



An Introduction to the MIPI CSI-2 Image Sensor Standard and Its Latest Advancements

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- Available Features and Capabilities
- Emerging Features and Capabilities
- Present Developments and Summary
- Q&A

Available Features and Capabilities

- MIPI CSI-2 and frame format fundamentals
- CSI-2 low energy transport solutions
- Power Spectral Density Reduction
- Latency Reduction and Transport Efficiency
- Always On Sentinel Conduit for ultra low power inferencing
- Integrated and External Smart Region Of Interest
- Multi Pixel Compression
- CSI-2 over A-PHY capabilities
- Camera Service Extension and A-PHY

- MIPI CSI-2 was initially developed for mobile smartphone cameras and evolved to address the Consumer, Commercial and Infrastructure platforms.

CONSUMER

Mobile Smart Phones
Client Platform
Smart Homes
Emotional Metadata

COMMERCIAL

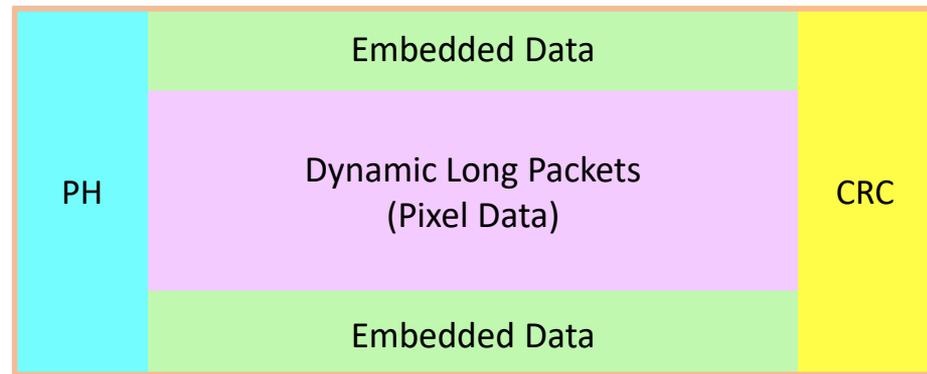
Commercial Surveillance
Autonomous Transportation
Medical & Industrial Platforms
Commercial Drones & Robotics

INFRASTRUCTURE

Smart Municipal City
Highway Traffic Monitoring
Environmental Monitoring
Space Exploration

CSI-2 Frame Format & Specifications

- Packet Header (PH) contains Frame Data Type, Virtual Channel protected by Error Checking and Correction or replication
- Dynamic Long Packet is structured as a best effort carrier with a Cyclic Redundancy Checker (CRC)
- Complimentary specifications supporting CSI-2 include: Physical layer transport (A-/C-/D-PHY & I3C), Functional Safety and Security (CSE), Unified Imaging SW Drivers (CCS & DisCo), and Conformance Test Suite (CTS)



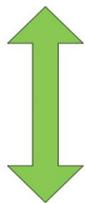
**Sensor and Application
Processor Alignment**

Low Energy Transport

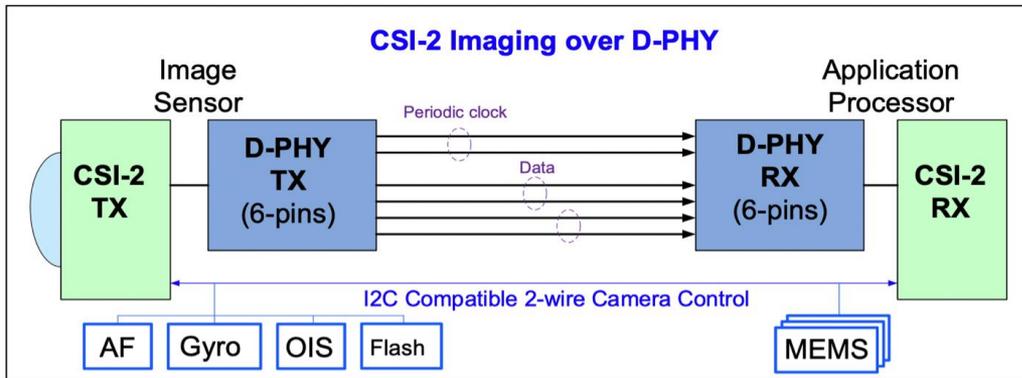
**Applications Driven
Provisions**

CSI-2 Low Energy Transport Solutions

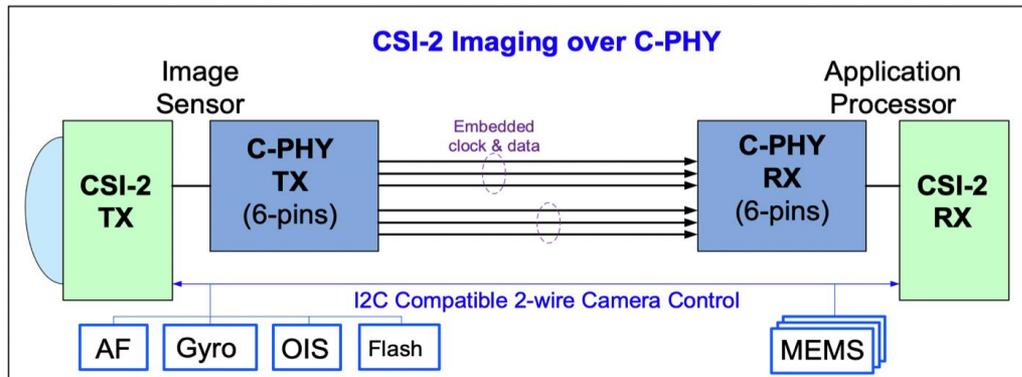
CSI-2
D-PHY



CSI-2
C-PHY



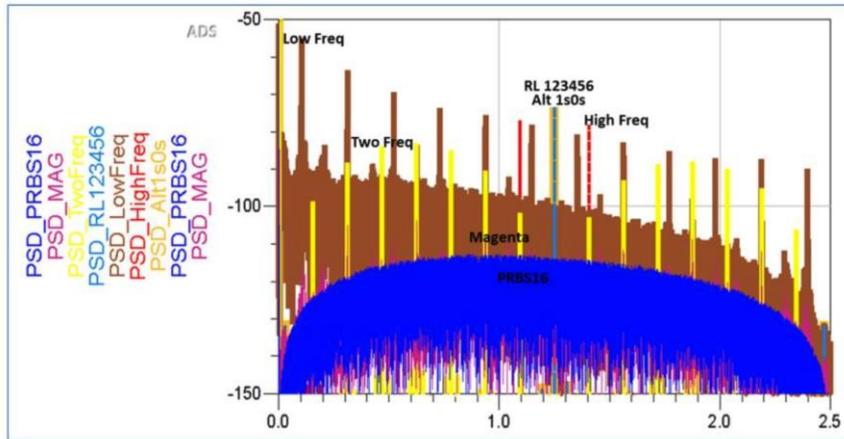
Pin compatible



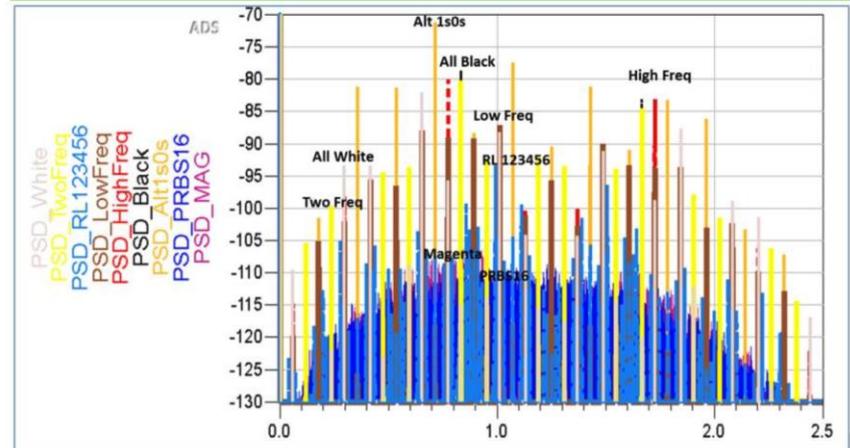
- Multiple classes of CSI-2 over C/D-PHY image sensors deployed
- CSI-2 over C-PHY offers ternary coding gain of 2.28
- Select sensors may offer CSI-2 over combo C/D-PHY signaling
- Illustration depicts a CSI-2 over D-PHY two-lane port, and a CSI-2 over C-PHY two-lane port
- Imaging System Benefits: low energy consumption, scalable lanes, and broad industry adoption.

Power Spectral Density Reduction

CSI-2 over D-PHY PSD emission reduction with scrambling (data lanes)

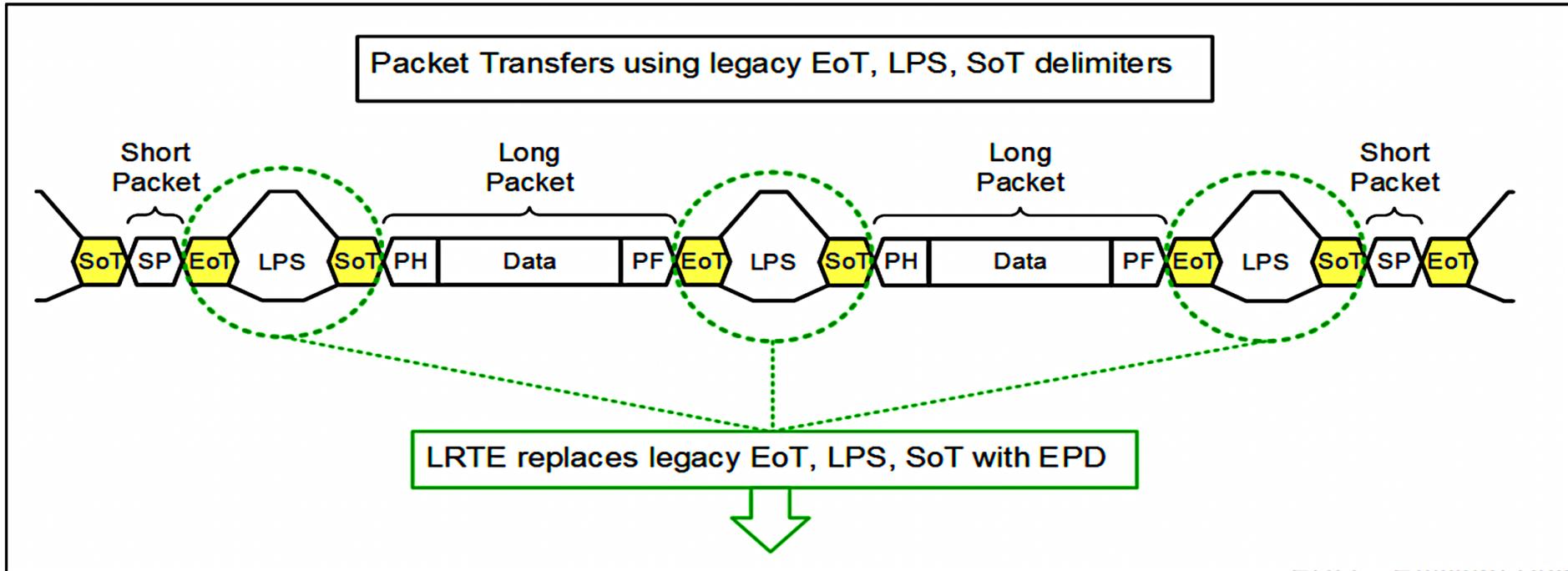


CSI-2 over C-PHY PSD emission reduction with scrambling (embedded clock and data)



Imaging System Benefits: Pseudo Random Binary Sequence to help reduce shielding costs

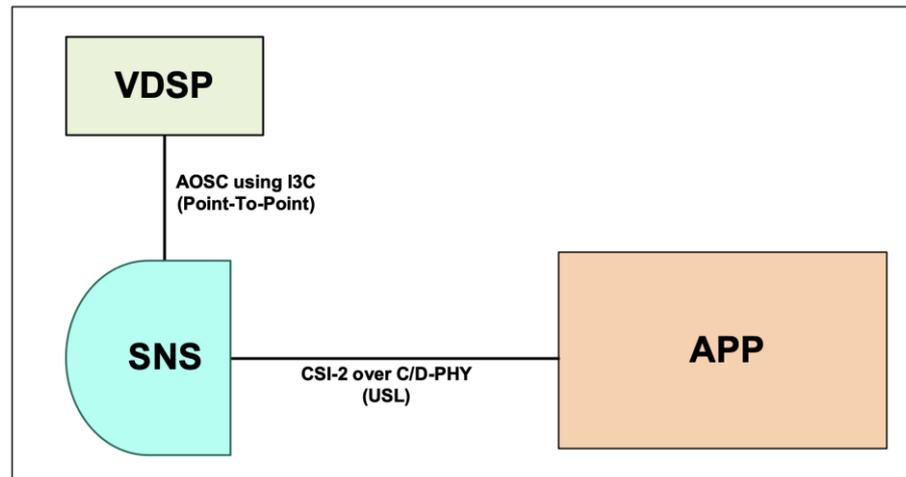
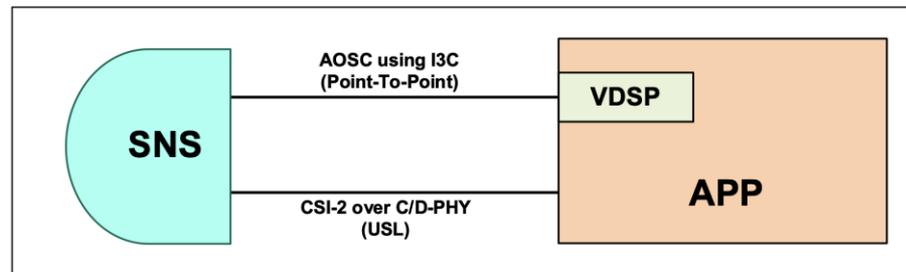
Latency Reduction and Transport Efficiency



Imaging System Benefits: Improve Sensor Aggregation | Alleviate Dual Voltage Signaling | Support Long Reach

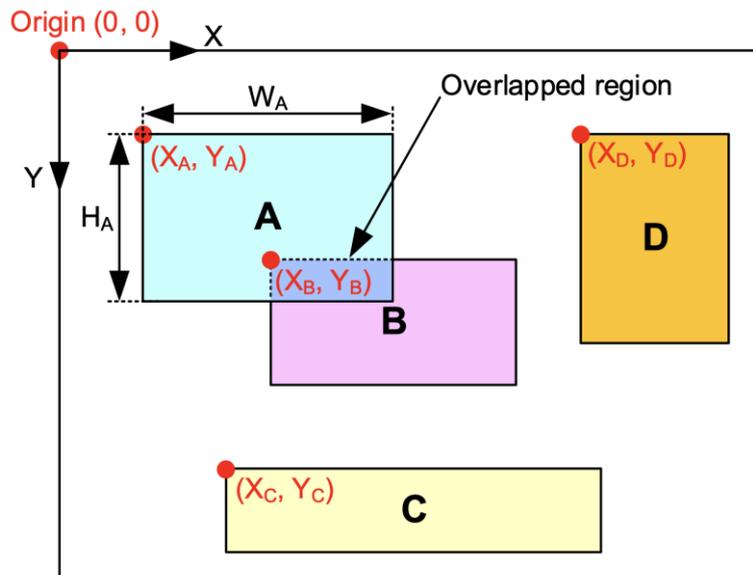
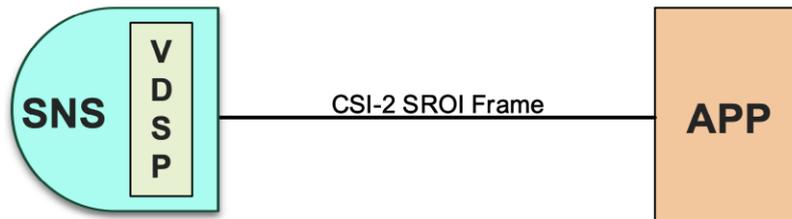
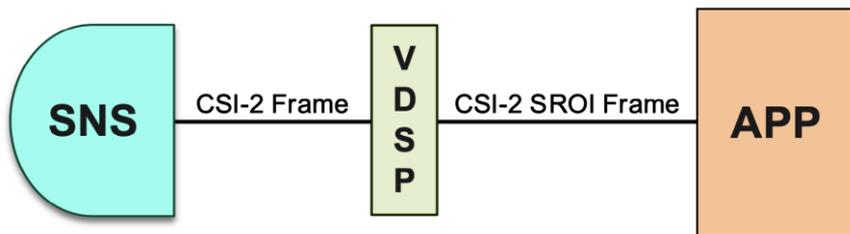
Always On Sentinel Conduit for Ultra Low Power Inferencing

- Targeting single digit mW system power
- Low-cost two-wire GPIO pins
- Imaging system options:
 - AOSC over I3C
 - AOSC over I3C & CSI-2 over C/D-PHY
 - Switch between AOSC and CSI-2
- Example system configurations:
 - QVGA at 10 FPS using RAW10 (8.5 Mbps) = 1 lane Standard Data Rate (11 Mbps effective bandwidth)
 - 720p at 10 FPS using RAW8 (81 Mbps) = 4 lane High Data Rate Bulk Transport (95 Mbps effective bandwidth)

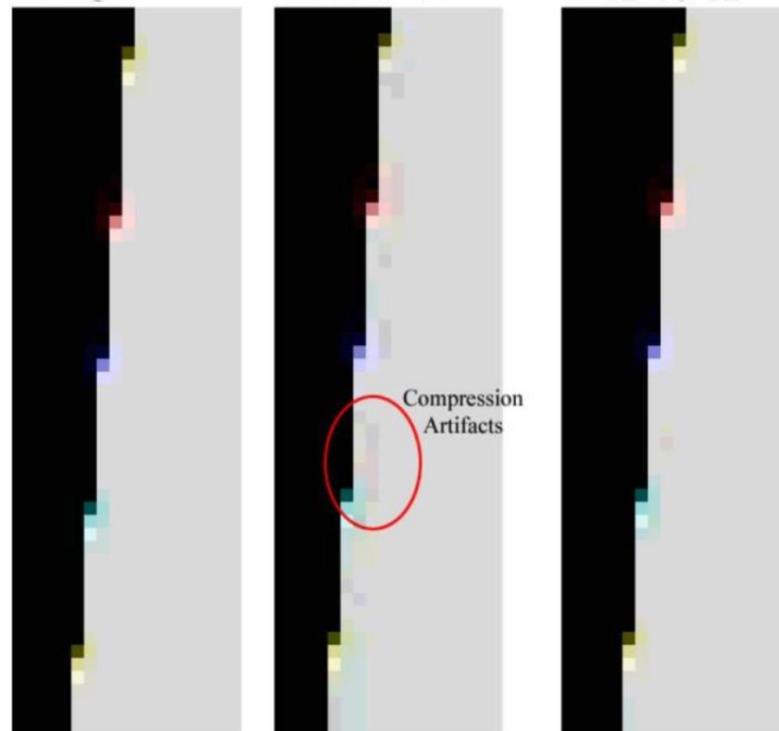


Integrated and External Smart Region of Interest

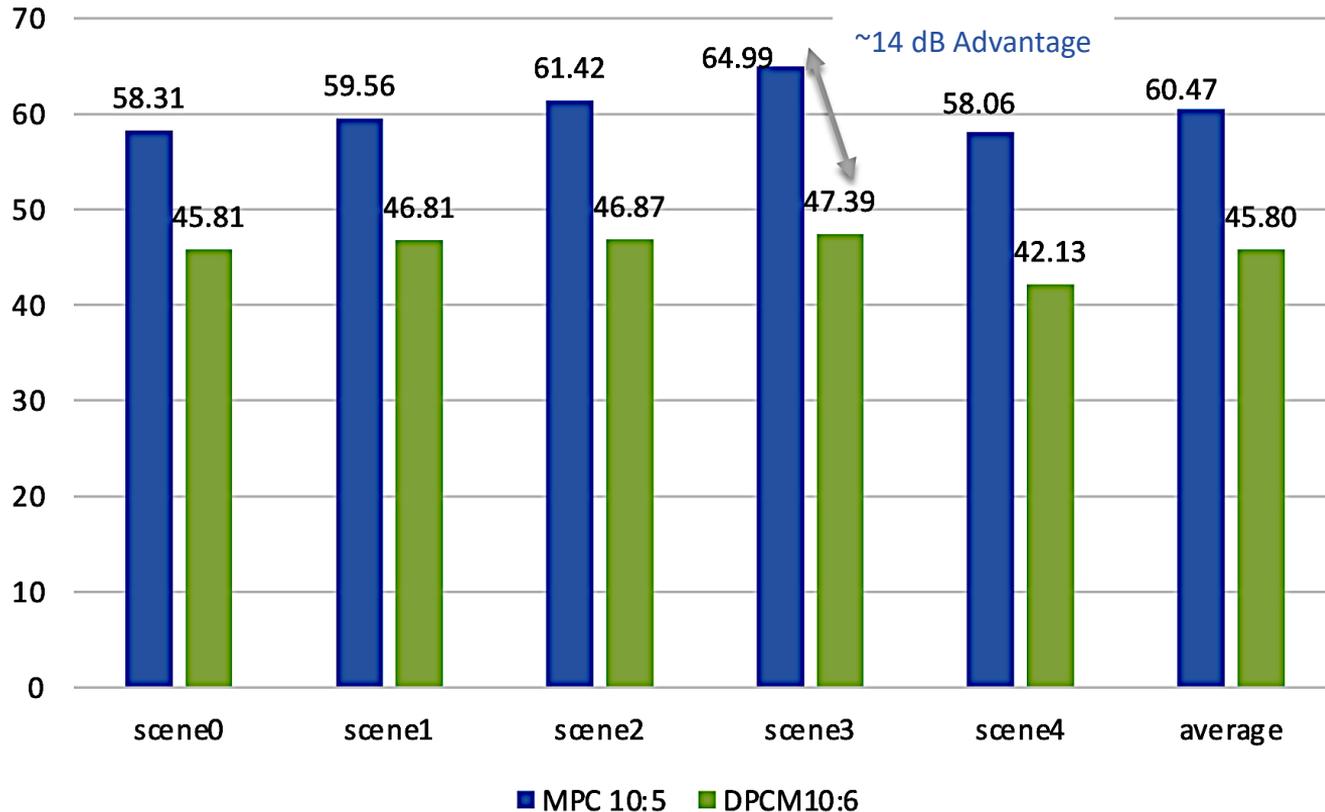
- The Smart Region of Interest (SROI) feature supports the adaptive transfer of rectangular Regions of Interest (ROI)
- SROI can be used to reduce data bandwidth by selectively transmitting one or more smaller ROIs carved out from the original frame, such as a human face or a license plate
- CSI-2 over DPHY_FCM with original ECC: 4 virtual channels
- CSI-2 over DPHY_FCM with enhanced ECC: 16 virtual channels
- CSI-2 over C-PHY: 32 virtual channels (+Res = 1024)



- Differential Pulse Code Modulation alleviates compression artifacts
 - Qualified 5-degree slanted edge input image with low, medium, and high illumination levels
 - MTF frequency response analysis closely track the original (HI/MI/LI X LC/MC/HC)
 - Reduce maximum absolute error of single-bit change in pixel value by a factor of 4.43x
- Transport SerDes network bandwidth reduction & system cost reduction



Multi Pixel Compression



- MPC offers 20% superior compression efficiency over DPCM
- Statistical probability of similar neighboring pixels
- Multi-pixel sensor architectures (Tetra-cell or Nona-cell)
- Superior image quality - ~14 dB Peak Signal to Noise Ratio (PSNR) improvement

- Low energy, emission resilient, long-reach, asymmetric SerDes physical layer solution developed within MIPI for CSI-2 image sensors native integration
 - Meets the stringent automotive electromagnetic interference (EMI) and electromagnetic compatibility (EMC) requirements
 - Contains provisions to meet the ISO 26262 functional safety requirements (CRC32, Message Counter, Timeout Monitoring)
 - The A-PHY v1.1.1 specification supports up to 16 Gbps downlink rate and 200 Mbps uplink data rates using NRZ / PAM signaling
 - Mean Time Between Failure rate of 1 error over the vehicle lifespan
 - Supports long reach of 15 m using SDP, STQ, and coax cables

Camera Service Extension and A-PHY Specifications

- The CSE specification enhances the CSI-2 image sensors with end-to-end functional safety and security targeting automotive platforms
 - CSE meets the functional safety requirements defined in the ISO 26262 standard targeting Automotive Safety Integrity Levels B to D for transmission of CSI-2 image sensor data and control
 - CRC-32 is used to detect data transmission errors ensuring the image data captured by the sensor is accurate when received at the ECU
 - Frame Counter is used to detect frame loss or duplication, with its accuracy verified by the CRC, ensuring the continuity of video streams from camera to ECU
 - Message Counter is used as a timeout checker to detect potential loss of data caused by a dropped or stuck transmission between an image sensor and ECU

Emerging Features and Capabilities

- Imaging System Benefits of D-PHY Embedded Clock Mode (ECM)
- Event Sensing and Processing

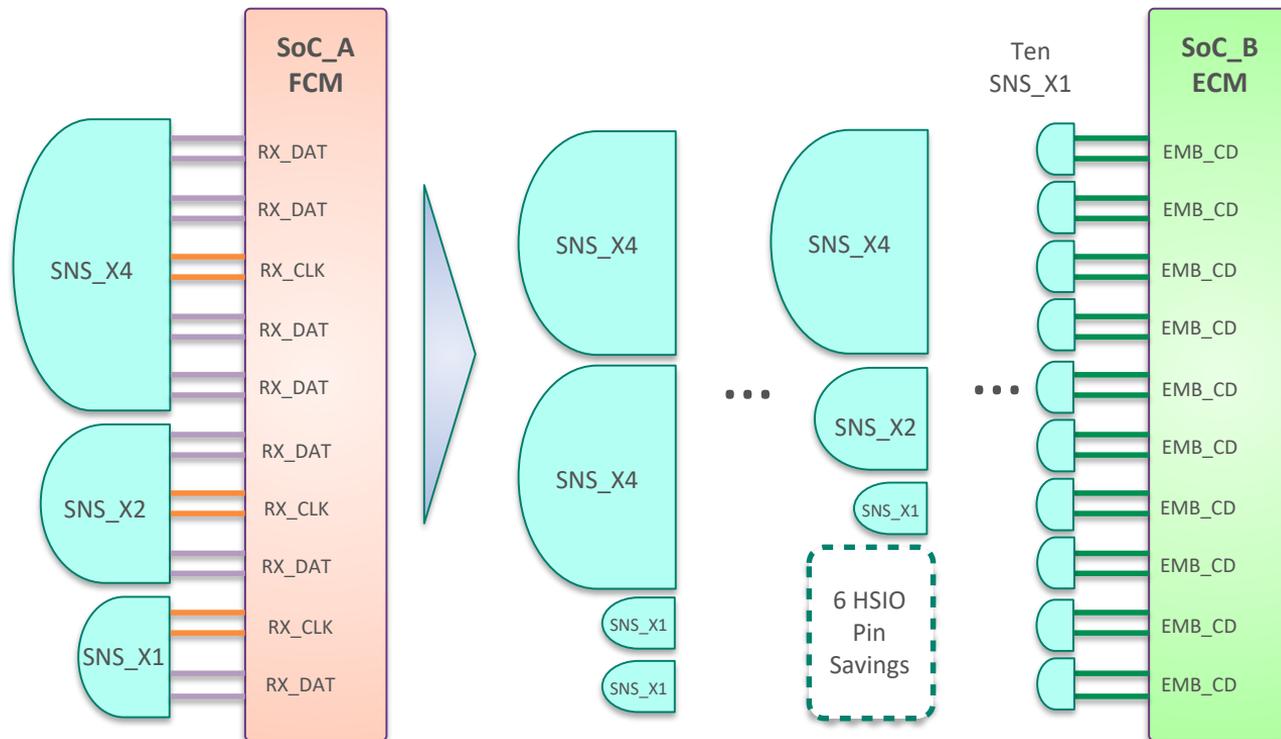
Imaging System Benefits of D-PHY Embedded Clock Mode (ECM)

- **System SoC A - FWD CLK & DAT**

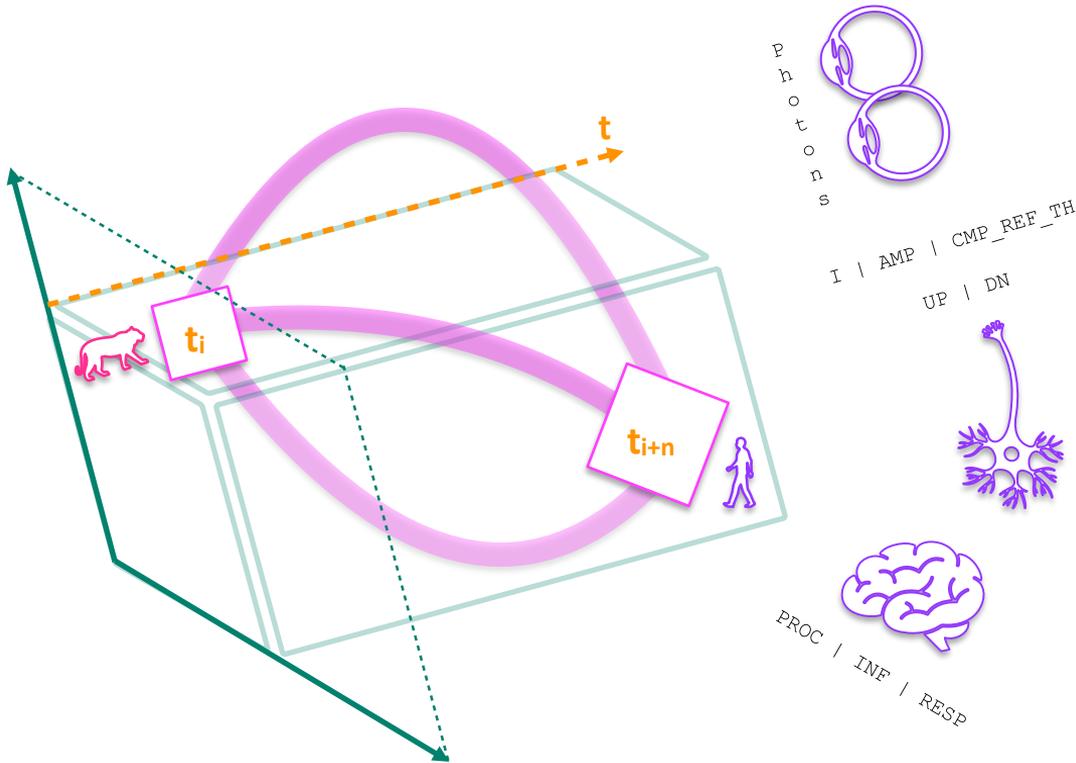
- 20 Pins HSIO SoC
- 10 D-PHY lanes
- Max 3 sensors (X4 | X2 | X1)
- Static frozen ports at pins

- **System SoC B - EMB CLK & DAT**

- 20 Pins HSIO SoC
- 10 D-PHY lanes
- Max 10 sensors
- Emission reduction
- Reduce HSIO macros
- Logical dynamic ports



Event Sensing and Processing



- Traditional Bayer - Process entire image frame at fixed temporal intervals determined by the limited ISP.
- ESP - Process only the relevant events asynchronously at higher frame rate (filter out static pixels):
 - Ideal for challenging lighting conditions (<50 mx)
 - Reduce image processing & inferencing requirements (< 1000x)
 - Decrease imaging system energy (100 to 1000x)
 - Supports higher dynamic range (> 120 dB)
 - Higher frame rate capture (10,000 FPS)
 - Superior temporal fidelity (1 us time stamp)

Present Developments and Summary

What's Done

- Single Voltage Signaling
- Ternary Coding
- Multiple Sensor Aggregation
- DPCM and MPC Compression
- Always On Sentinel Conduit
- Emissions Reduction
- Smart Region Of Interest

Almost Out

- Event Sensing and Processing
- CSI-2 over DPHY_ECM Dynamic Logical Ports

Present Developments

- Plesiochronous Imaging System Provisions
- Two-Wire ECM Unified Serial Link
- Three-Wire 16b7s Unified Serial Link
- Scalable ISP Interface & APIs
- Multi Drop Bus Support
- Dual PHY Macro Support
- Virtual Channel Extension

Summary

- MIPI CSI-2 had the first mover advantage with smartphones, and continues to evolve for beyond platforms.
- D-PHY (FCM & ECM), C-PHY (16b7s & 32b9s), and A-PHY transports offer low-energy native integration.
- MIPI Camera Interest Group is exploring pathways to solve broad range of system engineering problems (CIG is open to both contributor and member companies).
- Baseline core imaging system features and capabilities are available today.
- Presently focused on emerging computer vision applications spanning several platforms.
- Welcome inputs on any provisions that may be helpful for emerging computer vision applications.

- MIPI Camera Working Group: <https://www.mipi.org/groups/camera>
- Reach out to: admin@mipi.org