Enabling MIPI Camera Applications Including Automotive ADAS
MIPI Specifications in New Applications
Automotive, IoT / Wearables, Virtual / Augmented Reality
Camera Market Trends

- Higher refresh rates for HDR image quality
- Electronic eyes in consumer, IoT, surveillance
- AI imaging multiple image sensors in devices
- Always on sentinel camera use case
- Myriad of automotive image sensors
- Long reach cameras in IoT
Embedded Display Market Trends

- Higher resolutions: 4K 5.5” in mass market
- Mobile display innovation: folding displays
- Higher refresh rates, AR/VR 120Hz
- Future technologies drive bigger display sizes and higher resolutions
- Displays in automotive and industrial
New Requirements for Automotive Market
ISO 26262 Functional Safety Compliance and ASIL Certification

Electronics failure can have hazardous impact
MIPI Specifications for Automotive Applications
Example of MIPI In Automotive

MIPI CSI-2℠ Sensors & MIPI DSI℠ Display

- Power Supply
- MPU
- Proprietary Link (MIPI A-PHY in near future)
- Front Camera Module
- Left Camera Module
- Right Camera Module
- Rear Camera Module
- Other Camera Module
- Other Camera Module
- DRAM
- Flash Memory
- CAN Interface
- MIPI CSI-2 Image Sensors
- V_{bat}

Diagram showing connectivity between components including a MIPI DSI Display, Power Supply, MPU, MIPI CSI-2 Image Sensors, and various camera modules.
MIPI A-PHY℠ – Standard Connectivity To/From ECU

Asymmetric, high speed, low latency, low power, ‘safety critical’ links, spec available end/2019

Highest Data Rate Asymmetrical Interfaces include those for Camera, Radar, & Display
MIPI Camera Serial Interface (CSI-2) Specification
De-facto standard interface used in car sensors
MIPI CSI-2 Evolution

• From mobile platform to imaging and vision

Mobile
Human vision

Imaging
Aggregator possibilities increased
Beyond human vision

Vision
Longer reach
In-band control signaling
## MIPI CSI-2 Versions

- From Mobile to Imaging & Vision to Automotive

<table>
<thead>
<tr>
<th>CSI-2 Specification</th>
<th>v1.x</th>
<th>v2.x</th>
<th>v3.X</th>
<th>V4.X</th>
</tr>
</thead>
<tbody>
<tr>
<td>VX.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29-Nov’05</td>
<td>28-Mar’17</td>
<td></td>
<td>10-Sep’19</td>
<td>Target: Q4’19</td>
</tr>
<tr>
<td>• First release</td>
<td>D-PHY 2v1 support</td>
<td>D-PHY v2.5 support</td>
<td>Always ON Sentinel Controller (AOSC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MIPI C-PHY℠ 1v2 support</td>
<td>C-PHY v2.0 support</td>
<td>Functional Safety (FuSa)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RAW 16/20 &amp; DPCM 12-10-12</td>
<td>RAW24</td>
<td>Imaging Security (ISEC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PPI width extension (up to 32)</td>
<td>EoTp</td>
<td>Multi-Sensor Support</td>
<td></td>
</tr>
</tbody>
</table>
|                     | LRTE | USL | •  
|                     | Scrambling | sROI | A-PHY 1v0 support |
|                     | Extension of Virtual Channel |      | (through Link Layer) |
| VX.1                | 09-Nov’10 |      |      |      |
| • MIPI D-PHY℠ 1.0 support |      | - |      |
| VX.2                | 22-Jan’13 | 09-Apr’18 |      |      |
| • D-PHY 1.0 support | I3C SDR & HDR_DRR support | - |      |
| VX.3                | 10-Sep’14 |      |      |      |
| • D-PHY 1.2 support |      | - |      |
MIPI CSI-2 Over MIPI D-PHY

Frame Buffer

CSI-2 Host

Packet Decoder
Lane Merger

CSI-2 Receiver

MIPI CCI℠ Master

SCL
SDA

CSI-2 Packet

D-PHY

Packet Builder

Data Format Definition
Virtual Channel Identification

Packet

Lane Distribution

CSI-2 Transmitter

MIPI CCI Slave

SCL
SDA

CSI-2 Packet

Frame Buffer

CSI-2 Device

Packet Decoder
Lane Merger

LANE DISTRIBUTION

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SDA

CSI-2 Packet
RAW-16, RAW-20 & RAW-24 Color Depths

• CSI-2 v1.3 color depths are sufficient for Mobile applications, visible to human eye

• RAW-16/-20/-24 color depth bring advanced vision capabilities to Automotive and Industrial applications
  – Improves image capture when the environment changes suddenly and dramatically, for example in a big change in lighting condition

• Enable machines to make decisions from superior quality images
  – An autonomous vehicle, for example, could decipher whether darkness on an image is a harmless shadow or a pothole in the roadway to be avoided

Synopsys
Up to 32 Virtual Channels

- To accommodate the larger number of image sensors and their multiple data types
- To support multi-exposure & multi-range sensor fusion for ADAS

<table>
<thead>
<tr>
<th>Virtual Channel 0 – Line 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual Channel 0 – Line 1</td>
</tr>
<tr>
<td>Virtual Channel 0 – Line 2</td>
</tr>
<tr>
<td>Virtual Channel 0 – Line 3</td>
</tr>
<tr>
<td>Virtual Channel 0 – Line 4</td>
</tr>
<tr>
<td>Virtual Channel 0 – Line N</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Virtual Channel 1 – Line 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual Channel 1 – Line 1</td>
</tr>
<tr>
<td>Virtual Channel 1 – Line 2</td>
</tr>
<tr>
<td>Virtual Channel 1 – Line 3</td>
</tr>
<tr>
<td>Virtual Channel 1 – Line 4</td>
</tr>
<tr>
<td>Virtual Channel 1 – Line M</td>
</tr>
</tbody>
</table>
Added Latency Reduction & Transport Efficiency (LRTE)

- LRTE reduces frame transport latency & leakage power due to frequent “high speed - low power” transitions
- This enhances image sensor aggregation and multi exposure for real-time perception and decision making applications
Scrambling and New Compression Scheme

- Galois Field Scrambling reduces power spectral density (PSD) emissions
  - Minimizes PSD emissions from aggressor components, which are particularly beneficial when placed near sensitive receiver

- New DPCM 12-10-12 compression to further boost image quality
  - Superior SNR using reduced bandwidth PHY
  - Removes more compression artifacts when comparing with MIPI CSI-2 v1.3 compression mode
Smart Region of Interest (sROI)

- Delivering only data needed when it’s needed
- Reduces power consumption, enhances processing speed, solves bandwidth limitation, saving data storage space
- Improves image analysis, inferencing algorithms and making better deductions
  - Enable machines on a factory line to more quickly identify potential defects on a conveyor belt
  - Enable medical devices to recognize anomalies

Synopsys
MIPI D-PHY Architecture

The Popular Physical Layer for MIPI CSI-2 and DSI Protocols

- Synchronous Forwarded DDR clock link architecture
- One clock and multiple data lanes configuration
- Static/dynamic de-skew supported through calibration
- Calibration hand-shake not supported
- No encoding overhead
- Low-power and high-speed modes
- Primarily targeting camera and display
- Spread spectrum clocking supported for EMI/EMC considerations
- Large eco-system, proven in billions of phones and cars

Synopsys
MIPI C-PHY Architecture

Emerging Physical Layer for MIPI CSI-2 and DSI-2 Protocols

- Embedded clock enables assigning lanes
- Bit rate 2.28x the signaling rate, e.g. 1Gsym/s = 2.28Gb/s using encoding
- Multiple trio’s configuration to enable higher bandwidth
- Low-power and high-speed modes
- Low EMI/EMC considerations with embedded clock architecture
- Similar to D-PHY
  - LP (Low-Power) Mode is identical, functional definition & electrical specs
  - Common Channel models between the specs
  - PHY-Protocol Interface definition has a lot in-common
  - Similar High-Speed Mode voltage levels
  - A dual-mode C/D-PHY driver or receiver can be built to share the same pins enabling coexistence on same pins with existing D-PHY

Synopsys
Autonomous vehicles - Image sensor markets to 2027

- Standard saloon
  - Number of on-board image sensors: 0
- 2016 top Advanced Driver Assistance System (ADAS) model
  - Number of on-board image sensors: 11
- Fully automated driving (AD) vehicle
  - Number of on-board image sensors: 25+

World market growth factor 2016-2026
- ADAS vehicles: 3.45
- Full AD vehicles: 161.4

Forecast demand AD/ADAS sensor types (million units)
- Cameras: 2016 - 52, 2021 - 92, 2030 - 400
- RADAR: 2016 - 13, 2021 - 15, 2030 - 40
- LIDAR: 2016 - 1.6, 2021 - 3.5, 2030 - 50
## Overview of Sensor Technologies

<table>
<thead>
<tr>
<th></th>
<th>Mono Camera</th>
<th>Stereo Vision Camera</th>
<th>Trifocal Camera</th>
<th>Scanning/LiDAR</th>
<th>3D/ Flash LiDAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution of Feature Size</td>
<td>Weak</td>
<td>Good, but holes</td>
<td>Medium</td>
<td>Low</td>
<td>Dense Depth Map</td>
</tr>
<tr>
<td>Compute Processing</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Expensive</td>
<td>Medium</td>
</tr>
<tr>
<td>Configurability</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Flexible</td>
<td>Flexible</td>
</tr>
<tr>
<td>Distance Range</td>
<td>Long</td>
<td>Long</td>
<td>Long</td>
<td>Long</td>
<td>Medium</td>
</tr>
<tr>
<td>Low Light</td>
<td>Bad</td>
<td>Bad</td>
<td>Bad</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Sunlight</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Snow, Fog, Rain</td>
<td>Bad</td>
<td>Bad</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Medium</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Medium</td>
</tr>
<tr>
<td>Size</td>
<td>Small</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Small</td>
</tr>
</tbody>
</table>
Autonomous Cars Automation Levels

**LEVEL 0**
There are no autonomous features.

**LEVEL 1**
These cars can handle one task at a time, like automatic braking.

**LEVEL 2**
These cars would have at least two automated functions.

**LEVEL 3**
These cars handle "dynamic driving tasks" but might still need intervention.

**LEVEL 4**
These cars are officially driverless in certain environments.

**LEVEL 5**
These cars can operate entirely on their own without any driver presence.

SOURCE: SAE International
High Growth of Sensors in Cars
Over 20 Sensors Onboard

- **LIDARS**: High-precision laser sensors that detect fixed and moving objects.
- **CAMERAS**: Detect and track pedestrians / cyclists, traffic lights, free space and other features.
- **ARTICULATING RADARS**: Detect moving vehicles at long range over a wide field of view.
- **LONG-RANGE RADARS**: Detect vehicles and measure velocity.
- **SHORT-RANGE RADARS**: Detect objects around the vehicle.
## Today’s Image Sensor

<table>
<thead>
<tr>
<th>Feature</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera Resolution</td>
<td>2-5MP</td>
<td>8MP</td>
</tr>
<tr>
<td># of cameras</td>
<td>6-12</td>
<td>12 or more</td>
</tr>
<tr>
<td>Smart Camera with AI built-in</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Road profile (lane, curb, surface, free space, etc.)</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Vehicle detection</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Pedestrian detection</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Traffic light recognition (RGY, turn light, tail light, etc.)</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Traffic sign recognition</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Obstacle detection (construction, animal, outliner, etc.)</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Driver monitoring</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Trifocal and surround based detection</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Surround view</td>
<td>✅</td>
<td>✅</td>
</tr>
</tbody>
</table>
Challenges on Current Sensor Technology

• Bandwidth
  – Camera Resolution continues to increase, so as data bandwidth
  – LiDAR needs large data bandwidth

• Distributed networks versus centralized networks

• Real time update (low latency)

• Harsh weather conditions: rain, snow, fog (moisture)

• Redundancy for higher functional safety requirement (ASIL D)
Future Proof MIPI A-PHY to Meet Increased BW

- High bandwidth gears with vision to support 24-48Gb/s+
- Camera aggregation use case
- Flexibility in supporting distributed networks
- High bandwidth display interconnect

Synopsys
Meeting Automotive Requirements
Key Requirements of Automotive-Grade IP

• Reduce Risk & Accelerate Qualification for Automotive SoCs

- **Functional Safety**
  Accelerate ISO 26262 functional safety assessments to help ensure designers reach target ASIL levels

- **Reliability**
  Reduce risk & development time for AEC-Q100 qualification of SoCs

- **Quality**
  Meet quality levels required for automotive applications

*Synopsys*
ADAS Domain Controller SoC Architecture
Automotive Safety Features

- DesignWare MIPI CSI-2 Device Controller IP

  - Built-in interrupt injection
  - Built-in error injection for Memories
  - Interfaces and RAM protected by Parity
  - ECC protection on data stored in memory

Certification for ISO 26262 Part 5 HW
Synopsys MIPI IP for Automotive

- DesignWare MIPI Controllers & PHYs for Sensors, ADAS, and Infotainment SoCs
- ISO 26262 certified* IP helps accelerate SoC-level qualification & reach target ASILs
- AEC-Q100 designed and tested MIPI IP meets Grade 1 & 2 temperature requirements
- Quality management system meets automotive quality requirements

- MIPI PHYs
  - Functional Safety ISO 26262 ASIL B*
  - AEC-Q100 Grade1 and Grade2 options
  - Quality DFMEA
- CSI-2 and DSI controllers
  - Functional Safety ISO 26262 ASIL B*
  - Quality DFMEA

* Certification of IP for ISO 26262 Chapter 5 random HW failures
FABU Leverages Synopsys’ DesignWare MIPI IP to interface with high-definition cameras and displays
DesignWare IP Solutions for Cameras, Displays, Sensors

Single-Vendor Solution, Production-Proven in >1B units, Interoperable eco-system

- Complete end-to-end solution scaling to meet all project needs
- Optimized to deliver best power & area
- Production & interoperability proven to reduce risk
- Lowest integration effort to accelerate time-to-market
- Available silicon-proven MIPI PHYs in mainstream and advanced FinFET processes
Thank You
• www.synopsys.com/mipi