KEYSIGHT WORLD 2020

Demystifying Automotive Ethernet Testing

Created and presented in partnership with

University of New Hampshire InterOperability Laboratory

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Agenda

What is Automotive Ethernet?

Automotive Ethernet Standards

Becoming an 802.3 Specification

OPEN Alliance /ISO/SAE

Automotive Ethernet Test challenges

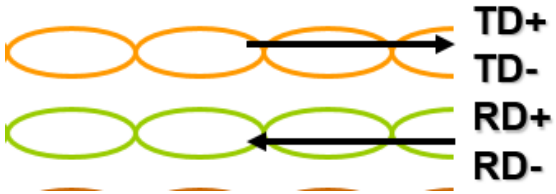
The Future of In-Vehicle Networking

What is Automotive Ethernet?

DIFFERENT FROM STANDARD ETHERNET

Not all Ethernet PHYs are created equal!

- Data rate: 10Mbps to 400Gbps
- Half-duplex vs Full-duplex transmission
- Receiver DSP complexity
- Media type and reach
  - Copper [coax, twinax, twisted pair], Fiber [single-mode, multi-mode]
  - Single meters to kilometers



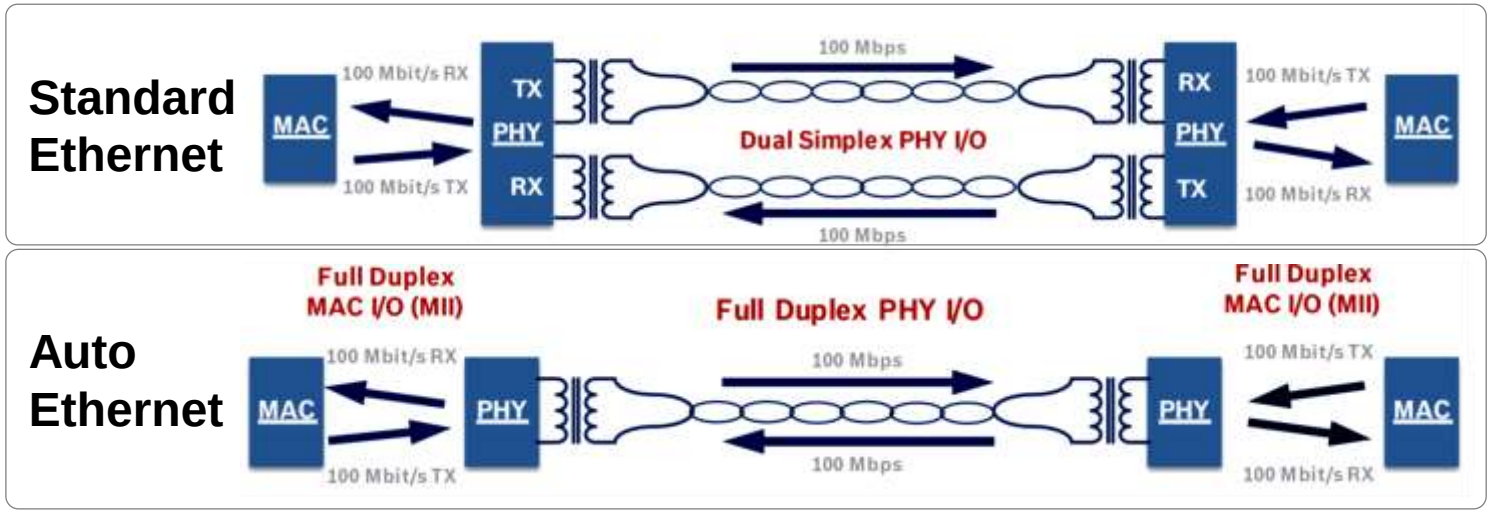
Two Twisted pair
Single direction

One Twisted pair
Bi-direction

Ethernet technologies are used in many markets and applications, with unique use-cases. These use-cases and applications are considered when developing the ‘Five Criteria’ during the 802.3 Study Group phase.

Why Use Automotive Ethernet?

- **Cable weight**
  - 100BASE-T1/1000BASE-T1 are physical full-duplex standards
  - Only a single unshielded-twisted pair cable is needed
- **Immunity and emissions requirements**
  - CISPR25 Class 5
  - PAM3 for noise immunity
- **Proven technology**
  - Decades of development
  - Standardized interface



What is Automotive Ethernet?

FOR USE IN VEHICLE

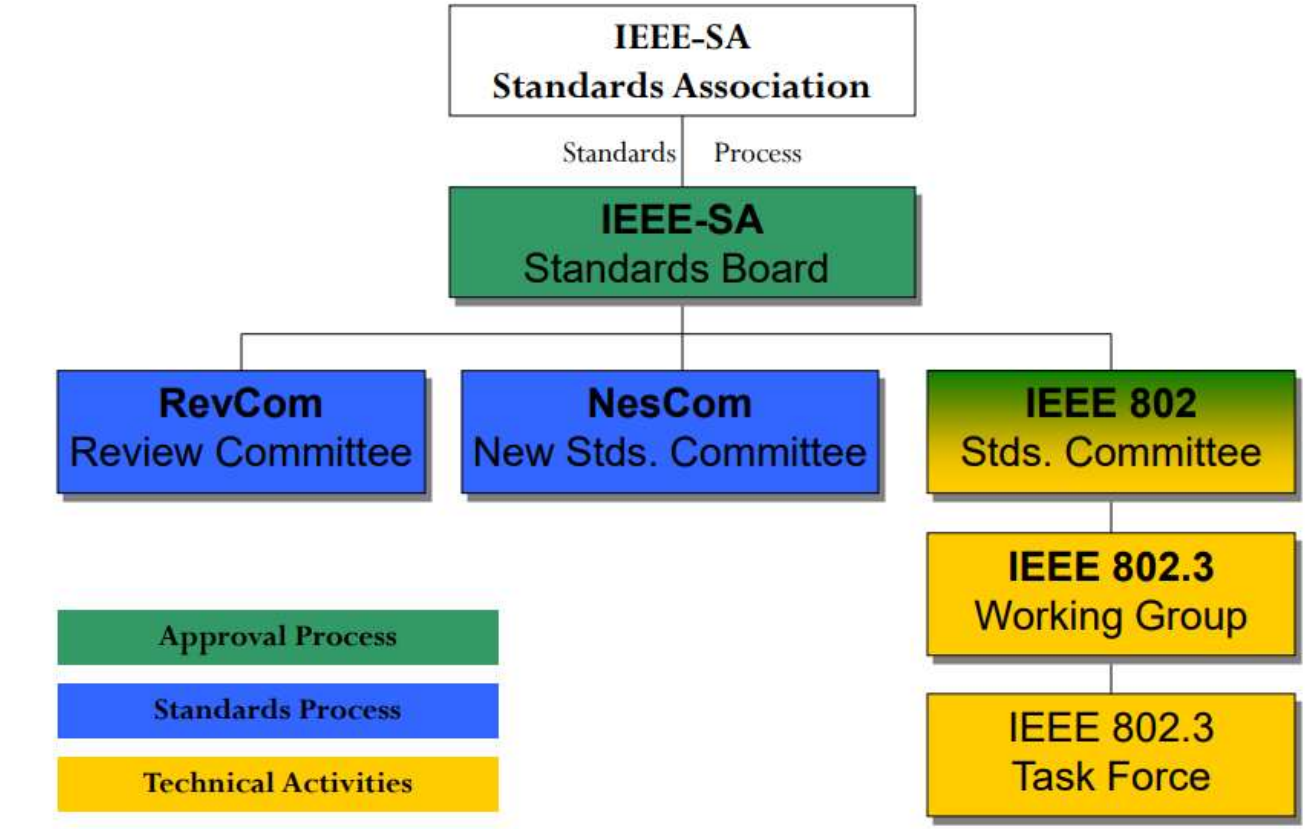
The operating environment within a vehicle is quite unique when compared to the typical office LAN use-case of Ethernet (-50C to +150C, dirt/grease/various engine and transmission fluids).

Additionally, car manufacturers are sensitive to weight since heavier vehicles lead to greater fuel consumption.

IEEE & IEEE-SA

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS

"The IEEE is the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity."

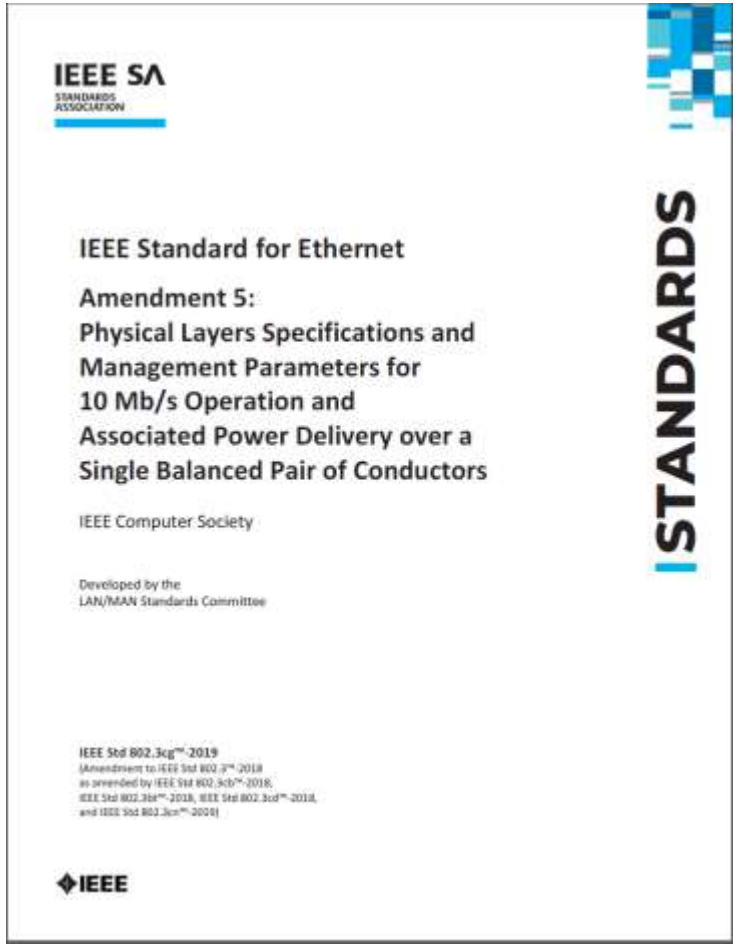


From IEEE.com

IEEE 802.3 Specification

IEEE Std 802.3™ was first published in 1985

- A single volume that has been amended by task forces for the last 35 years. Each task force project providing functionality or maintenance updates to the standard.
- Eight sections spanning over 5000 pages



IEEE 802.3 Specification

Each IEEE 802.3 project/amendment is identified with a suffix (e.g., IEEE Std 802.3cg™-2019)

An ‘amendment’ is a collection of edits made to the 802.3 Standard. Can include new **clauses** or modifications to existing clauses. The output specification from a Task Force is considered an amendment.

A ‘clause’ can be thought of as a chapters within the 802.3 Standard. Each clause is identified by a number and respective title
(e.g., Clause 96: Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 100BASE-T1)

Each clause defines the specification of a unique PHY type or PHY protocol. PHY types can be further divided into ‘sublayers’. Multiple sublayers can be defined within a single clause, or can be broken into multiple clauses.

- IEEE P802.3ca 25 Gb/s and 50 Gb/s Ethernet Passive Optical Networks Task Force.
- IEEE P802.3ch Multi-Gig Automotive Ethernet PHY Task Force.
- IEEE P802.3ck 100 Gb/s, 200 Gb/s, and 400 Gb/s Electrical Interfaces Task Force.
- IEEE P802.3cp Bidirectional 10 Gb/s, 25 Gb/s, and 50 Gb/s Optical Access PHYs Task Force.
- IEEE P802.3cr Isolation (Maintenance #14) Task Force.
- IEEE P802.3cs Increased-reach Ethernet optical subscriber access (Super-PON) Task Force.
- IEEE P802.3ct 100 Gb/s over DWDM systems Task Force.
- IEEE P802.3cu 100 Gb/s and 400 Gb/s over SMF at 100 Gb/s per Wavelength Task Force.
- IEEE P802.3cv Power over Ethernet (Maintenance #15) Task Force.
- IEEE P802.3cw 400 Gb/s over DWDM systems Task Force.
- IEEE P802.3cx Improved PTP Timestamping Accuracy Task Force.
- IEEE 802.3 Greater than 10 Gb/s Automotive Ethernet Electrical PHYs Study Group.
- IEEE 802.3 Multi Gigabit Automotive Optical PHYs Study Group.
- IEEE 802.3 10SPE Multidrop Enhancements Study Group.
- IEEE 802.3 100 Gb/s Wavelength Short Reach PHYs Study Group.
- IEEE 802.3 New Ethernet Applications Ad Hoc.
- IEEE 802.3 SCC18 Ad Hoc.

IEEE 802.3 Specification

Roughly every 3 years, the IEEE 802.3 Working Group revises the 802.3 Standard to include the project amendments that have been ratified since the last revision.

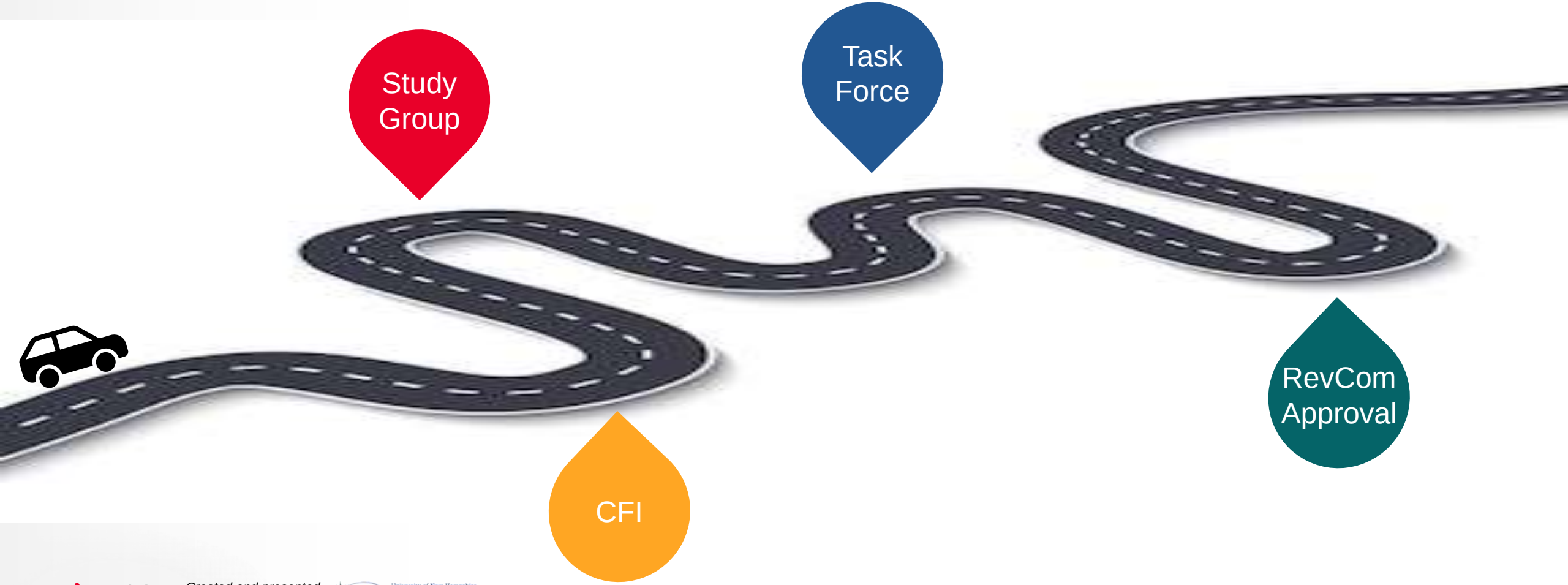
As of the 802.3-2018 release, there are 126 clauses in the Standard

And as of writing this, there have been 6 amendments since the release of the 2018 revision

- Adding 22 more clauses
- There are also 11 projects currently being developed within 802.3

Road to Becoming an 802.3 Ethernet Specification

HOW DOES A NEW TECHNOLOGY IDEA BECOME THE NEXT IEEE 802.3 PHY STANDARD?



Road to Becoming an 802.3 Ethernet Specification

CALL-FOR-INTEREST (CFI)

During an IEEE 802 Plenary, a CFI presentation can be requested to be added to the agenda that week

Typically, a small panel of presenters will discuss the potential issue they believe needs to be fixed, and why an Ethernet based solution is compelling

During the Closing Plenary meeting that week, the 802.3 Working Group members vote as to whether the idea presented in the CFI should progress to the next step… Study Group

Road to Becoming an 802.3 Ethernet Specification

STUDY GROUP

A SG exist for up to 6 months. If the SG has not completed its work within that time, a request for an extension of up to an additional 6 months can be made.

A SG generates responses to a document called the Criteria for Standards Development (CSD). The CSD details information like broad market potential, distinct identity, and technical feasibility.

Generally, it takes between 2 to 4 face-to-face meetings (4 to 8 months) for a SG to complete all necessary documentation and use-case study before going to the Working Group for the next step… Task Force.

Road to Becoming an 802.3 Ethernet Specification

TASK FORCE

When a Task Force is created, it is given a two-letter designation

- 802.3**bw** = 100BASE-T1 Project
- 802.3**cg** = 10BASE-T1S Project

Participants of a Task Force present technical material for proposals of how the new idea will be defined. These proposals become text in the draft amendment being edited by the Task Force editorial team.

On average, a Task Force exists for 4-5 years. The exact length is dictated by how quickly technical proposals can be made and accepted by participants and IEEE 802 minimum ballot review periods

OPEN Alliance

WHAT IS THE ROLE OF OPEN ALLIANCE?

- The OPEN Alliance wishes to facilitate the adoption of Ethernet based communication in automotive
- By ensuring that the additional required supporting standards needed when implementing Ethernet based communication in automotive are filled (by OPEN or others). These include qualification tests of PHYs and ECUs, interoperability tests, EMC requirements, channel requirements, switch requirements, etc.

OPEN Alliance

EXAMPLE

96.5.4.5 Transmit clock frequency

The symbol transmission rate of the MASTER PHY shall be within the range 66.66$\bar{6}$ MBd ±100 ppm.

Procedure:

1. Configure the DUT so that it is operating in transmitter test mode 2.
2. Connect BI_DA from the MDI to Test Fixture 1.
3. Using a narrow-bandwidth PLL, extract the clock frequency from the transmitted symbols.
4. For enhanced accuracy, repeat step 3 multiple times.
5. Measure the frequency of the transmit clock.

OPEN Alliance

5.5 Test 5.1.5 – Transmit Clock Frequency

Purpose: To verify that the frequency of the Transmit Clock is within the conformance limits.

References:

[1] IEEE Std. 802.3bw, section 96.5.4.5 - Transmit clock frequency

Resource Requirements:

- DSO
- Differential probe, or 2-pin to SMA Adapter with matched length 50 Ω coaxial cables
- Short Automotive Cable

Discussion:

Reference [1] states that all 100BASE-T1 devices must have a symbol transmission rate of $66\frac{2}{3}$ MHz ± 100ppm while operating in MASTER timing mode. This corresponds to a transmit clock of 66.6603 MHz to 66.6736 MHz.

The reference clock used in this test is the one obtained in test 5.1.3, Transmitter Timing Jitter - Case 1. The frequency of this clock, extracted from the transmitted test mode 2 waveform, shall have a base frequency of $66\frac{2}{3}$ MHz ± 100ppm.

Test Setup: Refer to test suite appendix 5.A.3.

Procedure:

1. Configure the DUT so that it is operating in transmitter test mode 2.
2. Connect BI_DA from the MDI to Test Fixture 1.
3. Using a narrow-bandwidth PLL, extract the clock frequency from the transmitted symbols.
4. For enhanced accuracy, repeat step 3 multiple times.
5. Measure the frequency of the transmit clock.

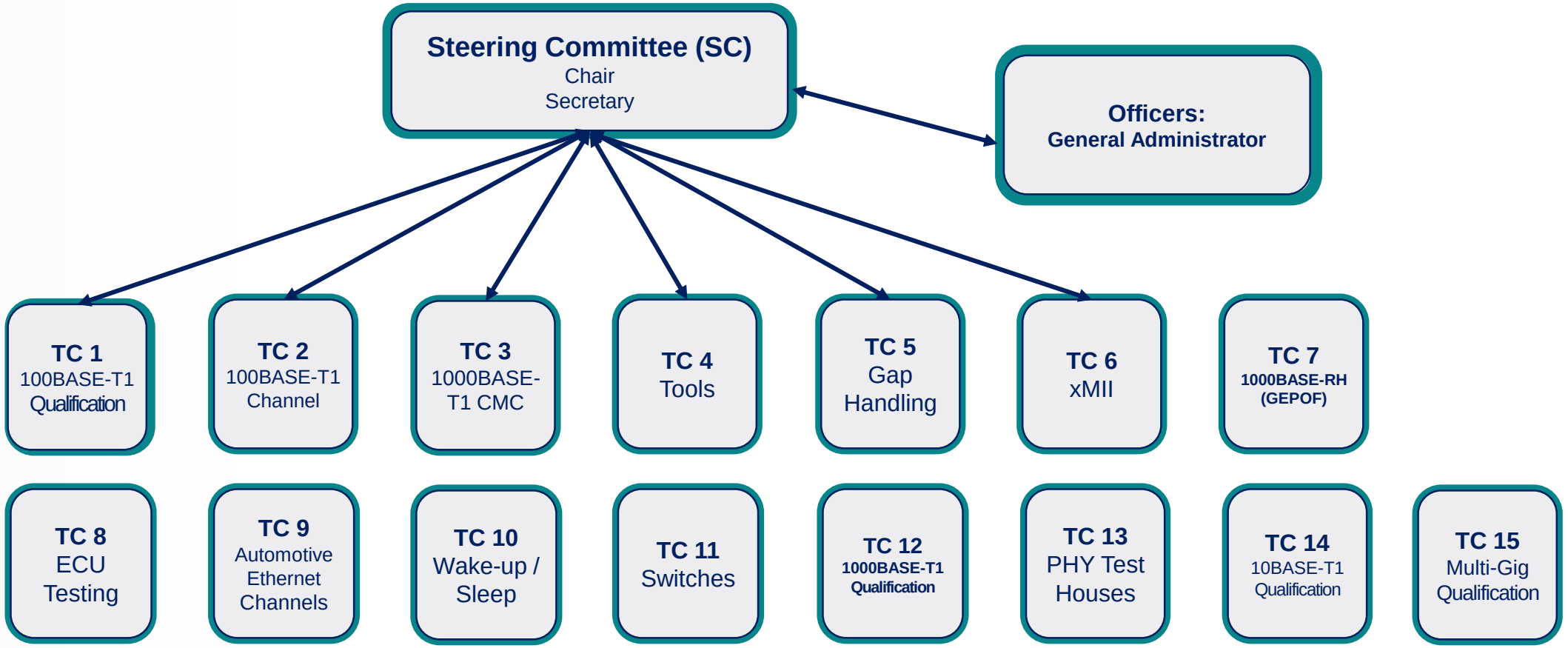
Observable Results:

a. The transmit clock generated by the DUT shall have a frequency between 66.6603 MHz and 66.6736 MHz.

Possible Problems: None.

OPEN Alliance

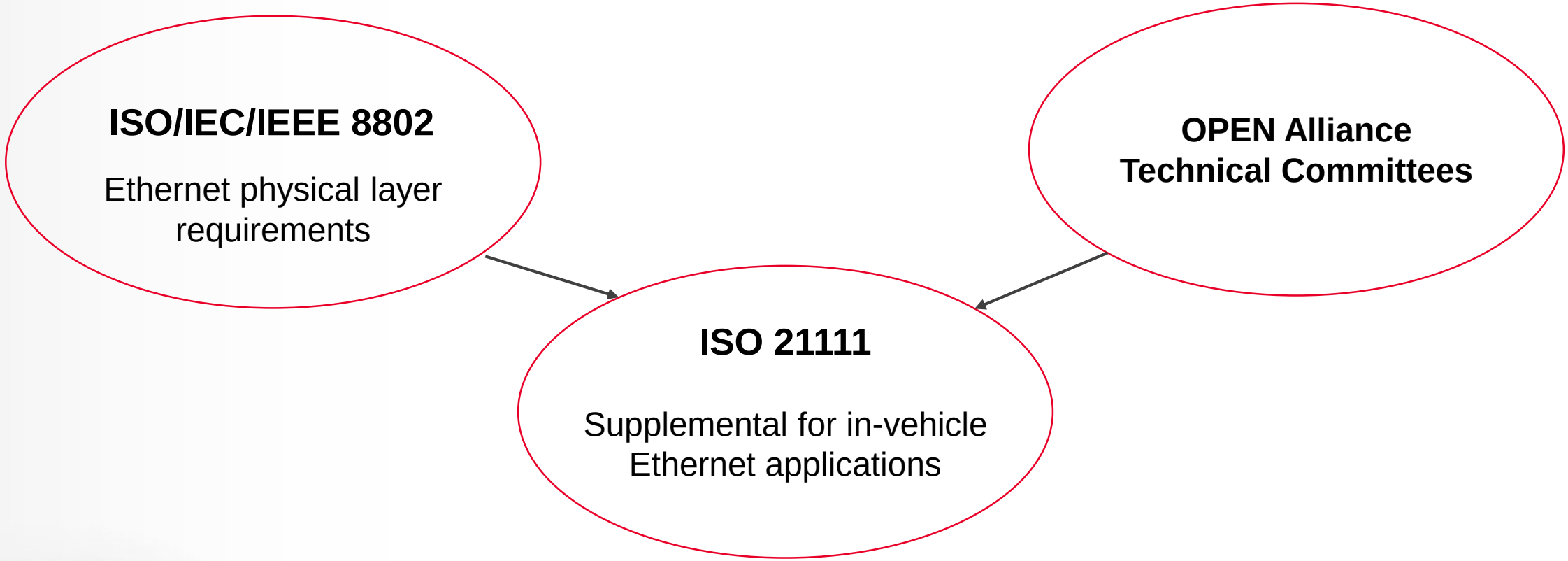
STRUCTURE/TECHNICAL COMMITTEES



ISO

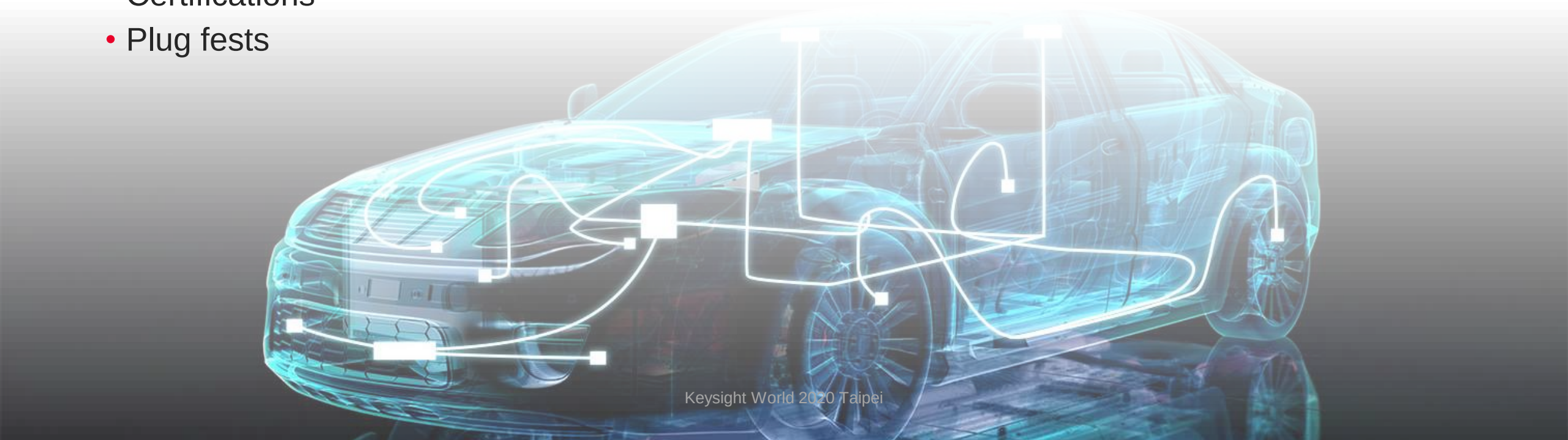
OPEN ALLIANCE/ISO RELATIONSHIP

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization



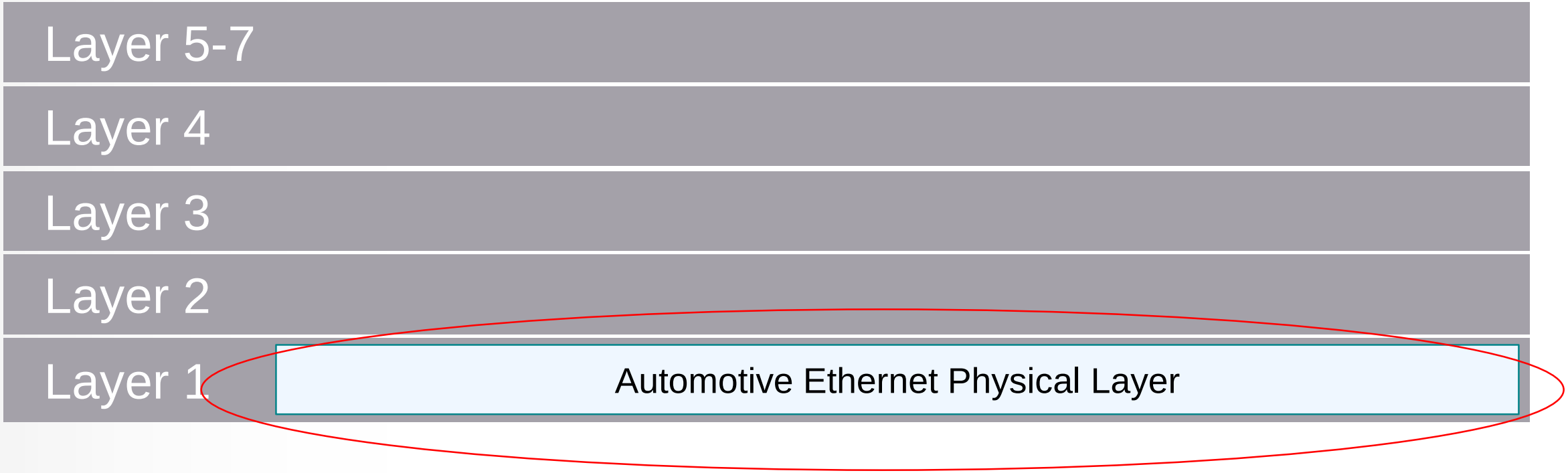
Other Automotive Ethernet Standards

- SAE - SAE International is a global association of more than 128,000 engineers and related technical experts in the aerospace, automotive and commercial-vehicle industries.
  - J2962/3 – Ethernet - Communication Transceivers Qualification Requirements
- Ethernet Alliance - The Ethernet Alliance is a global, non-profit, industry consortium of member organizations that are dedicated to the continued success and advancement of Ethernet technologies.
  - Certifications
  - Plug fests



Automotive Ethernet Test Challenges

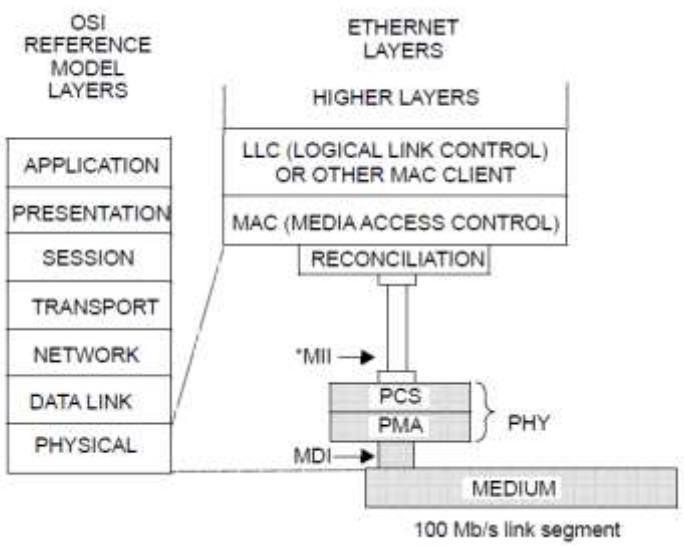
PHYSICAL LAYER TESTING



Current Automotive Ethernet PHY Architectures

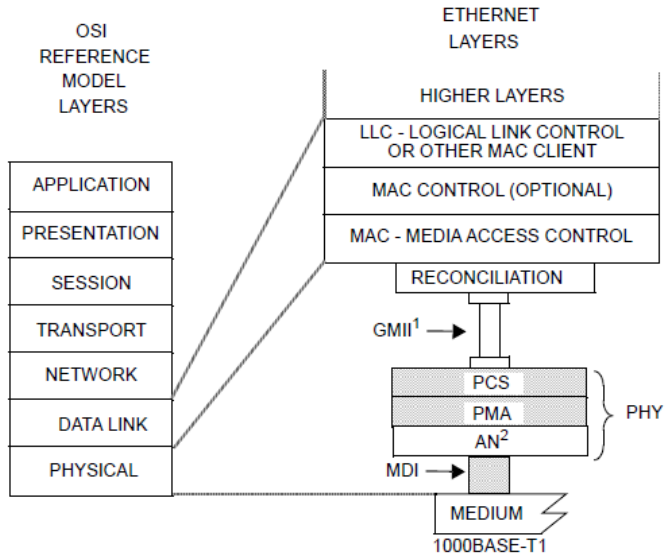
- Automotive Ethernet PHY architectures are similar to 4-pair BASE-T Ethernet PHYs, reduced to a single twisted pair
- 100BASE-T1 and 1000BASE-T1 Physical Layers are very much alike, both having a PCS and PMA sublayer defined

100BASE-T1



Architectural positioning of 100BASE-T1 (from IEEE 802.3bw-2015 specification)

1000BASE-T1

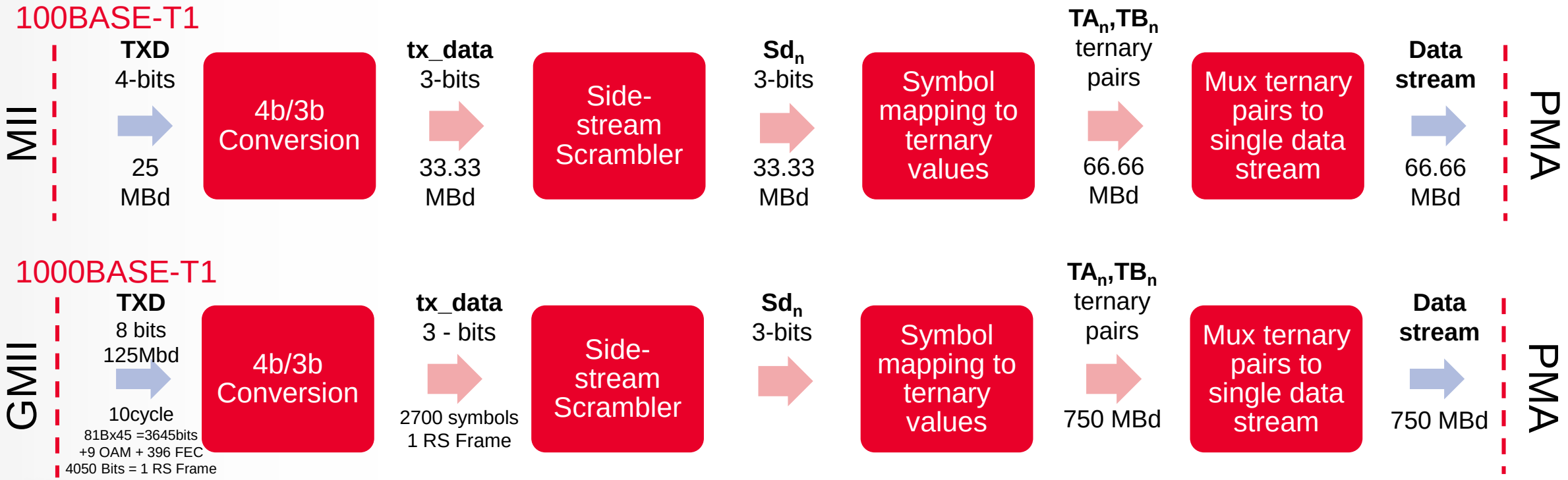


Architectural positioning of 1000BASE-T1 (from IEEE 802.3bp-2016 specification)

Automotive Ethernet PHY Sublayers- PCS Functions

Physical Coding Sublayer

- Scrambles data using ‘side-stream scrambler’
  - Increasing the number of transitions for ease of clock recovery
- Converts MII or GMII binary groups to ternary values {-1, 0, +1}, and vice-versa



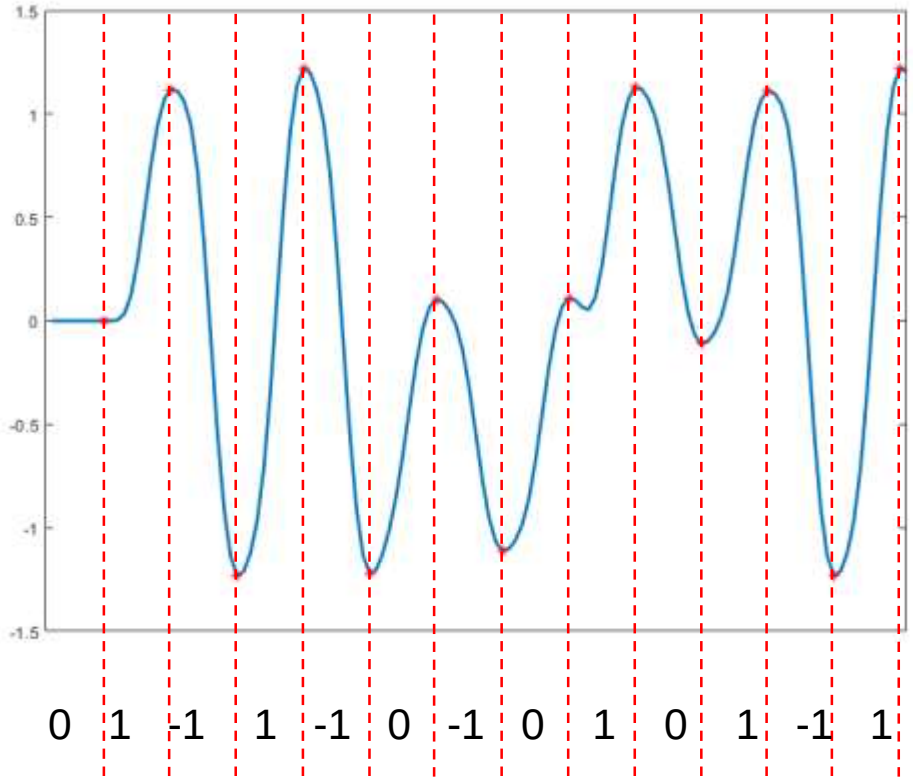
750 MBd = 1.125 GBd raw before FEC, encoding and OAM

Automotive Ethernet PHY Sublayers

PMA FUNCTIONS

Physical Media Attachment

- Provides link management functions
- Converts PCS data stream to analog signal (PAM3 modulation)
- Equalization and clock recovery on received data stream (implementation specific)

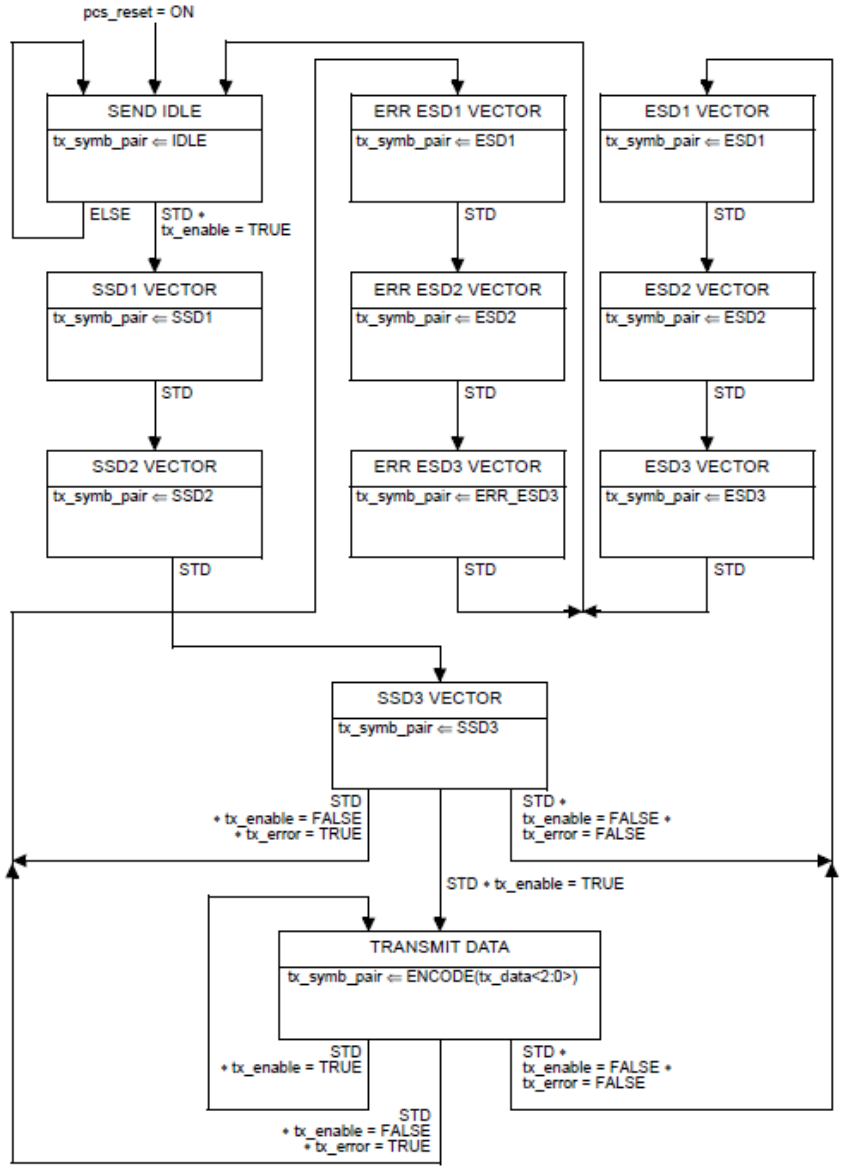


Conformance Testing

PCS

- Conformance requirements are based on timers and state transitions governed by state machines

- PCS Test Specification cases verify PHY behavior when transition requirements are within conformance limits, as well as when errors are introduced

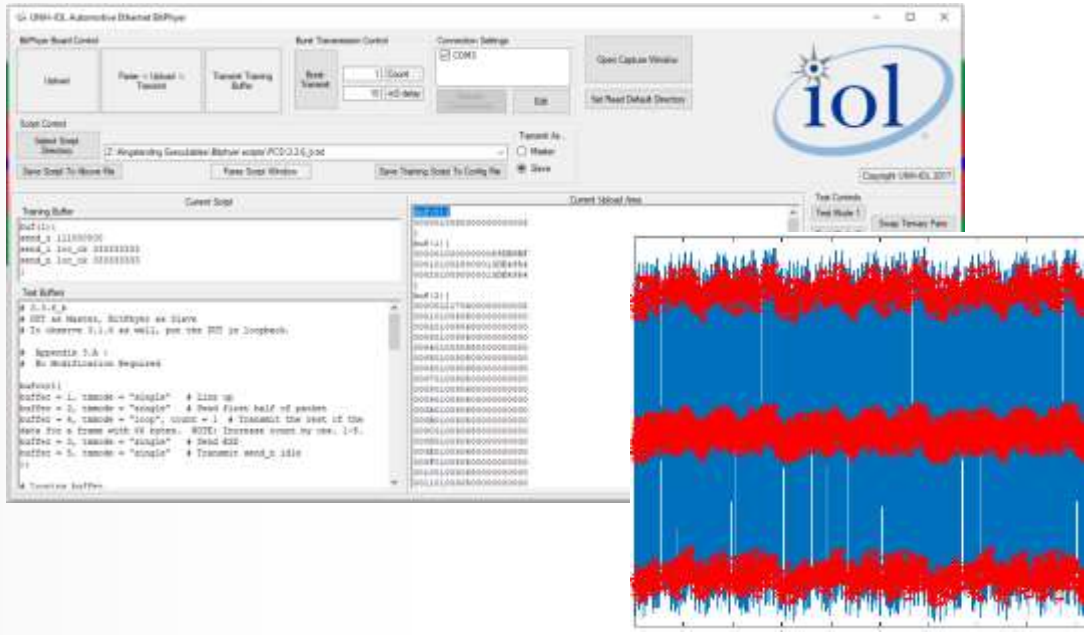


PCS Transmit state diagram (from IEEE 802.3bw-2015 specification)

Conformance Testing

PCS

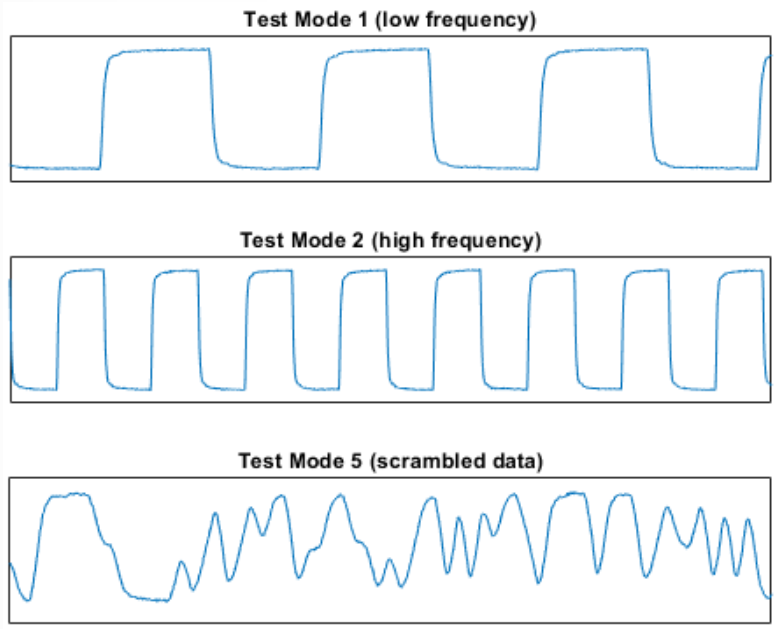
- The UNH-IOL developed BitPhyer, an FPGA based solution that acts as a 100BASE-T1 link partner, able to generate custom transmit sequences based on test scripts
- Custom MATLAB® based software tool is used to descramble/decode the signal to determine bit-level behavior



Conformance Testing

PMA TRANSMITTER

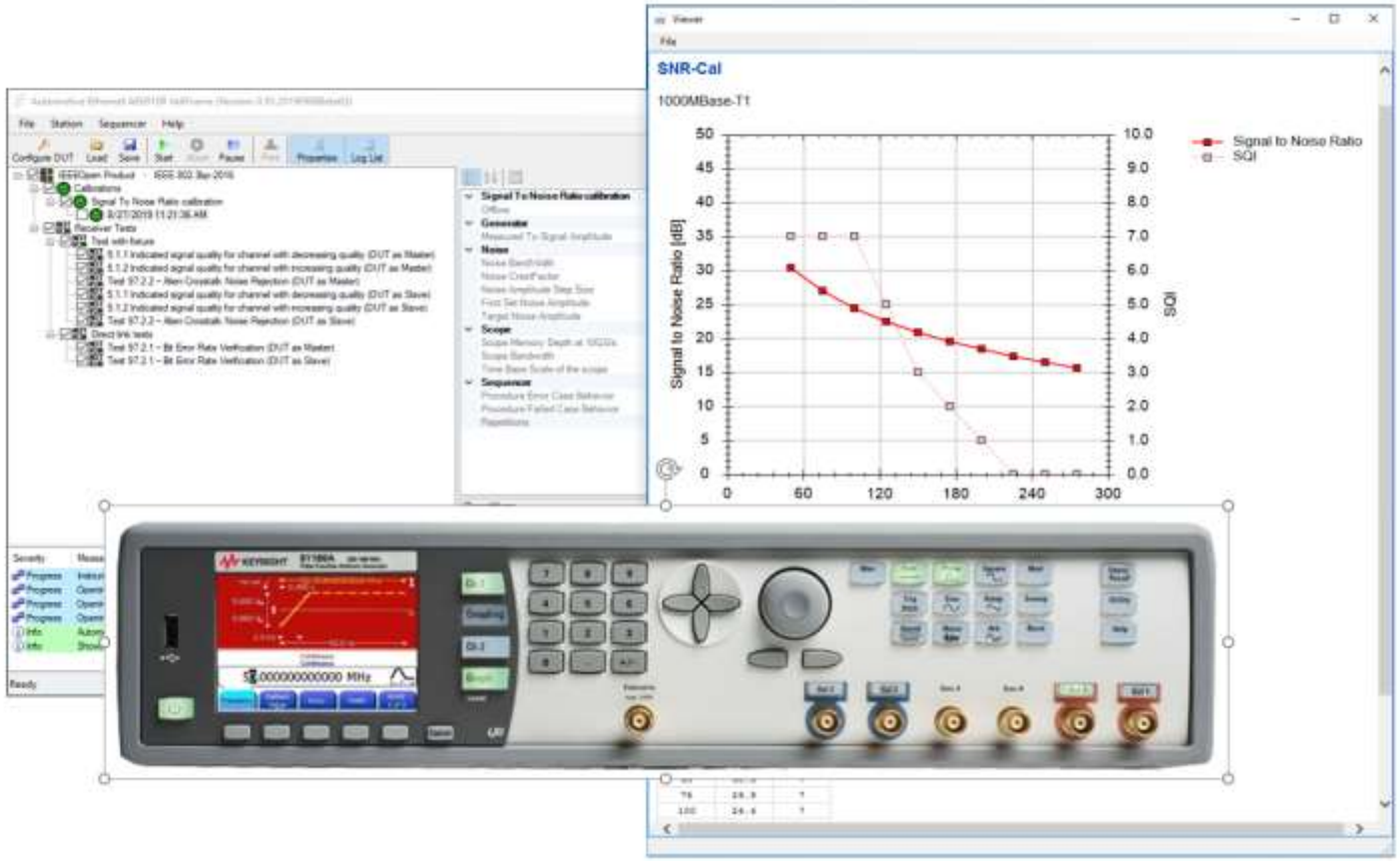
- Transmitter cases are performed with ‘test modes’, forced transmit patterns that bypass the PCS scrambler
  - T&M equipment is then used to measure the analog signal (oscilloscope, spectrum analyzer, vector network analyzer)



Conformance Testing

PMA RECEIVER

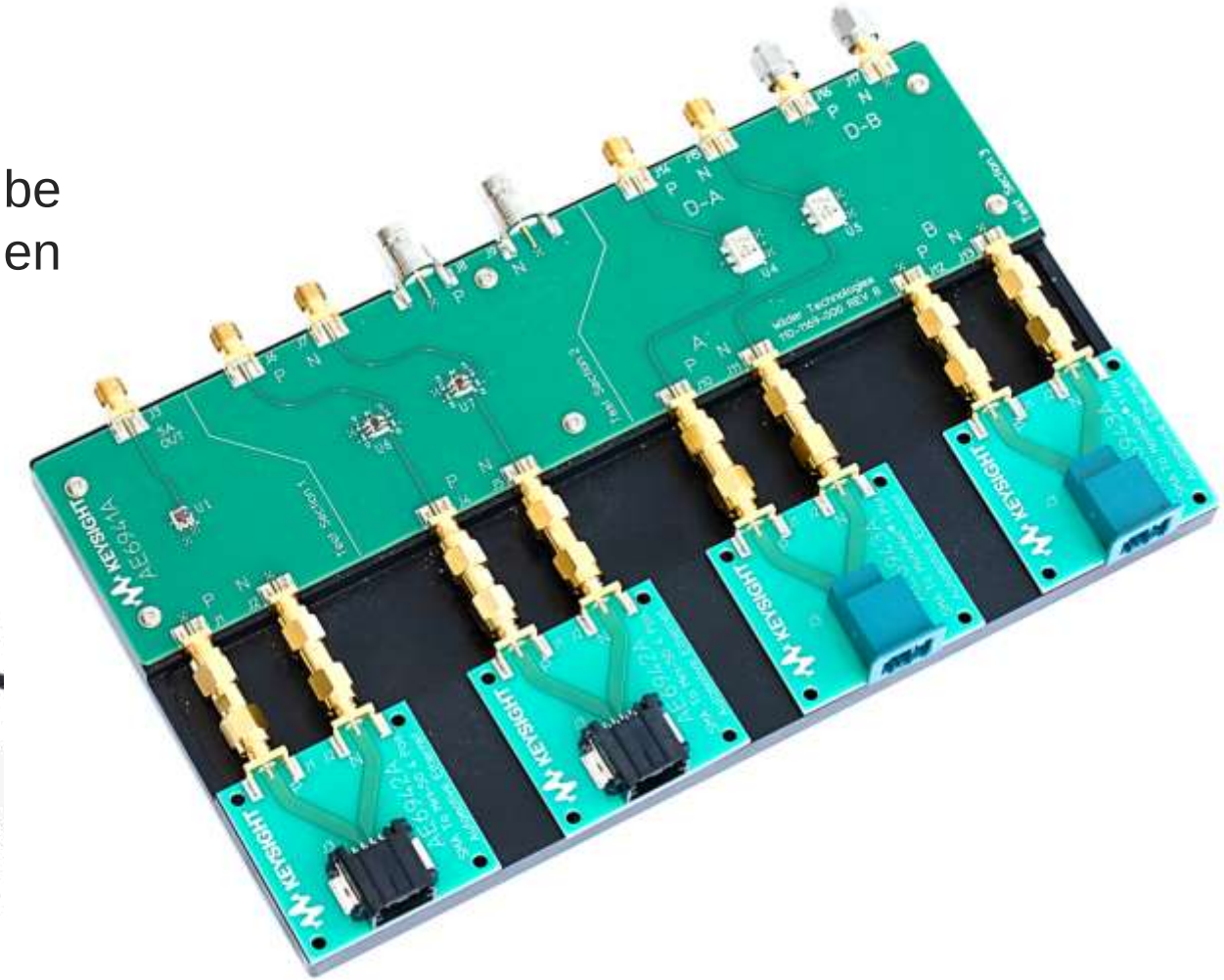
- Receiver cases verify the BER requirement in several test environments
  - Multiple channel lengths
  - Receiver frequency tolerance: link partner intentionally transmits at ±100 ppm
  - Alien crosstalk noise rejection: AWG noise is coupled into the channel



Implementations of Compliance Test Setups

PMA TEST FIXTURES

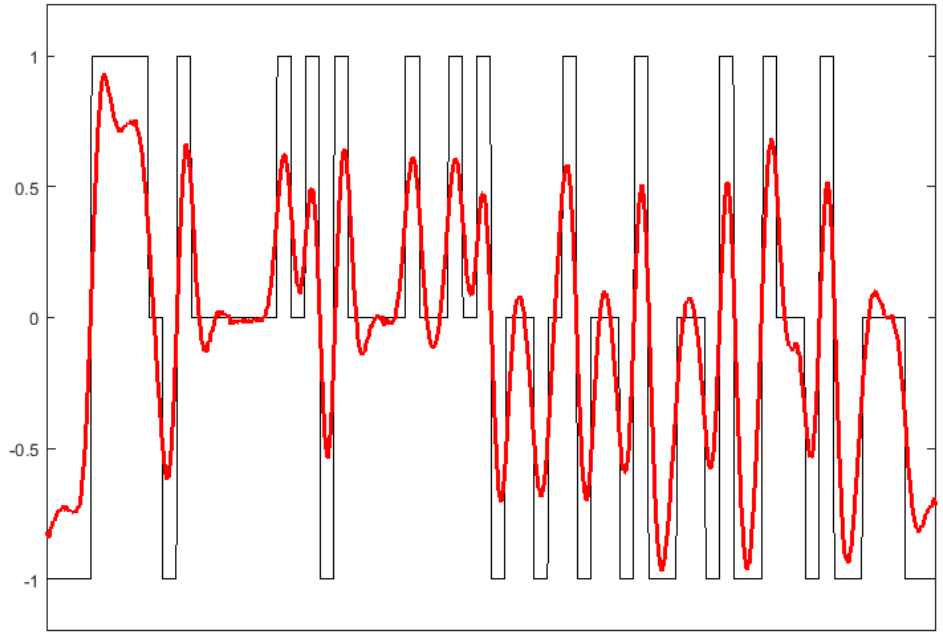
‘Test fixtures’ are presented in the IEEE specifications as test setup diagrams that can be used to measure the test mode waveforms when performing conformance testing



Implementations of Compliance Test Setups

100BASE-T1/1000BASE-T1 PMA TRANSMITTER DISTORTION

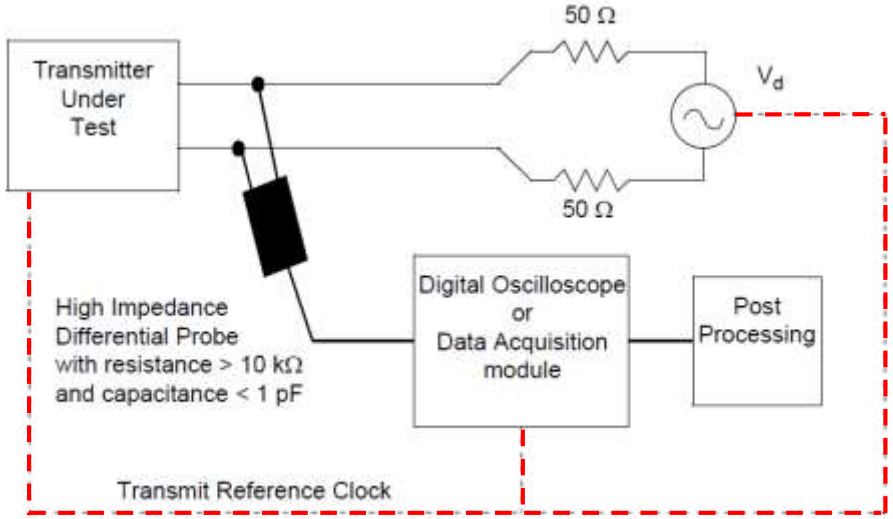
- PHY transmits ‘test mode 4’ (pseudo-random pattern 2047 symbols in length) while receiving a ‘disturber signal’ (sine wave of 1/6th the PHY transmit clock frequency)
- A probe is then used to measured the summed signals
- IEEE provided MATLAB® script is used to process waveform and calculate distortion values



Implementations of Compliance Test Setups

100BASE-T1/1000BASE-T1 PMA TRANSMITTER DISTORTION

- However, the Distortion test case is very sensitive to phase differences between the 3 independent clock domains
  - Oscilloscope acquisition clock, PHY transmit clock, disturber sampling clock
- It is heavily recommended to have all three share a single reference clock to minimize error introduced by phase offsets



Test Fixture 2 (from IEEE 802.3bw-2015 specification)

Implementations of Compliance Test Setups

100BASE-T1/1000BASE-T1 PMA TRANSMITTER DISTORTION

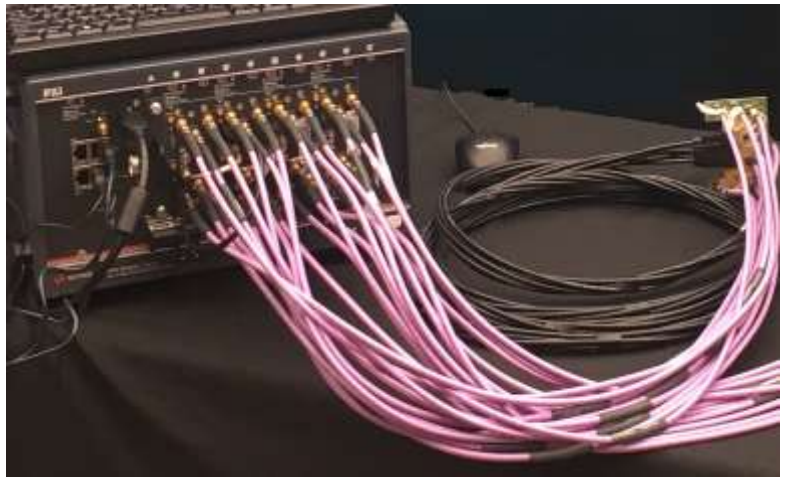
- To achieve this, the preferred approach is use the TX_TCLK (66.66MHz or 125Mhz) clock output of the PHY to generate a 10MHz reference clock for the T&M equipment
- Several T&M vendors have such a ‘frequency divider’ fixture

- However, the TX_TCLK is only necessary for conformance testing and has no value to the end user. For this reason, silicon vendors typically do not break out this signal

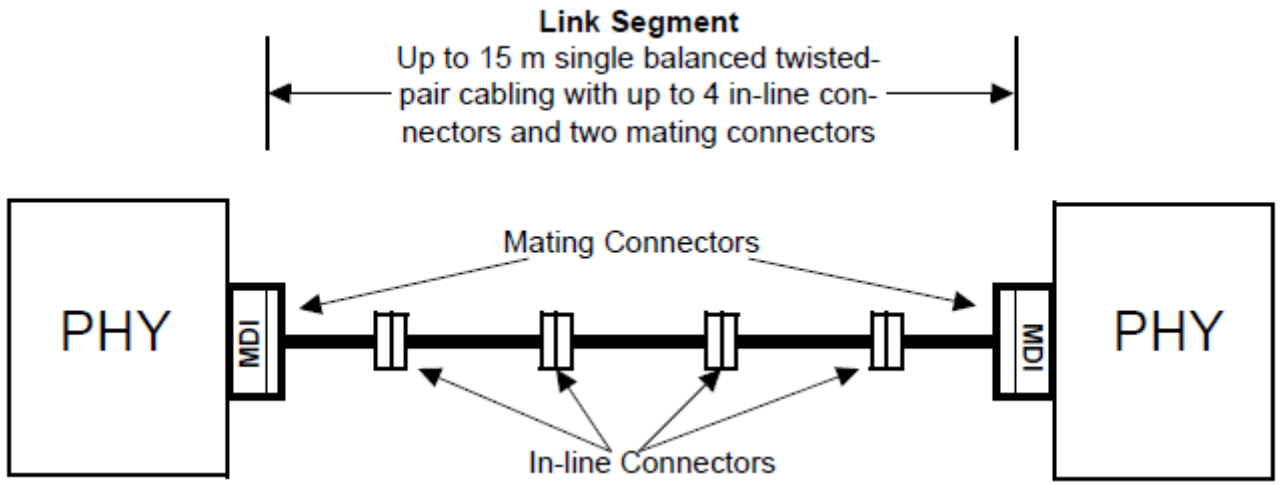
What Makes Up a Link/Channel Test?

CABLES/CONNECTORS/FIXTURES

- Cabling
  - Up to a 15 meter single balanced unshielded cable
- Connectors
  - Up to 4 inline connectors
  - 2 mating interfaces to the PHY known as Media Dependent Interface (MDI)
- Fixturing
  - Bulk Cable fixture
  - MDI Specific fixture



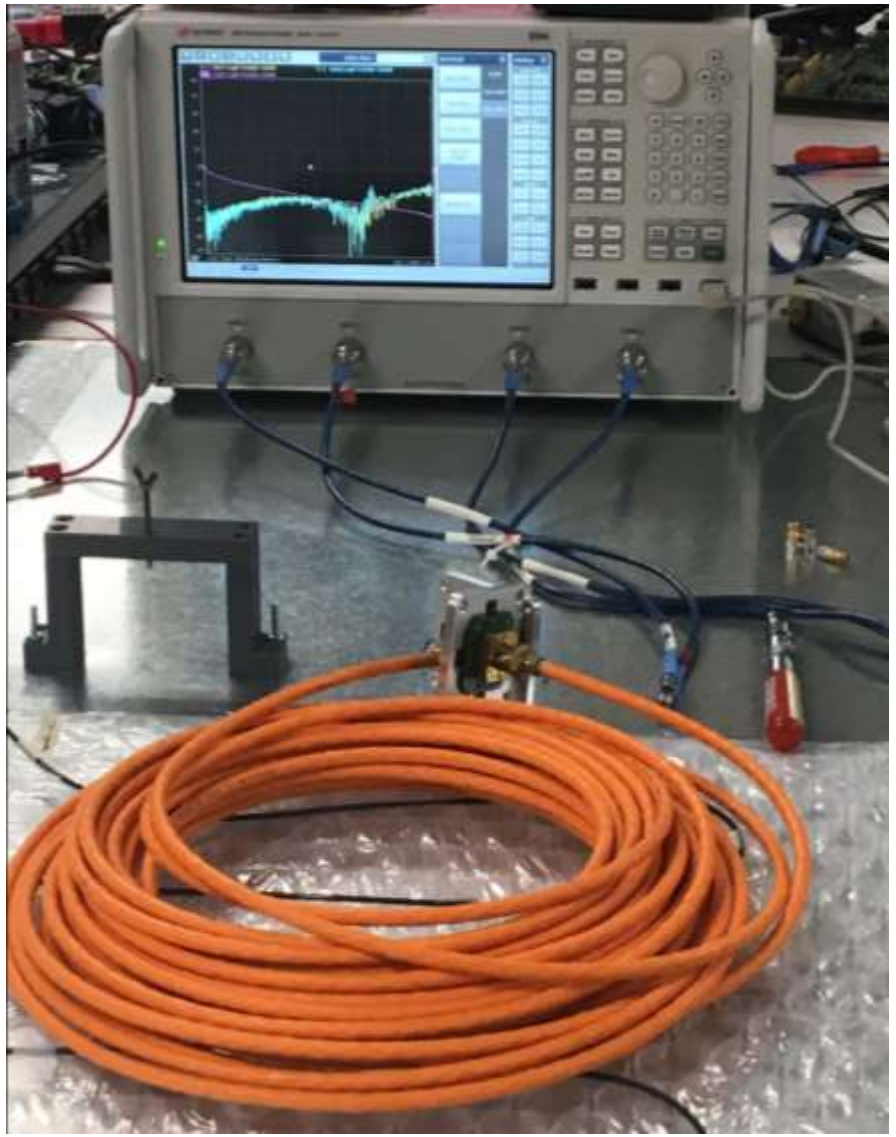
Channel Visualization



- Link Segment = Cabling + Inline Connectors + Mating Connectors
- No real standard for MDI connectors geometry – specific to connector vendors

Measurement Setup

- VNA
  - For frequency domain < 1 GHz is suitable
  - For time domain characterization at least a 9 GHz version is recommended for equivalent rise time requirements
- Calibration Kit
  - Should match or exceed frequency range of VNA and match connectors on test fixture
- High Quality Test Cables (phase stable preferable)
  - Should mate directly with connectors on test fixture
- Fixturing
  - Bulk cable fixture
  - MDI fixture
  - Ground plane

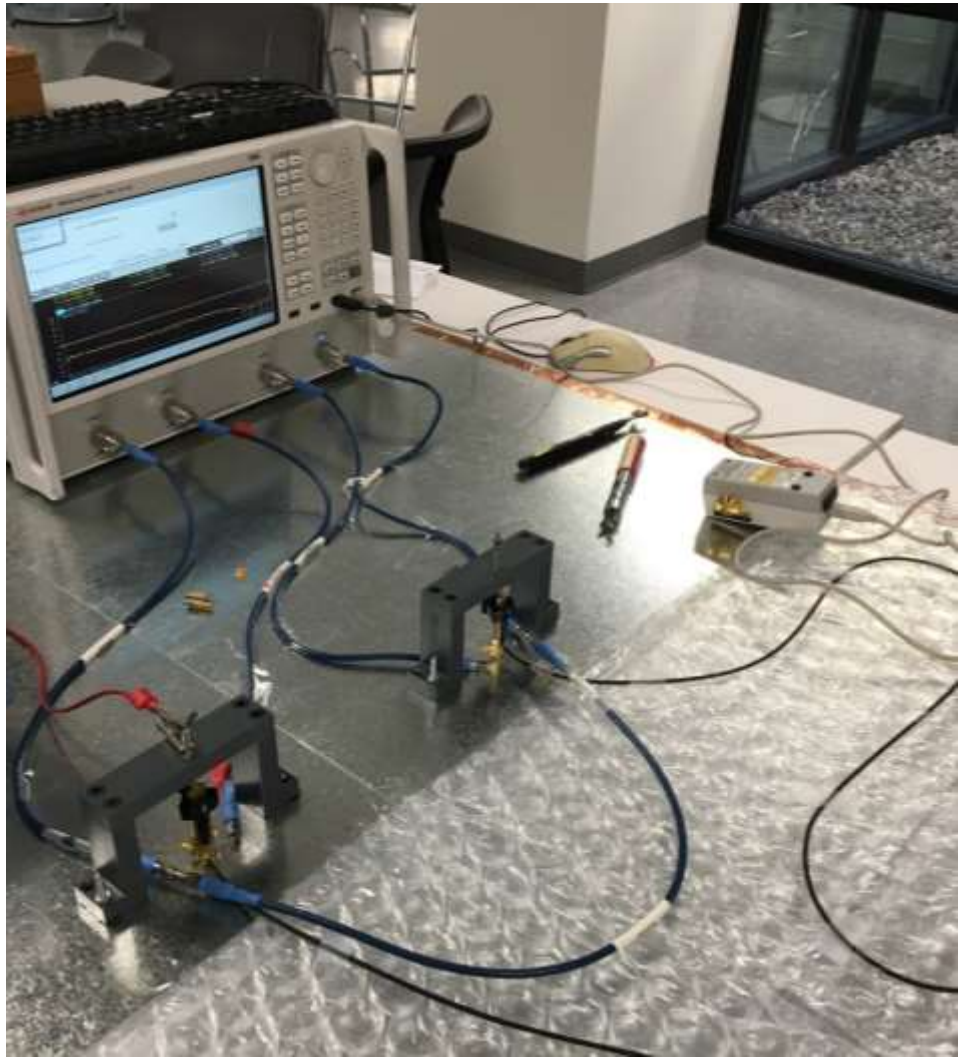


Example MDI Connectorized Test Setup
Photo courtesy of Chris Diminico

Link Measurements

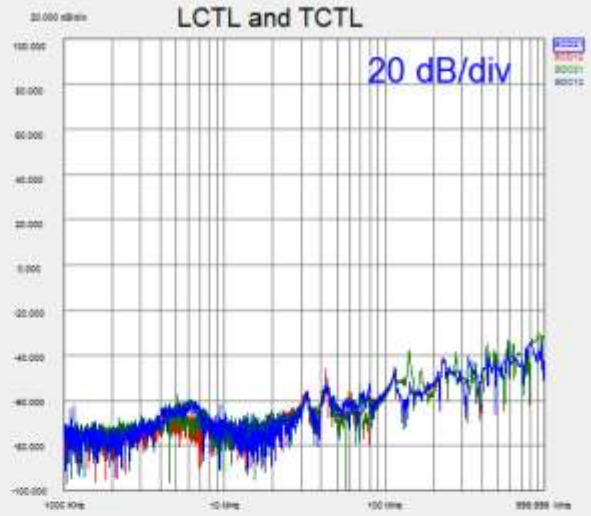
- Link Segment
  - Characteristic Impedance (Zo) = Tdd11 and Tdd22
  - Insertion Loss (IL) = Sdd21 and Sdd12
  - Return Loss (RL) = Sdd11 and Sdd22
  - Longitudinal Conversion Loss (LCL) = Sdc11 and Sdc22
    - Alternate, Transverse Conversion Loss (TCL) = Scd11 and Scd22
  - Longitudinal Transmission Conversion Loss = Sdc21 & Sdc12
    - Alternate, Transverse Trans. Conversion Loss (TCTL) = Scd21 and Scd12
- MDI Connector specific
  - Return Loss (RL) = Sdd11 and Sdd22
  - Longitudinal Conversion Loss (LCL) = Sdc11 and Sdc22
    - Alternate, Transverse Conversion Loss (TCL) = Scd11 and Scd22

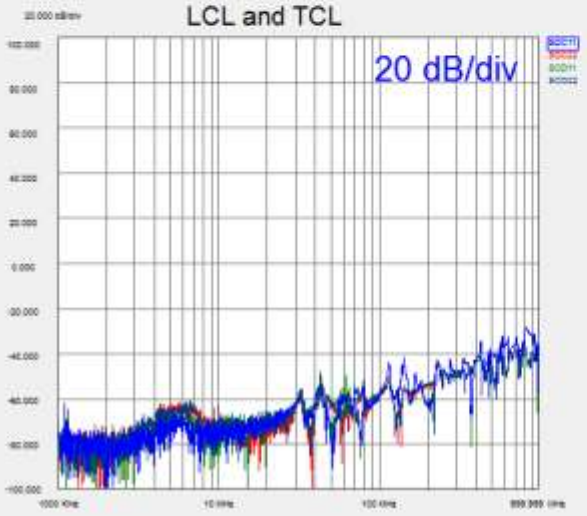
*Consistency for S-parameter definitions need to be followed



Example Bulk Cable Test Setup
Photo courtesy of Chris Diminico

Link Measurements Visualized





Bundle Measurements

CROSSTALK

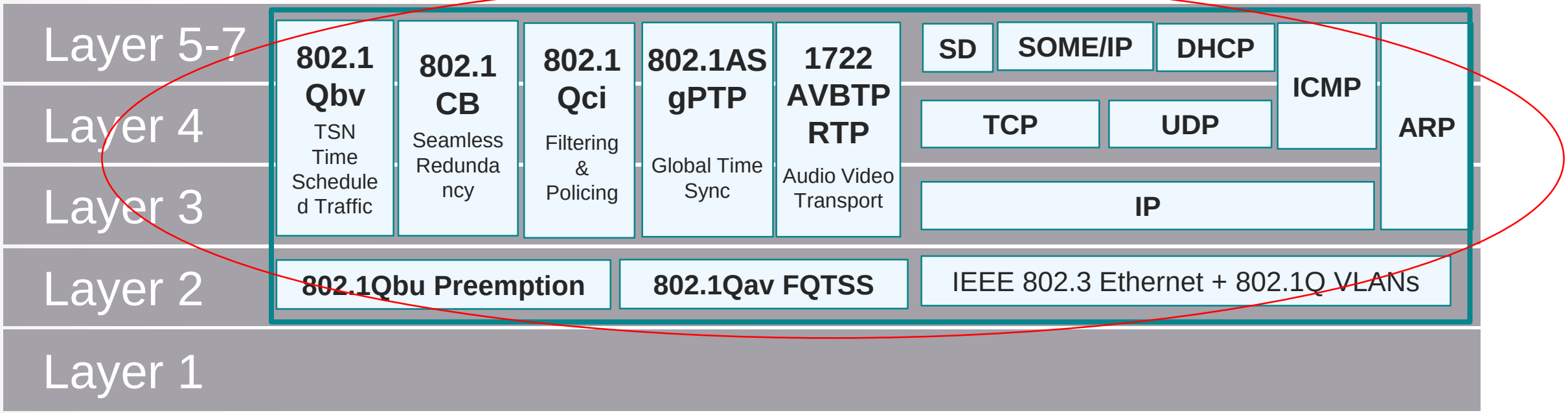
- Additional measurements are made when up to 5 cables are bundled together
- These are more traditional Ethernet measurements for crosstalk
- Measurements
  - Power Sum Alien Near End Crosstalk (PSANEXT)
  - Power Sum Alien Attenuation to Crosstalk Ratio Far End (PSAACRF)

Measurement Challenges

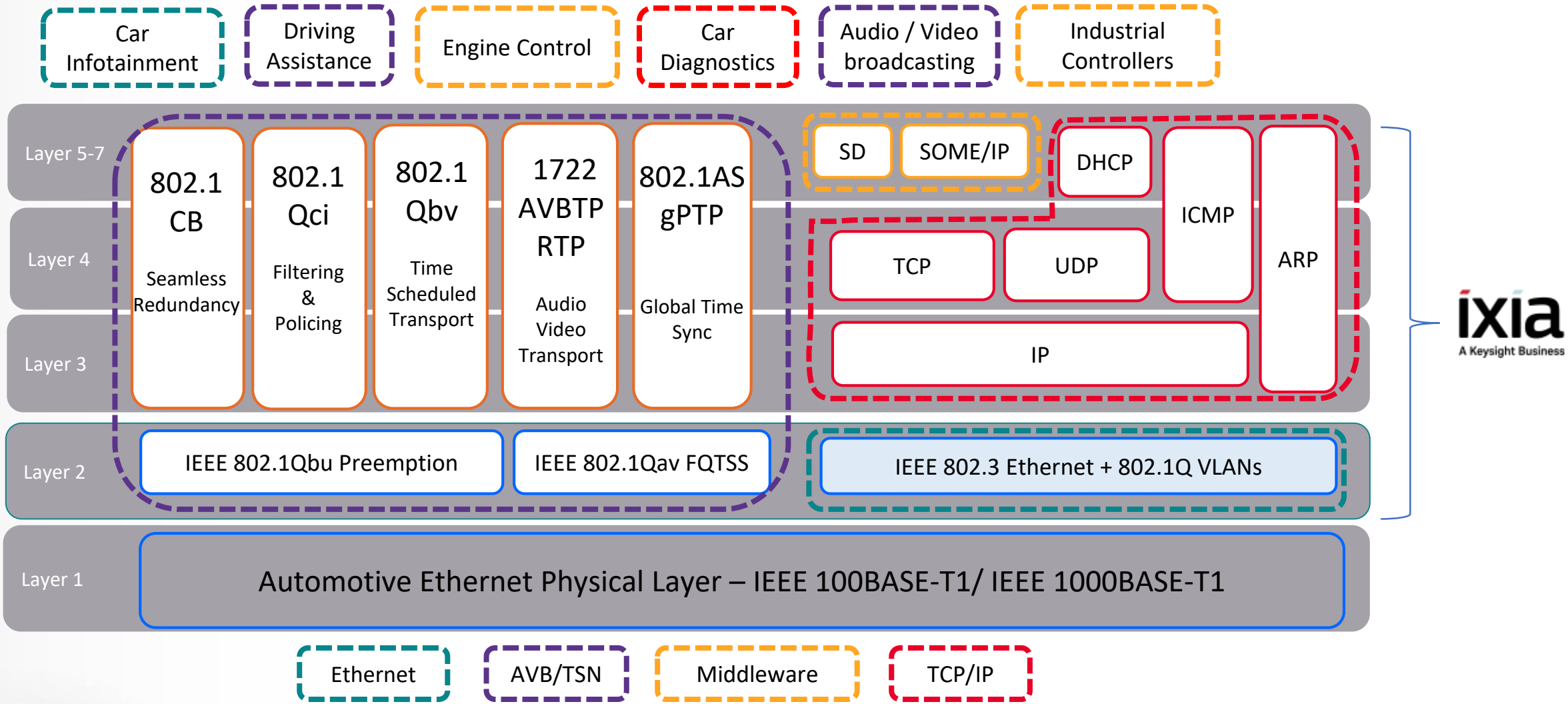
- For bulk cable without a MDI connector, care needs to be made when soldering the cable to the test fixture and when trimming the cable
- Fixture balance is an important performance characteristic
- Keeping the test cables stable for mode conversion measurements
  - It may be necessary to tape down the test port cables
  - Modifying calibration steps for thru paths to make it where cable movement is kept to a minimum
  - Using alternate calibration techniques that allow for the use of additional transmission line between the reference planes

Automotive Ethernet Test Challenges

AVB/TSN TESTING

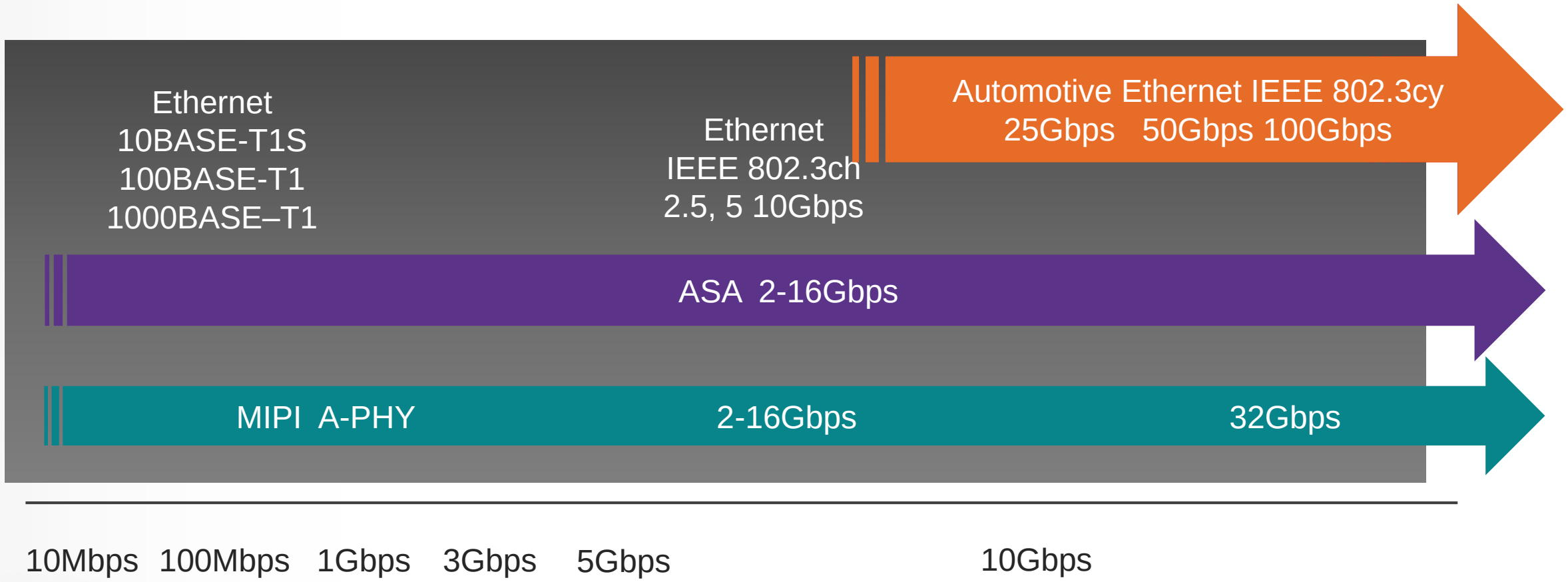


Automotive ethernet protocol stack



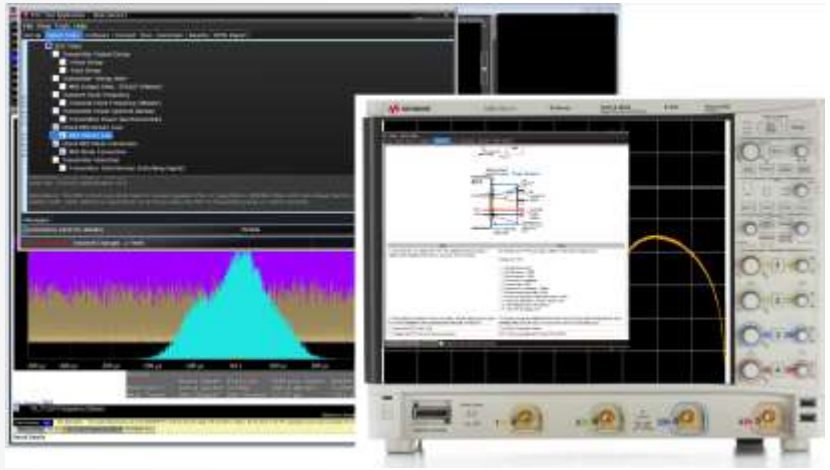
Future In-Vehicle Networking

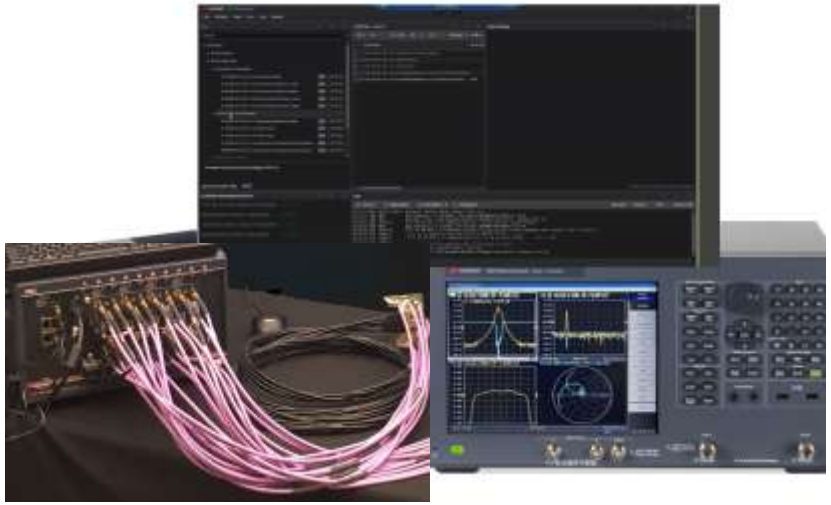
AUTOMOTIVE



Keysight Automotive Ethernet Solutions

PHYSICAL LAYER TEST COVERAGE





Transmit

- Complete 1000BASE-T1 & 100BASE-T1 compliance
- Protocol trigger & decode

Link Segment

- 100% test coverage for harness & connector
- Guided test setup and pass/fail report with margin analysis

Receiver

- Bit Error Rate verification
- SQI – Signal Quality
- Alien Crosstalk

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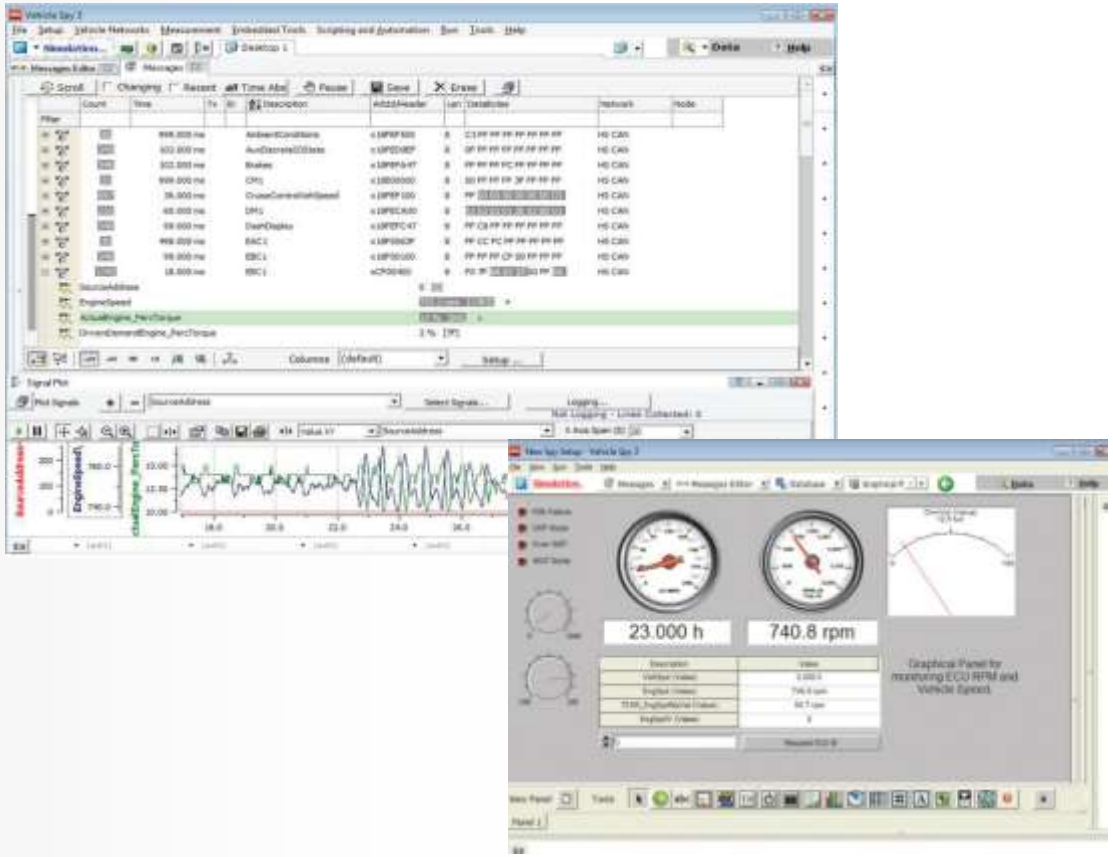
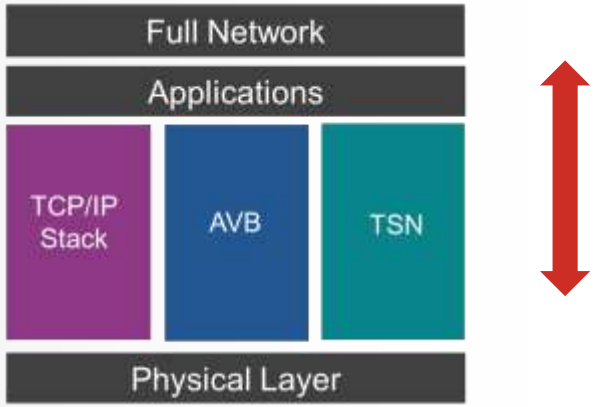
PROTOCOL ANALYZER AND LOGGING



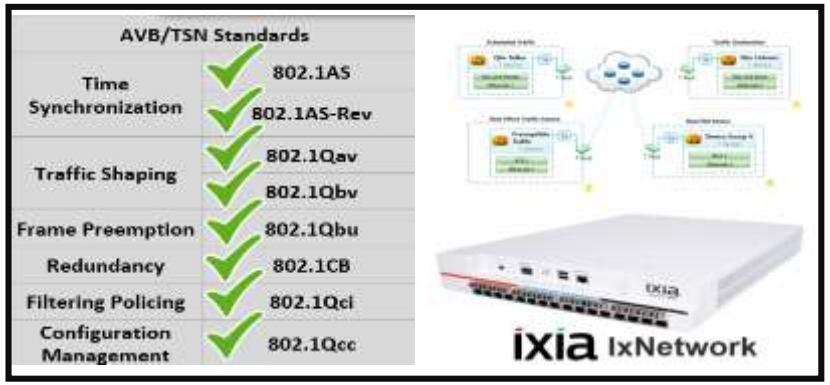
Media converters and taps

Automotive Ethernet

END-TO-END TSN VALIDATION SOLUTION



- **OPEN ALLIANCE TC8, TC11**
- **AVNU ALLIANCE**
- **AUTOSAR**



Layer 1 – 7 Coverage

- Only vendor for validation solution spanning across layer 1 to layer 7
- Solution for functionality, conformance and performance validation

Time Tested Conformance

- More than 1300 test cases for TCP/IP stack
- Test cases matured over last 20 years of use by NEMs.
- Conformance package for Avnu automotive profile

Powerful Test Platform

- AVB / TSN Protocol emulation at scale
- Realistic data traffic for car workload
- Extensive statistics for identifying and debugging failures

UNH-IOL Compliance and Interoperability Testing

AUTOMOTIVE ETHERNET TEST TOOLS AND SERVICES

UNH-IOL BitPhyer System

- **Ethernet Protocol Compliance**

Current Automotive Packages

- OPEN Alliance TC1
  - 100BASE-T1 PCS & PHY Control
- OPEN Alliance TC10
  - 100BASE-T1 Wake/Sleep

UNH-IOL QualiPhyer GUI

- **Software packaged used for test automation of PHY electrical conformance**
- **Supports test equipment from any T&M vendor**

Current Automotive Packages

- OPEN Alliance TC1
  - 100BASE-T1 PMA
- OPEN Alliance TC12
  - 1000BASE-T1 PMA

UNH-IOL Testing Services

Automotive PHY Services

- OPEN Alliance TC1
  - 100BASE-T1 PMA
  - 100BASE-T1 PCS & PHY Control
- OPEN Alliance TC10
  - 100BASE-T1 Wake/Sleep
- OPEN Alliance TC12
  - 1000BASE-T1 PMA

Additional Automotive Services

- MAC (Layer 4)
- Preemption
- Time Sensitive Networking (TSN)
- Point-to-Point Interoperability
- Cable Testing


KEYSIGHT
WORLD 2020