Tektronix

Automotive Multigigabit Ethernet (IEEE802.3ch) - Compliance Test

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MIPI Test WG Chair

Agenda

- Automotive Ethernet overview
- Automotive Ethernet test requirement as per IEEE and Open Alliance
- New measurement requirement for Multigigabit Ethernet
- Test challenges to measure linearity, jitter measurements
- Demo of multigigabit Ethernet compliance
- System level test for automotive Ethernet
- Demo of protocol decode with non-intrusive approach of signal separation for 100BASE-T1

Automotive Trends

Motivation

Challenges

Safety

Sensors, Display,
Complex Architecture

Green Energy

Battery, Range, Cost,
Power Electronics,

Connected

Wireless Standard,
Cloud, Connectivity

3.5 years

Service

Fewer Resource, Tighter Timeline

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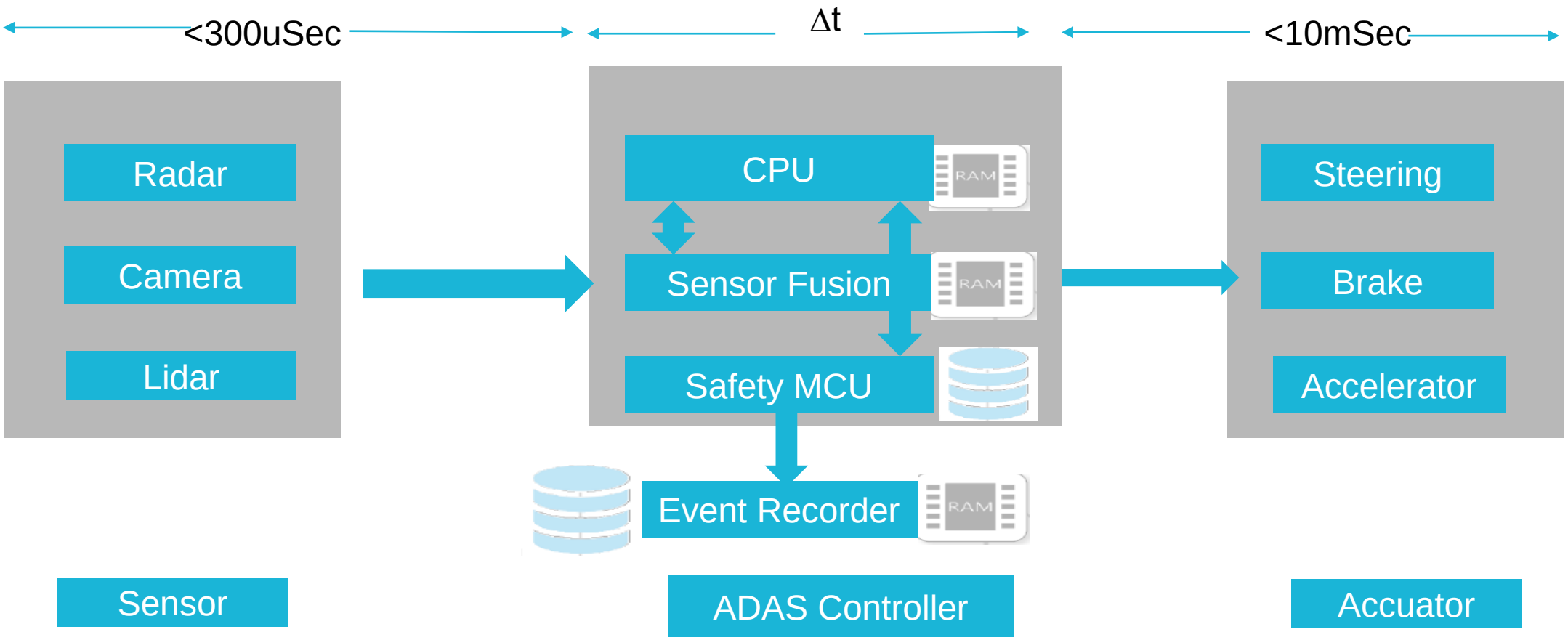
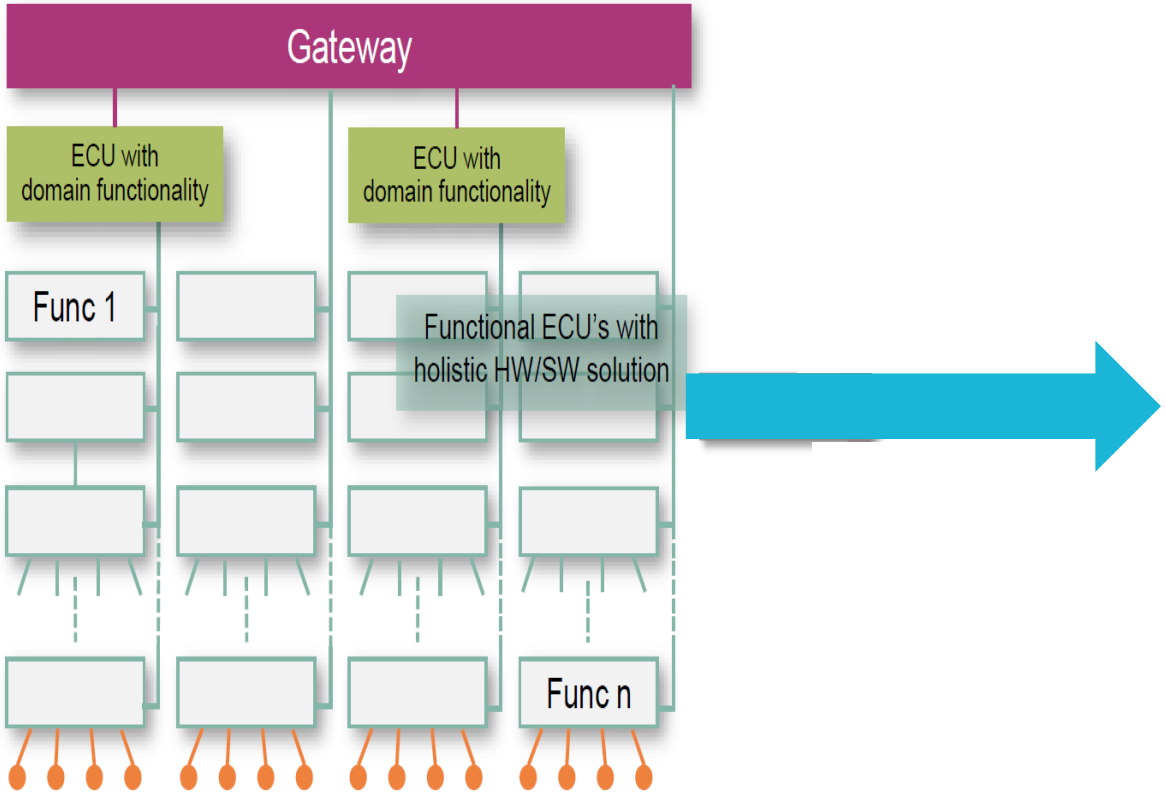
1 Autonomous Car

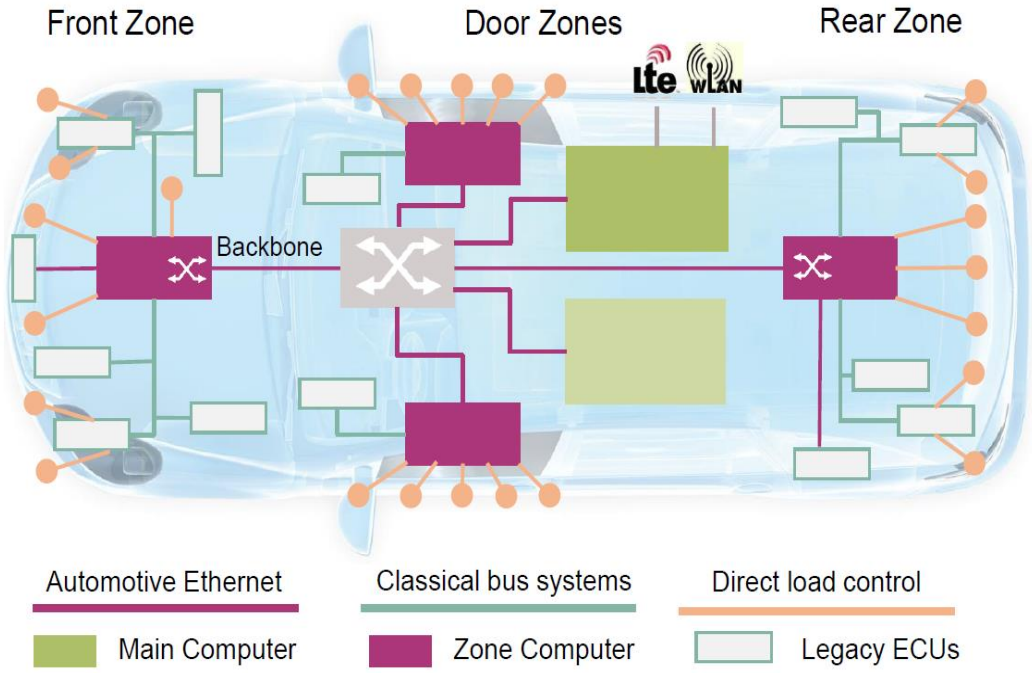


New Sensors, Faster In-Vehicle Network Standards to Transfer Data

2 Architecture



Traditional

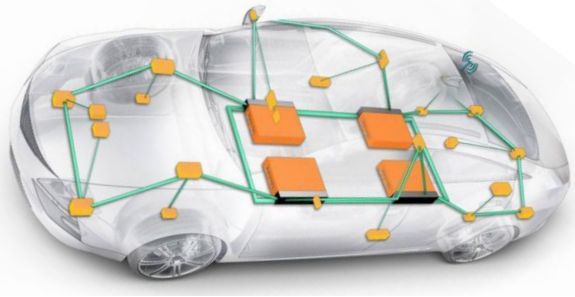


Zone Architecture

New Architecture to Meet Latency Requirement

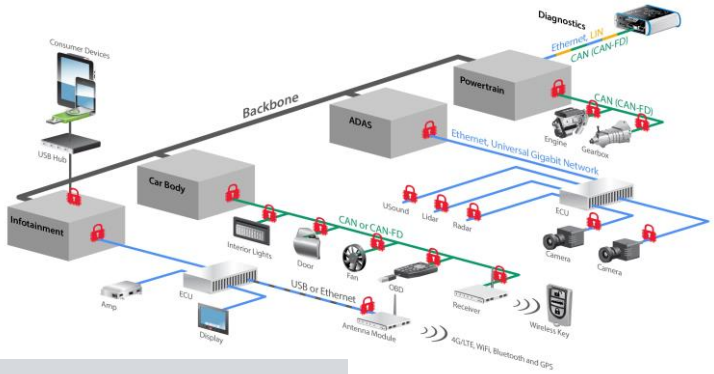
In-Vehicle Network Standards

IVN Requirement



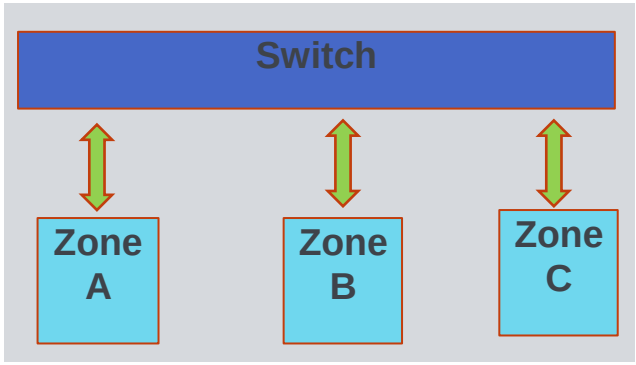
What is IVN?

- Electronics inside the car communicate with each other over In-Vehicle-Network.
- CAN, CAN-FD, LIN, FlexRay, PSI5, CXPI etc.



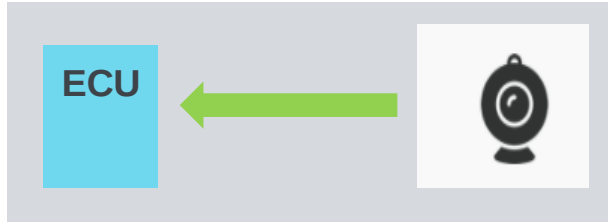
IVN basic requirements:

- Reliable data transfer at Automotive harsh environment like Noise and Temperature
- EMI/EMC
- Low weight, low cost, low power



New Requirements:

- Faster In-Vehicle Network standards for newer applications
- Symmetric and Asymmetric communication



In-Vehicle Network Technologies

High Speed IVN (>10Mbps)

Symmetric IVN standards for ECU-to-ECU communication

- 100BASE-T1, 1000BASE-T1
- Multigigabit Ethernet (10G)
- 25G/50G Automotive Ethernet

Asymmetric IVN standards for Display/Camera

- Multigigabit Ethernet (Half-duplex version)
- MIPI A-PHY (upto 16G)
- ASA (upto 16G)
- HDBaseT
- FPD-Link, GMSL, GVIF, Apix

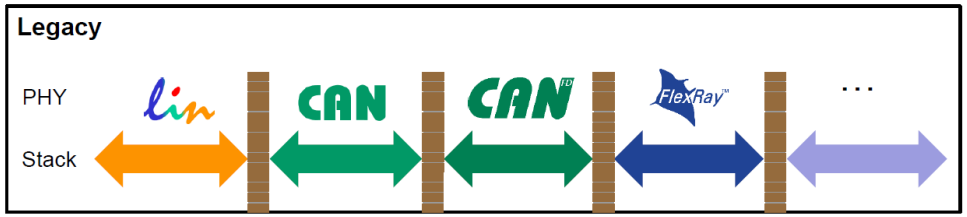
Low speed IVN (<10Mbps)

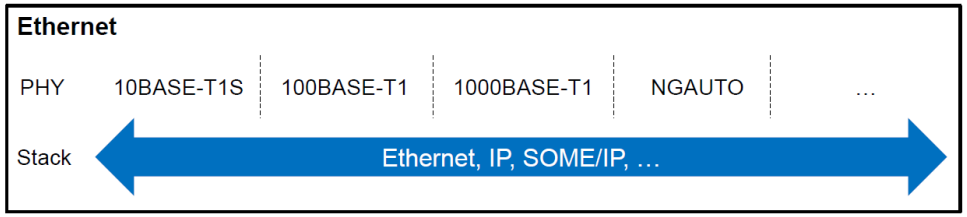
- 10BASE-T1S
- CAN-XL
- Others: CAN-FD, LIN, PSI5

Tektronix is an active contributor in IEEE, Open Alliance, MIPI and ASA standard bodies

Automotive Ethernet Overview

- **Standards:**
  - 10BASE-T1S (802.3cg) – 10Mbps
  - 100BASE-T1 (802.3bw) – 100Mbps
  - 1000BASE-T1 (802.3bp) - 1000Mbps
  - Multigigabit Ethernet (802.3ch) – 10Gbps
  - 25G/50G Automotive Ethernet (802.3cy*)
  - Multigigabit Optical Automotive Ethernet (802.3cz*)
- **Why Automotive Ethernet?**
  - Derived from proven Ethernet standards
  - Offers Common Architecture with multiple speed option
  - Cost: Unshielded cable, Full-duplex cable reduces cost by 80% and cable weight up to 30%
- **What is the difference between Ethernet and Auto Ethernet?**
  - Single pair of cable
  - Full-Duplex communication
  - PAM3/4 modulation





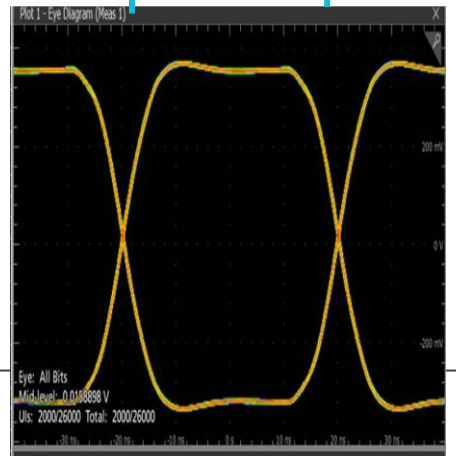
OSI	Automotive Ethernet
7 Application	Applications (HTTP, FTP, SMTP..)
6 Presentation	
5 Session	
4 Transport	TCP
3 Network	IP
2 Data Link	Network Access
1 Physical	10/100/1000/NGBASE-T1

* Under development

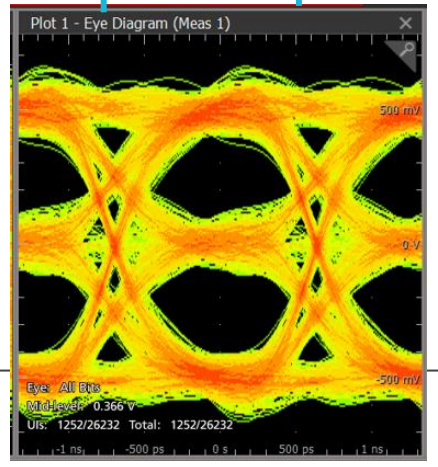
Automotive Ethernet- 10Mbps to 10Gbps

	10BASE-T1S	100BASE-T1	1000BASE-T1	Multigigabit
Datarate	10Mbps	100Mbps	1Gbps	2.5/5/10Gbps
Symbol rate	12.5MHz	66.66MHz	750MHz	1.4/2.8/5.6 GHz
Line coding	4B/5B, DME	PAM3	PAM3	PAM4
Voltage	1Vpp	2.2Vpp	1.3Vpp	1.3Vpp
Communication	Half Duplex	Full Duplex	Full Duplex	Full Duplex
Configuration	Point to Point Multidrop	Point to Point	Point to Point	Point to Point
Cable length	15m/25m	15m	15m	15m
Cable Type	24-26 AWG	Unshielded twisted pair	Unshielded twisted pair	Shielded twisted pair

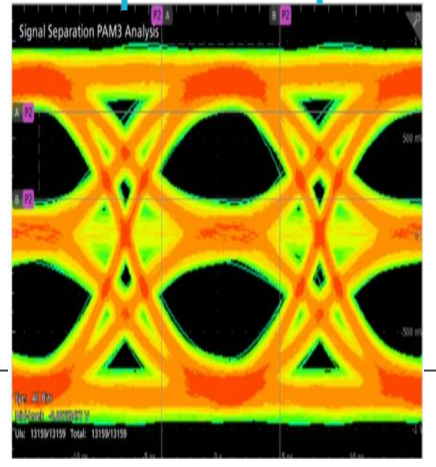
40ns



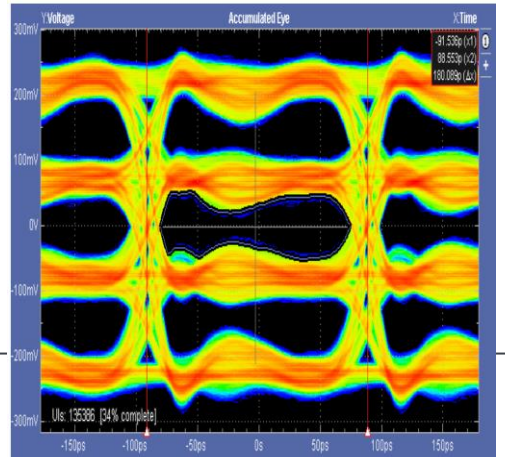
15ns



1.33ns



0.714/0.357/0.179ns



Automotive Ethernet Test Requirements

PHY layer test Requirement

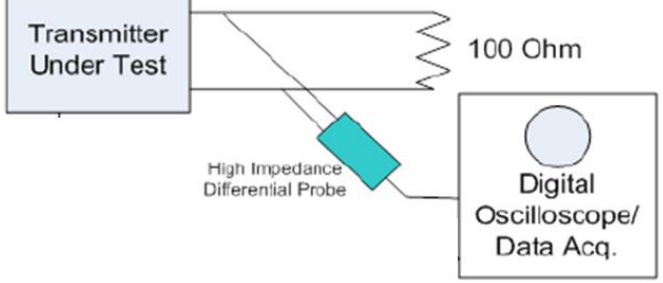
- PMA Compliance Test as per IEEE/Open Alliance
- System Level Noise Test
- Protocol Timing Measurement

Automotive Ethernet Compliance

100BASE-T1	1000BASE-T1	10BASE-T1S	MultiGBASE-T1
PHY and Protocol IEEE 802.3bw	PHY and Protocol IEEE 802.3bp	PHY and Protocol IEEE 802.3cg	PHY and Protocol IEEE 802.3ch
Open Alliance TC1	Open Alliance TC12	Open Alliance: TC14 In Progress	Open Alliance: TC15 In Progress

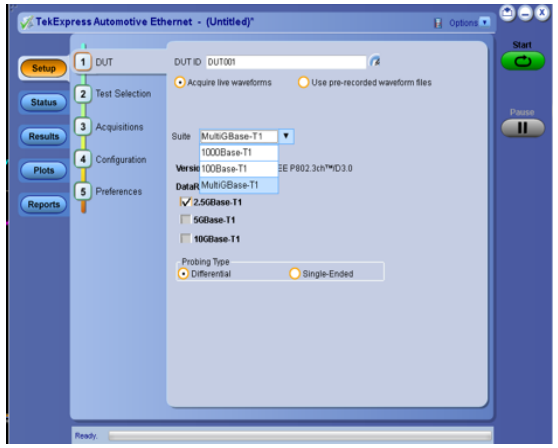
TC8 ECU Specification

Automotive Ethernet PMA Test Specification



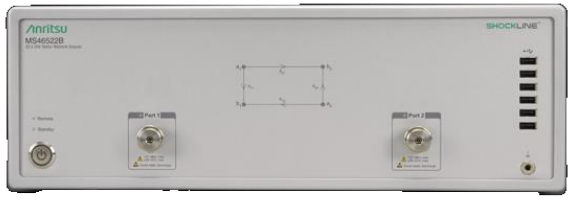
Test Name	Details/ Subtest	10BASE-T1S	100BASE-T1	1000BASE-T1	MultiGBASE-T1
Transmitter Output Droop	1) Positive Droop 2) Negative Droop	✓	✓	✓	✓
Transmitter Distortion			✓	✓	
Transmitter Linearity					✓
Transmitter Timing Jitter in Master/Slave Mode	1) RMS/p2p MASTER Tx CLK 2) RMS/p2p SLAVE Tx CLK	✓	✓	✓	✓
Transmitter MDI Jitter		✓	✓	✓	
Tx MDI Random Jitter (Master)	1) RMS/p2p MDI Jitter				✓
Tx MDI Deterministic Jitter (Master)	1) pk-pk DJ 2) pk-pk EOJ				✓
Transmitter Power Spectral Density	PSD, Power Level	✓	✓	✓	✓
Transmit Clock Frequency		✓	✓	✓	✓
Transmitter Peak differential output		✓	✓	✓	✓
MDI return Loss		✓	✓	✓	✓
MDI Mode conversion			✓	✓	
Common Mode emission			✓		

Compliance Test Workbench



TekExpress
Automated
Compliance Test

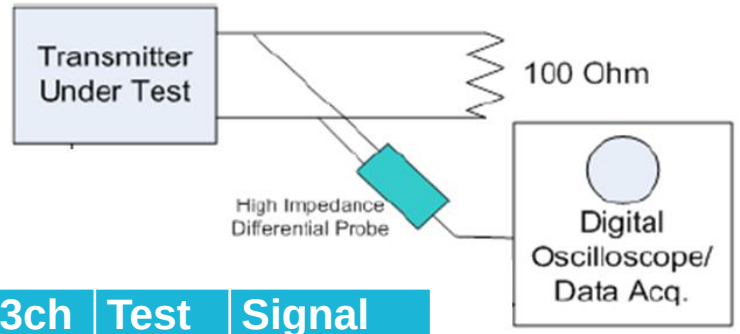
DPO70K DX/SX, MSO 6B series



Anritsu VNA

Multigigabit Ethernet Compliance Test

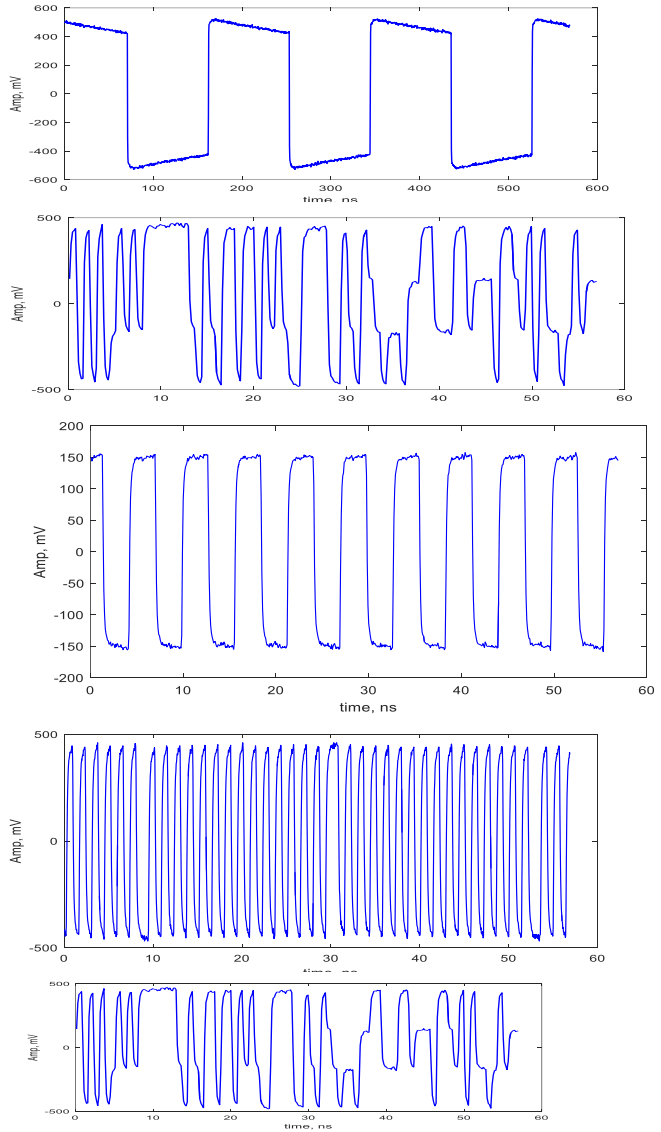
MultiGBASE-T1 PMA Test Specification



Test Name	Details/ Subtest	IEEE 802.3ch Spec ID	Test Mode	Signal Type
Transmitter output Droop	1) positive droop 2) negative droop	149.5.2.1	6	Square
Transmitter Linearity		149.5.2.2	4	PAM4
Transmitter Timing Jitter in Master/Slave Mode	1) RMS/p2p MASTER Tx CLK 2) RMS/p2p SLAVE Tx CLK	149.5.2.3	1	Clock
Tx MDI Random Jitter (Master)	1) RMS/p2p MDI Jitter	149.5.2.3.1	2	Square
Tx MDI Deterministic Jitter (Master)	1) pk-pk DJ 2)pk-pk EOJ	149.5.2.3.2	2	JP03A JP03B
Transmitter Power Spectral Density (PSD)	PSD Power Level	149.5.2.4	5	PAM4
Transmit Clock Frequency		149.5.2.6	1	Clock
Transmitter Peak differential output		149.5.2.5	5	PAM4
MDI return Loss		149.8.2.1	Slave	

Test Mode: Details

TestMode	SignalType	Signal Rate
TM6	TWO_LEVEL	43.9453125 MHz
TM4	PAM4	1.40625 GHz (2.5GBASE-T1) 2.8125 GHz(5GBASE-T1) 5.625 GHz(10GBASE-T1)
TM1	DUT TX_TCLK_175 line	175.78125 MHz
TM2- Square Wave	CLK	175.78125 MHz
TM2 - JP03A(DJ) TM2 - JP03B(EOJ)	PAM4 - 2 symbols	1.40625 GHz (2.5GBASE-T1) 2.8125 GHz(5GBASE-T1) 5.625 GHz(10GBASE-T1)
TM5	PAM4	1.40625 GHz (2.5GBASE-T1) 2.8125 GHz(5GBASE-T1) 5.625 GHz(10GBASE-T1)



TM6

TM4

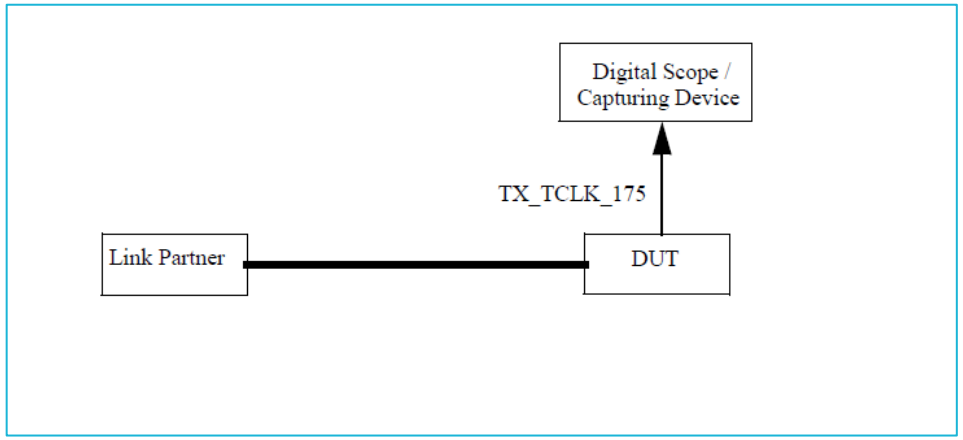
TX_TCLK_175

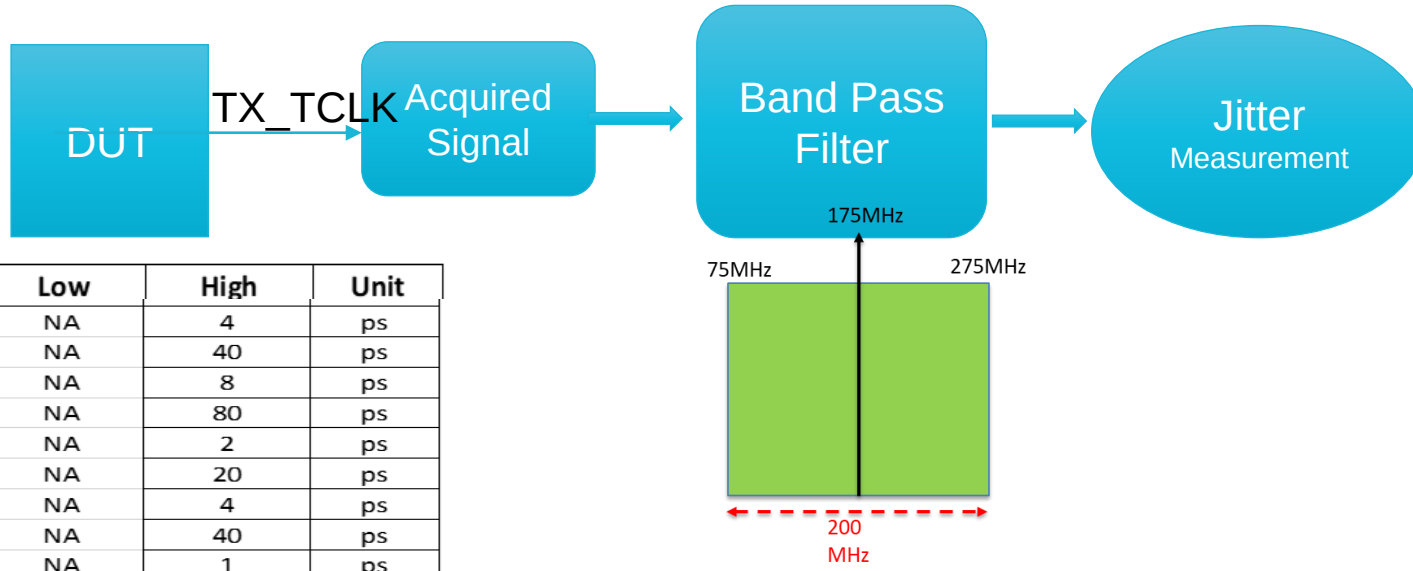
TM2 -JP03B

TM5

Transmitter Timing Jitter

- DUT set to Test Mode#1 and measure at DUT CLK line :TX_TCLK_175
  - 175.78125 MHz
- Spec recommends 200MHz Band Pass Filtering

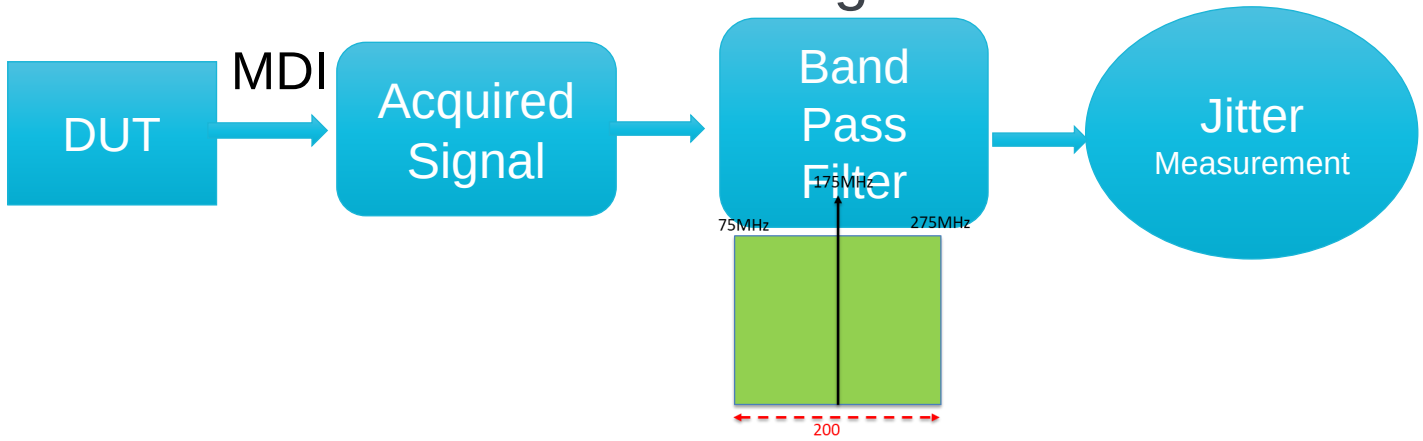




		Details/Sub tests	Low	High	Unit
Transmitter timing jitter	2.5GBASE-T1	1) RMS MASTER Tx CLK	NA	4	ps
		2) p2p MASTER Tx CLK	NA	40	ps
		3) RMS SLAVE Tx CLK	NA	8	ps
		4) p2p SLAVE Tx CLK	NA	80	ps
	5GBASE-T1	1) RMS MASTER Tx CLK	NA	2	ps
		2) p2p MASTER Tx CLK	NA	20	ps
		3) RMS SLAVE Tx CLK	NA	4	ps
		4) p2p SLAVE Tx CLK	NA	40	ps
	10GBASE-T1	1) RMS MASTER Tx CLK	NA	1	ps
		2) p2p MASTER Tx CLK	NA	10	ps
		3) RMS SLAVE Tx CLK	NA	2	ps
		4) p2p SLAVE Tx CLK	NA	20	ps

MDI Random Jitter

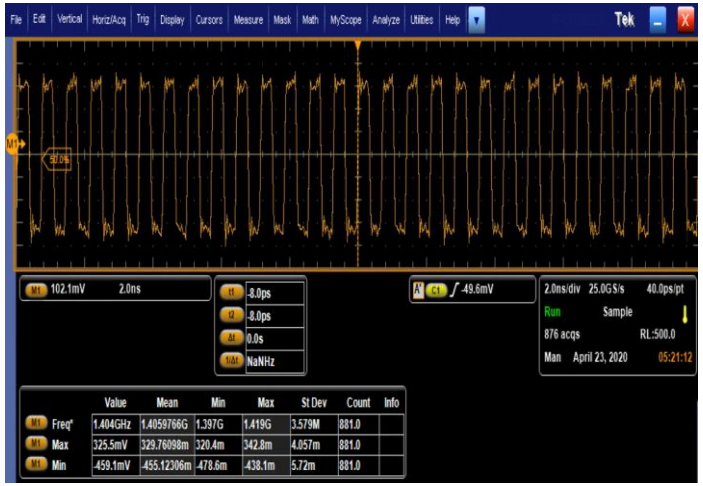
- DUT set to Test Mode#2 - Square Wave
- Test at MDI
- Spec recommends 200MHz Band Pass Filtering



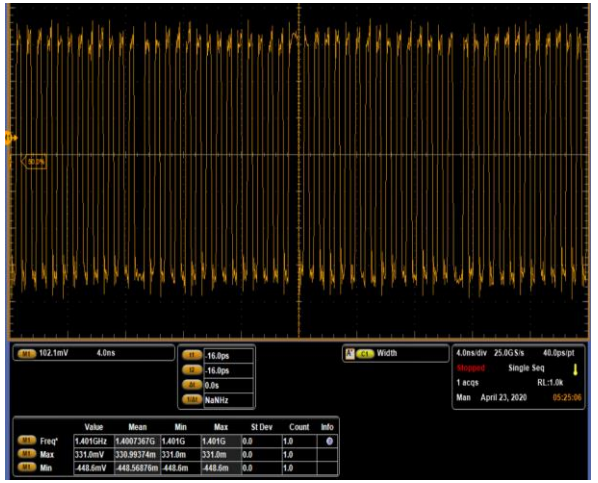
Transmit MDI random jitter in master mod	2.5GBASE-T1	1) RMS	NA	4	ps
		2) p2p	NA	40	ps
	5GBASE-T1	1) RMS	NA	2	ps
		2) p2p	NA	20	ps
	10GBASE-T1	1) RMS	NA	1	ps
		2) p2p	NA	10	ps

MDI Deterministic Jitter

- Transmitter MDI deterministic Jitter:
  - Test mode 2 with JP03A and JP03B pattern, Master mode
  - Dj: JP03A pattern: 9/S ps (pk-pk)
  - JP03B pattern: Even odd jitter: 4/S ps (pk-pk)
  - Measurement to be performed with a population of >=10^7 symbols
  - For 2.5GBASE-T1, this translates to 7.111 ms
  - Sample rate of 12.5Gsps, implies a waveform record of ~88 M samples



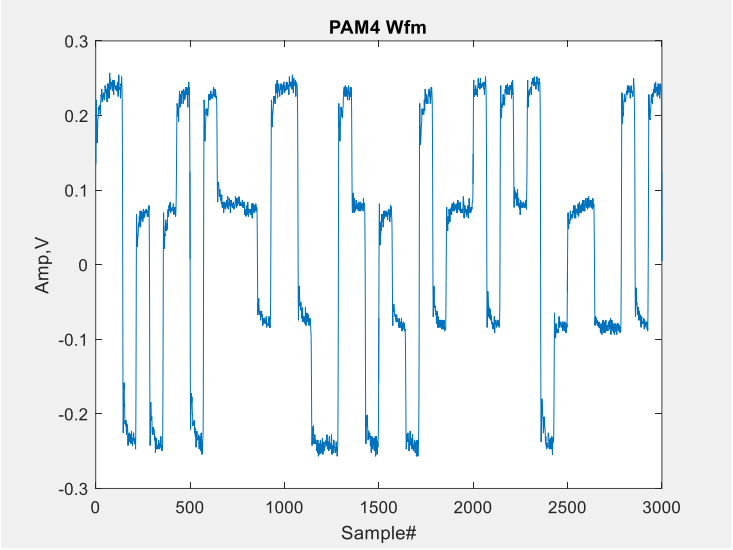
JP03A_5G



JP03B_5G

Transmit MDI deterministic jitter in master mode	2.5GBASE-T1	1) DJ pk-pk	NA	36	ps
		2) EOJ pk-pk	NA	16	ps
	5GBASE-T1	1) DJ pk-pk	NA	18	ps
		2) EOJ pk-pk	NA	8	ps
	10GBASE-T1	1) DJ pk-pk	NA	9	ps
		2) EOJ pk-pk	NA	4	ps

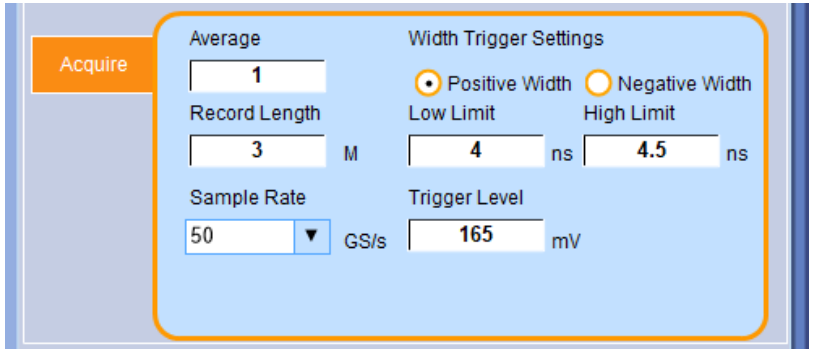
Transmitter Linearity



- Linear fit pulse response *p(k)* and linear fit error *e(k)*
  - σ_e Standard deviation of *e(k)*
  - p_{max} maximum value of *p(k)*

σ_n RMS deviation from the mean voltage

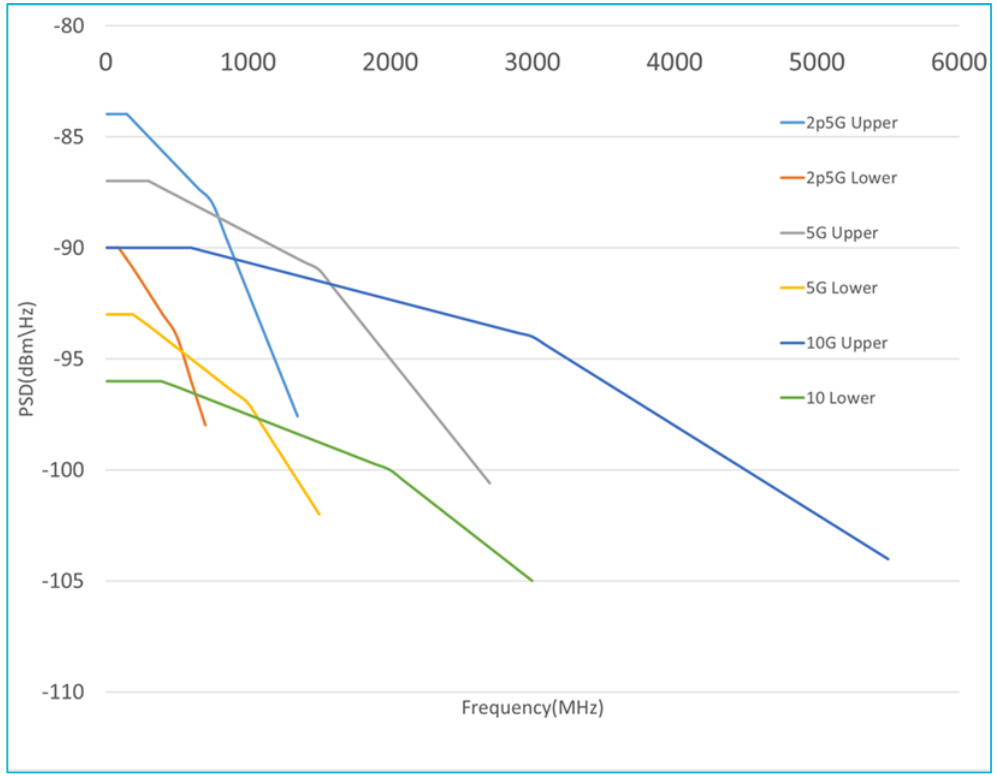
- SNDR is computed as defined below
  - $SNDR = 10Log10\left(\frac{p_{max}^2}{\sigma_e^2 + \sigma_n^2}\right)$
- Spec allows to average multiple waveform captures to remove instrument noise

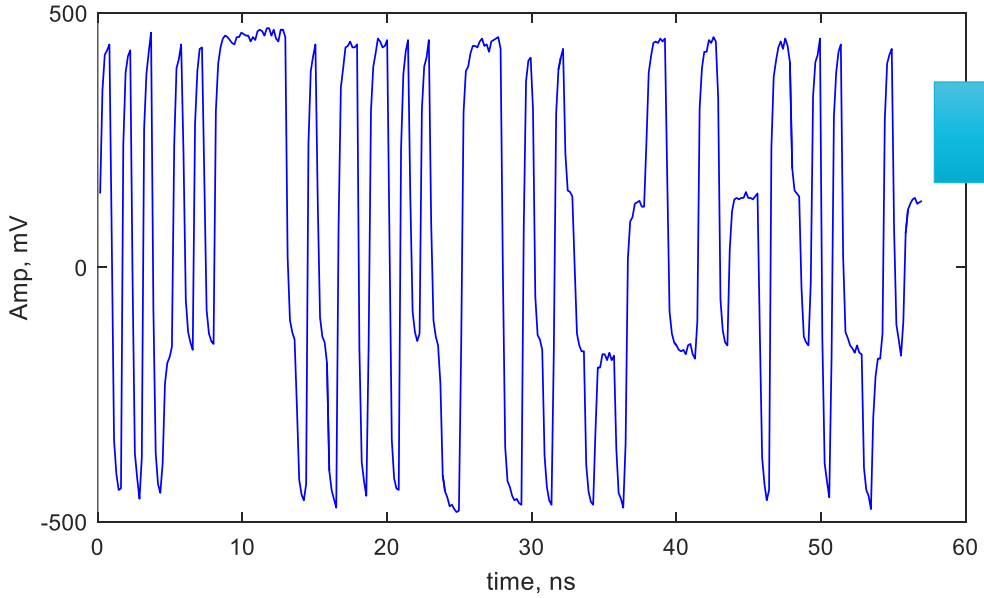


		Details/Sub tests	Low	High	Unit
Transmitter linearity	2.5GBASE-T1		38	NA	dB
	5GBASE-T1		36	NA	dB
	10GBASE-T1		35	NA	dB

Power Spectral Density

- Power Spectral Density
  - Configure Test Mode 5
  - Random sequence of PAM4 codes
  - Power level -1dBm to 2dBm



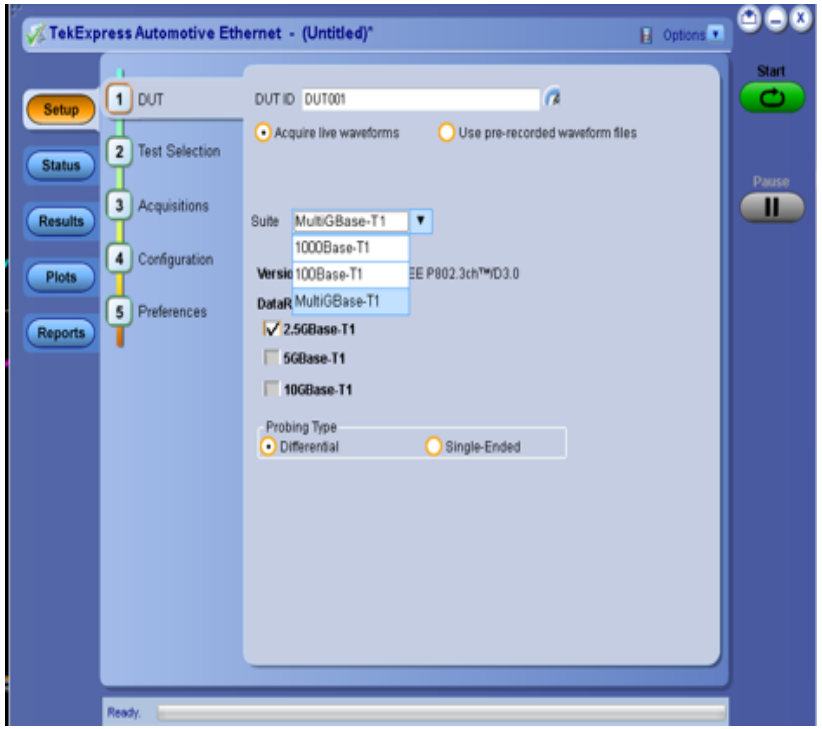


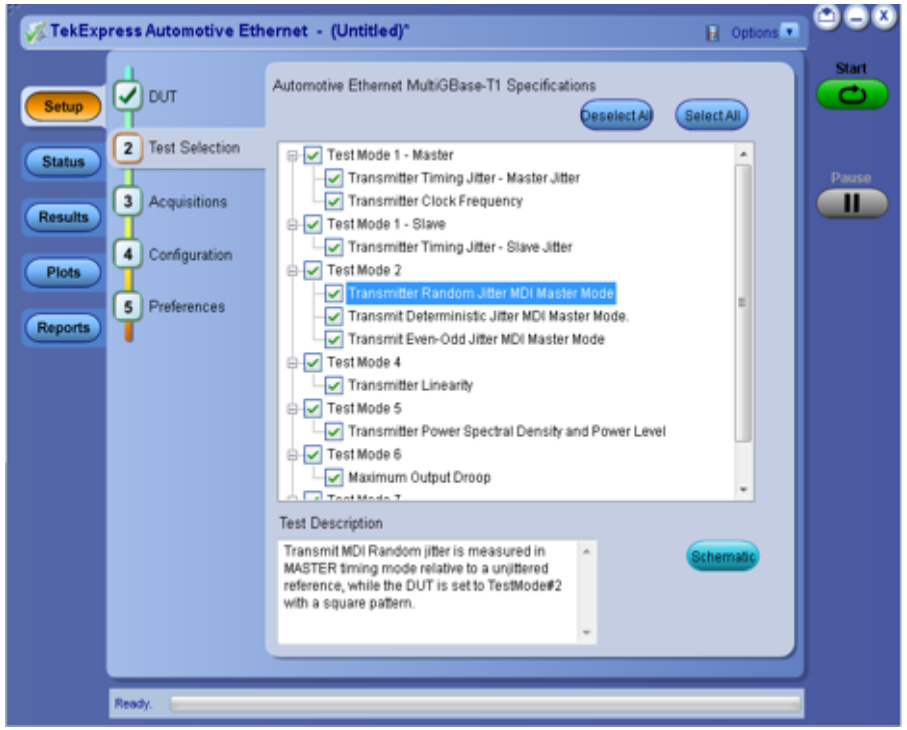
TM5

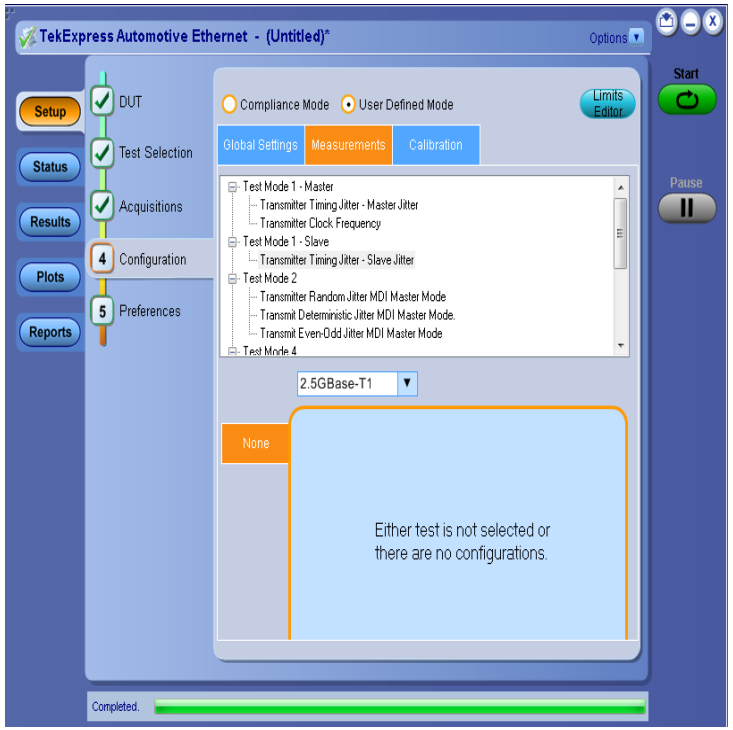
Tektronix Automotive Ethernet Solution

MultiGBASE-T1 – TekExpress Workflow

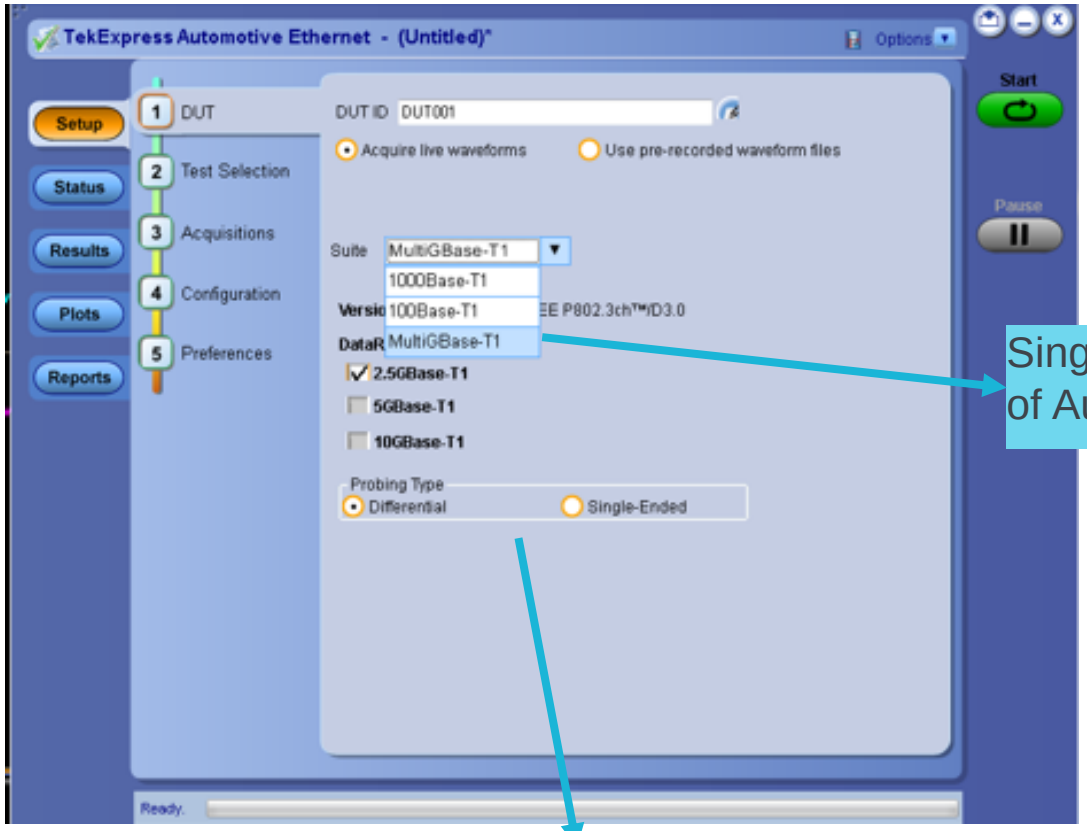
DUT Configuration → Test Selection → Measurement Configuration





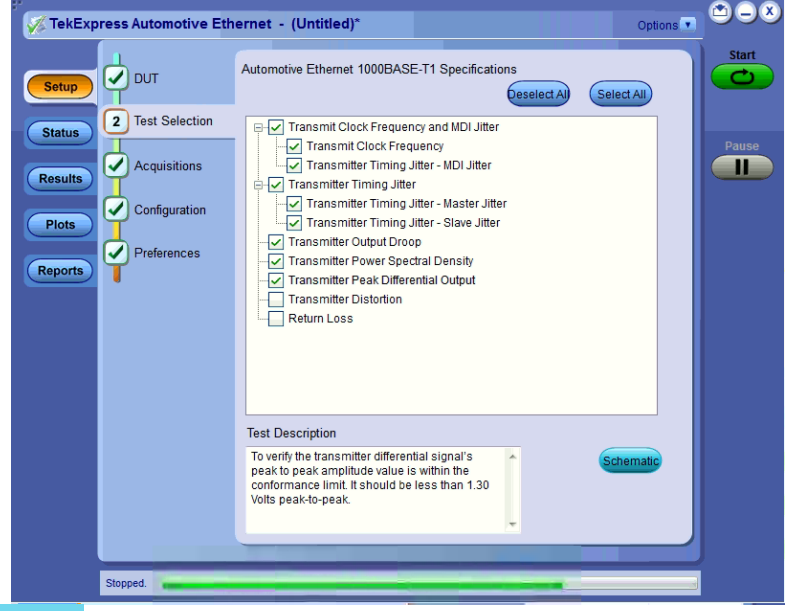


Multigigabit Ethernet Compliance

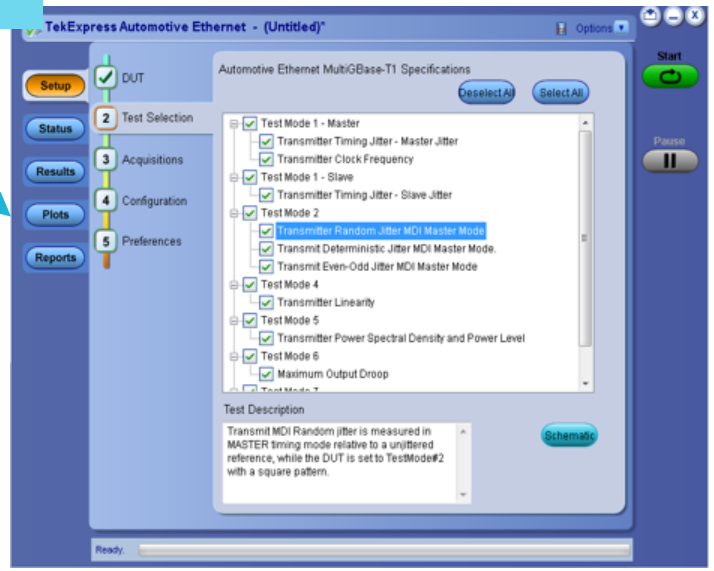


SMA Cable or Probe Support

Single UI for All Vvariants of Automotive Ethernet

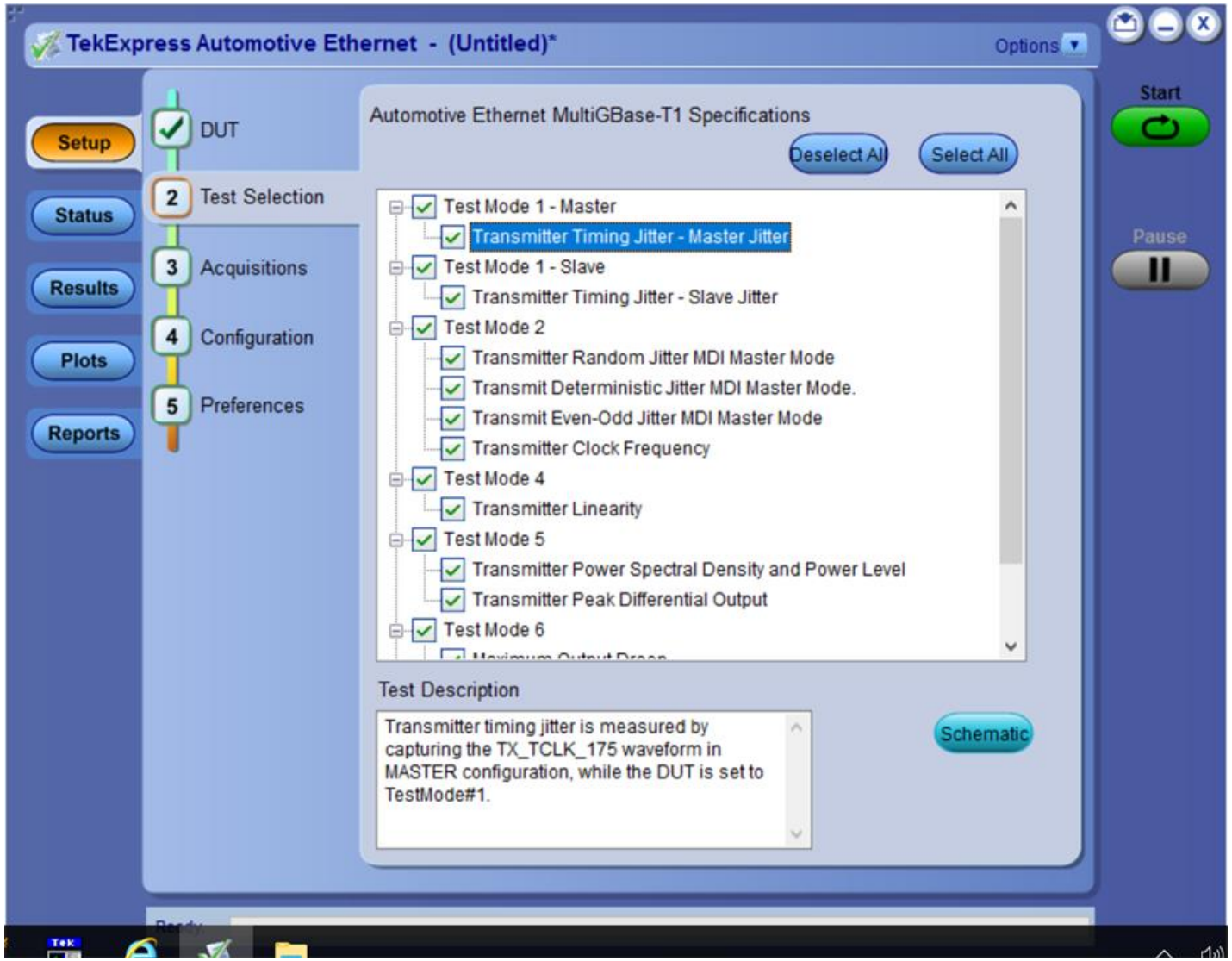


100/1000BASE-T1



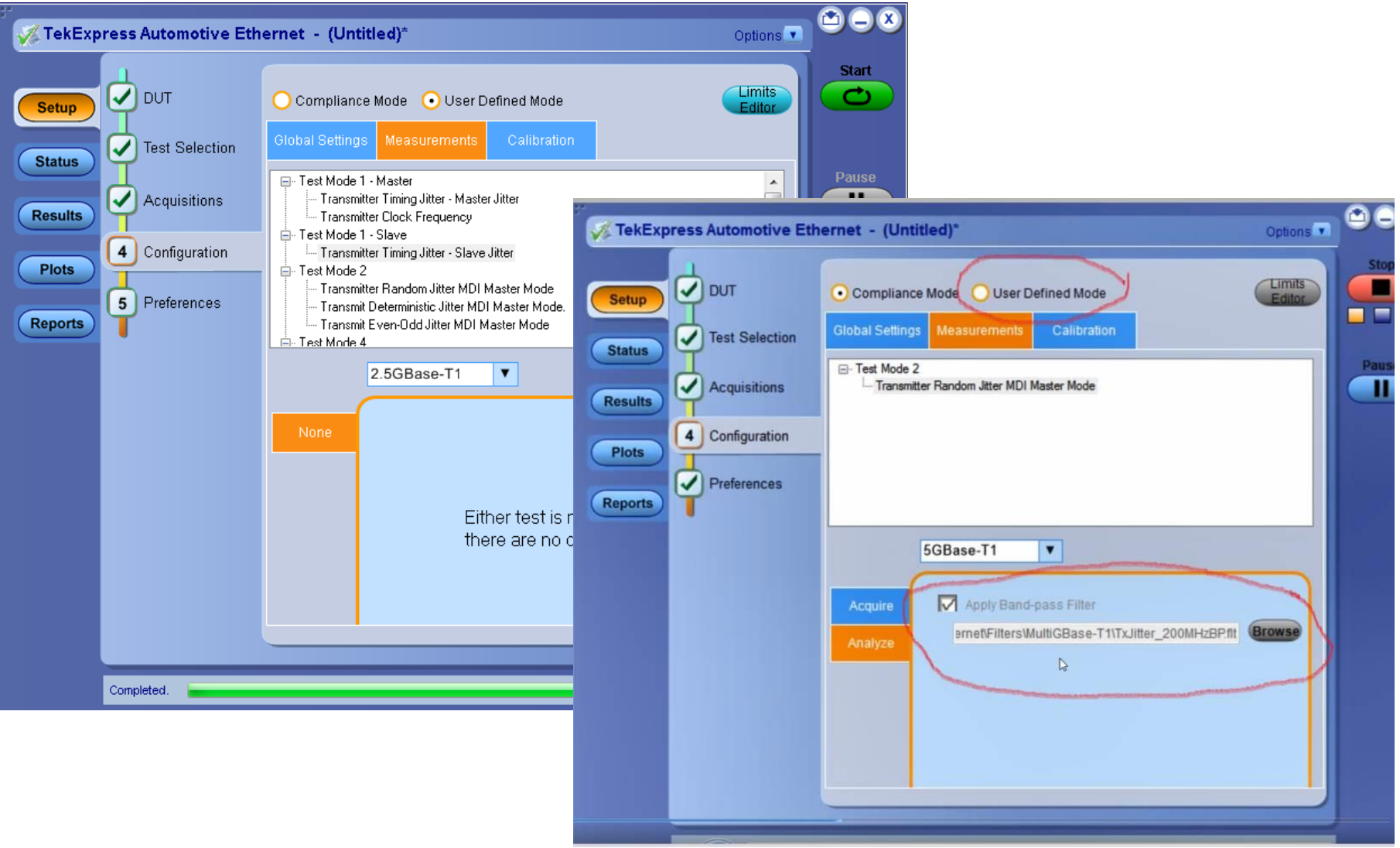
MultiGigBase-T1

Test Selection



- Test tree as per Test mode
- User can run multiple test within test tree without any interruption
- Test description, schematic guides user to avoid any error

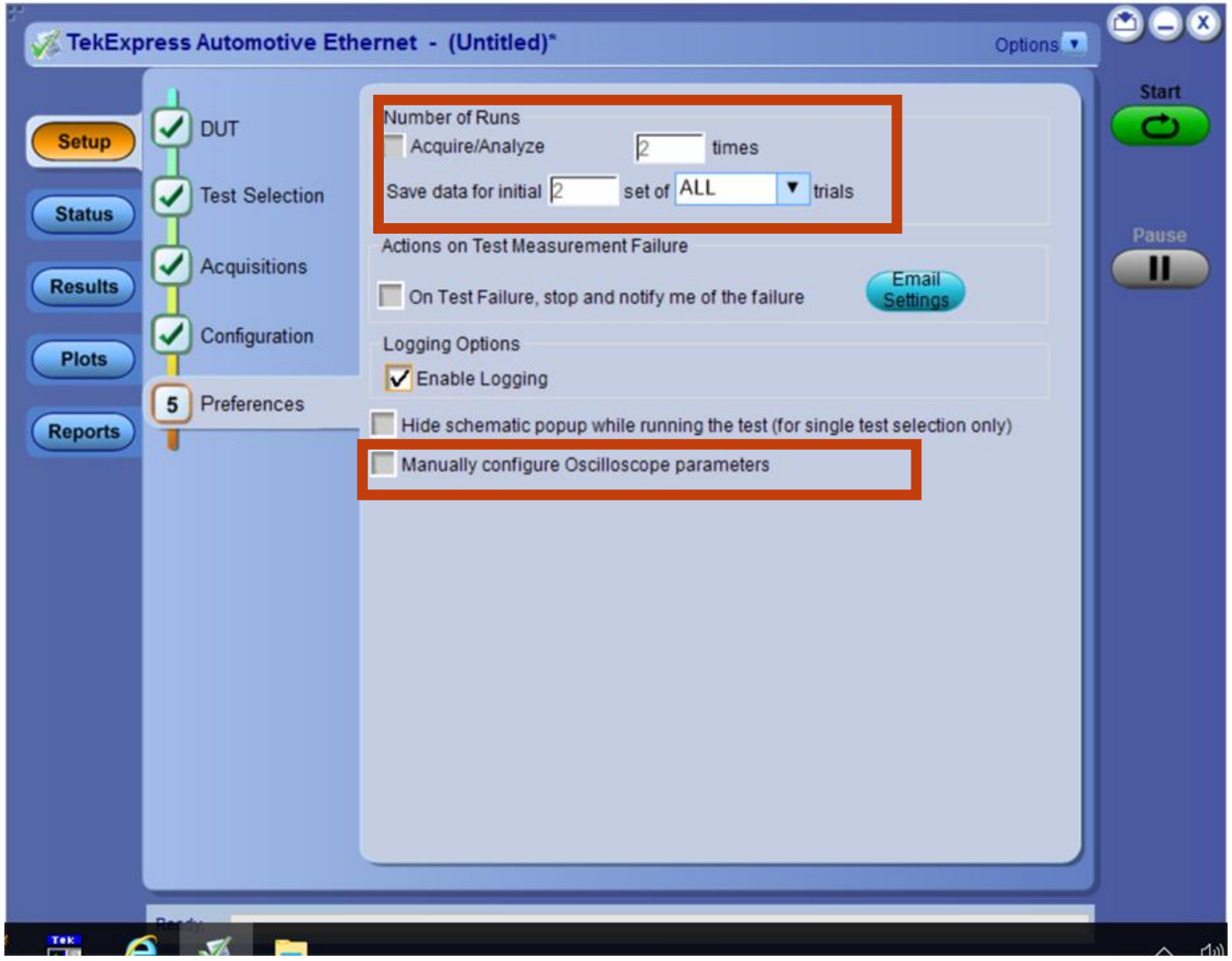
Test Configuration



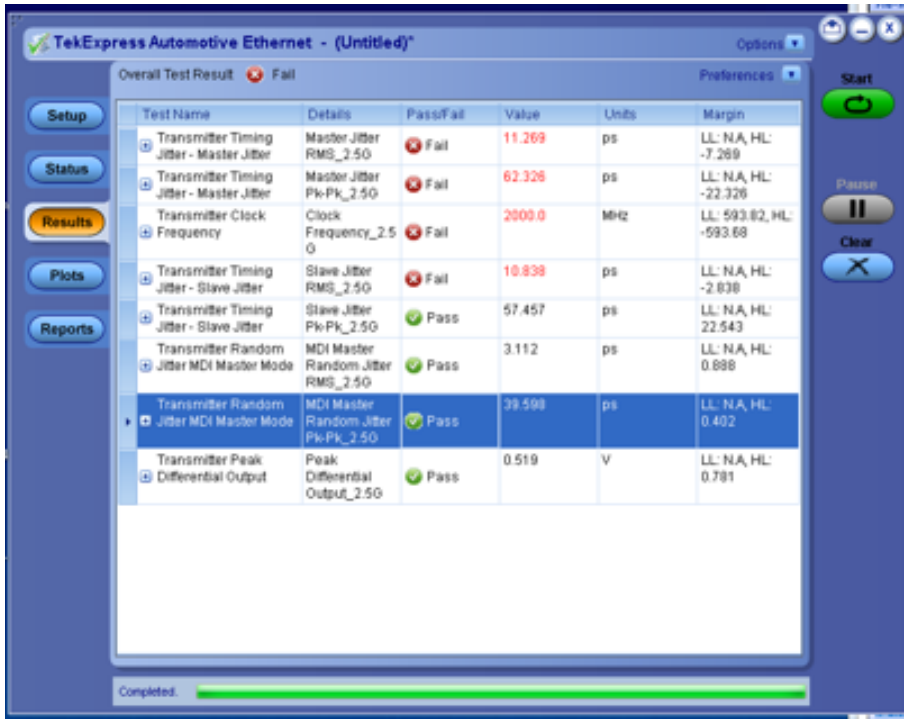
- Global Parameter
  - Sample Rate
  - Record Length
  - Number of Averages
- Power Spectral Density
  - Resolution BW
  - Start and Stop Frequency
  - Number of Spectral Averages
- Jitter Measurement
  - User defined Filter

Multirun, User Defined Acquisition Mode

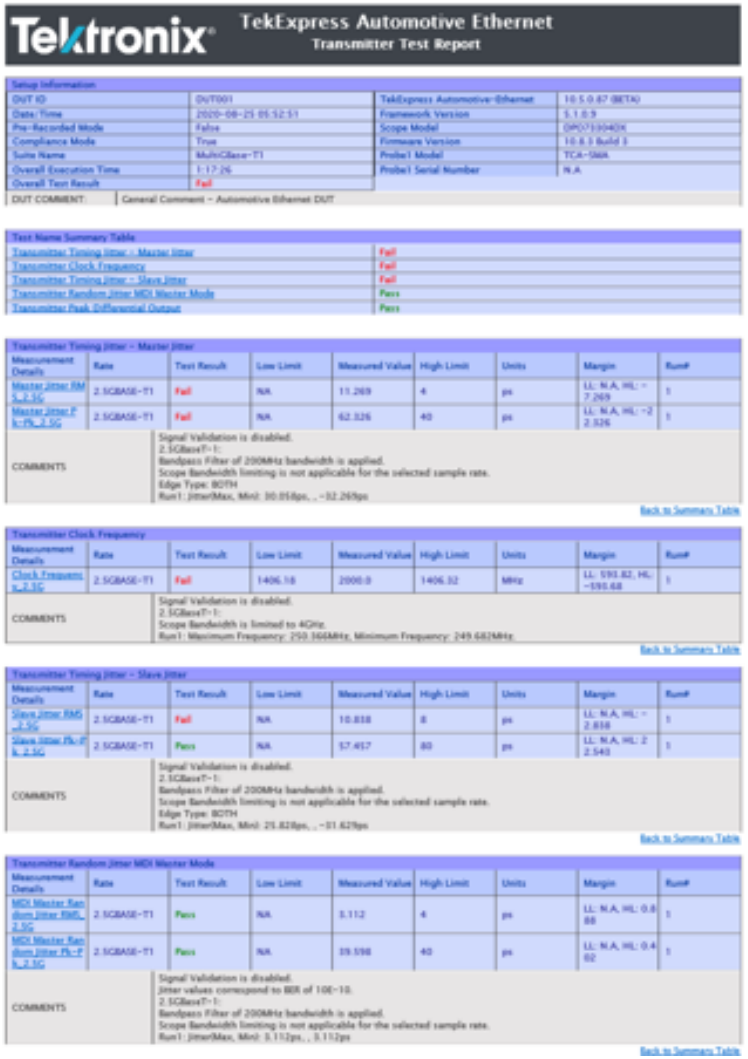
- Multirun:
  - Allows for automated sequential run-throughs of selected tests
  - Test results from each iteration saved and documented in the generated report
- UDA gives full control of the oscilloscope acquisition settings to the user
  - Will skip the default setup and autoset part of the test process
  - User can set Horizontal and Vertical scale



TekExpress Workflow - Results



At-a-Glance Results



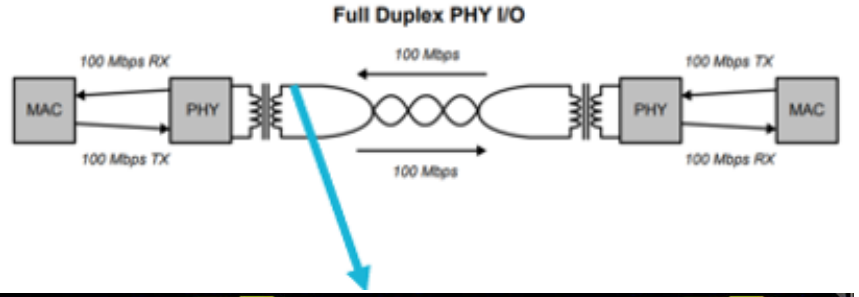
Generated Results Report

CSV file

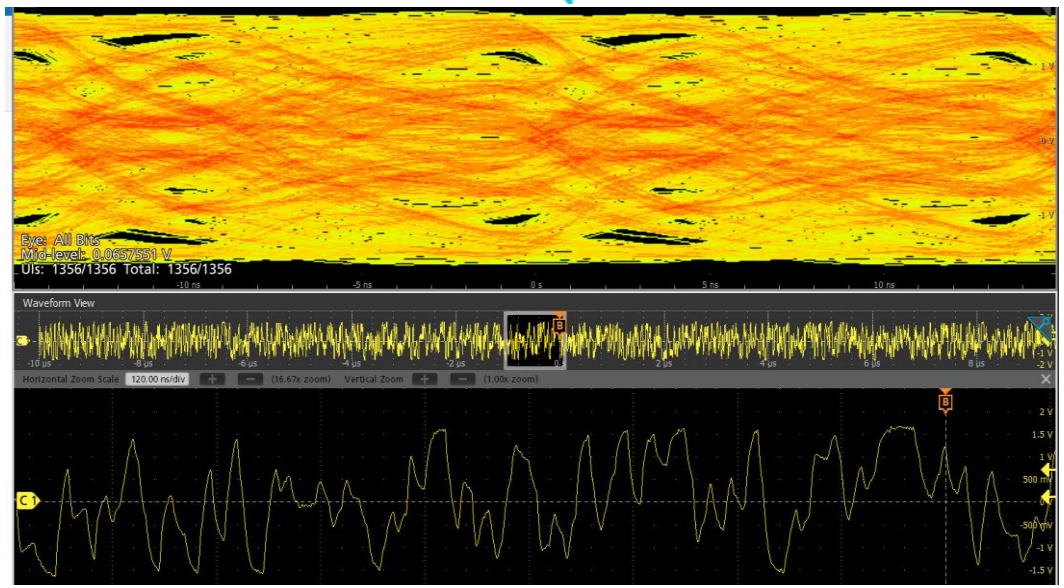
Details of Each Measurement

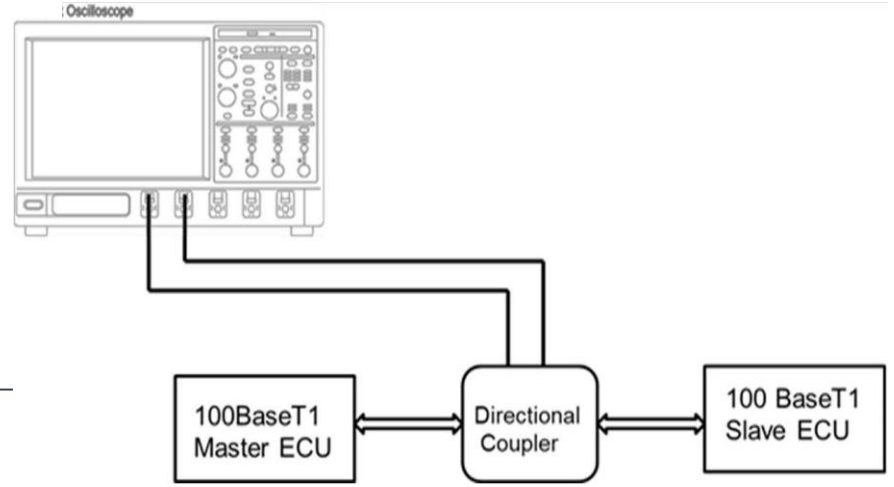
Automotive Ethernet Noise Test and Protocol Timing

Automotive Ethernet Eye Diagram



- **Why do we need eye diagram test?**
  - Any High speed SERDES Signal quality is determined by Eye diagram. In case of Automotive, even for CAN-FD standards, customer perform Eye diagram to validate noise performance.
  - Automotive Ethernet: customer would like to performance of link test in the presence of Noise (Signal Quality test). Eye diagram provides them insight of Link.
- **Full duplex signals:** signals overlay, meaning that connecting high impedance voltage probes yields no useful information.
- **Current available solution:**
  - Cut the cable and disturb the system
  - Directional coupler works on Directivity principle, would not show true Signal for Signal Integrity test
  - Insertion loss, Reflection, Mode conversion loss

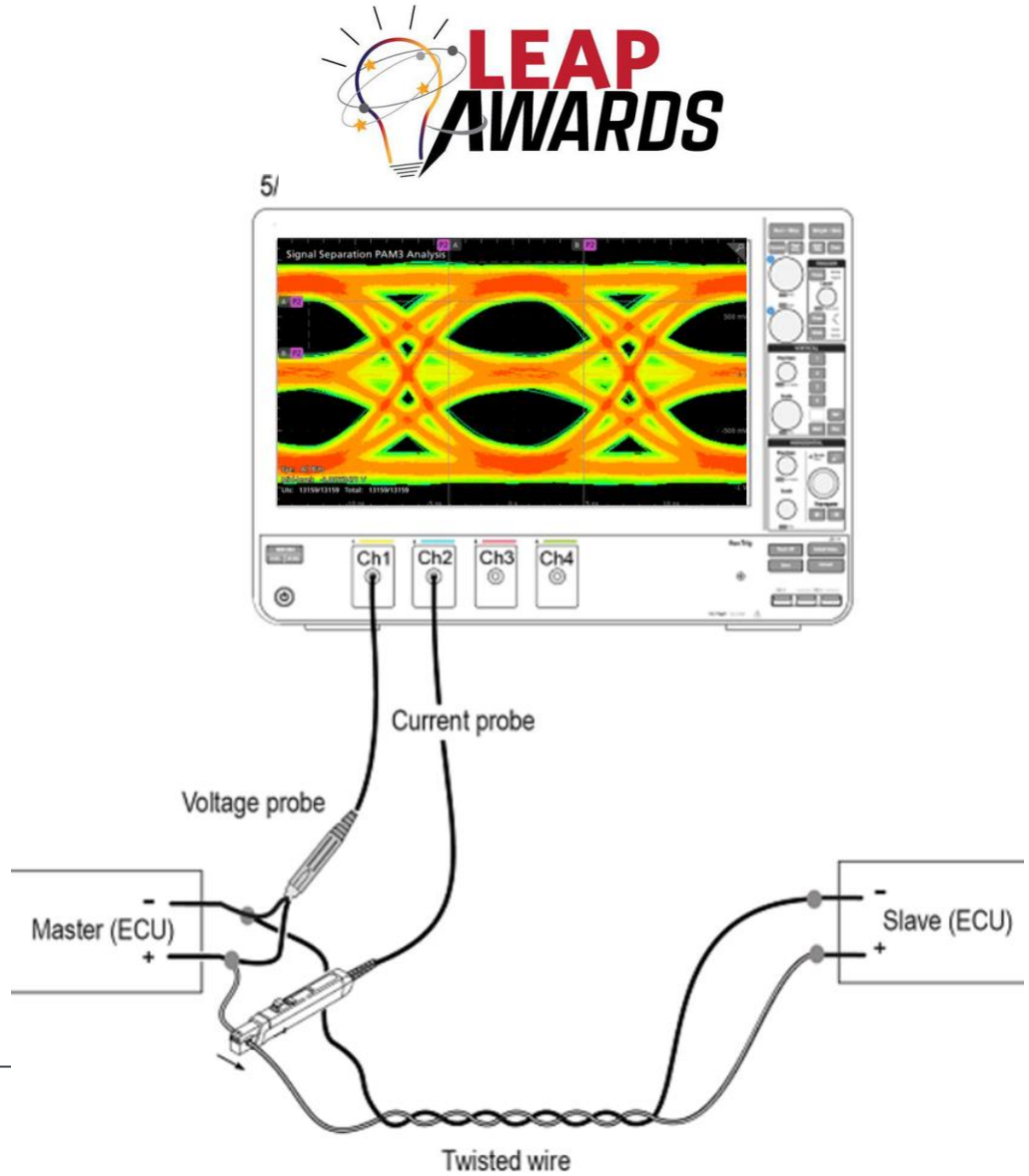




Tektronix Award Winning Signal Separation Solution

- Separates Transmitter and Receiver signals without interfering with the circuit
- Non-Intrusive method of Signal Separation: No cable cutting, no ECU loading
- Uses Voltage and Current probes
- Live Eye diagram and Protocol decode
- Added user defined Filter and Equalizer support for 100BASE-T1 and 1000BASE-T1.
- Patent pending, award winning
- Solution available for 100BASE-T1 and 1000BASE-T1
- Added CTLE equalizer support

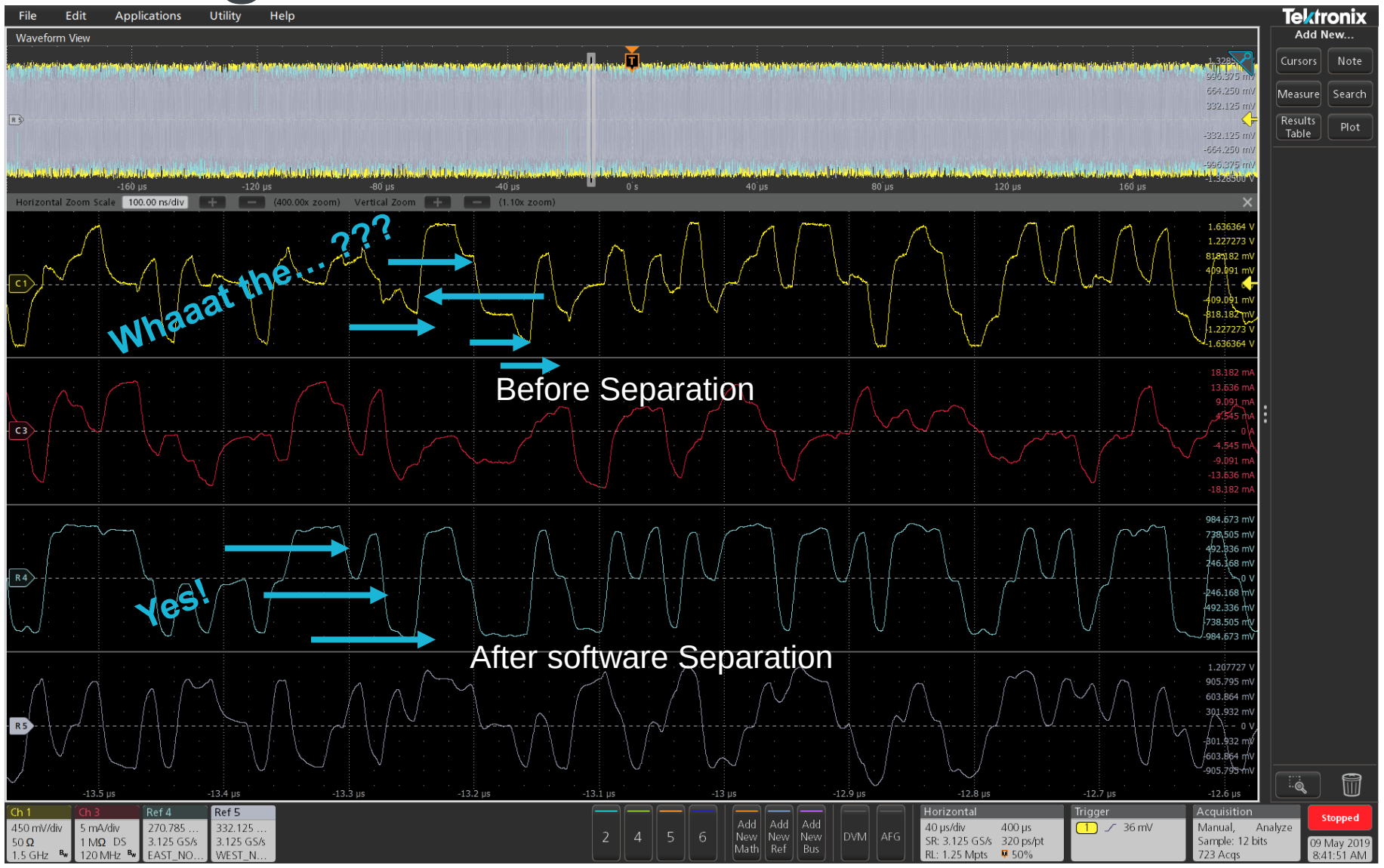
New



See the Real Signal with Tektronix

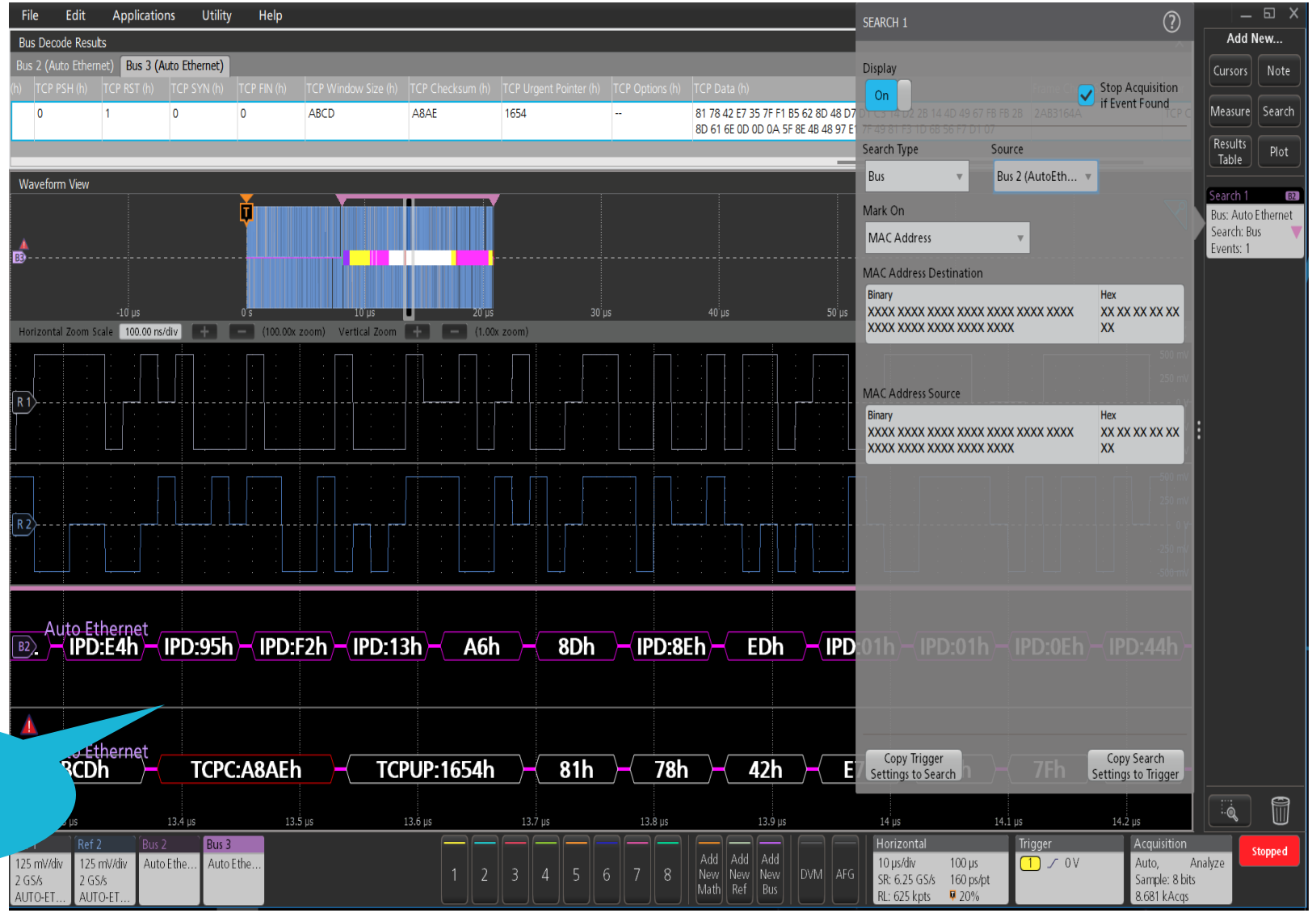
Full-Duplex Signal
Without Signal Separation

PAM3 signal



Protocol Decode

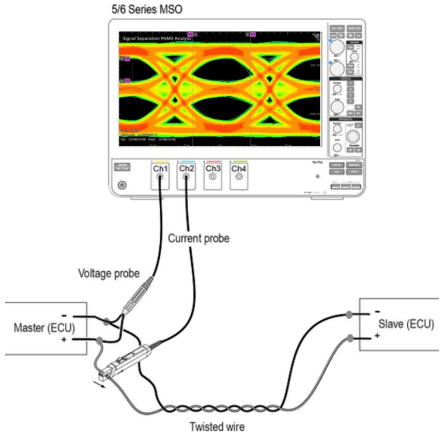
- Lets you assess protocol-level functionality (with timestamps, packet types, and logging errors)

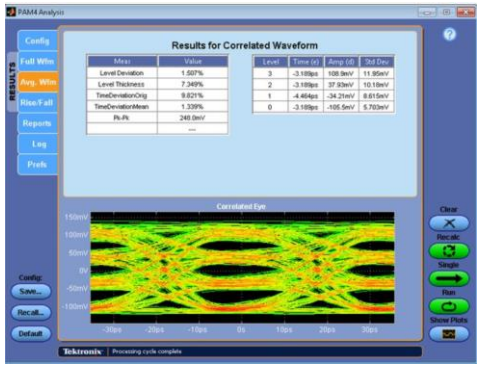


https://www.tek.com/video/automotive-ethernet-pam3-and-signal-separation-introduction

Tektronix Value proposition

- Industry's first Compliance Application
  - Cover all Automotive Ethernet variants compliance application (10BASE-T1S, 100/1000BASE-T1, MultiGBASE-T1)
- Working with major silicon companies on Multigigabit Ethernet
- Solution beyond compliance: patented Signal separation technique for System level signal integrity test, PAM4 Analysis, DPOJET
- Tektronix is leading key standard bodies like IEEE, Open Alliance, MIPI and ASA



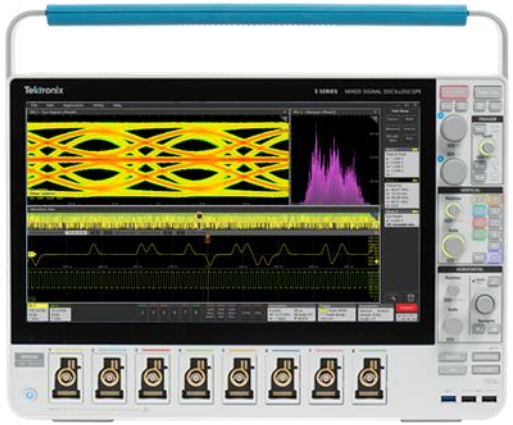


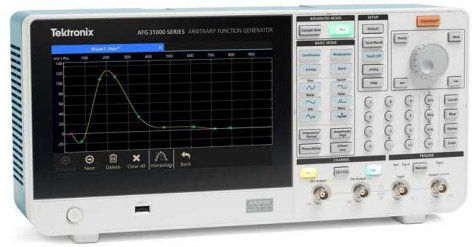
Automotive Ethernet Solution (DPO70K SX/DX)

- Oscilloscope: DPO70K SX/DX
  - 1 GHz minimum bandwidth (100BASET1)
  - 2 GHz Minimum bandwidth (1000BASET1)
  - 13 GHz Minimum bandwidth (MultiGBase-T1)
- Compliance Software:
  - BRR: 1000BASE-T1/100BASE-T1 compliance
  - AUTOEN10G: Multigigabit Ethernet compliance
- Debug: PAM4: PAM4 Signal Analysis
- Protocol Decode: SR-AUTOETH1: 100BASE-T1 Protocol decode
- Probe:
  - TDP1500- 10BASE-T1S/100BASET1
  - TDP3500 - 1000BASE-T1
  - P77xx- MultiGBase-T1 (Optional)
- Signal source: AFG310000 series (for 100/1000BASE-T1 Distortion test)
- Fixtures: 100/1000BASE-T1: TF-XGbT Ethernet test board, TF-BRR-CFD Clock divider
  DCDP MTD 309506: Directional Coupler for Protocol decode*
  MultiGBASE-T1 : PCB S3401 SB 396373 Rosenberger H-MTD to SMA*

Automotive Ethernet solution (5/6B MSO series)

- Oscilloscope: 5/6B series MSO
  - 350MHz min bandwidth for 10BASE-T1S
  - 1 GHz min bandwidth for 100BASET1
  - 2 GHz Min bandwidth for 1000BASET1
  - 4GHz for 2.5GBASE-T1 and 6 GHz for 5GBASE-T1
- Compliance Software:
  - CMAUTOEN10: 10BASE-T1S Compliance
  - CMAUTOEN: 1000BASE-T1/100BASE-T1 compliance
  - CMAUTOEN10G: Multigigabit Ethernet compliance
- Debug: PAM3: PAM3 Signal Analysis with Signal Separation
- Protocol Decode: SR-AUTOEN1: 100BASE-T1 Protocol decode
- Probe:
  - TDP1500- 10BASE-T1S/100BASET1
  - TDP3500 - 1000BASE-T1
- Signal source: AFG310000 series (for 100/1000BASE-T1 Distortion test)
- Fixtures: 100/1000BASE-T1: TF-XGbT Ethernet test board, TF-BRR-CFD Clock divider
  DCDP MTD 309506: Directional Coupler for Protocol decode*
  MultiGBASE-T1 : PCB S3401 SB 396373 Rosenberger H-MTD to SMA*





*3rd party hardware

Automotive IVN References

- Automotive Ethernet: https://www.tek.com/automotive/automotive-ethernet
- Compliance Datasheet:
  - 10BASE-T1S: https://www.tek.com/datasheet/10baset1s-automotive-ethernet-compliance-test-solution-option-5cmautoen10-and-6cmautoen10-datasheet
  - 100/1000BASE-T1: https://www.tek.com/datasheet/automotive-ethernet-test-solution
- Videos:
  - Compliance Test: https://www.tek.com/product-demo/demonstration-of-automated-automotive-ethernet-compliance-test-system
  - Signal Integrity Test: https://www.tek.com/video/automotive-ethernet-pam3-and-signal-separation-introduction
  - CAN Bus decode: https://www.tek.com/how-to/can-bus-decode-and-trigger-on-the-5-series-mso
  - SENT Bus decode: https://www.tek.com/product-demo/sent-bus-decode-and-trigger-on-5-series-mso
- Application Note:
  - IVN standards: https://www.tek.com/document/primer/ensuring-performance-and-conformance-vehicle-networks-new-generation-automobiles
  - Automotive Ethernet: https://www.tek.com/document/application-note/automotive-ethernet-see-true-signal
  - CAN/LIN/FlexRay: https://www.tek.com/document/application-note/debugging-can-lin-and-flexray-automotive-buses-oscilloscope
  - SENT Bus: https://www.tek.com/document/application-note/debugging-sent-automotive-buses-oscilloscope

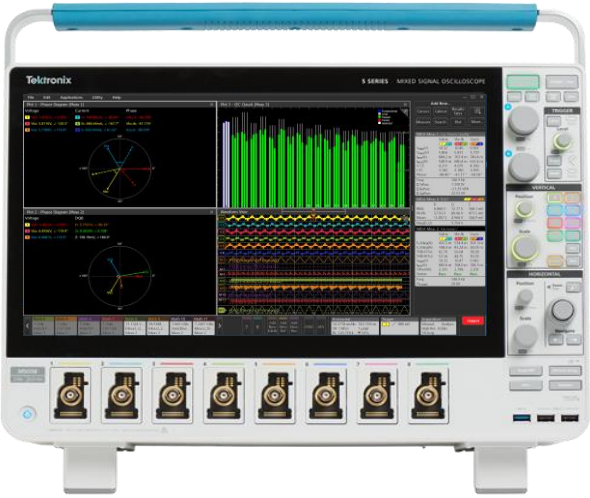
Tektronix Automotive Solution

LEAP AWARDS Winner

Award winning signal separation software simplifies Automotive Ethernet testing

- IVN Solution
  - 10Mbps to 10Gbps, complete solution for Automotive Ethernet PMA Transmitter compliance.
  - Transmitter validation solution for proprietary LVDS standards like FPD-Link, GVIF etc.
  - System Level Performance Test: Noise test, Cable performance is possible only with Award winning Non-Intrusive Signal separation technique

- Automotive Radar:
  - Multichannel Analysis
  - Down-convertor with in-built Local oscillator
  - Automotive Radar simulation and interference test



- Automotive Power:
  - 1 Box solution for Motor Drive Analysis
  - WBG Device test with unique IsoVue probe, AFG Double pulse generation

Tektronix®

Thank You!