Automotive

MASTER THE SIGNAL INTEGRITY CHALLENGES OF AUTOMOTIVE ETHERNET

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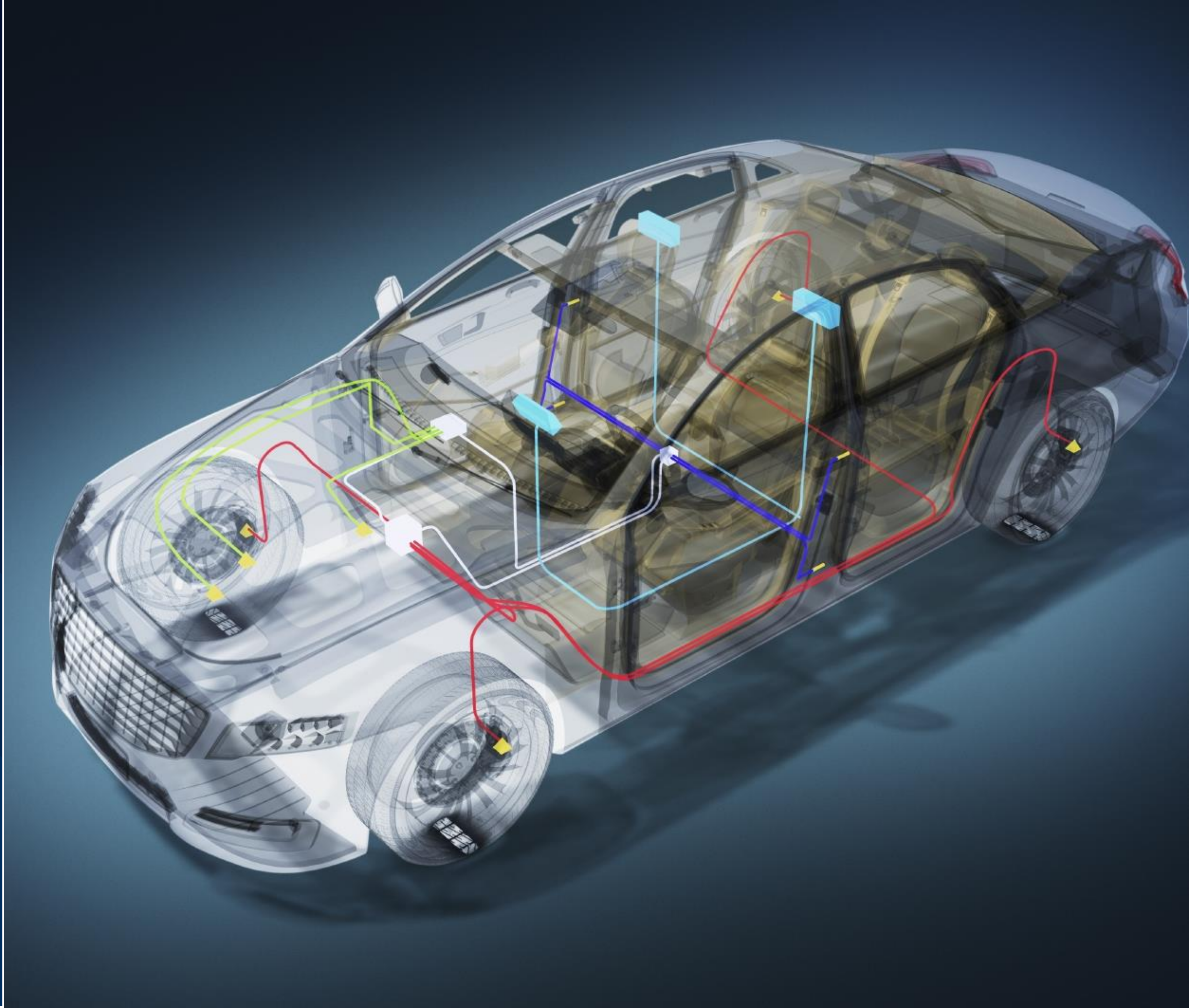
ROHDE & SCHWARZ

Make ideas real

AGENDA

- Introduction
- Evolution of in-vehicle network architecture
- Automotive Ethernet
  - Standards overview
  - Test requirements and solutions
- Summary and learnings



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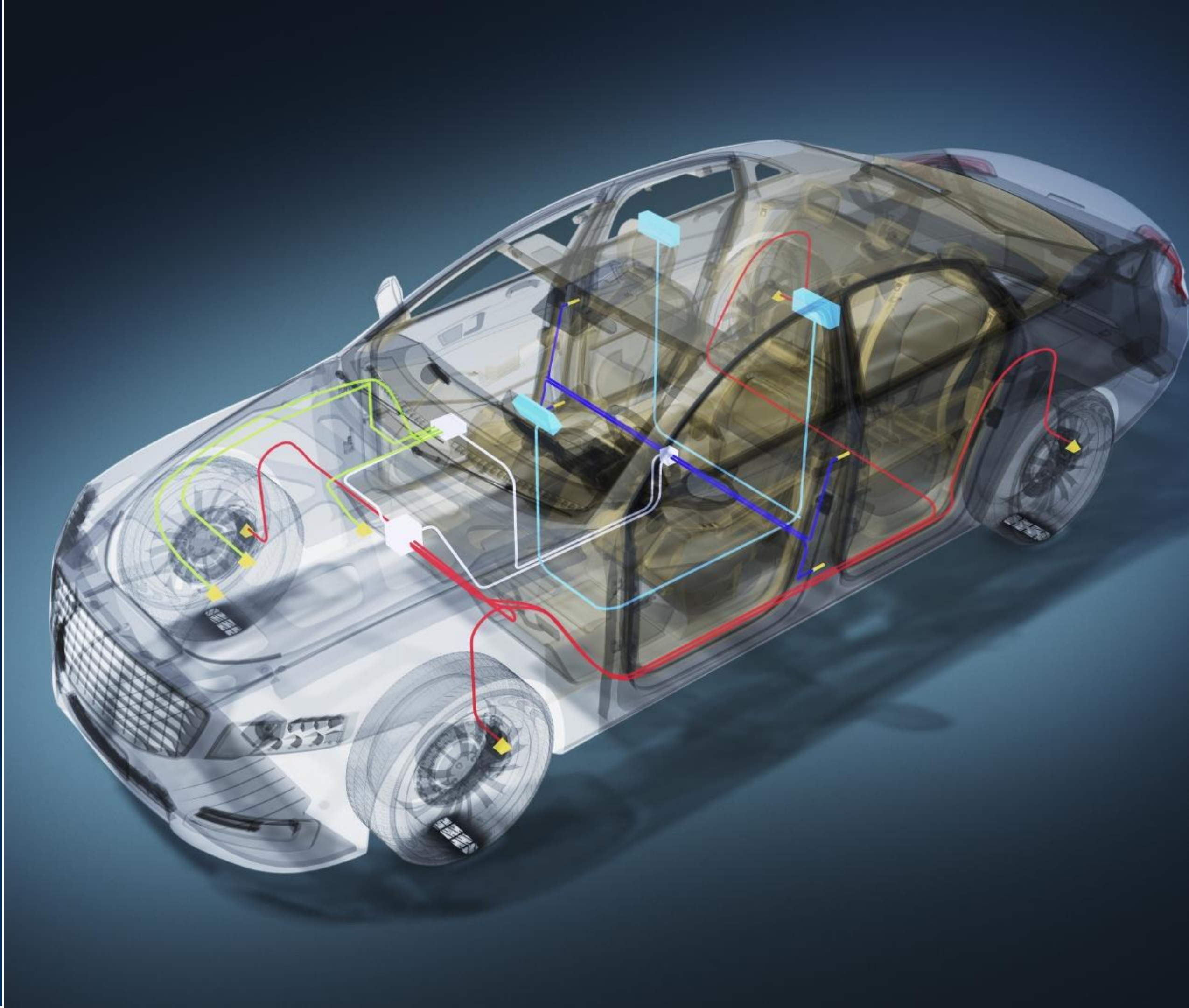
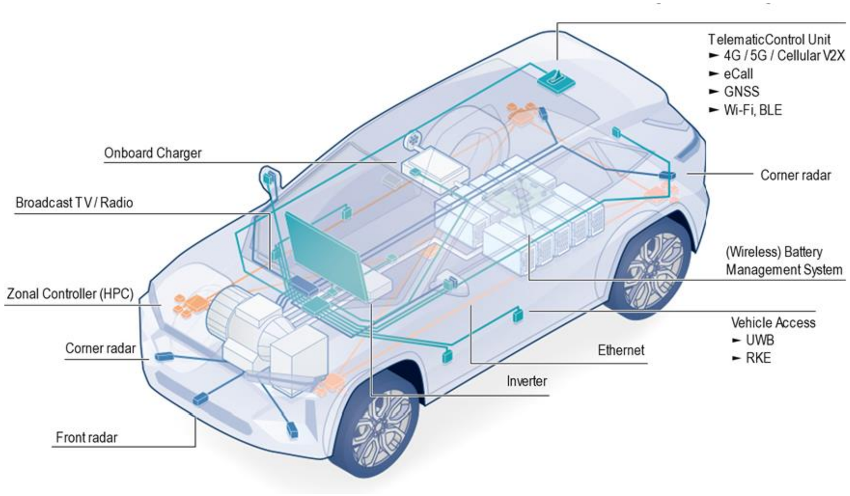


INTRODUCTION

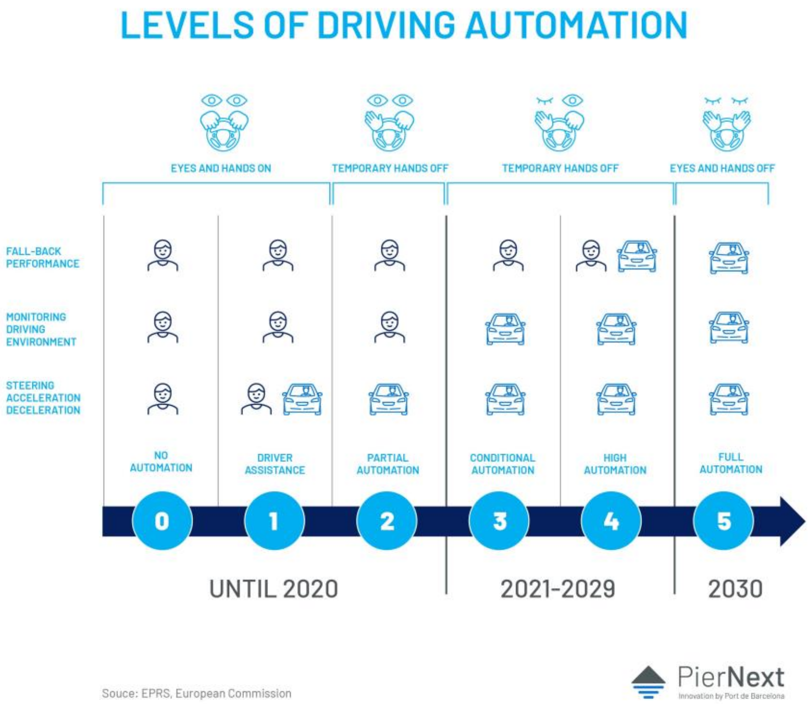
► The development of higher levels of autonomous driving and new services delivered by automotive connectivity require an increased number of more complex sensors.

► Automotive component suppliers and vehicle manufacturers need to ensure the performance, interoperability, data integrity and security of a much higher volume of data.



CHALLENGES

- Requirement for high-speed, low cost and power efficient communications, especially to achieve autonomous driving – introduction of new standards such as MultiGig and 10BASE-T1S.
- Reduction of IVN complexity and weight – migration to zonal architecture.
- Increased speed and reliability of data needed to support safety critical applications – signal integrity assurance.



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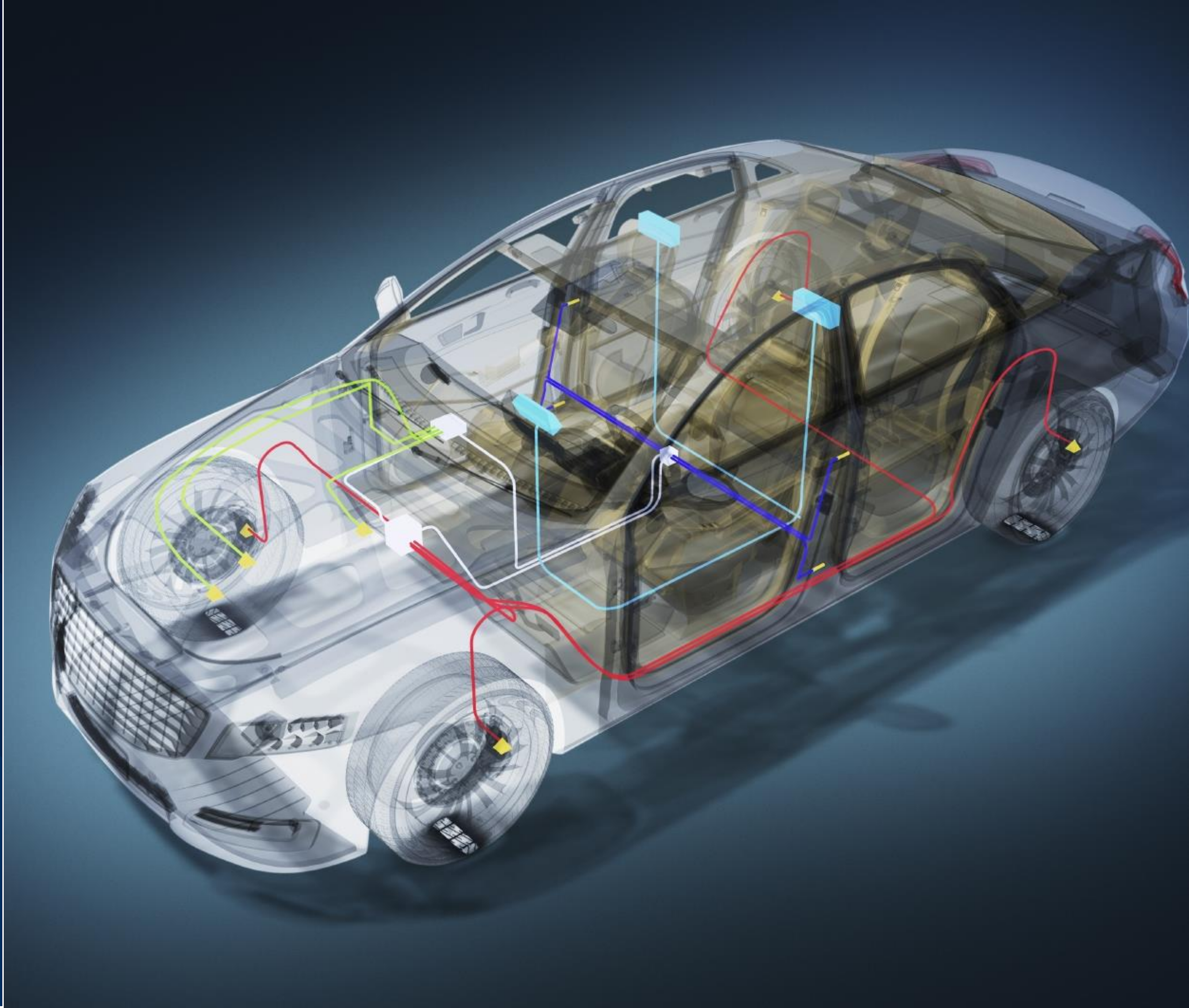
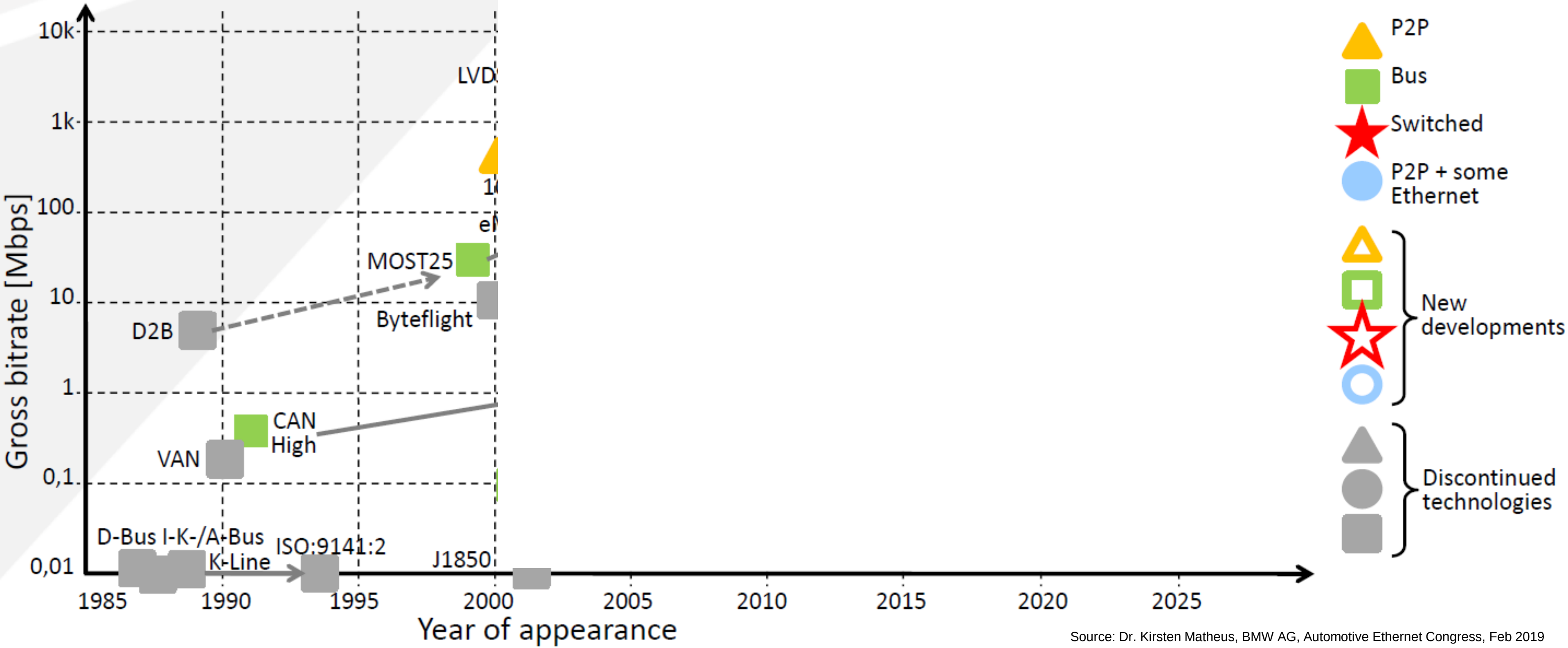


IN-VEHICLE NETWORKING TECHNOLOGIES



Source: Dr. Kirsten Matheus, BMW AG, Automotive Ethernet Congress, Feb 2019

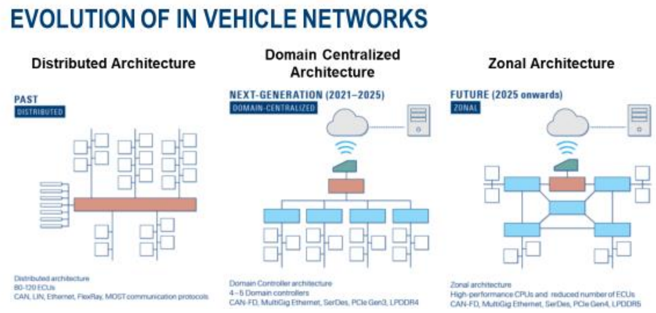
EVOLUTION OF IN-VEHICLE NETWORK ARCHITECTURE

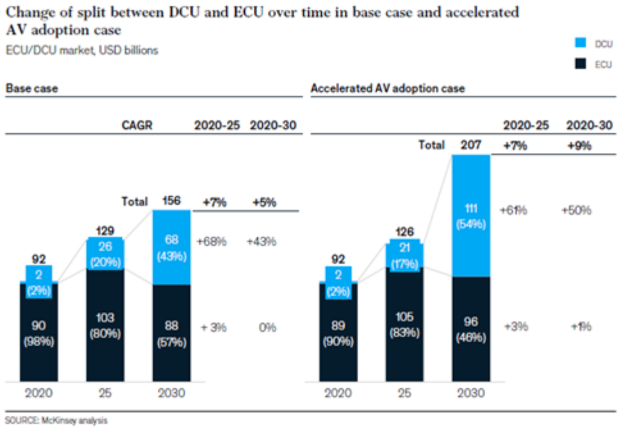
- IVN architecture evolved from a distributed gateway architecture with independent ECUs towards a domain centralized architecture.

- In a domain-centralized architecture, vehicle systems are grouped by function. Few domain controller units (DCUs) covering one vehicle domain each, such as connectivity, chassis, or infotainment.

- Communication is limited between domains that are controlled by a central gateway.

- Domain centralized architecture is suitable up to SAE level 3.

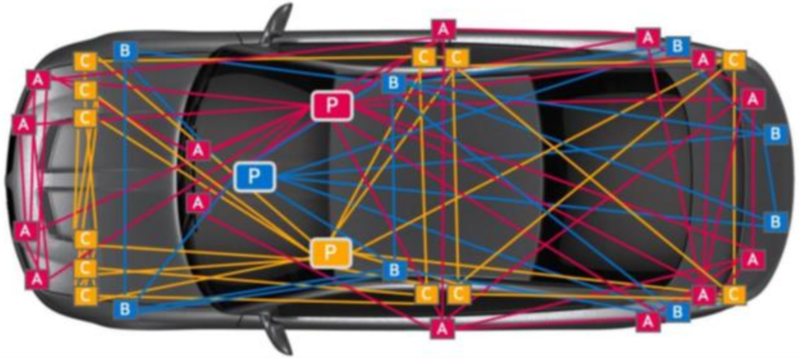




TRANSITION FROM DOMAIN TO ZONAL ARCHITECTURE

Domain architecture

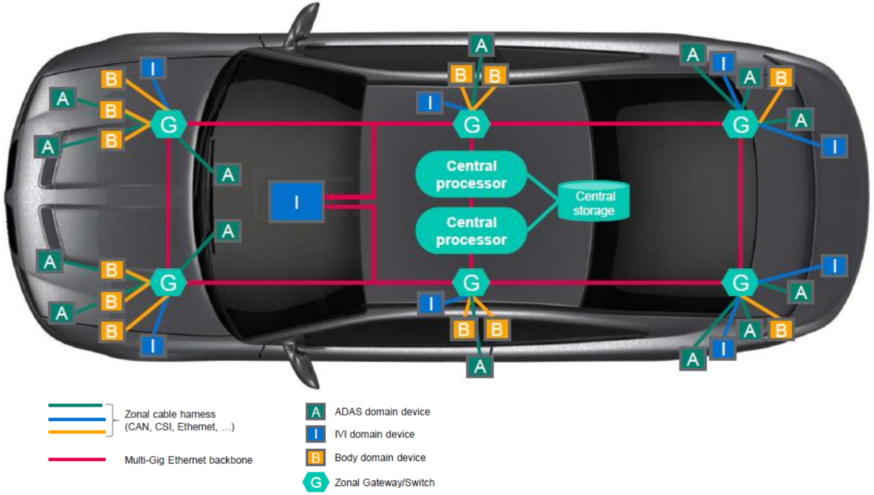
- Central domain controller/high performance computer
- Ability to handle more complex functions
- Consolidation of functions (cost optimization)
- But: cable harness is rigid and expensive



Source: Marvell Automotive Ethernet Congress 2022

Zonal architecture

- Local ethernet gateway per zone
- Ultra high-speed secured backbone between zones
- Centralized SW
- Central computing & storage



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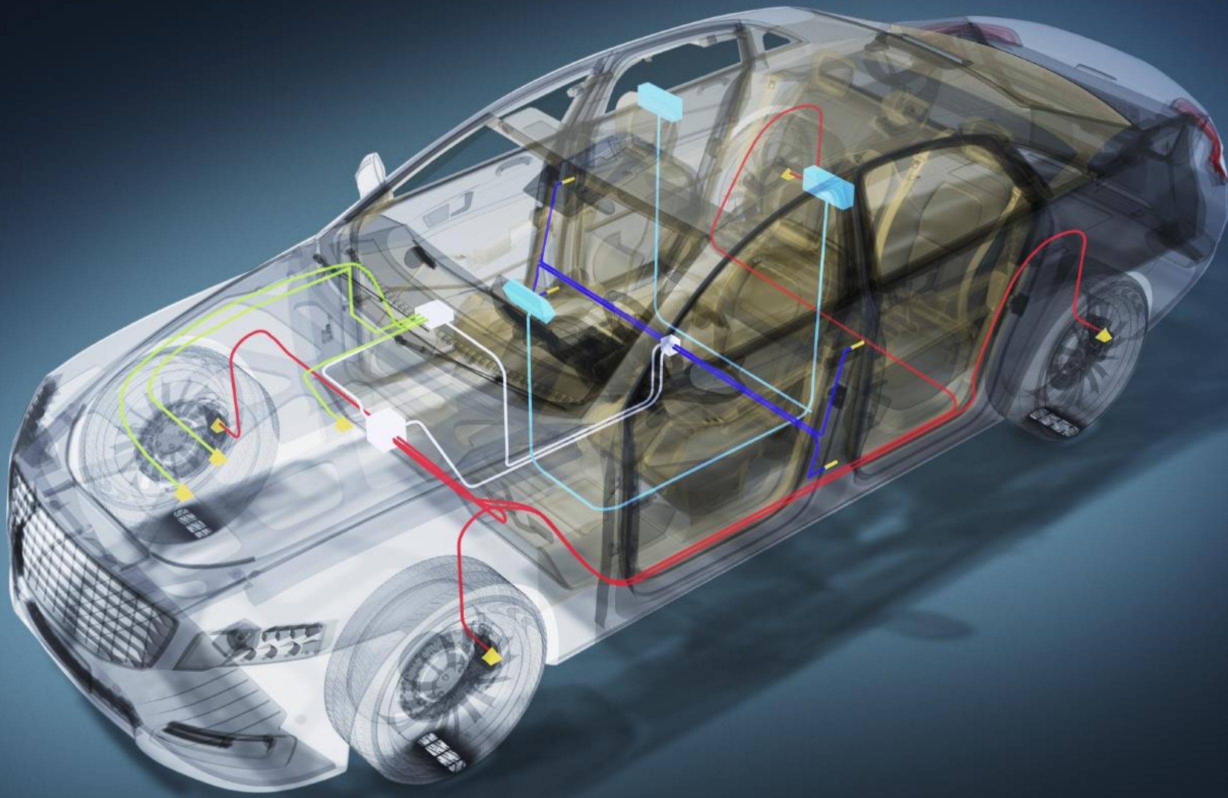
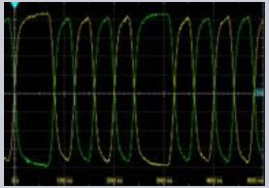
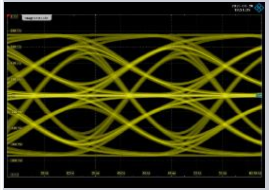
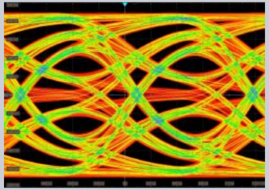
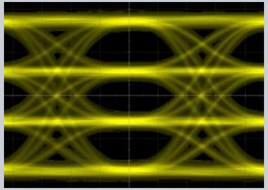
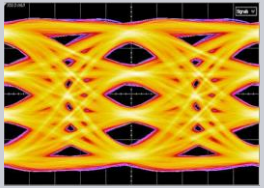
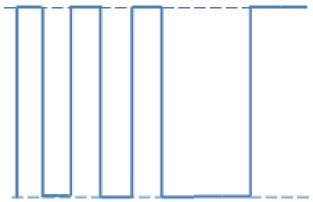


AUTOMOTIVE ETHERNET TODAY

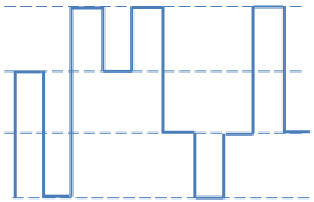
	10BASE-T1S	100BASE-T1	1000BASE-T1	2.5/5/10GBASE-T1	25GBASE-T1
IEEE 802.3 Reference	802.3cg-2019 Clause 147	802.3bw-2015 Clause 96	802.3bp-2016 Clause 97	802.3ch-2020 Clause 149	IEEE P802.3cy Clause 165
OPEN Alliance	TC14	TC1 (Closed)	TC12	TC15	N/A
Bit Rate (Gbps)	0.010	0.100	1.0	2.5 / 5.0 / 10.0	25.0
Baud Rate (MBd)	12.5	66.66	750	1406.25 / 2812.5 / 5625	14062.5
Encoding	2-Level DME 	PAM3 		PAM4 	
Cabling	UTP (Unshielded Twisted Pair)		UTP (STP optional)	STP (Shielded Twisted Pair)	

INTRODUCTION TO PAM SIGNALLING

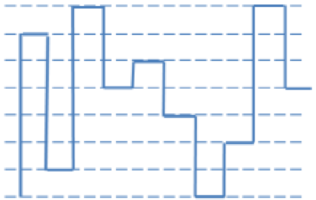
- **What are PAM signals?**
  - PAM stands for Pulse Amplitude Modulation
  - Type of signal modulation where amplitude of the pulses is varied according to data
  - Multilevel signalling is more bandwidth and spectral efficient
  - More sensitive to noise and distortion
- **Terminology** – Symbol rate (Gbaud) vs. Data rate (Gbps)
- **Technologies** –
  - Ethernet, Automotive Ethernet, USB 4.0, PCIe Gen6



NRZ: $2^1 = 2$



PAM4: $2^2 = 4$



PAM8: $2^3 = 8$

DIFFERENCE BETWEEN 100BASE-TX AND 100BASE-T1

100BASE-Tx standard Ethernet

Fast rise time

3 clear levels

100BASE-T1 Automotive Ethernet

Slower rise time

3 levels not clear

OBJECTIVE FOR AUTOMOTIVE ETHERNET TESTING

OSI		TCP/IP
7	Application	Applications: FTP, HTTP, SMTP…)
6	Presentation	
5	Session	
4	Transport	TCP
3	Network	IP
2	Data Link	Network Access
1	Physical	10/100/1000/MultiGBASE-T1

Correct protocol and data transmission

Error free communication

Validate Sleep/Wakeup Cycles

Resistant to EMI

Correct latency

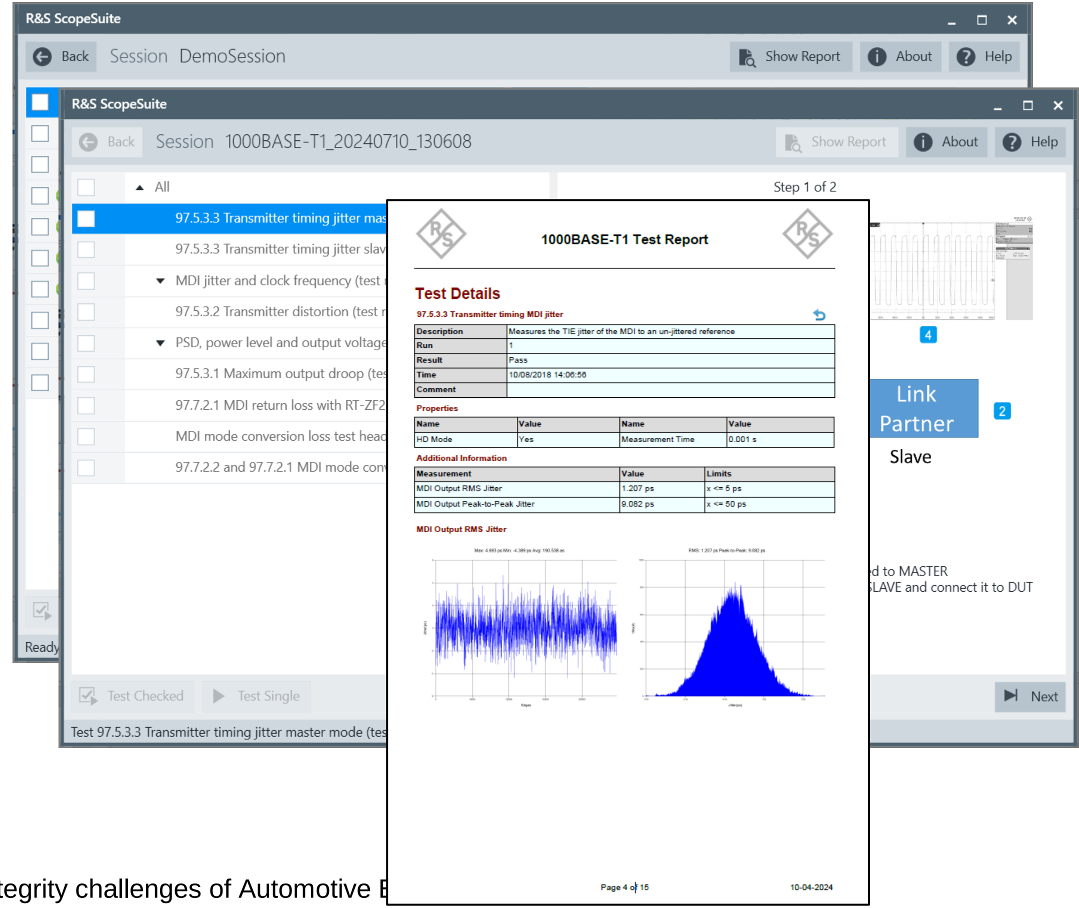
Correct boot time

Test OEM requirement

10/100/1000/MultiGBASE-T1 interface compliance

COMPLIANCE TESTING OPEN TC12 / 1000BASE-T1

- **Group 1: PMA Transmit Tests:**
  - Maximum Output Droop
  - Transmitter Distortion
  - Transmitter **T**iming **J**itter MASTER/SLAVE/MDI
  - Transmitter Power Spectral Density (PSD) and power level
  - Transmitter Peak Differential Output
  - Transmitter Clock Frequency
- **Group 2: PMA Receive Tests:**
  - Bit Error Rate Verification
  - Alien Crosstalk Noise Rejection
  - Receiver Frequency Tolerance (Optional)
- **Group 3: MDI Impedance Requirements:**
  - MDI return Loss
  - MDI mode conversion loss

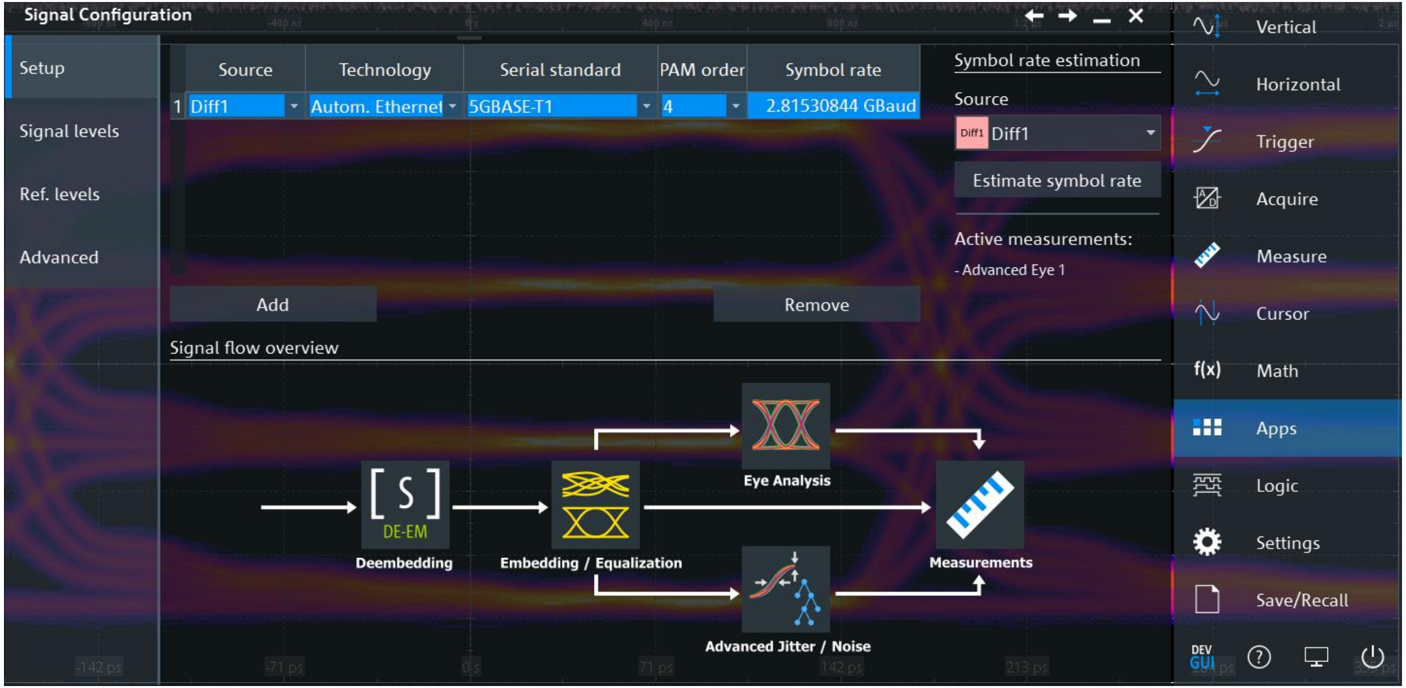


BUT WHAT IF WE FAIL COMPLIANCE?

- Signal Integrity tools on board the T&M Instrument
  - Cable & Connector characterization
  - Jitter analysis
  - Jitter & Noise decomposition
  - Live Eye
  - Eye analysis
  - Mask tests
  - De-embedding
  - Embedding
  - Equalization
  - Protocol trigger & decode
  - Serial Pattern trigger

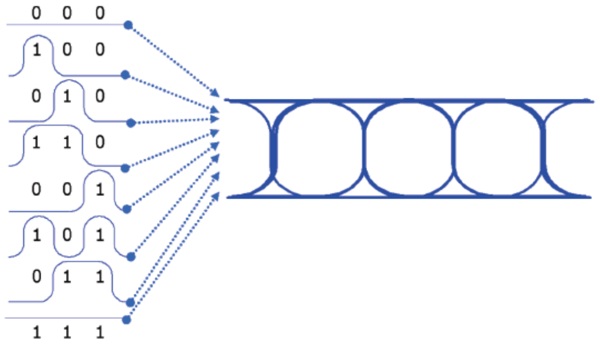
PAM-N ANALYSIS
SIGNAL INTEGRITY TOOLS

► All starts with the right configuration

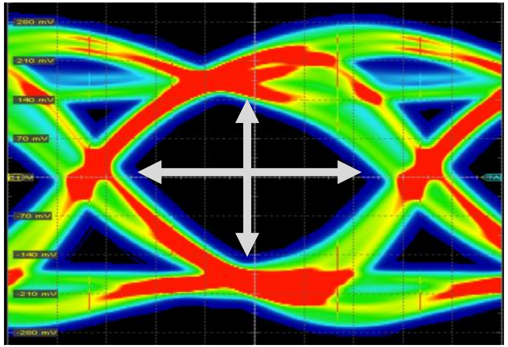


EYE DIAGRAM
INTRODUCTION

- Intuitive graphical tool for the evaluation of the quality and integrity of data signals
- Generated by superposition of multiple signal waveform segments aligned to well-defined reference time instants
  - Waveform segments commonly correspond to a data symbol
  - Reference clock provides timing information for alignment (e.g. symbol start instant)



Superposition of bit sequences form the eye diagram



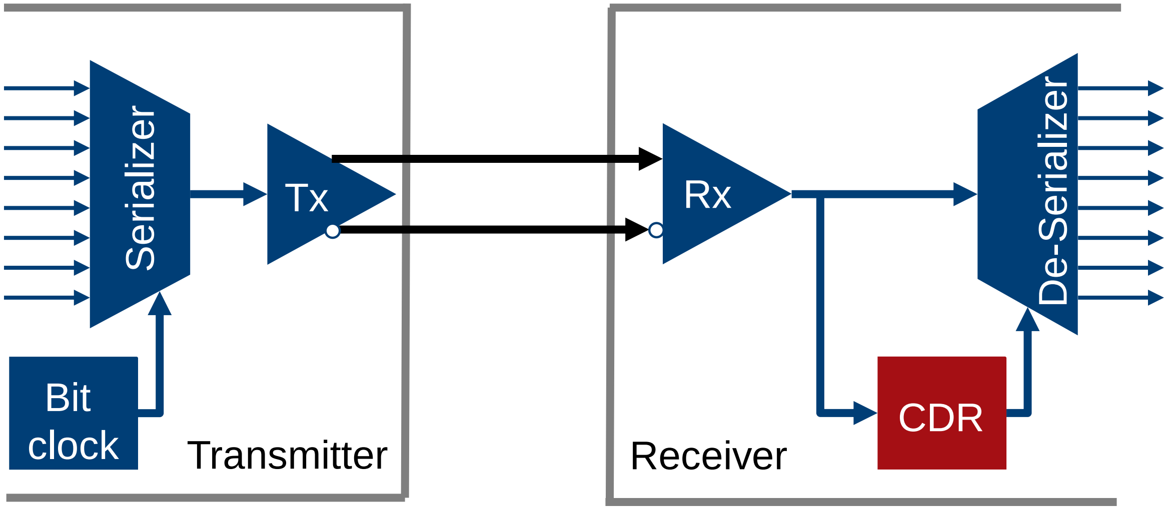
Eye diagram with color-coded frequency

Eye height
Eye width

REFERENCE CLOCK GENERATION FOR EYE DIAGRAMS
CLOCK-DATA-RECOVERY

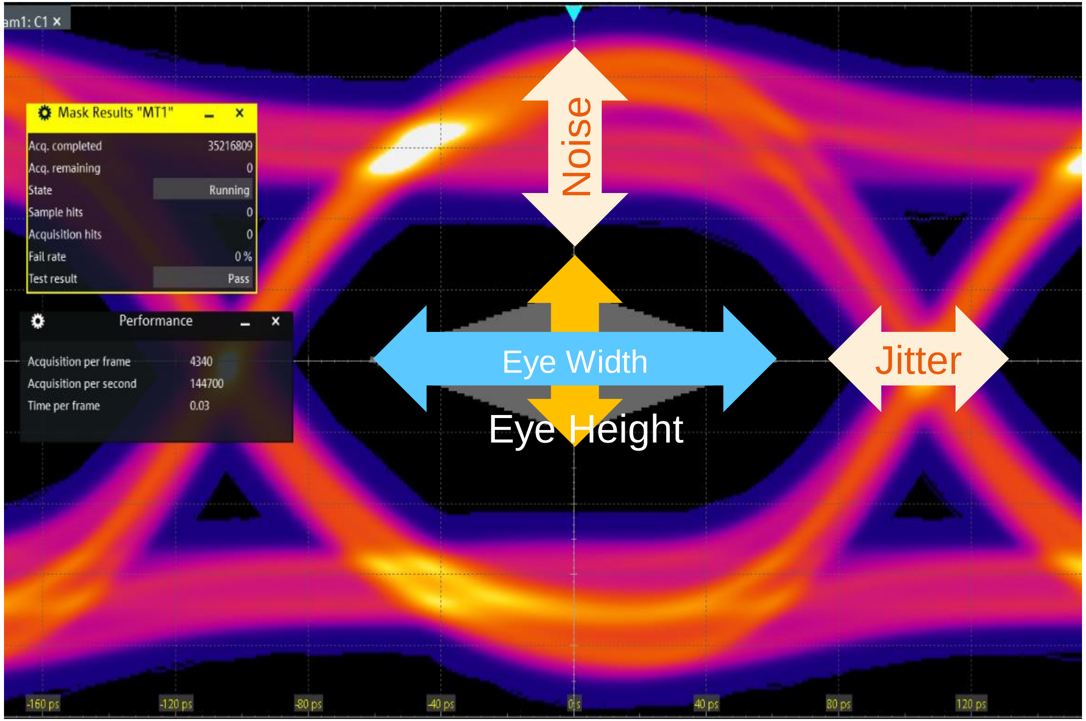
► **Timing reference:**
  – reference clock (parallel clock signal) or
  – from the data signal itself (embedded clock signal)

► Clock data recovery (CDR) typically uses a Phase Locked Loop (PLL) or Delay Locked Loop (DLL)



INFORMATION CONTAINED IN AN EYE DIAGRAM

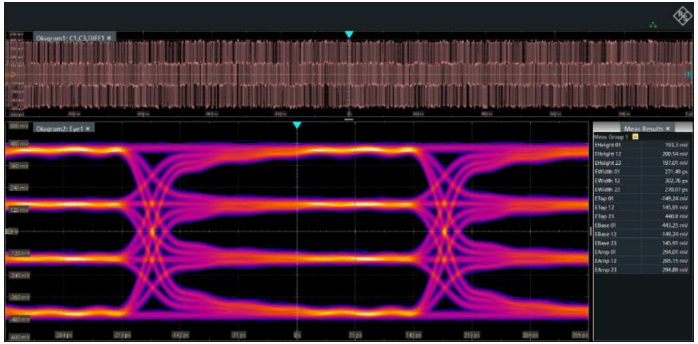
- **Jitter:** peak to peak, standard deviation
- **Noise:** peak to peak, standard deviation
- **Eye width:** minimum time interval over which no signal transition will occur
- **Eye height:** the minimum amplitude over which the signal level occur
- *Note: Eye parameters are based on statistics and require large sample size for repeatable measurements*

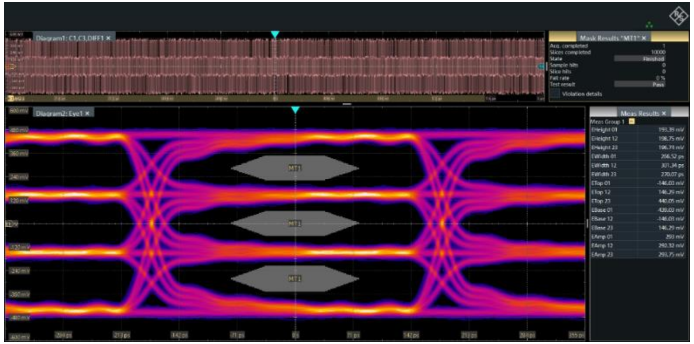


IF COMPLIANCE TEST FAILS?
ADVANCED ANALYSIS FUNCTIONS – EYE ANALYSIS

- Powerful Eye diagram and PAM-N analysis with RTx-K135/K136/K137 options

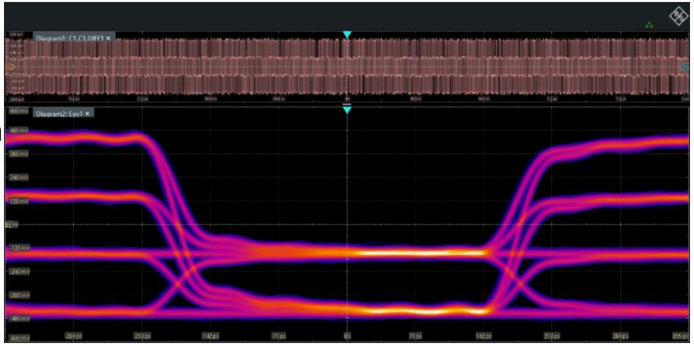
Eye Analysis on a 5GBASE-T1 PAM4 signal

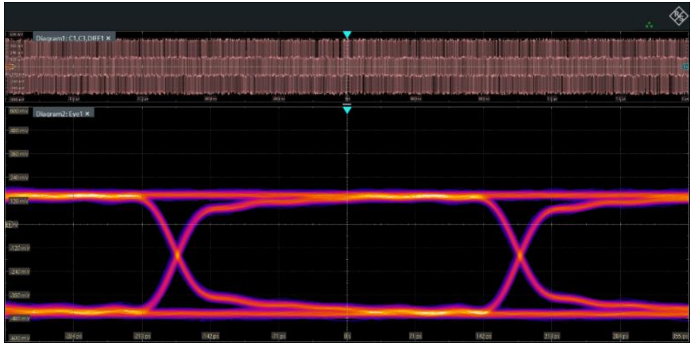




Mask test on PAM4 signal

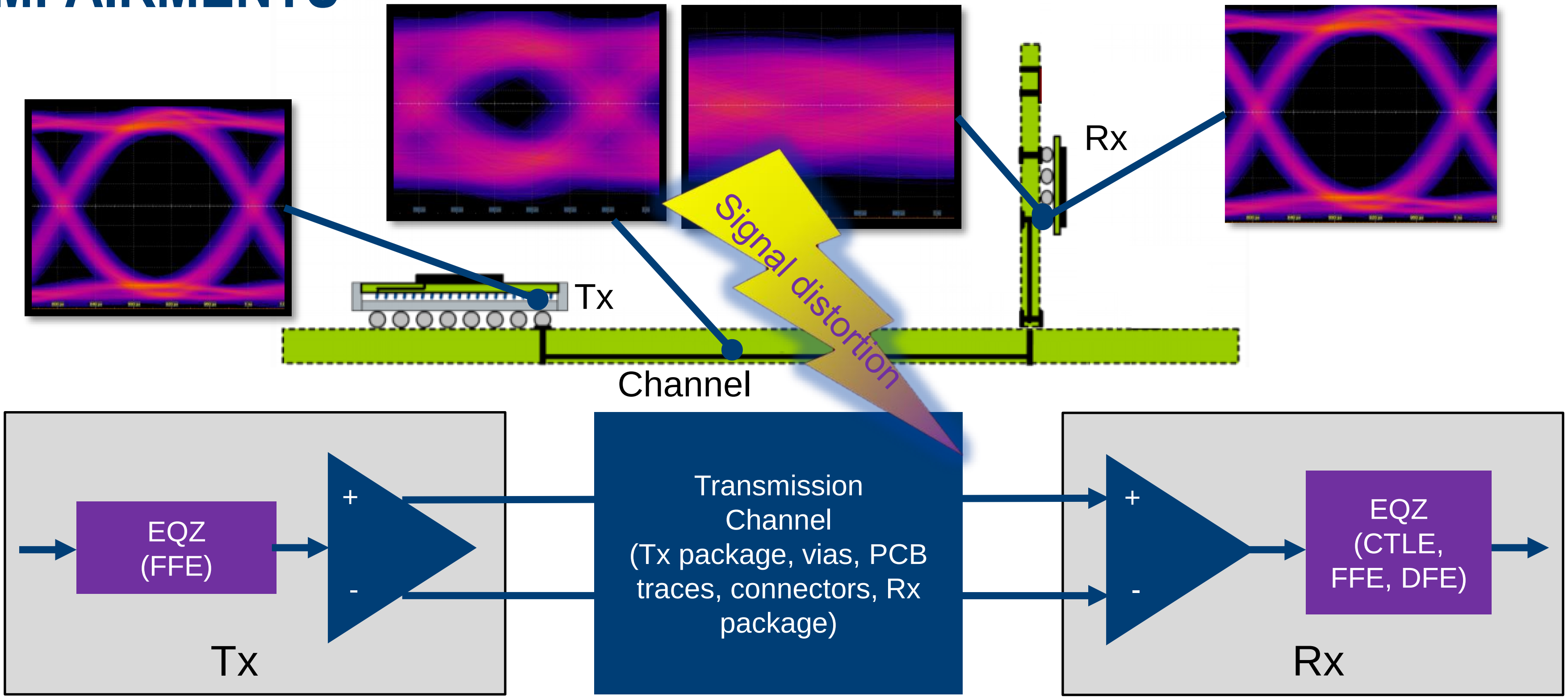
‘Specific Eye’ displays (e.g. transitions from 0-1) with all incoming and outgoing transitions





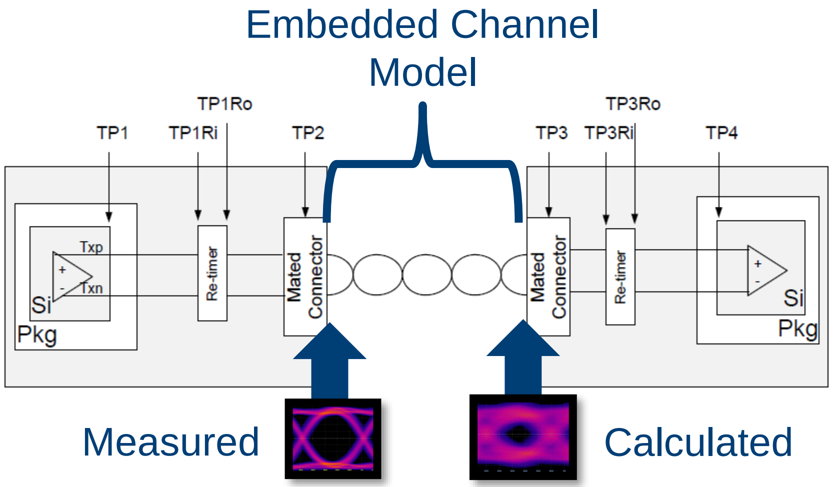
‘Selected Eye’ displays (e.g. transitions from 0-2) with only its own incoming and outgoing transitions

SIGNAL INTEGRITY TOOLS – CHANNEL & SIGNAL IMPAIRMENTS



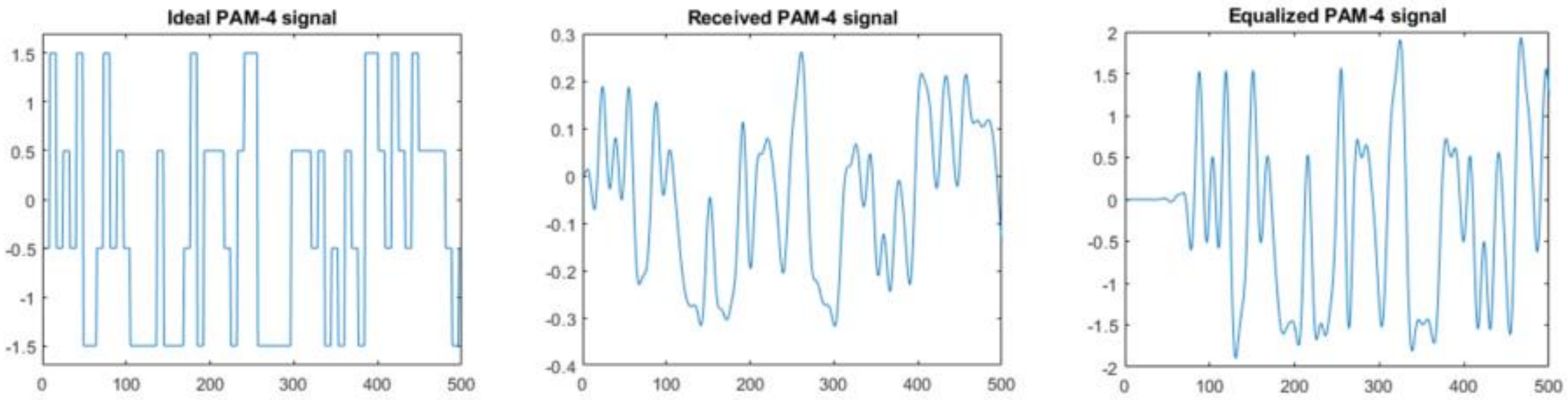
EMBEDDING

- ► Emulates additional signal distortion by adding mathematically „lossy“ components (e.g. cable)
- ► Components are expressed by S-parameters (typically 2-port or 4-port)
- ► Several components can be cascaded
- ► FIR filter gets designed to simulate respective frequency response



WHAT IS EQUALIZATION

- Equalizers compensate for some of the distortions introduced by the channel and can recover the transmitted PAM symbols:
  - \+ can compensate inter-symbol interferences
  - – can not remove noise or delays



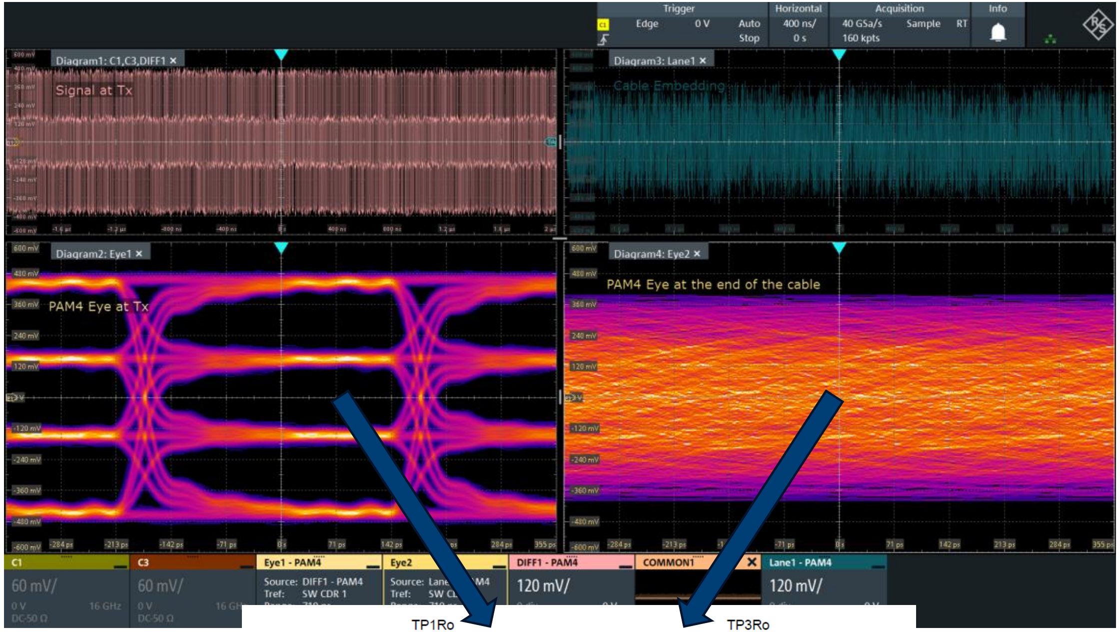
TYPES OF EQUALIZER

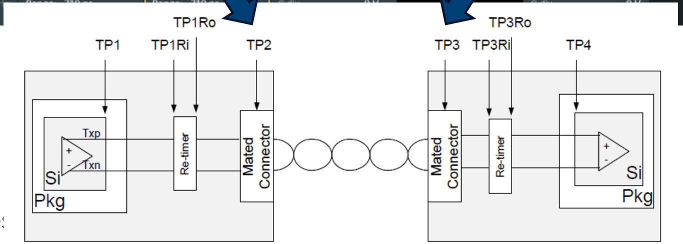
- Common Equalizer:
  - Transmitter side: **TX FFE** (pre-distortion / pre-emphasis / de-emphasis)
  - Receiver side: **CTLE** / **FFE** / **DFE**
- ***Note:*** *In a communications system, the output of the equalizer are generally the estimated PAM symbols, sampled at symbol rate. For debugging applications in the oscilloscope, we develop equalizers that output waveforms at the same sampling rate of the input waveform. This allows the computation of eye diagrams or jitter analysis.*

DEMO

PAM-N ANALYSIS
SIGNAL INTEGRITY TOOLS – EMBEDDING

- Measure the channel using a VNA
- Import the S-parameter files on to the oscilloscope





PAM-N ANALYSIS
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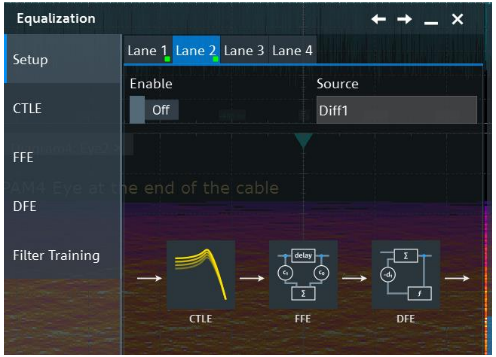

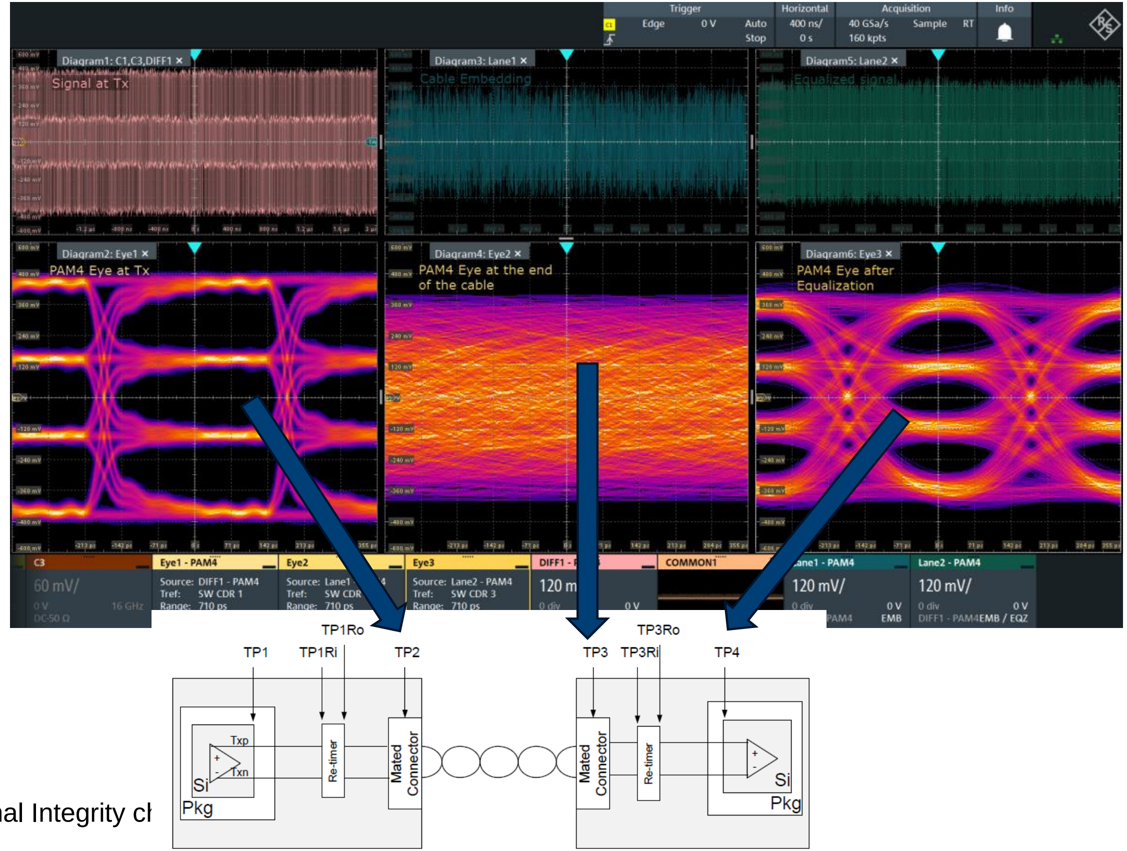

PAM-N ANALYSIS
SIGNAL INTEGRITY TOOLS – JITTER ANALYSIS

- Decomposition of Jitter and Noise components
- Signal-model based approach
- Step frequency, frequency response
- Histograms, Track, FFTs, bathtub curves
- PAM-N breakdown

SUMMARY AND LEARNINGS

- The development of higher levels of autonomous driving and new services delivered by automotive connectivity require an increased number of more complex sensors
- Requirement for high-speed, low cost and power efficient communications – introduction of new standards such as MultiGig and 10BASE-T1S.
- Reduction of IVN complexity and weight to achieve ADAS level 4 is driving migration to zonal architecture.
- Speed, reliability of data needed to support safety critical applications and EMI considerations puts increase demand for signal integrity.
- Interoperability and performance of different vendors' equipment can be ensured via OPEN Alliance compliance testing.
- Vast amount of powerful SI tools from R&S are available to verify and debug products faster and bring them to the market sooner.

www.rohde-schwarz.com/automotive/ivn

TEST IT. TRUST IT.