• About MIPI Alliance
• MIPI Automotive SerDes Solutions (MASS) Overview
• Functional Safety for Sensors
• Summary
• Q&A
About MIPI Alliance
About MIPI Alliance

TODAY’S MIPI MEMBER ECOSYSTEM

- Device OEMs
- Consumer Electronics (Cameras, Tablets, PCs/Laptops, Peripherals, Wearables)
- Software Providers
- IP and VIP Providers
- Test Equipment Companies
- Test Labs
- Semiconductor Companies
- Automotive OEMs / Tier 1 suppliers
- Application Processor Developers

375+ members
30 countries
48% Percentage of members active in automotive sector

MIPI ALLIANCE HAS DEVELOPED MORE THAN 50 SPECIFICATIONS COVERING THE FULL RANGE OF INTERFACE APPLICATIONS NEEDED FOR MOBILE DEVICES

At least one MIPI specification in every smartphone today

THE CELL PHONE MARKET

IN 2003 MIPI ALLIANCE WAS FORMED TO STANDARDIZE CAMERA AND DISPLAY INTERFACES

2003

2022

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MIPI Alliance Members in Automotive

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MIPI Members in Automotive »
MIPI in Automotive

Cameras, displays, audio, sensors, storage, RFFE for 5G, Wi-Fi, Bluetooth, NFC

**Reuse & extend** well-proven protocols == reduced NRE/cost

Intra-box usage has been limited due to lack of native long-reach PHY

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**SPECIFICATIONS IN AUTOMOTIVE TODAY**

Most MIPI interfaces are implemented as "**short reach**" (~15 to ~30cm+)

**CSI-2**
Camera Serial Interface protocol
Protocol for cameras, lidar, radar sensors

**DSI-2**
Display Serial Interface protocol
Protocol for smartphone, IoT and automotive displays

**C-PHY SerDes**
3-phase physical layer for CSI-2 & DSI-2
Short-reach physical layer for cameras and displays

**D-PHY SerDes**
Differential physical layer for CSI-2 & DSI-2
Short-reach physical layer for cameras and displays

**I3C**
Control and data bus protocol and interface
Sensor and general-purpose data and control interface within a module

**RFFE**
RF control protocol
Front-end control within a wireless module

**UniPro for JEDEC UFS**
Data transport protocol for UFS over M-PHY
Transport protocol for UFS storage

**M-PHY SerDes for JEDEC UFS**
Differential physical layer for UFS storage
Short-reach physical transport for UFS storage

**A-PHY SerDes**
Long-reach (up to 15m) asymmetrical physical layer (released Sep 2020)
MIPI Automotive SerDes Solutions (MASS)

Overview
MIPI A-PHY: SerDes System Foundation

First industry-standard asymmetric SerDes physical layer specification targeted for ADAS/ADS and infotainment applications

About A-PHY
(v1.0 released in Sep 2020)

- Direct coupling to native CSI-2/DSI-2/DP-eDP protocols
- High noise immunity, ultra low PER (< 10^{-19})
- Supports bridge-based and endpoint integration
- Support for automotive coax and SDP channels
- Upto 15m long reach with 4 inline connectors
- Power over cable
- Built-in functional safety according to ISO 26262
- Adopted by IEEE as IEEE 2977-2021

A-PHY v1.1 Enhancements
(released Dec 2021)

- Increased support for lower cost legacy cables
- Double uplink data rate
- Star quad cable support, enabling lower cost dual lane operation, for up to 32 Gbps data rate

A-PHY v2.0 Enhancements
(under development, coming in 2023)

- Double Downlink to 32Gbps / Lane
- Increase Uplink to 1.6Gbps
- Enable support of security for A-PHY network
- Expand power classes for Power over A-PHY

**MIPI A-PHY Performance**

<table>
<thead>
<tr>
<th>Downlink Gear Data Rate</th>
<th>Modulation</th>
<th>Modulation Bandwidth (MHz)</th>
<th>Max Net App Data Rate (Gbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 2 Gbps</td>
<td>NRZ-8B/10B</td>
<td>1</td>
<td>1.5</td>
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<td>PAM4 (Optional)</td>
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<td>1.8</td>
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<td>G2 4 Gbps</td>
<td>NRZ-8B/10B</td>
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<td>3</td>
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<td>PAM4 (Optional)</td>
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<td>3.6</td>
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<td>G3 8 Gbps</td>
<td>PAM4</td>
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<td>7.2</td>
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<td>G4 12 Gbps</td>
<td>PAM8</td>
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<td>10.8</td>
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<td>G5 16 Gbps</td>
<td>PAM16</td>
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<td>14.4</td>
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<thead>
<tr>
<th>Uplink Gear Data Rate</th>
<th>Modulation</th>
<th>Modulation Bandwidth (MHz)</th>
<th>Max Net App Data Rate (Mtps)</th>
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<td>U1 100 Mbps</td>
<td>NRZ-8B/10B</td>
<td>50</td>
<td>55</td>
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<tr>
<td>U2 200 Mbps</td>
<td>PAM4-8B/10B</td>
<td>50</td>
<td>125</td>
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</tbody>
</table>

PER: Packet Error Rate  SDP: Shielded Differential Pair
MIPI Automotive SerDes Solutions (MASS)
A framework for integrating sensors and displays with End-to-End Functional Safety and Security built in

Electronic Control Unit (ECU)
• Advanced driver assistance system (ADAS) based on sensor feeds
• Produces display feeds

Sensors
• Camera
• Lidar

Displays
• Dashboard
• Console
• Side-view mirrors
• Entertainment

(Optional) A-PHY bridges
• Translates between short-range MIPI C-PHY / D-PHY & long-range MIPI A-PHY
MASS Supported Topologies – Examples

Cameras and Sensors Aggregation
- Multi-port A-PHY RX SerDes with CSI-2 Aggregator
- End-to-End Protection

Daisy Chaining of Heterogeneous Displays
- MIPI DSI-2 + VESA eDP over A-PHY
- End-to-End Protection

Other common topologies are also supported but not shown

DID: Driver Instrument Display
CID: Central Information Display
CDD: Co-Driver Display
MASS Stack – Framework Nearly Completed

- **Applications**
  - MIPI Layered Protocol Stack
  - MIPI Functional Safety and Security
  - MIPI Protocol Layers

- **Camera / Lidar / Radar**
  - Camera Service Extensions (CSE)
  - Display Service Extensions (DSE)
  - Functional Safety Security

- **MIPI Display**
  - MIPI CCS
  - MIPI DCS
  - MIPI DSI-2
  - MIPI PAL/DSI-2

- **VESA Display**
  - VESA eDP / DP

- **Supporting Interfaces**
  - Ethernet
  - GPIO
  - MIPI I3C
  - I2C
  - SPI
  - Future Protocols

**Updated Command Set for Automotive Control**

**Protocol Extensions for Safety and Security**

**Updated Mobile Protocols**

**Adaptation Layers**

**Automotive Long-Reach PHY**

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Functional Safety for Sensors
Annex D – Communication bus safety mechanisms:

- One-bit hardware redundancy
- Multi-bit hardware redundancy
- Read back of sent message
- Complete hardware redundancy
- Inspection using test patterns
- Transmission redundancy
- Information redundancy
- Frame counter
- Timeout monitoring
- Combination of information redundancy, frame counter and timeout monitoring

ISO26262-5 Annex D – Communications Bus
1-5 Model: Reference Topology (Camera)
End-to-End Functional Safety and Security Protection

- Up to 5 functional components
- Controller connections to all components that include Bridges and Forwarding Elements

• Any combination of Bridges

Topologies options

End to End Protection

CCI: Camera Control Interface
3 Data Service Protocols (DSP): SEP, FSED, CCISE

End-to-End Functional Safety and Security Protection

**Data Service Protocols (DSP)**

- **SEP**: Service Extensions Packet
  - **Granularity**: Message-based
  - **Reach**: Sensor to Controller, End-to-End (1-5)
    - Bridge to Bridge (2-4), also (1-4) and (2-5)

- **FSED**: Frame-Based Service Extensions Data
  - **Granularity**: Frame-based
  - **Reach**: Sensor to Controller, End-to-End (1-5)

- **CCISE**: CCI Service Extensions
  - **Granularity**: I²C Transaction (Start to Stop)
  - **Reach**: Controller to all Targets, End-to-End (1-5)
    - End-to-End (1-2), (1-3), (1-4)

**In-Band, Data Plane Protection**

- SEP, FSED
  - (protecting CSI-2)

**Out-of-Band, Control Plane Protection**

- CCISE
  - (protecting the Target CCI & the A-PHY configurations)
MIPI Camera Service Extensions (CSE) Layering

Data Service Protocols (DSP) provide Security and Functional Safety Services for protecting CSI-2 and CCI traffic in the following order:

- TX Security first
- TX FuSa last

The receiver performs the operations in reverse order.

This layering applies to all 3 DSPs: FSED, SEP and CCISE.

Failure management policy is defined by the system.

MAC: Message Authentication Code
CRC: Cyclic Redundancy Check
MC: Message Counter
FuSa: Functional Safety

Data covered by (Security) MAC
Data covered by (FuSa) CRC

Opt Payload Encryption. When Encryption is ON, MAC and CRC are computed over Ciphertext.
CSI-2 Frame: Basics

- Example showing one CSI-2 Frame associated with a given Virtual Channel (VC)
- The Frame is partitioned into 5 Frame Partitions (FP), always beginning with a Frame Start and ending with a Frame End Packets.
- Embedded Data carrying sensor’s metadata are optional and are transmitted in FP-2 and/or FP-4
- Image Data supporting various formats (YUV, RGB, RAW) is transmitted in FP-3
- CSE provides great flexibility in that different Security or FuSa parameters may be assigned to the data in each FP

<table>
<thead>
<tr>
<th>Key</th>
<th>Embedded Data</th>
<th>FP: Frame Partition</th>
<th>PH: Packet Header</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image Data</td>
<td>SP: Short Packet</td>
<td>PF: Packet Footer</td>
<td>SP: Short Packet</td>
</tr>
</tbody>
</table>

The sequence of CSI-2 Packets comprising a Frame:

- **FP-1** Frame Start
  - SP
  - PH Embedded Data
  - PH Embedded Data
  - PF

- **FP-2** Top Block
  - PH Embedded Data
  - PH Embedded Data
  - PF

- **FP-3** Middle Block
  - PH Embedded Data
  - PH Image Data
  - PH Image Data
  - PF

- **FP-4** Bottom Block
  - PH Embedded Data
  - PH Embedded Data
  - PF

- **FP-5** Frame End
  - PH Embedded Data
  - SP
  - PF

Sensor Pixel Data
Service Extension Packet (SEP) over A-PHY

- CSI-2 Packets are extended with SEP
- SEP is protected End-to-End on application protocol level with
  - FuSa Message Counter in SEP Header
  - Security Message Counter in SEP Header
  - MAC in SEP Footer
  - CRC-32 with Hamming Distance ≥ 3 in SEP Footer
- SEP Header contains extended CSI-2 PH information
  - eVC: extended Virtual Channel
  - eDT: extended Data Type
  - Source ID: identifying the sensor
  - Other fields (timesamp, Row ID, Column ID etc.)
- SEP are chunked to multiple A-Packets when transported over A-PHY. Each A-Packet is protected with a Message Counter and CRC-32
## SEP Tag Modes

- **Three Tag Modes for MAC and CRC per CSI-2 Frame**
  - Per Message
  - Per Data Type
  - Per Frame

- **Provides a trade-off between Tag overhead and error detection latency**

- **Optional TOP Tag for early error detection in TOP Embedded Data when using a single Tag per Frame**

- **CSE v1.0 supports only Per Message CRC**

- **CSE v2.0 introduces Per DT and Per Frame Tag Modes**
Frame-Based Service Extensions Data (FSED)

- FSED protects End-to-End CSI-2 Frames at application protocol level
- PHY agnostic using “legacy” CSI-2 packets
- Adds FSED Messages to “regular” CSI-2 Frames
  - FSED CTRL_SYNC provides Frame information and security configuration
  - Optional FSED TOP_TAG protecting the Top Block
  - FSED FRAME_TAG protecting the full CSI-2 Frame
- FSED Messages transported as CSI-2 Embedded Data
Control Plane Protection with CCISE

- Command and Control Interface **Service Extensions** (CCISE) add Functional Safety and Security services to CCI (I2C)
- CCISE supports control of
  - Camera Control Interface CCI (I2C)
  - A-PHY bridges and forwarding elements
  - Any other device controlled via I2C (or virtual I2C with PAL/I2C)
- CCI (I2C) Messages are extended with Tags
  - Functional Safety Tags: Message Counter, CRC
  - Security Tags: Message Counter, MAC
  - Separate Tags for Read and Write Messages
- Two CCISE verification modes
  - **Mode 1: Per-Transaction.** Tags are transmitted with the Messages and can be **verified immediately by the Target** or the Controller
  - **Mode 2: Per-Frame.** Tags are not transmitted with the Messages. Tags are calculated over an entire CSI-2 Frame, both at the Controller and at the Target. Tags are sent from the Target to the Controller
    - Within CSI-2 Embedded Data or
    - Controller read access to the Tags
  Tags are verified by the Controller. Mode 2 is motivated by the speed limit of I2C interface
CCISE Mode 1
Tags are added as Footer to CCI (I2C) Read/Write Transactions

WRITE Transaction

READ Transaction

Security Write Tags

FuSa Write Tags

Security Read Tags

FuSa Read Tags

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CCISE Mode 2

WRITE TO RANDOM ADDRESS (16-BIT INDEX)

<table>
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<tr>
<th>TARGET ADDRESS</th>
<th>SUB ADDRESS</th>
<th>DATA[0]</th>
<th>DATA[7-1]</th>
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<tbody>
<tr>
<td>Byte 1</td>
<td>Byte 2</td>
<td>Byte 3</td>
<td>Byte 4</td>
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<td>Byte L+3</td>
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READ FROM RANDOM ADDRESS (16-BIT INDEX)

<table>
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<tr>
<th>TARGET ADDRESS</th>
<th>SUB ADDRESS</th>
<th>DATA[0]</th>
<th>DATA[7-1]</th>
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<tr>
<td>Byte 1</td>
<td>Byte 2</td>
<td>Byte 3</td>
<td>Byte 4</td>
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<tr>
<td>Byte 5</td>
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<td></td>
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<tr>
<td>Byte L+4</td>
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</table>

Exactly same transactions on the line as in CCI (I2C)
- No Tags on the wire
- No overhead

Both Controller and Target calculate independently the Functional Safety Tags accumulated over the CSI-2 Frame
- Write Message Counter (FWMC), Write CRC (WCRC)
- Read Message Counter (FRMC), Read CRC (RCRC)

Controller verifies Tags
Accumulated Tags are sent from the Sensor to the Controller at the end of the CSI-2 Frame
- As CSI-2 Embedded Data or
- Controller reads Tags registers
Built-in Self Tests (BIST) and Diagnostics

<table>
<thead>
<tr>
<th>FP-1</th>
<th>FP-2</th>
<th>FP-3</th>
<th>FP-4</th>
<th>FP-5</th>
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Summary

• MASS leverages and extends well-proven protocols (e.g. CSI-2)

• MASS provides a standardized framework enabling end-to-end functional safety and security protection at the application protocol level
  – Data plane with SEP and FSED
  – Control plane with CCISE

• Flexibility with message-based and frame-based protections to enable system integrator trade-offs

• Advanced self-testing and error injection features for a higher functional safety diagnosis level

• A-PHY and MASS are architected for seamless integration into sensors, providing an optimal robust and resilient solution for automotive safety applications
MIPI Automotive Resources

For automotive developers, system architects and engineering managers who are focused on the design, development, integration and test of next-generation automotive E/E architectures. Will cover:

- MIPI Automotive SerDes Solutions (MASS)
- Display and sensor (camera/lidar/radar) stacks
- Functional safety, security and data protection
- MIPI A-PHY v2.0, Power over A-PHY, system modelling and test

See 2021 workshop presentations »

More information can be found at:

- MIPI A-PHY Specification Webpage
- MIPI Automotive SerDes Solutions (MASS)
- MIPI White Paper: Introduction to MASS
Thank you