How MIPI® Interfaces Solve Challenges in ADAS/AD Sensor Validation
Vision „Autonomy“

From simplicity

- Driver
- Driving function
- Actuation

[Diagram showing the flow from driver to control to actuation]
Vision „Autonomy“

Towards complexity

Sensing
- Dozens of Sensors
  - Camera
  - Radar
  - Lidar

Perception and fusion
- Data pre-processing
- Data fusion
- Detection & tracking
- Localization

Driving function
- Scene understanding
- Prediction
- Motion planning
- Motion control

Actuation
- Hard real-time processing
  - Functional safety
  - ...

Artificial intelligence
- High Data Rates
  - Dozens of Gbit/s

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Vision „Autonomy“

Validation of sensors today

- Real test drives
  - Expensive
  - Lot of data
  - Critical situations
  - Sensor hardware upgrade
Data-driven development and validation
AD software stack – Validation and release testing

Sensing
- Sensor front end tests
- Data pre-processing
- Detection & tracking

Perception and fusion
- Data fusion
- Localization

Driving function
- Scene understanding
- Prediction
- Motion planning
- Motion control

Actuation

Data replay tests
 Closed-loop SIL and HIL simulation
 Real test drives

SIL: Software in the Loop
HIL: Hardware in the Loop
Automotive Front Camera Architecture

- **Short range** sensor interface: MIPI CSI-2℠ and MIPI D-PHY℠
- MIPI CSI-2℠ replaced proprietary interfaces
  - Parallel
  - LVDS
- Also used for Radar and Lidar applications
Automotive Surround View Camera Architecture

- **Long range** sensor interfaces
  - 1 cable for data, control, and power
  - Serializer and Deserializer (SerDes)
  - MIPI A-PHY℠
  - Proprietary: TI FPD-Link, Maxim GMSL

Diagram showing:
- Camera module
- Lens
- Image sensor (e.g. CMOS)
- Serializer
- SerDes Links (e.g. MIPI A-PHY℠)
- Image processing unit
  - (SoC, FPGA, DSP, … e.g. EyeQ™)
- RAM/flash
- Power
  - CAN
  - FlexRay
  - ETH
- ECU connector
- µC

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Data Logging of ADAS/AD Sensors
Automotive Surround View Camera Architecture

- **Long range** sensor interfaces
  - 1 cable for data, control, and power
  - Serializer and Deserializer (SerDes)

**Camera module**
- Lens
- Monochrome, RGB Bayer or RCCC filter
- Image sensor (e.g. CMOS)
- Camera

**Serializer**

**SerDes Links** (e.g. MIPI A-PHY℠)

**Processing module**
- Image processing unit (SoC, FPGA, DSP, … e.g. EyeQ™)
- RAM/flash
- Power
- CAN
- FlexRay
- ETH
- µC
- ECU connector
Surround View Camera: Data Logging with ECU

- **Camera module**
  - Lens
  - Camera
  - Image sensor (e.g. CMOS)

- **Serializer**

- **SerDes Links** (e.g. MIPI A-PHY℠)

- **Deserializer**

- **SerDes Links**
  - CAN
  - FlexRay
  - ETH

- **Processing module**
  - Image processing unit (SoC, FPGA, DSP, ... e.g. EyeQ™)
  - RAM/flash
  - Power

- **Logging platform**
  - High-End SSD

- **µC**

- **ECU connector**
Data Logging and Prototyping for ADAS/AD

**dSPACE AUTERA** - The power of a Server – in the vehicle!

- Intel Xeon CPU with 12 Cores (@2GHz)
- Support for CAN, Automotive Ethernet, etc.
- Up to 6x PCIe slots for extensions

- High End Data Logging Capability
  - Up to 64 TB Storage
  - Up to 50 Gbit/s logging bandwidth

- PCIe Grabber Card for Sensor Interfaces
  - Maxim GMSL and TI FPD-Link
    - Up to 6 Gbit/s per sensor
  - Additional Interfaces under development
  - MIPI A-PHY℠ once available

[Image of dSPACE AUTERA server with various connectivity options]
Virtual test drives

MOBILE & BEYOND
Video: Recorded and Simulated Test Data

Input: Camera Video

Result: Simulation Scenario
AD software stack – Validation and release testing

Virtual test drives – SIL simulation

Virtual ECUs

PC cluster

Real test drives

Virtual test drives – HIL simulation

Real ECUs

SIL: Software in the Loop
HIL: Hardware in the Loop
ECU: Electronic Control Unit
Front Camera: Hardware in the Loop testing

- **Short range** sensor interface: MIPI CSI-2℠ and MIPI D-PHY℠
Front Camera: Hardware in the Loop testing

- **Short range** sensor interface: MIPI CSI-2℠ and MIPI D-PHY℠
Front Camera: Hardware in the Loop testing

- **Short range** sensor interface: MIPI CSI-2℠ and MIPI D-PHY℠
- Test system simulates the sensor
  - MIPI CSI-2℠ data stream incl. timing
  - Sensor control interface (e.g. I2C)
Surround View Camera: HIL testing

- **Long range** sensor interfaces
  - 1 cable for data, control, and power
  - Serializer and Deserializer (SerDes)
Surround View Camera: HIL testing

- Camera module
  - Lens
  - Image sensor (e.g. CMOS)
  - Serializer

- Raw data (Recorded or simulated)
  - Serializer

- LVDS Link (e.g. MIPI A-PHY℠)

- Deserializer

- Image processing unit
  - (SoC, FPGA, DSP, ... e.g. EyeQ™)

- RAM/flash
- Power
- CAN
- FlexRay
- ETH

- ECU connector

- µC
Virtual Test Drives – Recorded Sensor Data
Virtual Test Drives – Recorded Sensor Data

- Camera module
  - Lens
  - Image sensor (e.g. CMOS)
- LVDS Link (e.g. MIPI A-PHY℠)
- Serializer
- Deserializer
- Image processing unit (SoC, FPGA, DSP, ... e.g. EyeQ™)
- RAM/flash
- Power
- μC
- CAN
- FlexRay
- ETH
- ECU connector
Sensor Data Replay HIL

Data Replay solution

Playback

Recorded data

Ground truth

Compare “KPI”

Test results

Annotated recorded data

Test Management

Cloud

Data center

Raw sensor data

Camera

Radar

LiDAR

GPS

V2X

Ultrasonic

Network/Bus data

Ethernet

Some/IP

CAN(FD)

FlexRay

System under Test
Sensor Data Replay HIL

Sensor fusion and environment perception tests

Key takeaways

- Test sensor components and ADAS/AD platforms
- High quality data synchronization through gPTP
- Modular solution to fit variant bandwidth
- Flexible adaption of sensor interfaces via plug-in modules e.g. MIPI CSI-2℠, LVDS, ...

gPTP: generalized precision time protocol
Virtual Test Drives – Simulated Sensor Data
Virtual Test Drives – Simulated Sensor Data

- Simulated traffic scenarios
  - Testing relevant **corner-cases**
  - Thousands of different scenarios based on one test-drive
  - Change, e.g., weather, # pedestrians, etc.
- Closed-loop simulation
Simulation of ADAS/AD Sensors

dSPACE Sensor Simulation HIL

Vehicle & Environment Models

Sensor Models

Interfaces

AD controller

SCALEXIO (ASM)

Sensor Simulation (powerful GPUs)

ESI Unit (powerful FPGAs)

SERDES interface

Ethernet

Displayport

Key takeaways

- Vehicle & Environment Models
  - Running in hard real-time
- Camera Sensor Model on GPU
  - Lens simulation
  - Bayer Pattern Simulation
- FPGA provides SERDES sensor interfaces
- Camera Sensor Model on FPGA

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Simulation of ADAS/AD Sensors - GPU

**GPU-based Camera Simulation**

- Vehicle & Environment Models
- Sensor Models
- Interfaces
- AD controller

**Key takeaways**

**Challenges**
- Verification of sophisticated AI algorithms for AD
- ISO 26262 ASIL checks

**Solution**
- Accurate and verified sensor models for Camera, Radar, Lidar
  - Ray tracing
  - Weather simulation
  - Lens simulation
- Open standard for sensor simulation
  - OpenSimulationInterface (OSI)
  - OpenDrive, OpenScenario
Simulation of ADAS/AD Sensors – ESI Unit

dSPACE Sensor Simulation HIL

Key takeaways

- Support for all relevant sensor interfaces (Up to 10 Gbit/s)
- Raw data simulation for Camera, Radar, and Lidar
- FPGA-based sensor models
  - E.g., I2C simulation
- Up to 50 Gbit/s aggregated data rate per ESI Unit
- Synchronous simulate of up to 12 sensors per ESI Unit
- Synchronization of multiple ESI Units and SCALEXIO
Conclusion

Data-driven development and validation