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20-21 SEPTEMBER 2022

Raj Kumar Nagpal, Edo Cohen
MIPI A-PHY WG co-chairs
Ariel Lasry
MIPI A-PHY WG vice-chair

# MIPI Automotive SerDes Solutions: New Developments in A-PHY® and the MASS℠ Connectivity Framework

# Agenda

- MIPI Automotive SerDes Solution (MASS)
- A-PHY Overview
- Next Generation A-PHY
- Summary
- Q&A

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# MIPI Automotive SerDes Solution (MASS)

# MIPI Automotive SerDes Solutions (MASS)

A framework for integrating sensors and displays with functional safety and security built in

**Electronic Control Unit (ECU)**

- Advanced driver assistance system (ADAS) based on sensor feeds
- Produces display feeds

**Sensors**

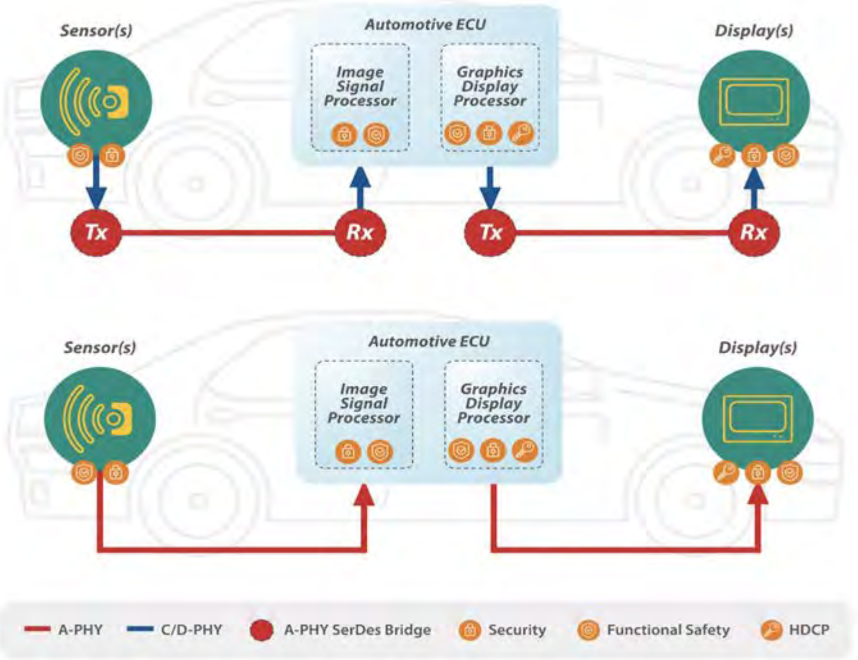
- Camera
- Lidar

**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 solution using A-PHY bridges

MASS solution using integrated A-PHY

# MASS Guiding Principles

**Service Extensions**

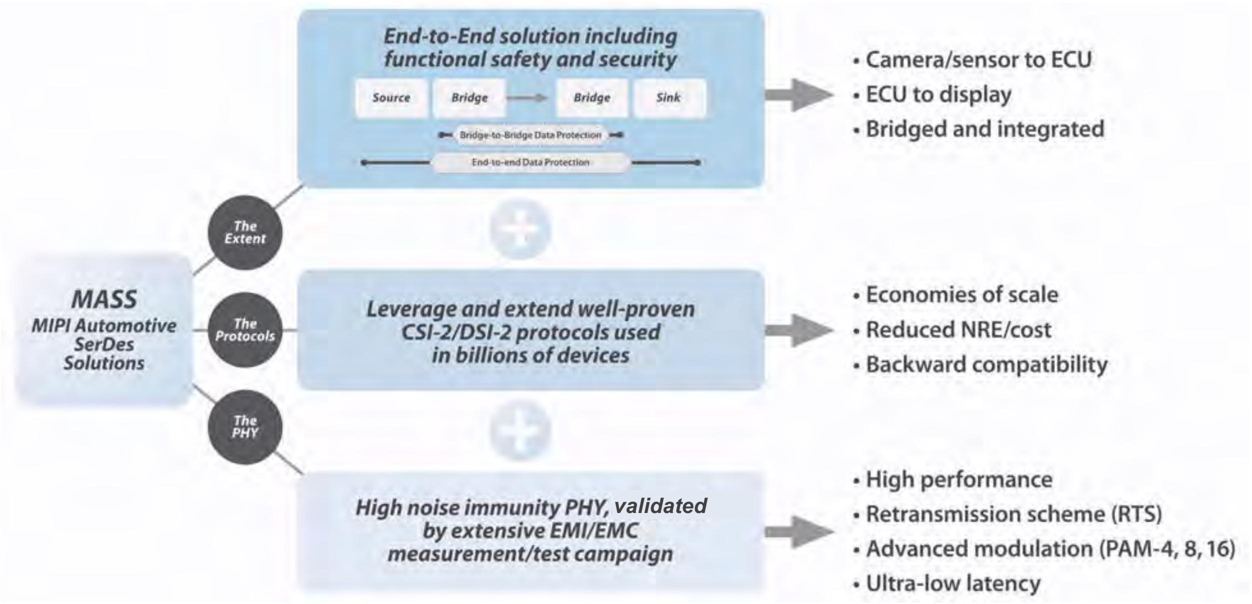
- CSE℠: Camera Service Extensions
- DSE℠: Display Service Extensions
- CCISE℠: Command and Control Interface Service Extensions
- MIPI Security Specification

**PALs: Protocol Adaptation Layers**

- MIPI CSI-2®, MIPI DSI-2℠, I3C®
- VESA eDP/DP
- Ethernet, I2C, GPIO, SPI, Audio

**A-PHY**

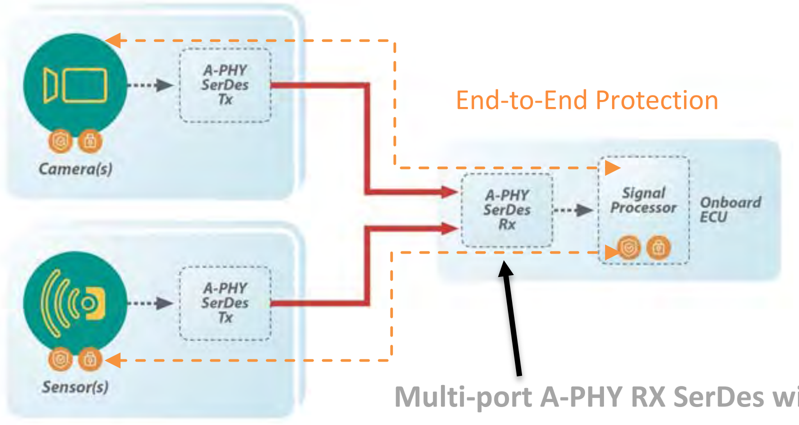
- Robust PHY for Automotive
- MTBF of 1 error over the full vehicle life-span
- Long reach PHY (15m)
- Coax, SDP and STQ cables




**MTBF:** Meantime Between Failure **SDP:** Shielded Differential Pair **STQ:** Star Quad (shielded dual differential pair)

# MASS Supported Topologies - Examples

## Camera and Sensor Aggregation

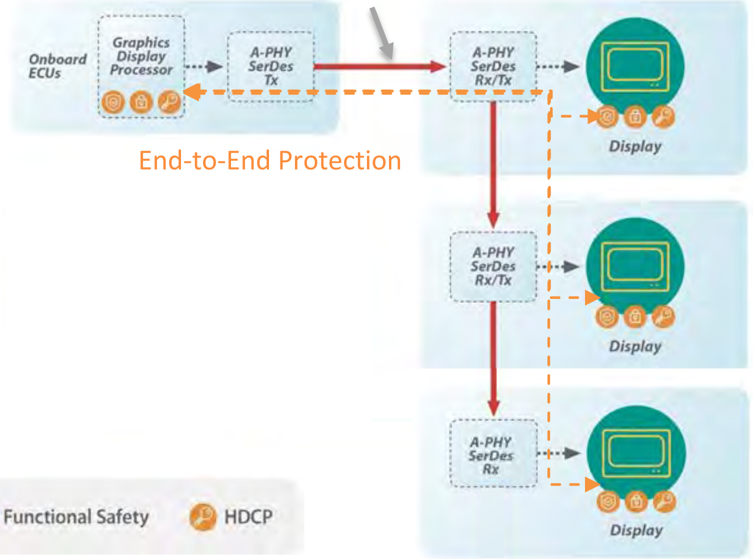



Multi-port A-PHY RX SerDes with CSI-2 Aggregator

MIPI CSI-2 Sensors

## Daisy Chaining of Heterogeneous Displays

MIPI DSI-2 + VESA eDP over A-PHY




DID DSI-2

CID eDP

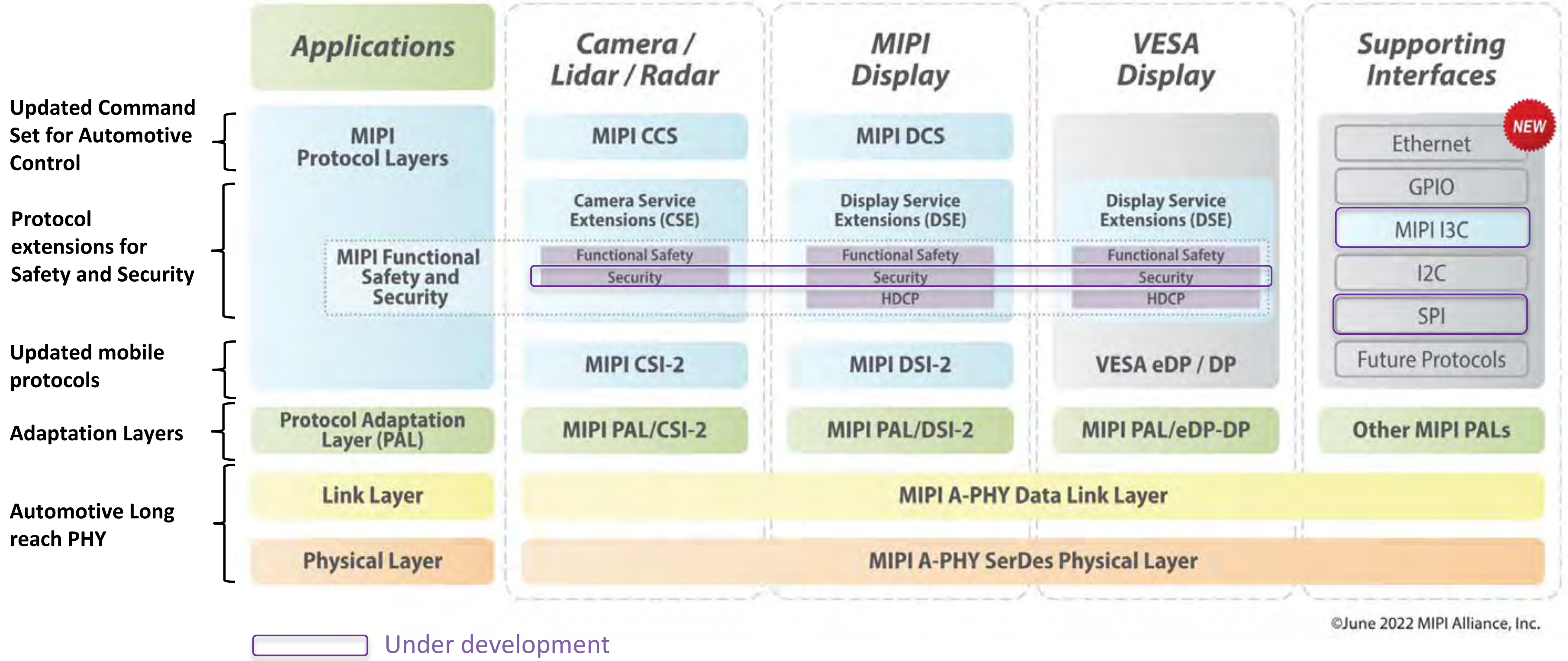
CDD eDP

A-PHY | Security | Functional Safety | HDCP

**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



# MASS Status

## Adopted Specifications

- A-PHY v1.0
- A-PHY v1.1
- PAL/CSI-2 v1.0
- PAL/DSI-2 v1.0
- PAL/eDP/DP v1.0
- PAL/GPIO v1.0
- PAL/I2C v1.0
- PAL/Ethernet v1.0
- CSE v1.0
- DSE v1.0

## Under Development

| | |
|---|---|
| A-PHY v1.1.1 | Inclusive Terminology |
| A-PHY v2.0 | Higher data-rate, Security |
| PoA℠ v1.0 | New specification NEW |
| PAL/SPI v1.0 | New specification NEW |
| PAL/I2C v1.0.1 | Inclusive Terminology |
| PAL/ETH v1.1 | Support for frame preemption |
| PAL/I3C v1.0 | New specification NEW |
| MIPI Security v1.0 | New Specification NEW |
| CCISE v1.0 | Command and Control Interface Service Extensions NEW |
| CSE v2.0 | Security, FSED, Timestamping |
| DSE v1.1 | Advanced FuSa, FSED, Timestamping, Audio |
| DSE v2.0 | Security |
| DCS℠ v2.0 | Automotive related commands |

## In Adoption Process

- PAL/CSI-2 v1.1
  - timestamping and synchronization

## Published Application Notes

- A-PHY Profile 1 and Profile 2

## Upcoming Application Notes

- A-PHY RTS and Retraining
- PoA: Power over A-PHY

**RTS:** Retransmission

**FuSa:** Functional Safety

**FSED:** Frame Service Extensions Data

# Camera Service Extensions (CSE)

## CSE v1.0

- End to End Functional Safety Services
- Message-based Functional Safety protection
- CSI-2 Packets are extended with SEP
- Message Counter and CRC are added per SEP
- Test pattern generation and Error Injection
- ESS-CCI Protocol for End to End Control Plane protection

## CSE v2.0

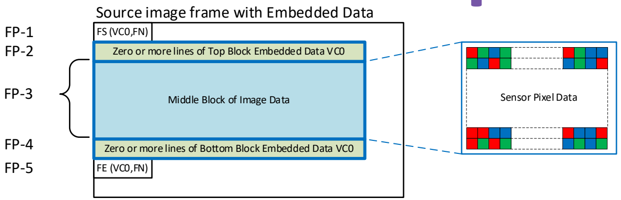
- End to End Security Services: Encryption, Authentication
- FSED Protocol
- Frame-based protection
- SEP per “multiple messages” protection

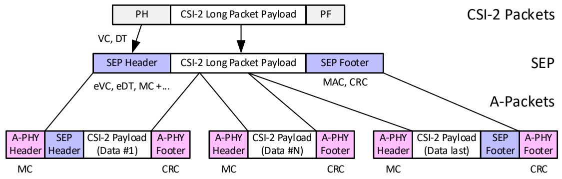
## CCISE v1.0

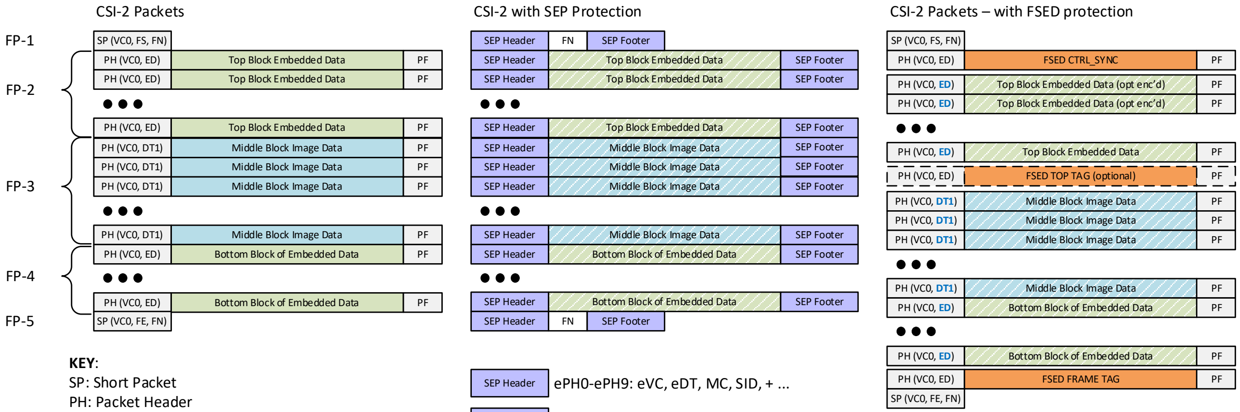
- Separate specification
- End to End protection of the Control Plane
- Backwards compatible to ESS-CCI in CSE v1.0
- Adding Security Services

**SEP:** Service Extensions Packet
**FSED:** Frame Service Extensions Data
**CRC:** Cyclical Redundancy Check
**CCISE:** Command and Control Interface Service Extensions
**ESS-CCI:** Enhanced Safety and Security Camera Control Interface

# SEP and FSED – Example with CSE / CSI-2




**KEY**:
SP: Short Packet
PH: Packet Header
PF: Packet Footer
VC0: Virtual Channel 0
FS: Frame Start
FE: Frame End
FN: Frame Number
ED: Embedded Data type (DT=0x12)
nED: non-Embedded Data Type (DT!=0x12)
DTm: Data Type m
FP-n: Frame Partition n

SEP Header: ePH0-ePH9: eVC, eDT, MC, SID, + ...

SEP Footer: ePH0 : CRC-32; ePH1: MAC

(Plaintext) ED CSI-2 Packet

(Plaintext) nED CSI-2 Packet

(Opt Encrypted) ED CSI-2 Packet

(Opt Encrypted) nED CSI-2 Packet

FSED CTRL_SYNC: Frame Control information for Security and FuSa. Protected with CSMAC and CSCRC

FSED TOP TAG (optional): Optional protection of TOP Block with TOP MAC and TOP TAG CRC

FSED FRAME TAG: Full Frame protection with FRAME MAC and FRAME CRC

**MAC:** Message Authentication Code

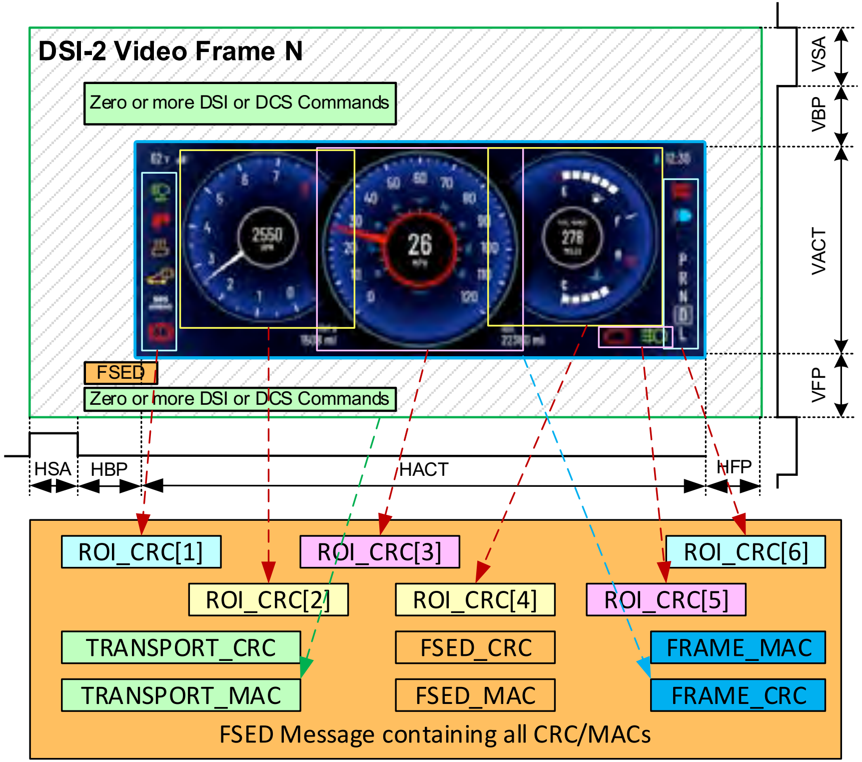
**CRC:** Cyclical Redundancy Check

**"Legacy" CSI-2 without FuSa/Security Protection**

**CSI-2 with SEP FuSa/Security Protection per Message**

**"Legacy" CSI-2 packets with FSED FuSa/Security Protection per Frame**

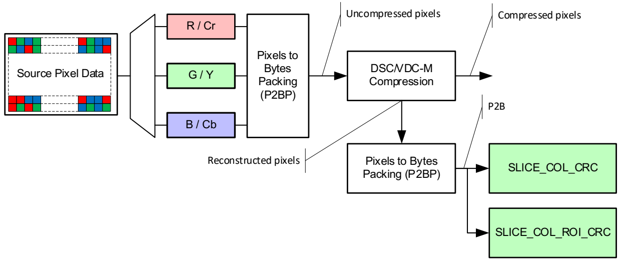
# FSED in Display Service Extensions (DSE)

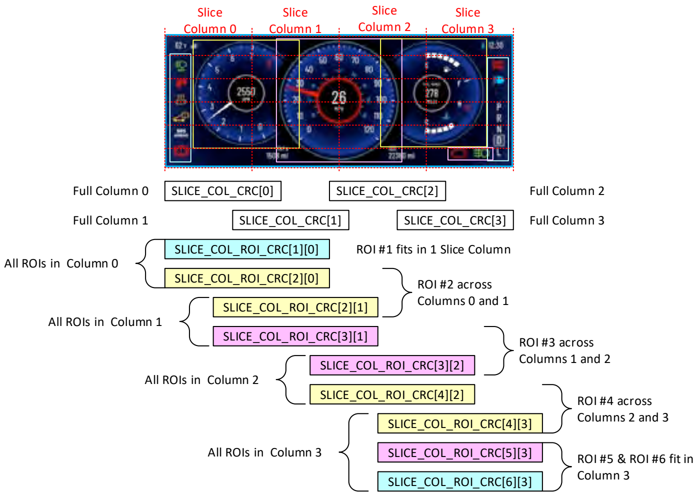



- One FSED Message per DSI-2 Video Frame
- Contains FuSa & Security extension data
  - Frame number
  - CRCs
  - MACs
- FRAME CRC/MAC for Active Video Area
- TRANSPORT CRC/MAC for “meta data” (display commands and control)
- Region of Interest (ROI)
  - Up to 16 ROIs – ROIs can overlap
  - 1 CRC per ROI
- Note: Security support from DSE v2.0 only

**FSED:** Frame Service Extensions Data

# FuSa support for Compression



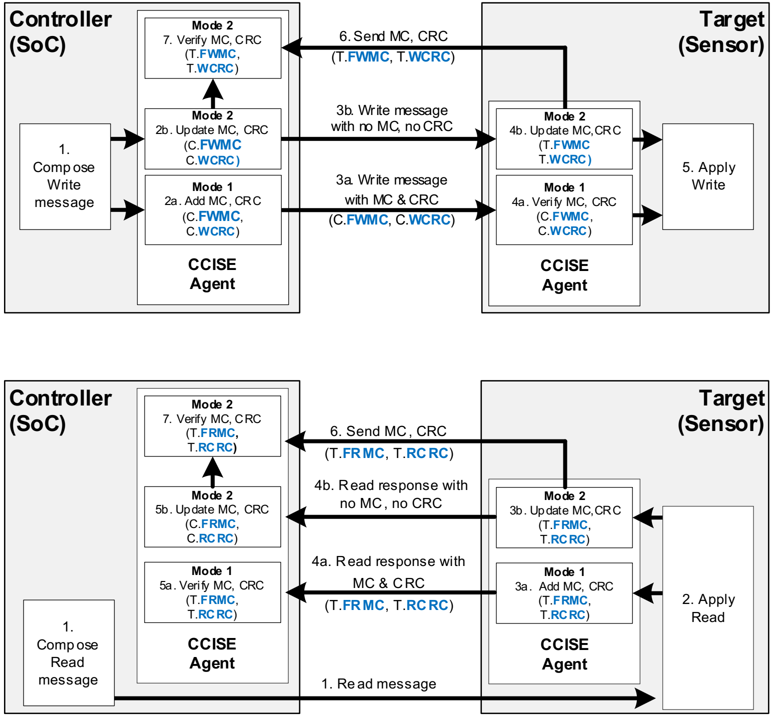

- Visually lossless compresssion with VESA DSC and VDC-M
- CRCs are calculated over the “reconstructed“ pixels
  - Matching between TX and RX
  - Compression engine is covered by the CRC
- Compression engine runs over slices. To ease the implementation DSE defines Slice Columns
- Each Slice Column has its own CRC
- For ROI, CRC are calculated over the Slice Columns
- All CRCs are sent in the FSED Message at the end of the DSI-2 Video Frame
- DSE aligning with VESA on CRC calculations

# Control Plane Protection with CCISE

- Command and Control Interface **Service Extensions** (CCISE) add Security and FuSa services to CCI (I2C)
- CCISE Supports control of
  - A-PHY bridges and forwarding elements
  - Any other device controlled via I2C (or virtual I2C with PAL/I2C).
- CCI (I2C) Transactions are extended with Tags
  - FuSa 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 Functional Safety Protection Flow



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# A-PHY 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

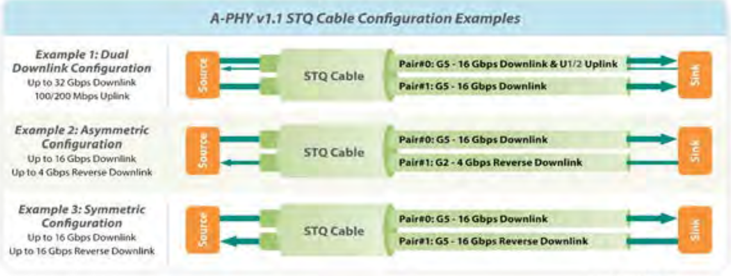
**PER:** Packet Error Rate **SDP:** Shielded Differential Pair

### MIPI A-PHY Performance

A-PHY v1.1 enhancements shown in orange

| Uplink Gear Data Rate | Modulation | Modulation Bandwidth (MHz) | Max Net App Data Rate (Mbps) |
|---|---|---|---|
| U1 100 Mbps | NRZ-8B/10B | 50 | 55 |
| U2 200 Mbps | PAM4-8B/10B | 50 | 125 |

| Downlink Gear Data Rate | Modulation | Modulation Bandwidth (GHz) | Max Net App Data Rate (Gbps) |
|---|---|---|---|
| G1 2 Gbps | NRZ-8B/10B | 1 | 1.5 |
| | PAM4 (Optional) | 0.5 | 1.8 |
| G2 4 Gbps | NRZ-8B/10B | 2 | 3 |
| | PAM4 (Optional) | 1 | 3.6 |
| G3 8 Gbps | PAM4 | 2 | 7.2 |
| G4 12 Gbps | PAM8 | 2 | 10.8 |
| G5 16 Gbps | PAM16 | 2 | 14.4 |

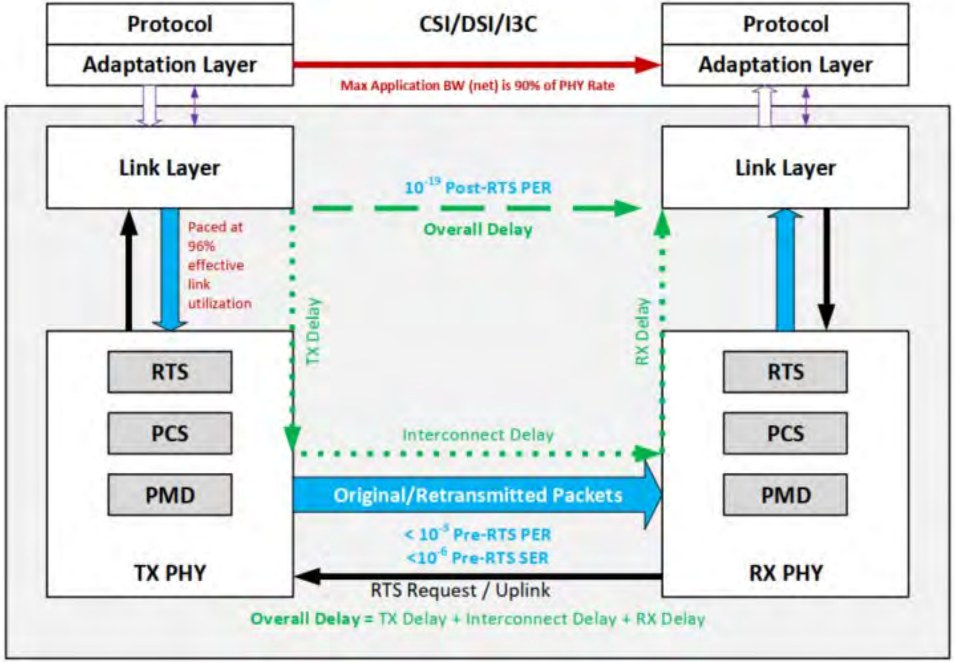


# What Makes MIPI A-PHY So Robust and Efficient?

## High throughput automotive links are EMI-limited — not AWGN limited

### RTS + NBIC

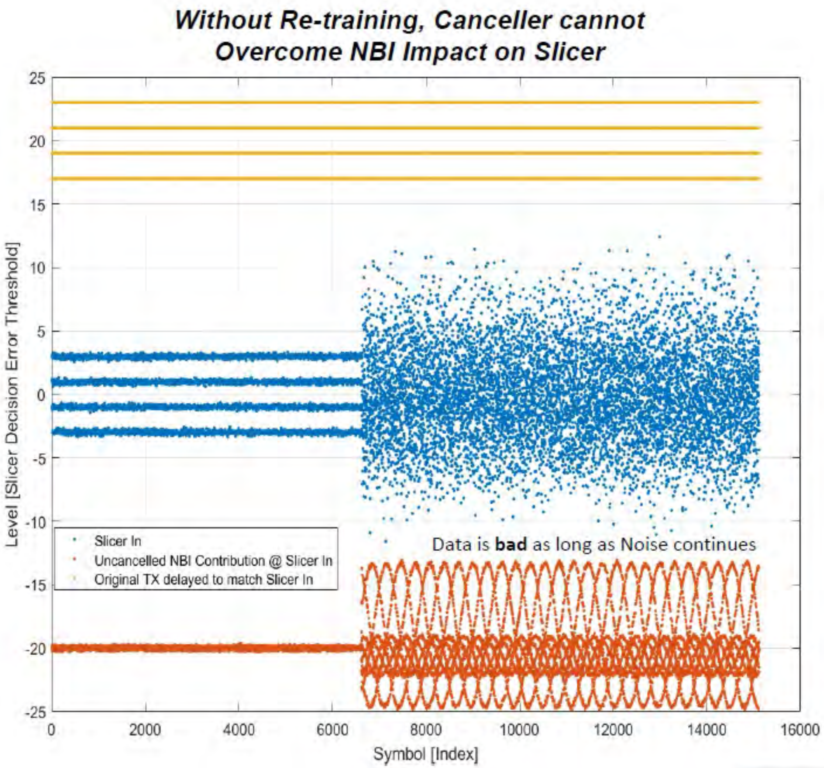
- **Time bounded local PHY-level retransmission**
  - Only within pre-defined "Overall Delay" (~6µs@G5)
  - Local: Transparent to the upper layers
  - Local: Happens within a single A-PHY hop
- **Dynamic modulation for retransmitted packets with better error resistance**
- **Highly resilient**
  - Overcomes large thousands symbols-long error bursts
  - Multiple 10s mV, instantly attacking NBI peaks
- **High reliability → PER < $10^{-19}$**
- **Low overhead → 90% net data rate**

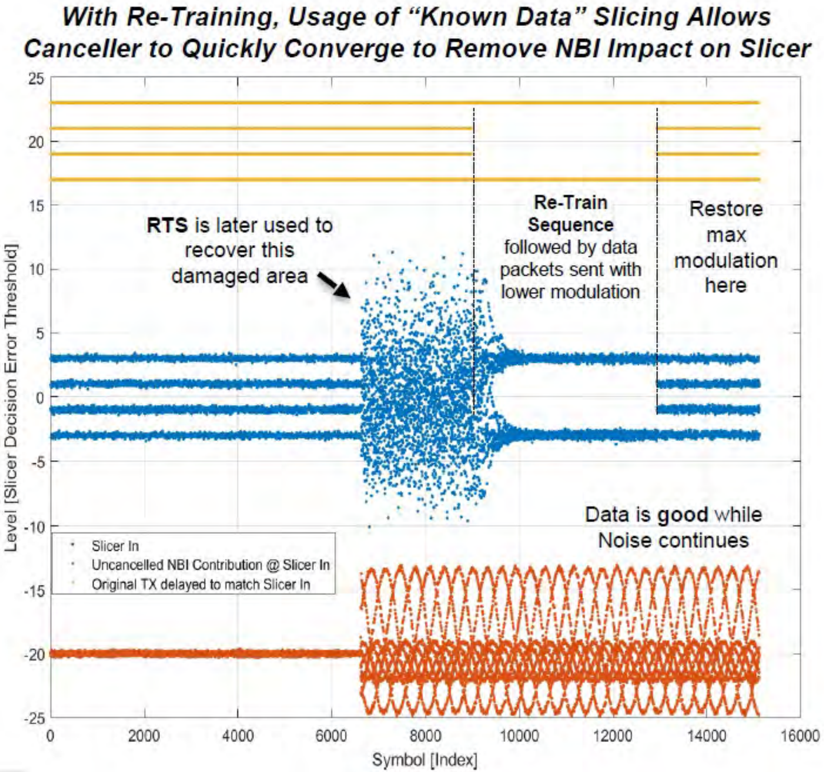



**NBI:** Narrow Band Interferences
**NBIC:** Narrow Band Interferences Canceller
**PCS:** Physical Coding Sub-Layer
**PMD:** Physical Media Dependent
**RTS:** Re-Transmission Sub-Layer
**AWGN:** Additive White Gaussian Noise

# To Speed Up/Ensure JITC Convergence, JITC Re-training Is Used

Example: 4GBaud PAM4, 40mVpeak 3 Tone NBI, instant attack, without re-training




**JITC:** Just In Time Canceller

# A-PHY Channel models

- Application note providing technical details on system modeling both for Profile 1 and Profile 2 is available to MIPI members.
- Along with this application note, we provided the complete system model in ADS and Matlab at the MIPI member site.
- Information Location (for registered members) -
  - System model - https://members.mipi.org/wg/A-PHY/document/folder/14078
  - Application note – https://members.mipi.org/wg/All-Members/document/download/84933

**FuSa:** Functional Safety

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# Next Generation A-PHY

# What's Next for A-PHY?

## A-PHY v2.0

### GOALS

- Support emerging architecture and use cases:
- Zonal architecture and SDV (software-defined vehicle)
- Modern automotive cockpits
- Maintain backward compatibility
- Be forward compatible
- No changes in the upper layers for easy migration with minimal impact
- Maintain high EMC resilience and low packet error rate

### PROPOSED FEATURES

- Double downlink throughput up to 32Gbps (28.8Gbps net data rate) per single lane
- Uplink throughput increase up to 1.6Gbps (1.166Gbps net data rate)
- Enhance interface support
- Add 1Gb Ethernet support (based on the new uplink BW)
- Other interfaces may be added based on market demand
- Enable support of a secure A-PHY network

## A-PHY v1.1.1

- ❑ Inclusive Terminology
- ❑ Errata

## TEST PROGRAM

- ❑ Reference Compliance Test Suite nearly complete
- ❑ Pilot Compliance program under development

## IEEE ADOPTION

- ❑ v1.1.1 to be submitted to IEEE for adoption

## NEW RESOURCES

- ❑ Retraining and Retransmission App Note
- ❑ Power Over A-PHY App Note
- ❑ Power Over A-PHY specification
- ❑ Link Layer and Link Layer Services App Note

# A-PHY v2.0 – Initial Downlink Gear Table (per LANE)

| Downlink Gear | Modulation | Modulation Bandwidth [GHz] | Data Rate [Gbps] | Max Net App Data Rate [Gbps] |
|---|---|---|---|---|
| G1 | NRZ-8B/10B | 1 | 2 | 1.5 |
| | PAM4 | 0.5 | | 1.8 |
| G2 | NRZ-8B/10B | 2 | 4 | 3 |
| | PAM4 | 1 | | 3.6 |
| G3 | PAM4 | 2 | 8 | 7.2 |
| | NRZ-8B/10B | 4 | | 6 |
| G4 | PAM8 | 2 | 12 | 10.8 |
| G5 | PAM16 | 2 | 16 | 14.4 |
| | PAM4 | 4 | 16 | 14.4 |
| G6 | PAM8 | 4 | 24 | 21.6 |
| G7 | PAM16 | 4 | 32 | 28.8 |

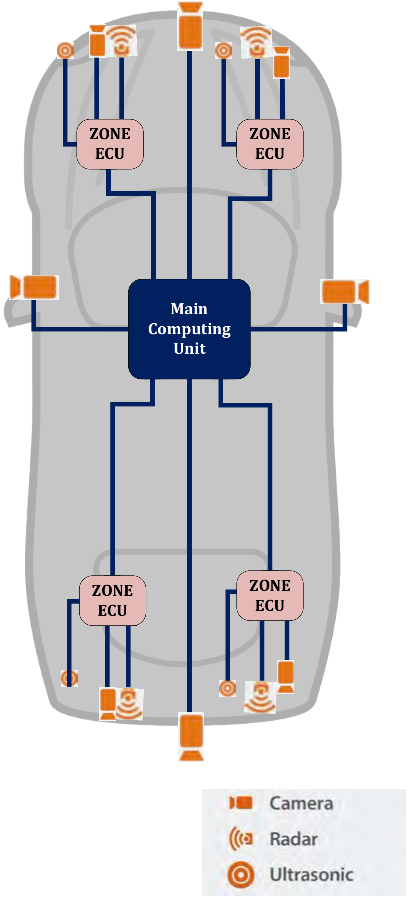
**Note:**
Green – New speeds @ 8GBaud
Orange – Under discussion

# A-PHY v2.0 – Initial Uplink Gear Table

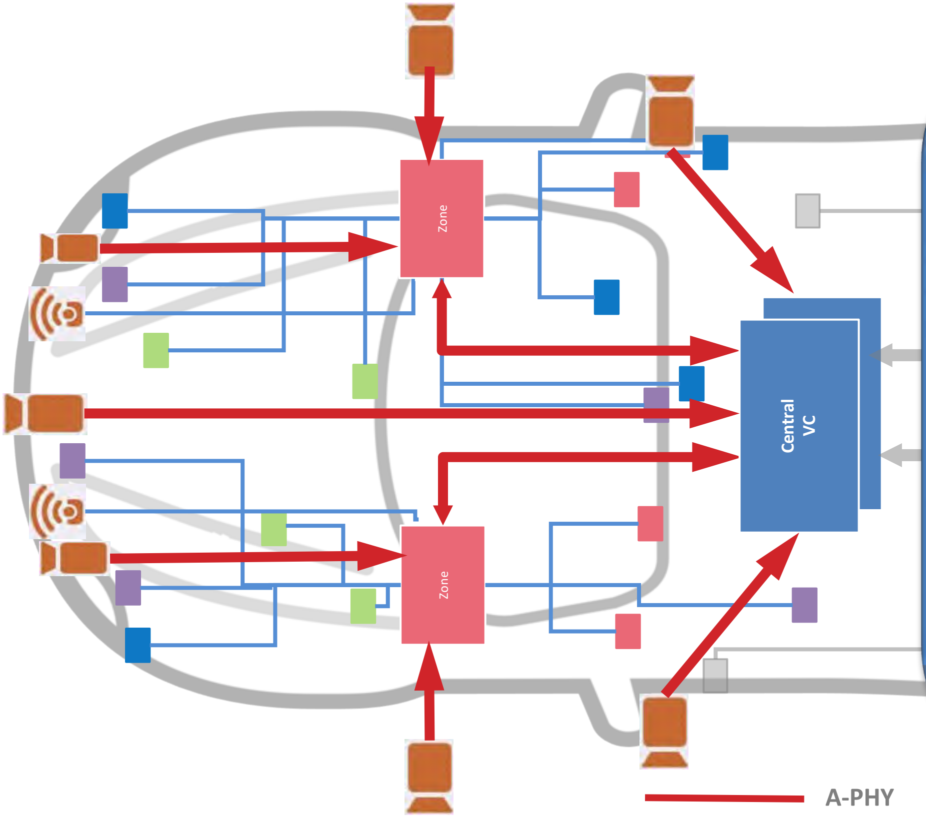
| Uplink Gear | Modulation | Modulation Bandwidth [MHz] | Data Rate [Mbps] | Max Net App Data Rate [Mbps] |
|---|---|---|---|---|
| U1 | NRZ-8B/10B | 50 | 100 | 53 |
| U2 | PAM4-8B/10B | 50 | 200 | 125 |
| U3 | PAM4-8B/10B | 400 | 1600 | 1166 |

# Zonal Architecture

- Zonal architecture is adopted by many OEMs, many times in conjunction with SDV.
  - Aggregation of sensors and actuators in spatial proximity by zone ECUs
  - Unlike domain architecture that integrates functions by specific domains (e.g., ADAS)
- The aggregation of the local devices is relatively low bandwidth (i.e., < 1Gbps) except for cameras and other emerging new sensors as radar and lidar
- These new sensors are asymmetric, driving high-speed data toward the zone ECU and main ECU, and require only low bandwidth control data, with low latency
- A-PHY as a highly asymmetric PHY is well-situated to support use cases of zonal architecture that require high-speed data aggregation to the main computing unit

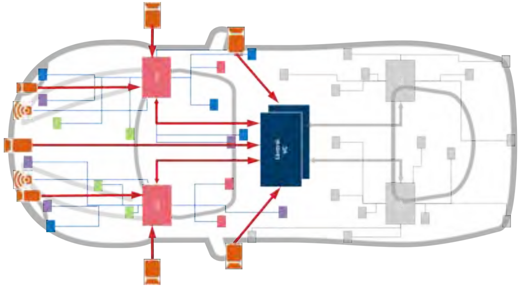


# A-PHY-Based Zonal Architecture – Example




- Focus on front end of vehicle to reduce clutter
- Each zone ECU aggregates multiple sensors and actuators
- Very high-speed data in direction of central computing unit
  - Camera (could be more than one)
  - Radar
  - Lidar
- Bidirectional information up to 1Gbps is supported for the aggregation of low-speed sensors and actuators

# A-PHY-Based Zonal Architecture

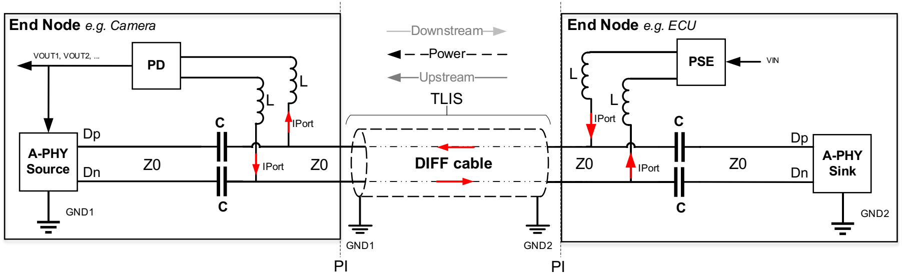


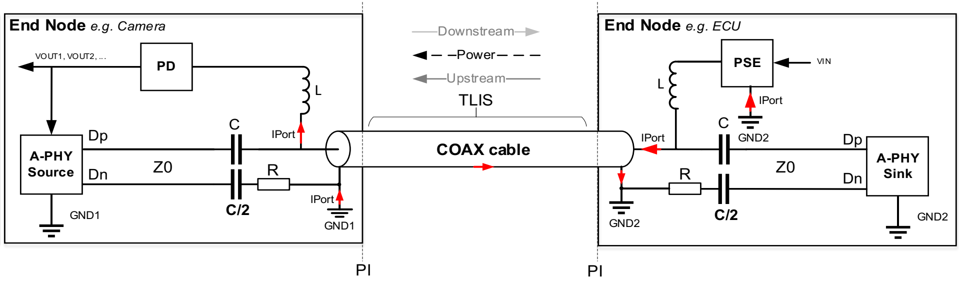
- Simplification of zonal ECU
  - Low computing overhead
  - Lower protocol overhead – Maintain native protocols for MIPI CSI-2 (e.g., camera) or Ethernet (e.g., lidar)
  - Designed for ultra-low PER at high noise environment for the entire lifespan of the vehicle
- Future-looking design and easy migration path
  - Scalable downlink speed from 2Gbps to 64Gbps over a single cable
  - Flexible and rich protocol support
  - Layered security scheme supporting variety of use cases
  - Embedded functional safety
- Guaranteed interoperability and backward/forward compatibility

# Power over A-PHY – PoA

- A-PHY v1.0/1.1 include a section on PoA
- Seperate specification is developed to provide better flexibility and enhanced capabilities without impacting the A-PHY specification
  - This specification will be backward compatible with current defintions.
- A-PHY v2.0 will be aligned with the new PoA specification
- The new PoA specification introduces new power types A-PHY link can support to enable power over cable to multiple types of devices and use cases.

| | | PoA System Type | | | | | |
|---|---|---|---|---|---|---|---|
| | | Type 1 | Type 2 | Type 3 | Type 4 | Type 5 | |
| | | 12 V | 12 V | 24 V | 24 V | 48 V | |
| | | Unregulated | Regulated | Unregulated | Regulated | Regulated | |
| | **Requirement** | Class 1 [9] | Class 3 [9] | Class 5 [9] | Class 7 [9] | Class 9 [9] | **Additional Information** |
| 1 | $VPSE_{max}$ (V) [1] | 18 | 18 | 36 | 36 | 60 | See *Section 7.2.2* |
| 2 | *$VPSE\_OC_{min}$ (V)* [2] | *8.4* | *14.4* | *12* | *26* | *48* | |
| 3 | $VPSE_{min}$ (V) [3] | 8 | 14.4 | 11.7 | 26 | 48 | |
| 4 | $Icont_{max}$ (mA)[4] | 293 | 500 | 500 | 500 | 500 | See *Section 7.2.4*<br>See Equation 5 for $I_{CONT}$ when Vpse > Vpsemin. |
| 5 | $Ppse_{min}$ (W)[5] | 2.34 | 7.2 | 5.85 | 13 | 24 | See *Section 7.2.5*<br>See Equation 6 for Ppse when Vpse >$Vpse_{min}$. |
| 6 | $VPD_{min}$ (V) [6] | 6.83 | 12.4 | 9.7 | 24 | 46 | See *Section 8.3.3* |
| 7 | $VPD_{max}$ (V) [7] | 18 | 18 | 36 | 36 | 60 | |
| 8 | $PPD_{max}$ (W) [8] | 2 | 6.2 | 4.85 | 12 | 23 | See *Section 8.3.1* |



# A-PHY & MASS Summary and Takeaways

- A-PHY provides a resilient and robust automotive SerDes standardized solution for camera, sensor and display applications
- MASS provides End-to-End functional safety and security protections enabling flexible in-vehicle network topologies.
- Native support for standard protocols CSI-2, DSI-2, VESA eDP and DP along with related interfaces.
- CSE v1.0 and DSE v1.0 are already including End-to-End FuSa services
- Next versions of CSE and DSE will include security and additional Frame-based FuSa services
- Future versions of A-PHY and MASS continue to scale and increase design flexibility.

# ADDITIONAL 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.

https://resources.mipi.org/knowledge-library/webinars/events/2022-automotive-workshop

Information on A-PHY can be found at:

- MIPI A-PHY Specification Homepage
- MIPI White Paper: Introduction to MASS

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# THANK YOU!

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# Q&A