A-PHY:
The Cornerstone of MIPI Automotive System Solutions

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Presentation Outline

About MIPI Alliance
Peter Lefkin
MIPI Alliance Managing Director

MIPI A-PHY – System View
Ariel Lasry
Director, MIPI Alliance Board of Directors

MIPI A-PHY - Specification Overview
Edo Cohen
MIPI A-PHY Subgroup Vice-Lead

Q&A
About MIPI Alliance

Peter Lefkin
MIPI Alliance Managing Director
About MIPI Alliance

The Cell Phone Market

In 2003, MIPI Alliance was formed to standardize camera and display interfaces.

2020

MIPI Alliance has developed roughly 50 specifications covering the full range of interface applications needed for mobile devices.

Today's MIPI Member Ecosystem

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

Number of countries: 27
Percentage of members active in automotive sector: 45%

332 members

CONFIDENTIAL
<table>
<thead>
<tr>
<th>MIPI Specifications in Automotive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CSI-2</strong></td>
</tr>
<tr>
<td>Camera Serial Interface protocol</td>
</tr>
<tr>
<td>Protocol for cameras, lidar,</td>
</tr>
<tr>
<td>radar sensors</td>
</tr>
<tr>
<td><strong>DSI-2</strong></td>
</tr>
<tr>
<td>Display Serial Interface protocol</td>
</tr>
<tr>
<td>Protocol for smartphone, IOT and</td>
</tr>
<tr>
<td>automotive displays</td>
</tr>
<tr>
<td><strong>C-PHY</strong></td>
</tr>
<tr>
<td>3-phase physical layer for CSI-2</td>
</tr>
<tr>
<td>&amp; DSI-2</td>
</tr>
<tr>
<td>Short-reach physical layer for</td>
</tr>
<tr>
<td>cameras and displays</td>
</tr>
<tr>
<td><strong>D-PHY</strong></td>
</tr>
<tr>
<td>Differential physical layer for</td>
</tr>
<tr>
<td>CSI-2 &amp; DSI-2</td>
</tr>
<tr>
<td>Short-reach physical layer for</td>
</tr>
<tr>
<td>cameras and displays</td>
</tr>
<tr>
<td><strong>I3C</strong></td>
</tr>
<tr>
<td>Control and data bus protocol and</td>
</tr>
<tr>
<td>interface</td>
</tr>
<tr>
<td>Sensor and general purpose data</td>
</tr>
<tr>
<td>and control interface within a</td>
</tr>
<tr>
<td>module</td>
</tr>
<tr>
<td><strong>RFFE</strong></td>
</tr>
<tr>
<td>RF control protocol</td>
</tr>
<tr>
<td>Front end control within a</td>
</tr>
<tr>
<td>wireless module</td>
</tr>
<tr>
<td><strong>SoundWire &amp; SWI3S</strong></td>
</tr>
<tr>
<td>Digital audio and control interface</td>
</tr>
<tr>
<td>Audio interface within a module</td>
</tr>
<tr>
<td><strong>UniPro for JEDEC UFS</strong></td>
</tr>
<tr>
<td>Data transport protocol for UFS</td>
</tr>
<tr>
<td>over M-PHY</td>
</tr>
<tr>
<td>Transport protocol for UFS storage</td>
</tr>
<tr>
<td><strong>M-PHY for JEDEC UFS</strong></td>
</tr>
<tr>
<td>Differential physical layer for</td>
</tr>
<tr>
<td>UFS storage</td>
</tr>
<tr>
<td>Short-reach physical transport for</td>
</tr>
<tr>
<td>UFS storage</td>
</tr>
</tbody>
</table>

Fundamentally, usage rights are granted to members royalty free for implementation of MIPI specifications from all MIPI members.
MIPI A-PHY – System View

Ariel Lasry
Director, MIPI Alliance Board of Directors
Honda and GM Partner to Develop Mass Produced, Driverless Cars
Source: October 4, 2018, Automotive News

Auto Industry Transformation

**CASE:**
- **Connected**
- **Automated**
- **Shared**
- **Electrified**

And . . .

**Safety:** Improved government safety regulations (FCWS, AEB, RVS, LDWS, etc.)

**Fuel economy:** Aggressive regulations

MIPI directly supports **CASE** via:
- **Connected** (RFFE, others)
- **Automated** (A-PHY, CSI-2, others)
Levels of Driving Automation:
MIPI A-PHY Contributes to Levels 2-5, Moving Sensor Data Efficiently

MIPI A-PHY contributes to Levels 2-5
NCAP Regulations Driving Sensors & Display Adoption

- Worldwide NCAP ADAS standards driving adoption of multiple high data rate “surround sensors”
- Displays for driver viewing of assistance imaging and information also required
**Autonomous Driving System/Architecture**

**CENTRAL CHALLENGE:** Transport raw image sensor and/or radar data to fusion processor, and processor/other generated data to the displays

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**Data Rates**

**For camera/image sensors,** 10Gbps link could support:
- RAW16 **10MP 1 max exposure channel @ 60fps**
- RAW 16 **2MP 4 max exposure channels @ 60fps**

**For radar,** 12.5Gbps link could support:
- Four “typical” 4-RX-channel (50MS/sec, 12b res)
- Two “max” 4-RX-channel (80MS/sec, 16b res)

**For display subsystems,** 16Gbps link could support:
- Ultra-HD **3840x2160 24-bits/pixel RGB 4:4:4 60 Hz**
What is MIPI A-PHY?

MIPI A-PHY is a physical layer specification targeted for ADAS/ADS surround sensor applications and Infotainment display applications in automotive. Version 1.0 will provide a 15-meter reach and data rates of 2-16 Gbps, with a roadmap to 24, 48 Gbps and beyond.

MIPI A-PHY is the ONLY standard interface to support native camera (CSI-2) and display (DSI-2) interfaces for automotive. An adaptation layer is also being developed for VESA DisplayPort and eDP.

TODAY’S PROPRIETARY INTERFACE BRIDGE SOLUTIONS

TOMORROW A-PHY STANDARD INTERFACE BRIDGE SOLUTIONS

FUTURE INTEGRATED A-PHY (NO BRIDGES: Lower cost, weight, power)
A-PHY Topology Examples

Cameras example with direct connection

Displays example with daisy-chain
Challenges To Be Solved Require: A-PHY + MIPI Protocols

- **PER = 10^-18**: 1 packet error in ~10,000 car-lifetimes
- High speed downlink and aggregation to support **multiple** 4K cameras and displays
- Asymmetric high speed link with fixed low latency ~6\(\mu\)s @G5

**Robust Automotive Long-Reach Link**

**End to End Functional Safety**

- Enabling integration of devices using MIPI protocols over A-PHY in ASIL B or ASIL D systems
- A-PHY and Protocols (CSI-2, DSI-2) FuSa from Source to Sink

**End to End Security**

- Authentication; prevention of tampering (malicious and non-malicious)
- Content protection for display applications (HDCP)

**Heterogeneous Interfaces**

- Common support for multiple display protocols: DSI, DisplayPort, eDP, OpenLDI
- Agnostic to source/sink PHY configuration: C-PHY, D-PHY, Lanes count
MIPI Vision for End-to-End System
Scalability: Additional PHY Adaptation Layers (PALs) can be developed to expand interoperability.
An Overview of A-PHY

Edo Cohen
MIPI A-PHY Subgroup Vice-Chair
Gears and Profiles

- One rate/line-code/modulation per downlink gear
- Single uplink gear
- A-PHY Device supporting Gear N (i.e., N could be 1–5) shall support all lower gears.
- Two noise/performance profiles (with full inter-profile interoperability):
  - Profile 1: Optimized for low cost/power implementations for the lower gears with lower noise immunity and target BER of $<10^{-12}$
  - Profile 2: Optimized for vehicle lifespan, link robustness for all gears with high noise immunity and target PER of $<10^{-19}$

<table>
<thead>
<tr>
<th>Gear Data Rate</th>
<th>Modulation [One modulation per Gear]</th>
<th>Symbol Rate [GBaud]</th>
<th>Net Application Data Rate [Gbps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 2 Gbps</td>
<td>NRZ-8b/10b</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>G2 4 Gbps</td>
<td>NRZ-8b/10b</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>G3 8 Gbps</td>
<td>PAM4</td>
<td>4</td>
<td>7.2</td>
</tr>
<tr>
<td>G4 12 Gbps</td>
<td>PAM8</td>
<td>4</td>
<td>10.8</td>
</tr>
<tr>
<td>G5 16 Gbps</td>
<td>PAM16</td>
<td>4</td>
<td>14.4</td>
</tr>
<tr>
<td>Uplink, All Gears 100Mbps</td>
<td>NRZ-8b/10b</td>
<td>0.1</td>
<td>0.055 (55Mbps)</td>
</tr>
</tbody>
</table>
High Level Structure

- **Native Protocol**
  - e.g., CSI-2, DSI-2, I²C, GPIO

- **Protocol Adaptation Layer (PAL)**
  - Mapping to/from Native Protocol to A-Packet

- **APPI**
  - Interface between A-PHY Port and PAL

- **Data Link Layer**
  - Performs A-Packet scheduling, prioritization and forwarding

- **Physical Layer**
  - Encodes and decodes symbols extracted from A-Packets according to the modulation scheme used per gear
  - Modulated symbols are transmitted and received over the A-PHY interconnect according to the medium-dependent electrical specifications.
A-Packet

• The A-Packet is structured to carry the Native Protocol data and all information that the A-PHY Data Link Layer requires to perform its functions efficiently.
• Downlink and uplink use the same packet structure.
• Structure optimized supporting multiple protocols aggregation with minimal overhead and latency
• The A-Packet Header contains all required information (e.g., QoS, Priority, Destination, Protocol Type).
• The A-Packet structure:
  – Header - 8 Byte including MC (Message Counter)
  – Payload
  – Tail – 4 Byte (CRC-32)
Interconnect

- A-PHY is a single lane, point-to-point, serial communication technology
- Support for multiple cable types – SDP/Coax
- Power over cable support
- Up to 15m with 4 inline connectors
## Low Tx Amplitude - Optimized for Low PSD

**TX Amplitudes to over 50 Ω Coax channel**

<table>
<thead>
<tr>
<th>Gear</th>
<th>Downlink [mVp-p]</th>
<th>Uplink [mVp-p]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>2</td>
<td>350</td>
<td>500</td>
</tr>
<tr>
<td>3</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>4</td>
<td>500</td>
<td>250</td>
</tr>
<tr>
<td>5</td>
<td>500</td>
<td>250</td>
</tr>
</tbody>
</table>

- Example Comparing ~4Gbps Downlink TX Voltage solutions (Single Ended)
  - A-PHY G2 – 350mVp-p
  - FPD Link III (DS90UB953-Q1) – 575mVp-p
  - GMSL (MAX9277-9281) – 500mVp-p
Noise Immunity

• There is a major variance in the OEM EMC requirements, from those who aim for minimal noise immunity, to OEMs that apply stringent requirements to protect their system.

• A-PHY two profiles provide two noise immunity levels to accommodate this variance:
  – P1 has lower noise immunity, similar to other SERDES solutions and is applicable for G1 and G2 (optional G3).
  – P2 has very high noise immunity based on MIPI Alliance analysis of expected noise level for the car lifetime period.

• MIPI conducted multiple tests in an independent lab evaluating the noise levels and shielding effect degradation after mechanical stress and aging.
  – The results helped evaluate the different available technologies.
  – The research continues as part of MIPI A-PHY SG activities.
Characteristics of RF Ingress Test

**Test Conditions**

**Cable:** Two types of Dynamics Coax cables in length of 2m and 15m

**Lab Conditions:**

<table>
<thead>
<tr>
<th>Mechanical condition</th>
<th>Bending angle</th>
<th>180°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending diameter</td>
<td>60 mm</td>
<td></td>
</tr>
<tr>
<td>Bending Speed</td>
<td>10 times/min</td>
<td></td>
</tr>
<tr>
<td>Weight load</td>
<td>3 N (~0.3kgf)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature condition</th>
<th>Temp. cycle</th>
<th>See below fig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. range</td>
<td>-25<del>25</del>105℃</td>
<td></td>
</tr>
</tbody>
</table>

Total number of bending 36000 times
Total time Roughly 72 hours

**Bending Fatigue & Temperature Cycling Test**

**Screening Attenuation Test Result**
# Noise Immunity Levels

<table>
<thead>
<tr>
<th>Interference</th>
<th>P1 [mVpeak]</th>
<th>P2 [mVpeak]</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Ingress</td>
<td>5</td>
<td>40</td>
<td>Based on the ALSE method ISO 11452-2, CW/AM/PM modulation scheme</td>
</tr>
<tr>
<td>Bulk Current Injection</td>
<td>21</td>
<td>40</td>
<td>Based on ISO 11452-4, CW/AM modulation scheme</td>
</tr>
<tr>
<td>Fast Transient</td>
<td>15</td>
<td>150</td>
<td>Based on ISO7637-2/3, with modifications for higher frequency pulses</td>
</tr>
</tbody>
</table>

**Notes:**
- Noise levels are defined at the Receiver pads when using the specified typical worst-case cable.
- P2 limits are in line with similar results shown in IEEE research paper: [https://ieeexplore.ieee.org/document/8825296](https://ieeexplore.ieee.org/document/8825296) (Requires IEEE member access).
- 40mVpeak corresponds to 89dBuV RMS.
Functional Safety

• A-PHY packets are end-to-end protected as recommended in ISO-26262:2018:
  – CRC-32 for each packet, providing a Hamming-Distance of more than 3.
  – Message Counter that is 8 bits wide.
  – Timeout monitoring is fulfilled by the Keep-Alive function.

• The above measures are necessary to argue a high diagnostic coverage for a communication bus, per Table D.6 in ISO 26262-5:2018.

• All other functional safety features necessary in order to fulfill the required system-level safety goal with ASIL are expected to be managed by upper layers.
A-PHY Port

• A-PHY Port mandatory Baud Rates: 2GBaud or 4GBaud
• A-PHY Source Port shall supply the clock, and A-PHY Sink Port shall receive it.
• MIPI A-PHY refers to TPA and TPB throughout the specification for clear interoperability and testability
Mode Of Operations

• Same state machine to A-PHY Source and Sink

• State transition may be triggered by:
  – Internal mechanism
  – Local host
  – Remote controller

• All changes are reported to the local system
  – The local system will take any needed decisions based on the provided information

• Some activities are “automatic” and do not require local system intervention
PHY Layer

- Unified structure to reduce complexity
- Shared 8B/10B PCS for G1/G2 and Uplink
- RTS Sub-Layer
  - Manage Data Pacing and buffering
  - Assign Message Counter (MC) and CRC
  - P2 - the retransmission process for A-Packets that are erroneous or that are not received
- PCS Sub-Layer
  - Specifies the conversion of Data Link Layer A-Packets into PHY Symbols
  - In P2, PCS also handles the JITC(*) Re-Training
- PMD Sub-Layer
  - Defines the electrical specifications and the physical medium

(*) JITC – Just In Time Cancelers
RTS - Time Bounded Local PHY Level Retransmission

- Local Retransmission (RTS) mechanism is used in order to:
  - Recover damaged packets due to the effect of large in-car electrical transients which create long bursts of errors
  - Recover damaged packets due to instant attack of yet un-cancelled large NBI which create long bursts of errors
  - Ensure steady link throughput to enable seamless higher layers operation even at extreme PHY operation points
RTS - Time Bounded Local PHY Level Retransmission

- **Time Bounded**
  - Retransmission is attempted only within predefined “Overall Delay” (e.g. ~6µS @G5)

- **Local PHY Level**
  - Transparent to upper layers
  - Happens within a single A-PHY Hop

- **Dynamically Modulated**
  - Retransmitted packets have better error resistant data payload Sub-Constellation

- **Highly Reliable**
  - PER (Packet Error Rate) < $10^{-19}$

- **Highly Resilient**
  - Overcome thousands symbols-long error bursts
  - Multiple 10s of mVs, instantly attacking, NBI Peak

- **Low Overhead**
  - Overall PHY + Link < 10% → 90% Net Data rate
Link Layer

- The A-PHY Data Link Layer is a protocol agnostic layer that performs scheduling, prioritization and forwarding of A-Packets.
- Each Protocol Adaptation Layer has at least one APPI connection to the A-PHY Data Link Layer.
- A-PHY Data Link Layer may be connected to multiple Protocol Adaptation Layers using a single Local Function.
- The A-PHY Data Link Layer may have a single A-PHY Network Function connected to it, or multiple A-PHY Network Functions.
Link Layer

The A-PHY Data Link Layer enables A-Packet:

- Forwarding
- Prioritization
- Duplication
- Scheduling
APPI – A-PHY Protocol Interface

- Based on MIPI current PPI (PHY Protocol Interface) for D-/C-PHY
- Simplified normative signal interface of A-PHY with protocol layers
- Flexible data width and clock speed
- Easy migration for higher speeds in next generation
Concluding Thoughts

• In-vehicle architecture is **rapidly evolving** . . .
• Increased focus on **surround sensor applications** for ADAS / autonomous driving . . . Best served by dedicated high-speed asymmetric interfaces from sensors to ECU.
• Standardization important for **economies of scale, lower cost & greater capabilities**.
• The native MIPI protocols (CSI-2, DSI-2, I3C, others, available in billions of devices) with **A-PHY deliver enormous benefit** to the automotive industry . . . performance, cost, noise immunity, and long-term EBOM reduction via elimination of interface bridges.
• The MIPI solution is being developed to **meet the broadest spectrum** of automotive industry needs . . . with anticipated SOP as early as 2024.
Additional Resources
Resources

More information can be found at:

- MIPI Alliance Completes Development of A-PHY v1.0, an Industry-Standard Long-Reach SerDes Physical Layer Interface for Automotive Applications (Press release, June 2020)

- MIPI Alliance rises to data-transport challenge (Article, AVT, April 2020)

- Advancing In-Vehicle Connectivity for ADAS and Other Automotive Applications (Webinar, March 2020)

- A Look Under the Hood at MIPI CSI-2 and MIPI DSI-2 in Automotive (Blog, January 2020)

- MIPI Automotive & A-PHY Update (DevCon presentation, October 2019)

- MIPI Alliance Advances Activities for ADAS, ADS and Other Automotive Applications (Press release, October 2019)

- Automotive Applications Drive MIPI A-PHY Development (Blog, May 2019)

Other Resources

- A-PHY specification page

MIPI in Automotive white paper