

車聯網時代之車載通訊的蛻變與挑戰

- 車用乙太網路測試

Rohde & Schwarz Taiwan Ltd.
Oscilloscope

ROHDE & SCHWARZ

Make ideas real

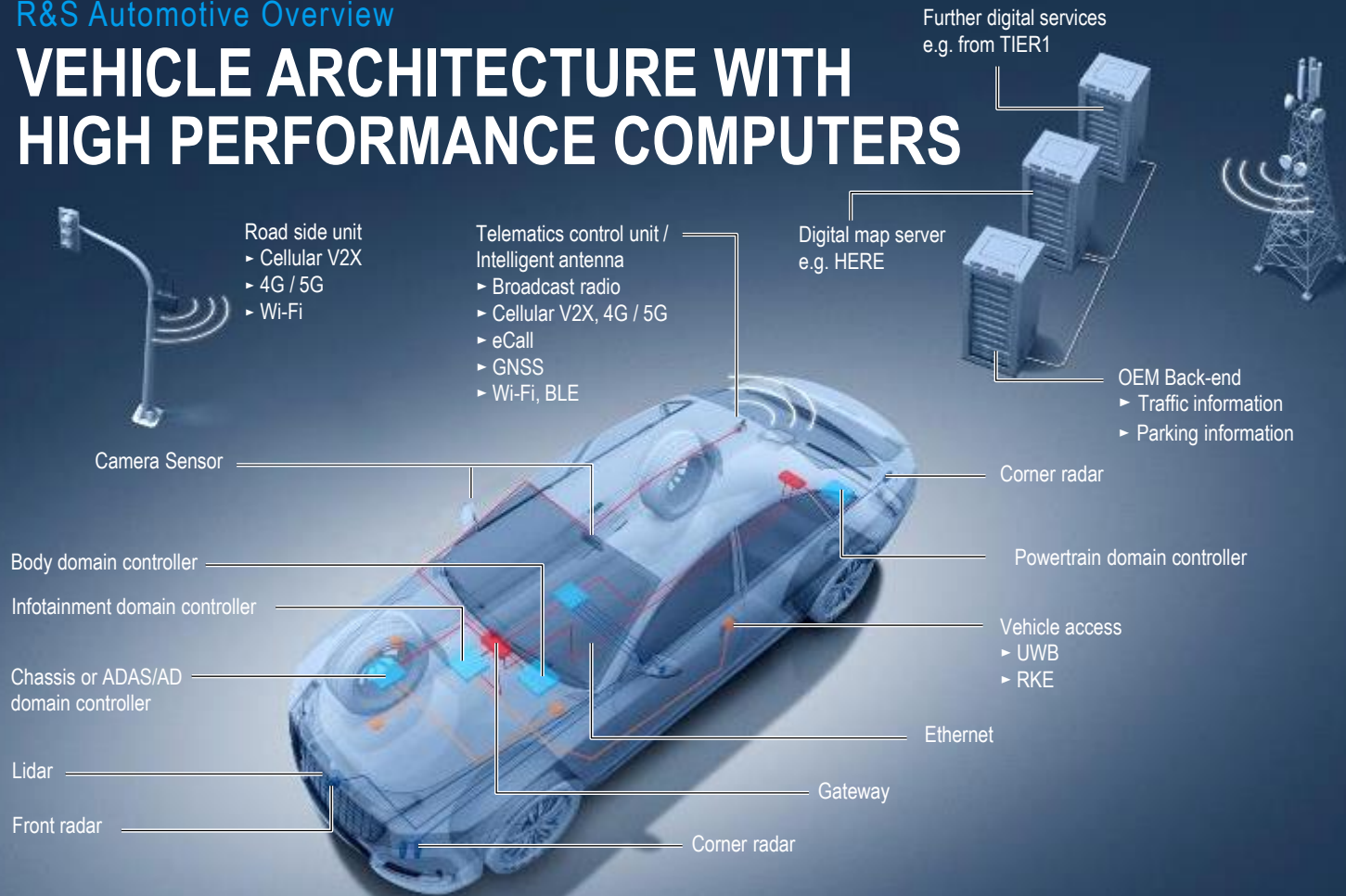


AGENDA

- ▶ Automotive In-Vehicle Network trends
- ▶ Introduce to Automotive Ethernet
- ▶ Automotive Ethernet Test Requirement
 - Compliance Test
 - Automotive bus protocol Decode
 - EMI debugging
- ▶ Summary



VEHICLE ARCHITECTURE WITH HIGH PERFORMANCE COMPUTERS



Automotive Test Solutions

Radar

Connectivity

4G / 5G Network; Quality Analysis

Infotainment

In-Vehicle Networks (AUT Ethernet)

ECU & Domain Controller Testing

Battery Management Systems

EMC / Full Vehicle Antenna Testing

Storage Solutions & Cybersecurity

Trends in Automotive Ethernet



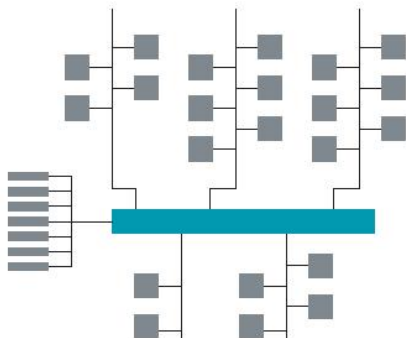
*average Ethernet ports per vehicle

** Photo courtesy of Marvell Technology Group

TRENDS TOWARDS IN-VEHICLE ARCHITECTURE

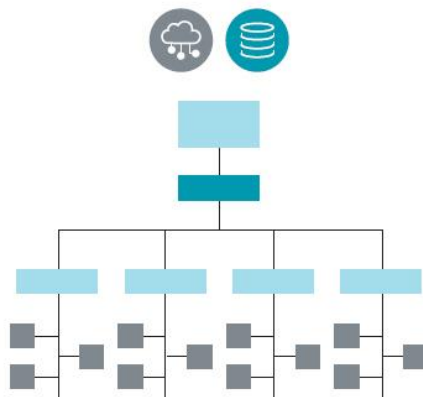
DISTRIBUTED

Established



DOMAIN-CENTRALIZED

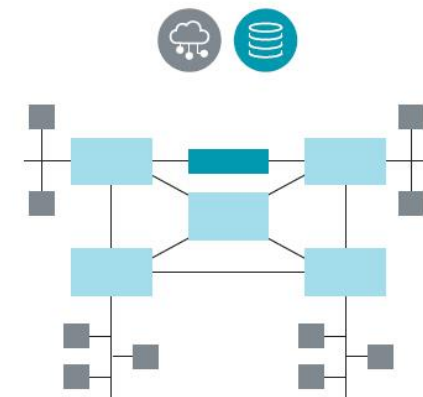
Next generation (~2021-2025)



*Distinctive hardware platforms,
limited HW abstraction*

ZONAL

Future (long term)



*Single software platform,
full hardware abstraction*

■ Gateway ■ DCU ■ ECU

Source: Elektrobit; Roland Berger

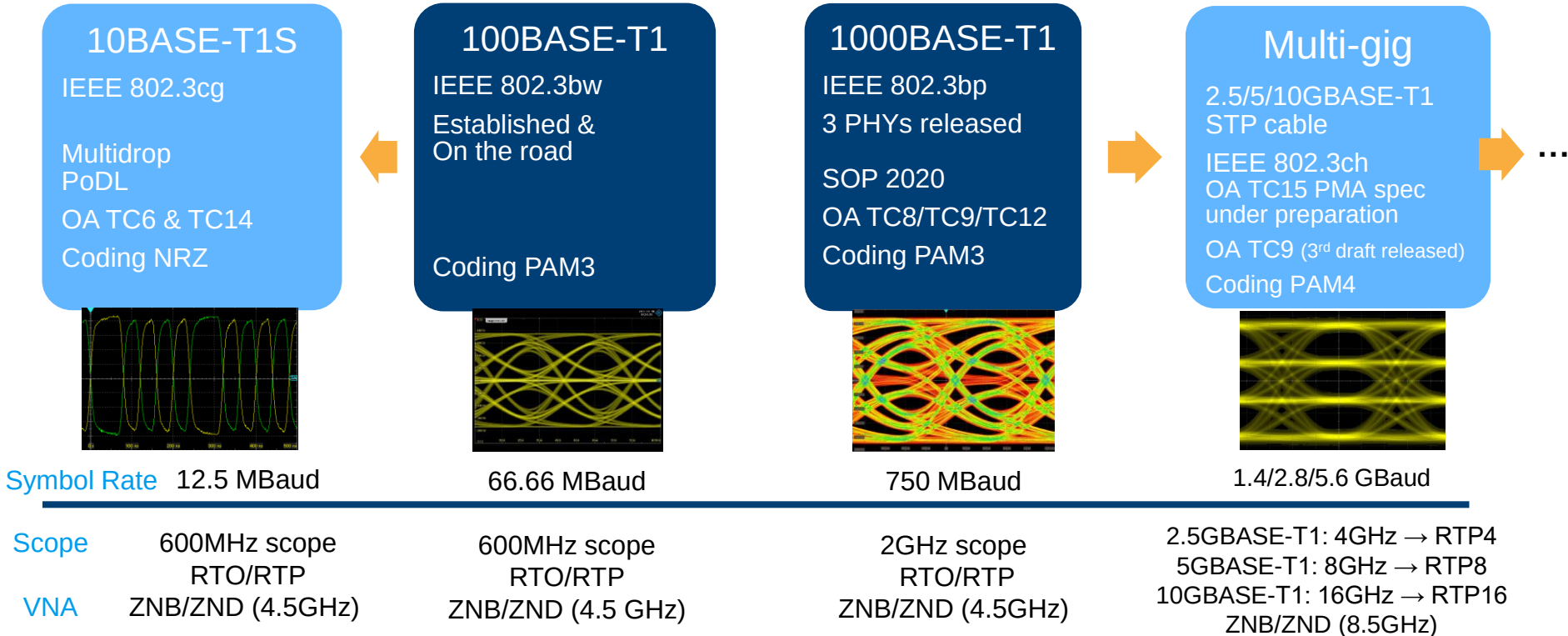
TECHNOLOGY

- 80-100 ECUs
- Multiple CAN, LIN, Ethernet, Flexray, MOST communication links

- 4-5 high-performance DCUs
- Multiple sensor/actuator ECUs
- 1 CAN bus per zone
- 1 Ethernet backbone

- Cluster of high-performance computers
- Multiple sensors/actuator ECUs
- 1 CAN bus per zone
- 1 Ethernet backbone

FUTURE AUTOMOTIVE ETHERNET STANDARDS



Members

[Member Login](#)[Promoters](#)[Adopters](#)[Membership](#)

OPEN Alliance SIG Promoter Members

BMW of North America
General Motors Co.
NXP
Toyota Motor Corporation

Broadcom Limited
Hyundai Motor Company
Renesas Electronics Europe GmbH
Volvo Car Corporation

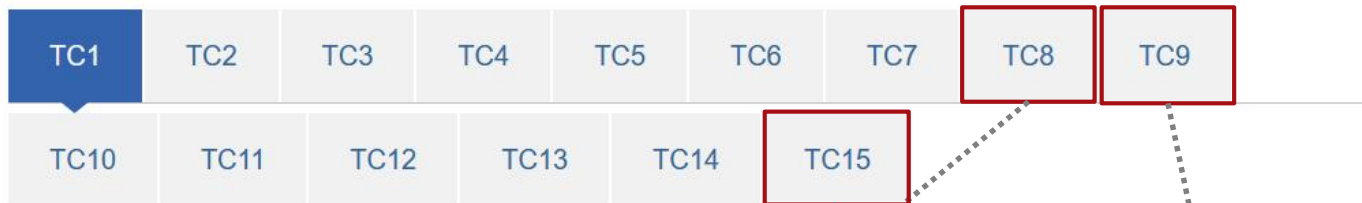
Continental
Marvell Semiconductor
Robert Bosch GmbH
VW Group

Driven by OEMs

12 Promoters
124 Adopters

<http://www.opensig.org/>

Tech Committees



TC15 group created for MultiGig Ethernet for 2.5/5/10GBASE-T1. (PMA under preparation)

1000BASE-T1 Ethernet Channel & Passive Components (v2.3)
 NGAuto Channel & Components for 1000BASE-T1
 2.5/5/10GBASE-T1 Link Segments (draft v0.3)

Automotive Ethernet ECU Test Specification (v3.0)
 Currently supports 100/1000BASE-T1

AUTOMOTIVE ETHERNET COMPLIANCE



10Base-T1S

- PHY & Protocol IEEE 802.3cg
- Open Alliance TC14

100Base-T1

- PHY & Protocol IEEE 802.3bw
- Open Alliance TC1

1000Base-T1

- PHY & Protocol IEEE 802.3bp
- Open Alliance TC12

NGBase-T1

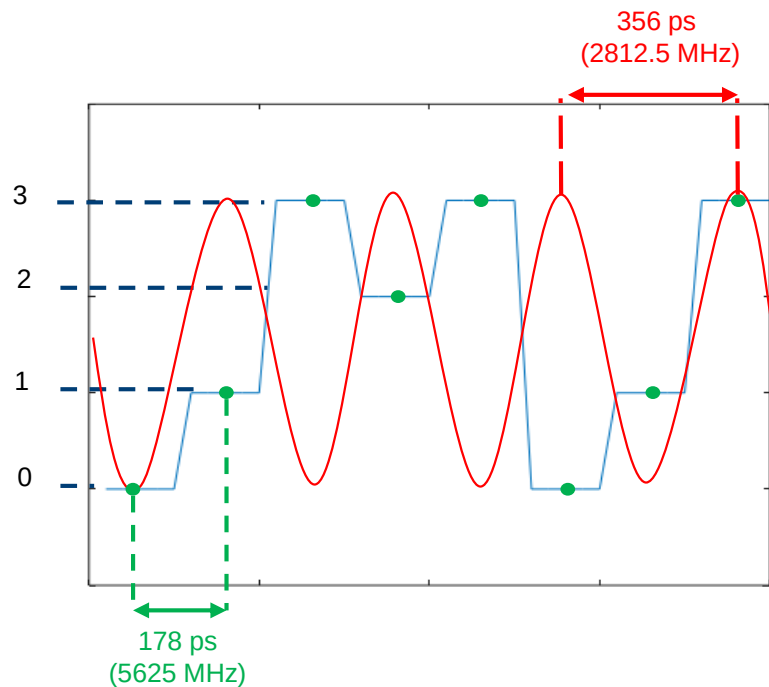
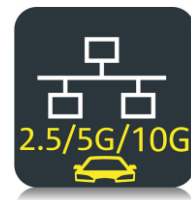
- PHY & Protocol IEEE 802.3ch (in progress)
- Open Alliance TC in progress

TC8 ECU Specification

AUTOMOTIVE ETHERNET SUMMARY

	10Base-T1S	100Base-T1	1000Base-T1	NGBase-T1
Datarate	10Mbps	100Mbps	1Gbps	2.5/5/10Gbps
Symbol rate	12.5MHz	66.66MHz	750MHz	1.4/2.8/5.6GHz
Coding	4B/5B, Differential Manchester Encoding(DME)	PAM3	PAM3	PAM4
Voltage	1Vpp	2.2Vpp	1.3Vpp	1.3Vpp
Communication	Half Duplex or Full Duplex	Full Duplex	Full Duplex	Full Duplex
Configuration	Point to Point Multidrop	Point to Point	Point to Point	Point to Point
Cable length	15/25m	15m	15m	15m
Cable type	24-26 AWG	Unshielded twisted pair	Unshielded twisted pair	Unshielded twisted pair
Application	Audio, Parking ECU, Engine ECU, Body ECU..	Infotainment, Driver Assistance systems	Infotainment, Driver Assistance systems	Infotainment, Driver Assistance systems, ECU to ECU

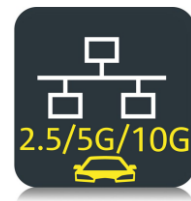
BAUD RATES



Key

- PAM4 Sequence
- Symbol Sample Time
- Highest Output Frequency

BAUD RATES

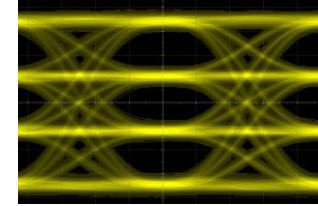


PHY Type	Symbol Rate	Associated 'S' Value See Table 149-1	Highest Output Frequency
10GBASE-T1	5625 Mbaud	1.0	2812.5 MHz
5GBASE-T1	2812.5 MBaud	0.5	1406.25 MHz
2.5GBASE-T1	1406.25 MBaud	0.25	703.125 MHz

DEMO

Objective: Verify general PMA performance (jitter, eye) and conduct TX compliance testing

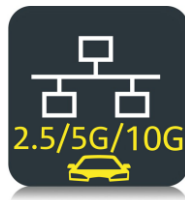
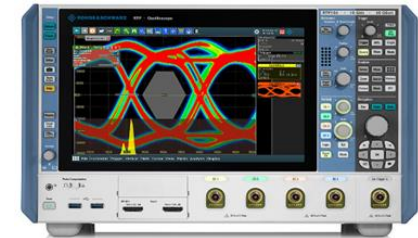
Step 1: Step through **test modes** to visually confirm patterns are correct



Step 2: Run 802.3 **PHY conformance tests** with ScopeSuite automation software

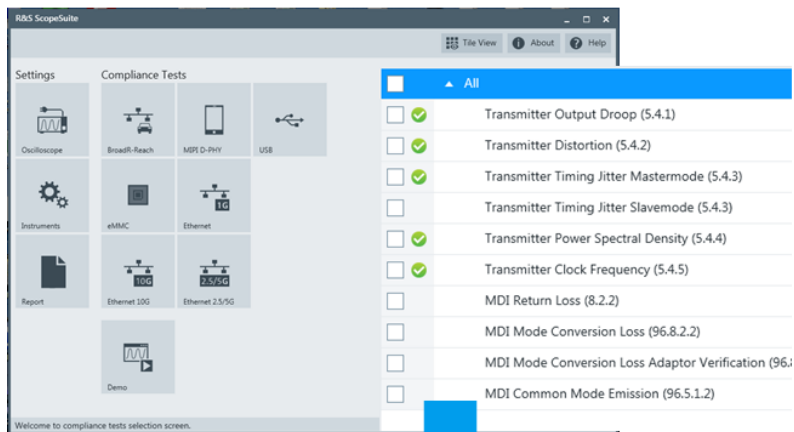


Step 3: **Characterize TX performance** with additional signal integrity analysis

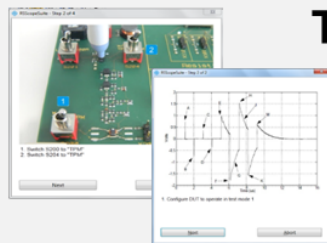


R&S ScopeSuite

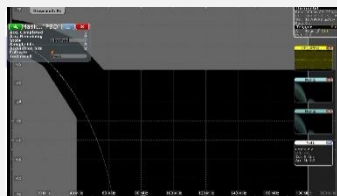
BUILT-IN COMPLIANCE TEST SOFTWARE & REPORTING TOOL



Test



Guided steps

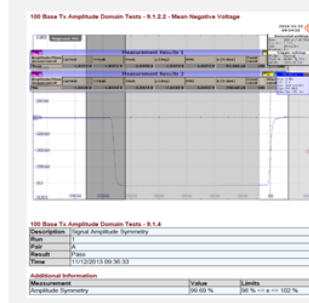


Auto measurements

Pass-Fail results

☐	Test	Description	Run	Result	Detail
☐	Output Droop		1	✓	2/2
☐	Transmitter Distortion No TX_TCLK No Disturber		1	✓	11/11
☐	Transmitter Timing Jitter Mastermode		1	✓	1/1
☐	Power Spectral Density		1	✗	0/1
☐	Power Spectral Density		2	✓	1/1
☐	Transmitter Clock Frequency		1	✓	1/1

Report



- Screenshot
- Measurement result
- Pass-Fail result
- Test summary

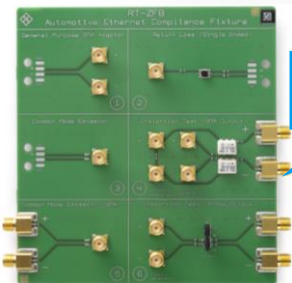
FROM 10BASE-T1 TO 10GBASE-T1 COMPLIANCE TEST



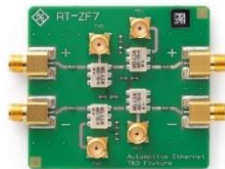
Key Features

- Complete test solution from R&S (PHY layer)
- Includes OEM required test cases
- Future proof solution for Automotive Ethernet
- UNH-IOL uses RTO + ZNB for all automotive Ethernet tests
- Dedicated test fixtures made by R&S – OA TC8 compliant!

New → MultiGBASE-T1 (only a software option – K88)



Compliance Test fixture RT-ZF8



Decoding fixture RT-ZF7

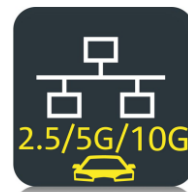


SMA adapter for TD & Compliance RT-ZF7A

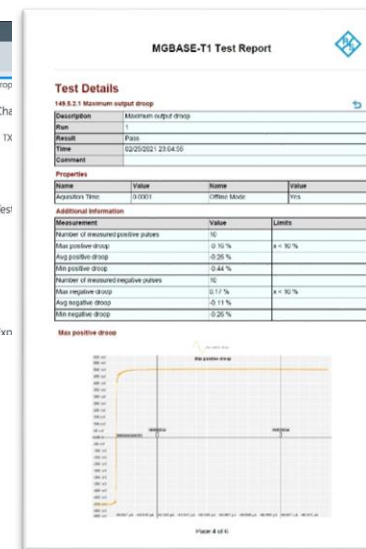
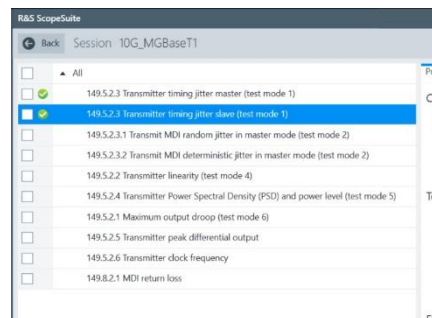


Frequency converter RT-ZF3/6

NEW MULTIGBASE-T1 COMPLIANCE TEST SOLUTION

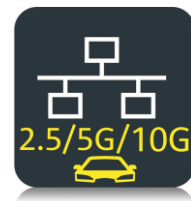


- ▶ New K88 AUT Ethernet compliance option for 2.5/5/10G speeds
- ▶ Based on the IEEE 802.3ch
- ▶ Uses PAM4 modulation with symbol rates of 1.4/2.8/5.6 GHz
- ▶ Runs exclusively on shielded twisted pair (STP)
- ▶ Additional information:
 - Available on both the RTO (up to 2.5G) and RTP
 - Coverage of all relevant test cases
 - No additional options required (e.g. jitter)
 - Complete solution with VNA and ZF7A test fixtures



IEEE 802.3CH CLAUSE 149 TEST PATTERNS

TABLE 149-17



149.5 PMA electrical specifications

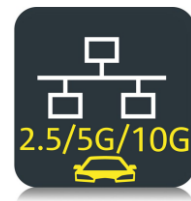
This subclause defines the electrical characteristics of the PMA and specifies PMA-to-MDI interface tests.

149.5.1 Test modes

Table 149–17—MDIO management registers settings for test modes

Register description
Normal (non-test mode) operation.
Test mode 1—Setting MASTER and SLAVE PHYs for transmit clock jitter test in linked mode.
Test mode 2—Transmit MDI jitter test in MASTER mode.
Test mode 3—Precoder test mode.
Test mode 4—Transmitter linearity test.
Test mode 5—Normal operation in Idle mode. This is for the PSD Mask test.
Test mode 6—Transmitter droop test mode.
Test mode 7—Normal operation with zero data pattern. This is for BER monitoring.

TEST MODE 1



149.5 PMA electrical specifications

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Test mode 6—Transmitter droop test mode.
Test mode 7—Normal operation with zero data pattern. This is for BER monitoring.

- ▶ “Normal operation” test mode
- ▶ Transmit reduced PHY symbol clock (TX_TCLK_175) to measure clock jitter
- ▶ Clock frequency of 175.78125 MHz
- ▶ Access through SMA connector or pin header

TEST MODE 2



149.5 PMA electrical specifications

This subclause defines the electrical characteristics of the PMA and specifies PMA-to-MDI interface tests.

149.5.1 Test modes

Table 149–17—MDIO management registers settings for test modes

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Normal (non-test mode) operation.
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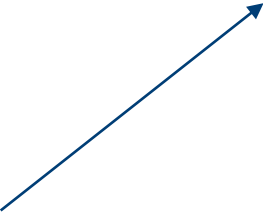
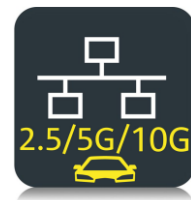


Table 149–18—Jitter test modes

Test pattern
Square wave: TX_TCLK_175
JP03A (as specified in 94.2.9.1)
JP03B (as specified in 94.2.9.2)

TEST MODE 2.1



149.5 PMA electrical specifications

This subclause defines the electrical characteristics of the PMA and specifies PMA-to-MDI interface tests.

149.5.1 Test modes

Table 149–17—MDIO management registers settings for test modes

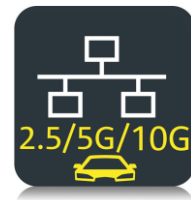
Register description
Normal (non-test mode) operation.
Test mode 1—Setting MASTER and SLAVE PHYs for transmit clock jitter test in linked mode.
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Test mode 4—Transmitter linearity test.
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Test mode 7—Normal operation with zero data pattern. This is for BER monitoring.

Table 149–18—Jitter test modes

Test pattern
Square wave: TX_TCLK_175
JP03A (as specified in 94.2.9.1)
JP03B (as specified in 94.2.9.2)

- ▶ 175.78125 MHz square wave
- ▶ Measures MDI random jitter

TEST MODE 2.2



149.5 PMA electrical specifications

This subclause defines the electrical characteristics of the PMA and specifies PMA-to-MDI interface tests.

149.5.1 Test modes

Table 149-17—MDIO management registers settings for test modes

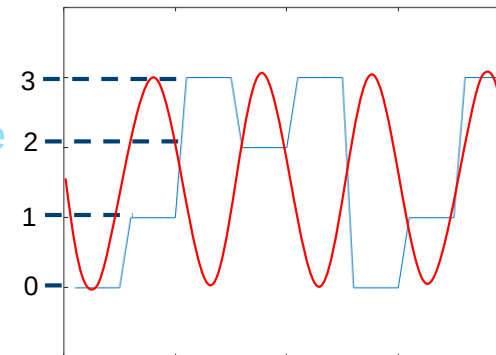
Register description
Normal (non-test mode) operation.
Test mode 1—Setting MASTER and SLAVE PHYs for transmit clock jitter test in linked mode.
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Table 149-18—Jitter test modes

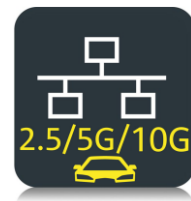
Test pattern
Square wave: TX_TCLK_175
JP03A (as specified in 94.2.9.1)
JP03B (as specified in 94.2.9.2)

- ▶ High frequency (sine wave) test pattern
- ▶ PAM4 encoded {0,3} sequence
- ▶ Measures MDI deterministic jitter

PAM4 Sequence
JP03A



TEST MODE 2.3



149.5 PMA electrical specifications

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149.5.1 Test modes

Table 149–17—MDIO management registers settings for test modes

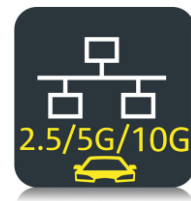
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Test mode 6—Transmitter droop test mode.
Test mode 7—Normal operation with zero data pattern. This is for BER monitoring.

Table 149–18—Jitter test modes

Test pattern
Square wave: TX_TCLK_175
JP03A (as specified in 94.2.9.1)
JP03B (as specified in 94.2.9.2)

- ▶ Mixed frequency test pattern
- ▶ PAM4 encoded sequence of $15 \times S \{0,3\} + 16 \times S \{3,0\}$ symbols
- ▶ Inserts “33” and “00” every 30 symbols
- ▶ Measures MDI Even-Odd jitter

TEST MODE 4



149.5 PMA electrical specifications

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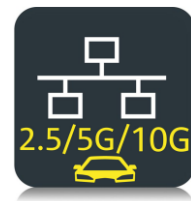
149.5.1 Test modes

Table 149–17—MDIO management registers settings for test modes

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Test mode 3—Precoder test mode.
Test mode 4—Transmitter linearity test.
Test mode 5—Normal operation in Idle mode. This is for the PSD Mask test.
Test mode 6—Transmitter droop test mode.
Test mode 7—Normal operation with zero data pattern. This is for BER monitoring.

- Used for transmitter linearity
- PRBS13Q – “Q” for quad or 4-level PRBS
- 8191 symbol sequence created from Gray coding two PRBS13 patterns into PAM4 symbols

TEST MODE 5



149.5 PMA electrical specifications

This subclause defines the electrical characteristics of the PMA and specifies PMA-to-MDI interface tests.

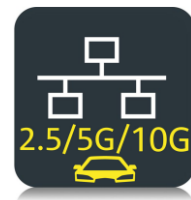
149.5.1 Test modes

Table 149–17—MDIO management registers settings for test modes

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Test mode 4—Transmitter linearity test.
Test mode 5—Normal operation in Idle mode. This is for the PSD Mask test.
Test mode 6—Transmitter droop test mode.
Test mode 7—Normal operation with zero data pattern. This is for BER monitoring.

- Used for TX PSD / Power level
- Scrambled PAM4 symbols
- MASTER mode scrambler from idle sequence

TEST MODE 5



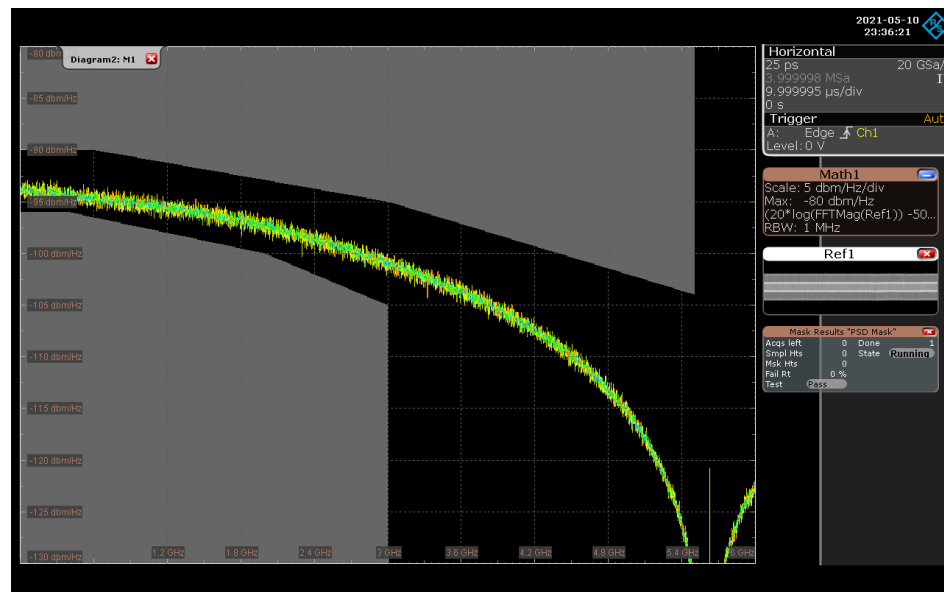
149.5 PMA electrical specifications

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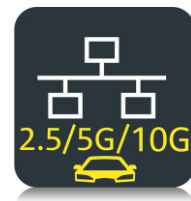
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Test mode 6—Transmitter droop test mode.
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TEST MODE 6



149.5 PMA electrical specifications

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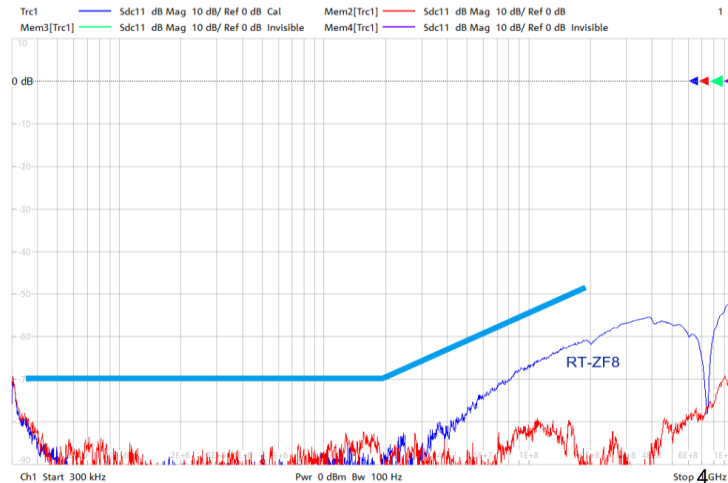
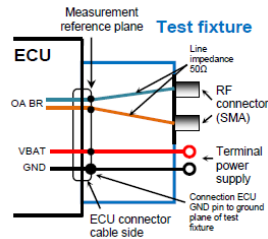
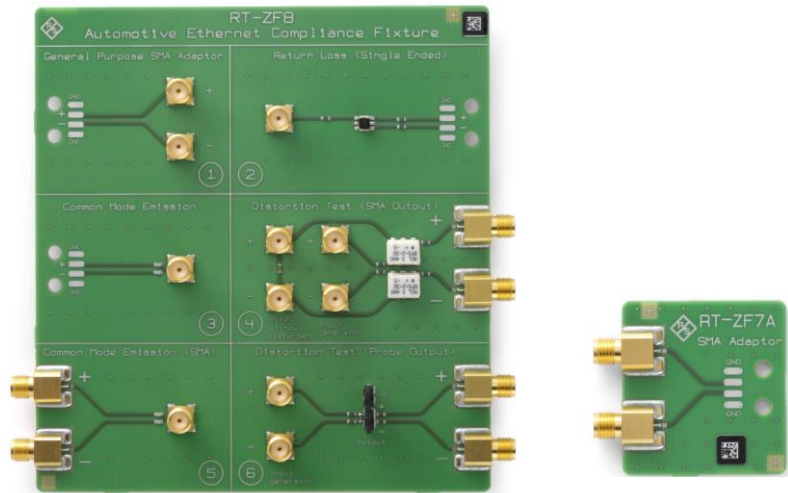
149.5.1 Test modes

Table 149–17—MDIO management registers settings for test modes

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Normal (non-test mode) operation.
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Test mode 3—Precoder test mode.
Test mode 4—Transmitter linearity test.
Test mode 5—Normal operation in Idle mode. This is for the PSD Mask test.
Test mode 6—Transmitter droop test mode.
Test mode 7—Normal operation with zero data pattern. This is for BER monitoring.

- ▶ Low frequency square wave for measuring TX droop
- ▶ $128 \times S \{+1\} + 128 \times S \{-1\}$ symbols

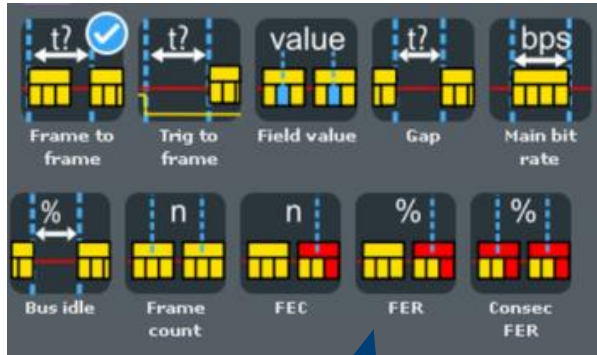
MDI Return loss 149.8.2.1



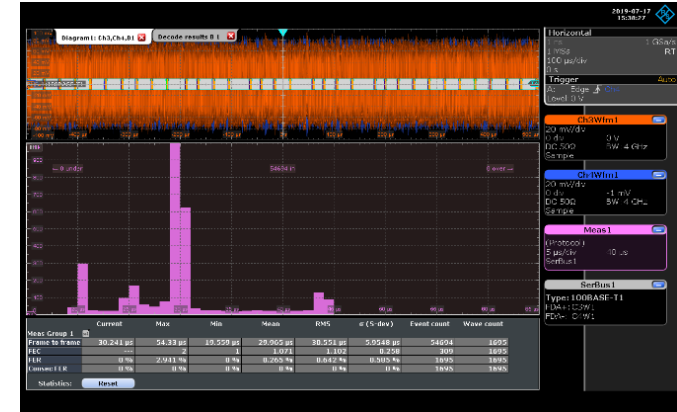
R&S®ZNB 4-port VNA
9kHz – 40GHz

BUS MEASUREMENT CAPABILITY AND SUPPORTED STANDARDS

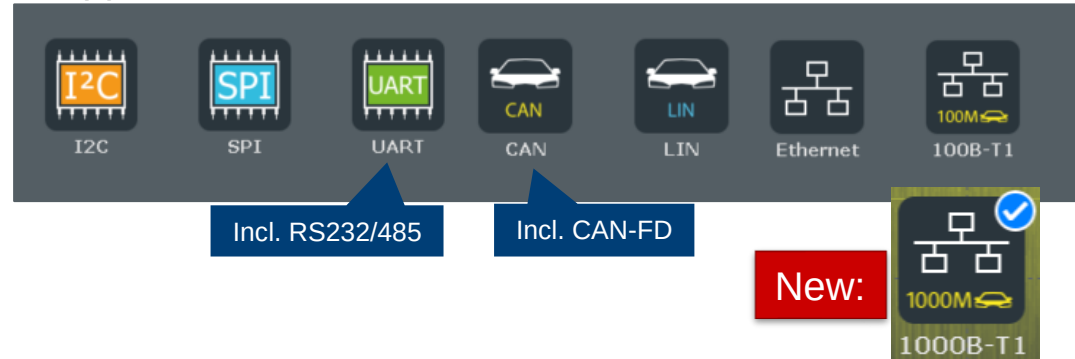
Capability:



Frame error counts,
rate and rate of
consecutive errors



Supported standards:



BUS MEASUREMENT CAPABILITY

EXAMPLE: AUT ETHERNET

Bus Idle %

Protocol measurement	Current	Max	Min	Mean	RMS	σ (S-dev)	Event count	Wave count
Bus idle	80.993 %	99.776 %	80.415 %	81.002 %	81.004 %	0.461 %	1798	1798
Frame count	67	2084	59	101.42	279.5	260.46	122836	1798
FEC	---	2	1	1.037	1.055	0.191	107	1798
FER	0 %	2.899 %	0 %	0.087 %	0.363 %	0.352 %	1798	1798
Consec FER	0 %	0 %	0 %	0 %	0 %	0 %	1798	1798

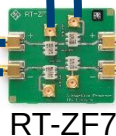
Frames

Frame error rate

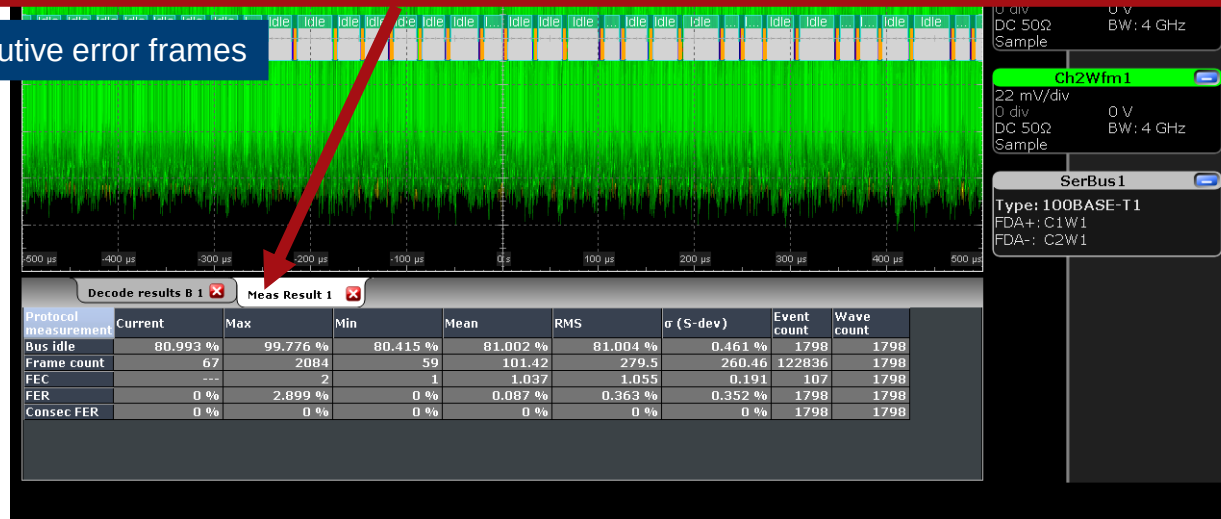
Rate of consecutive error frames



DUT
e.g. ECU

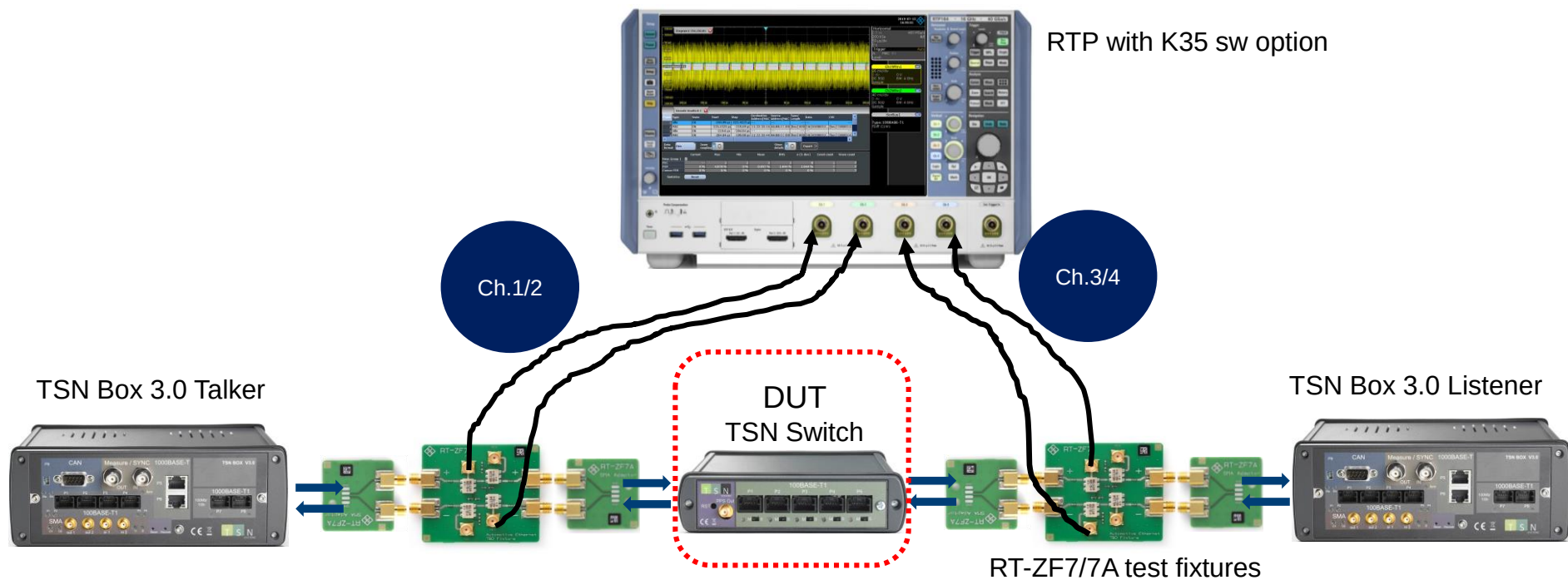


Link
Partner



100/1000BASE-T1 TRIGGER & DECODE APPLICATIONS

EXAMPLE: VERIFY TSN SWITCH PERFORMANCE



***Switch delay = Trig(Ch.1) to frame(Ch.2)**

Meas Result 1								
Protocol measurement	Current	Max	Min	Mean	RMS	σ (S-dev)	Event count	Wave count
Trig to frame	1.0998 μ s	1.1005 μ s	1.0675 μ s	1.0861 μ s	1.0862 μ s	12.315 ns	1009	1022

TELEMATICS CONTROL UNIT (TCU): THE GATEWAY TO CONNECTED CARS

Important to know:

- Some automotive 4G LTE modems implemented in the TCU can operate at 300-400 Mbps



Image source: Ficosa

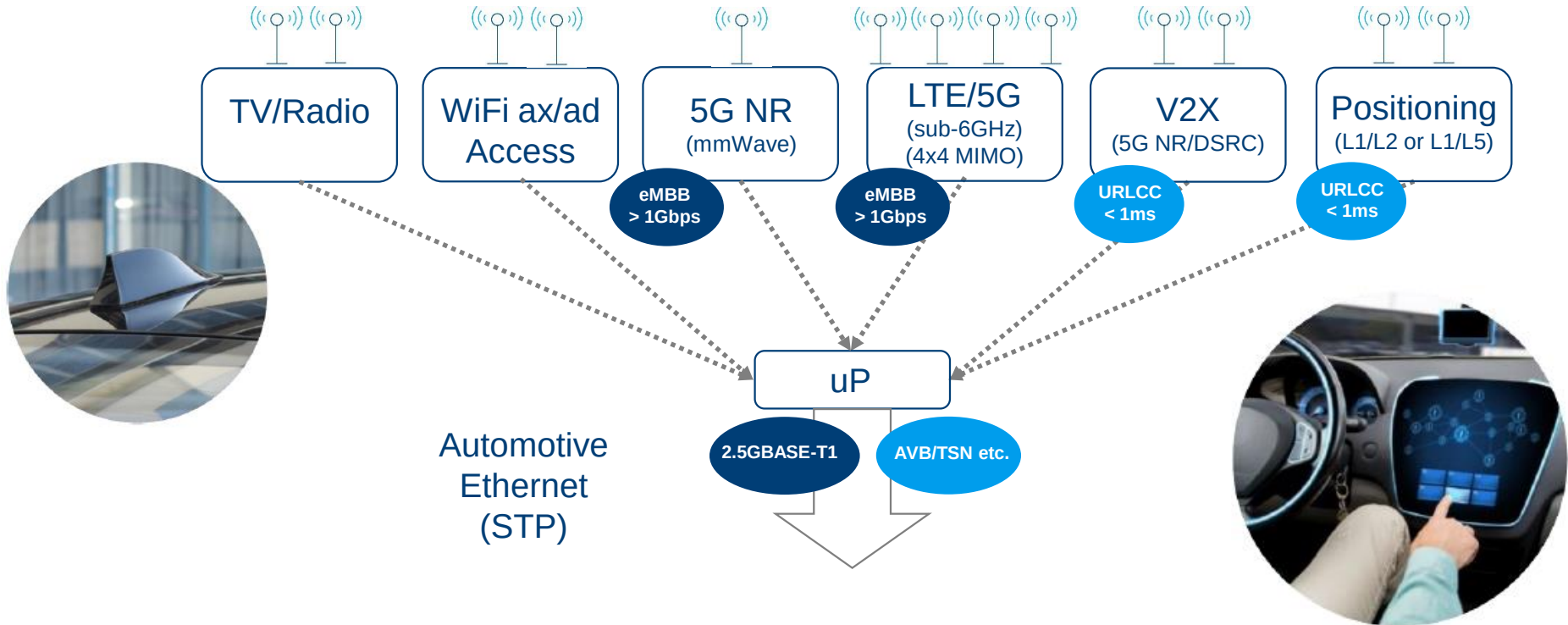
- IAM: 5G speeds up to 1.6Gbps*

*Maximum theoretical download speed

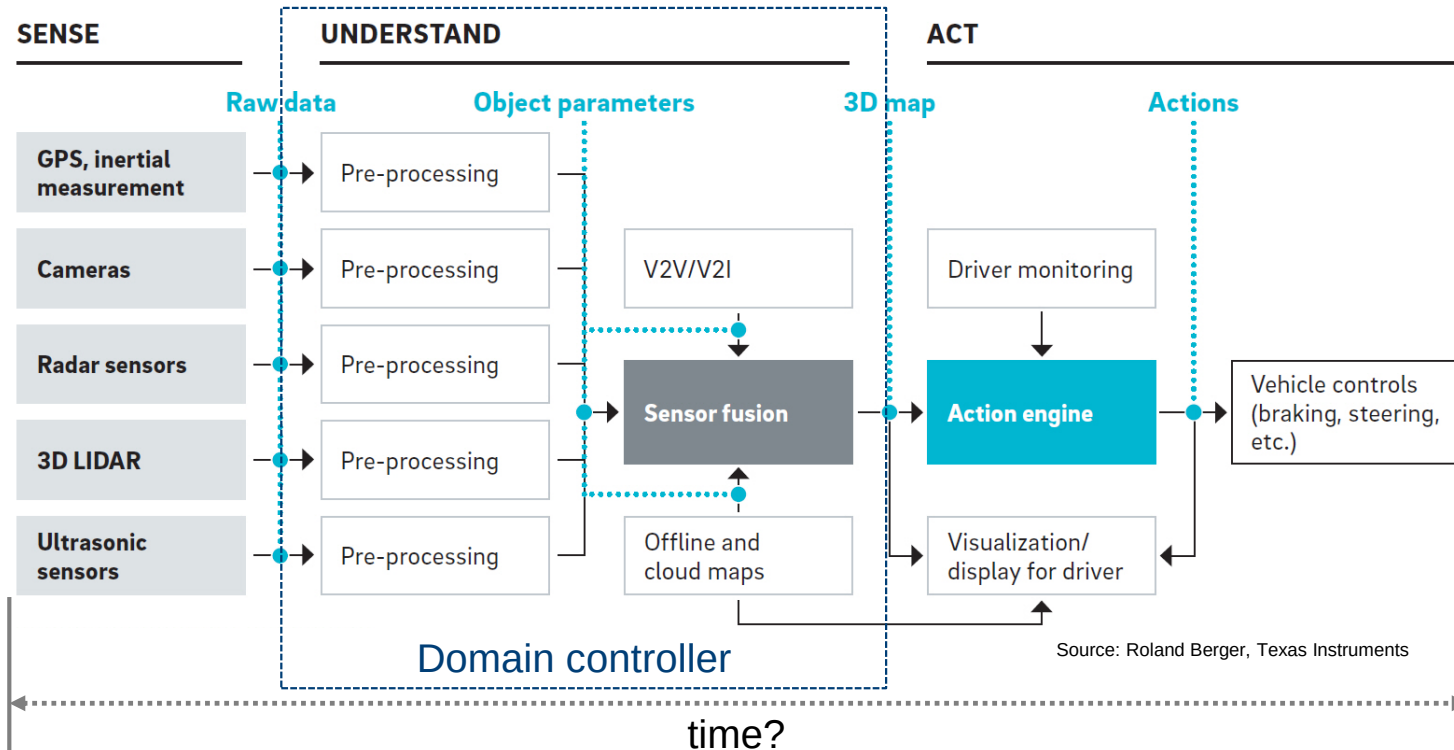


Image source: Continental

NEXT-GEN TCUs - IAM (INTELLIGENT ANTENNA MODULE)



AUTONOMOUS DRIVING: FROM SENSORS TO ACTUATORS

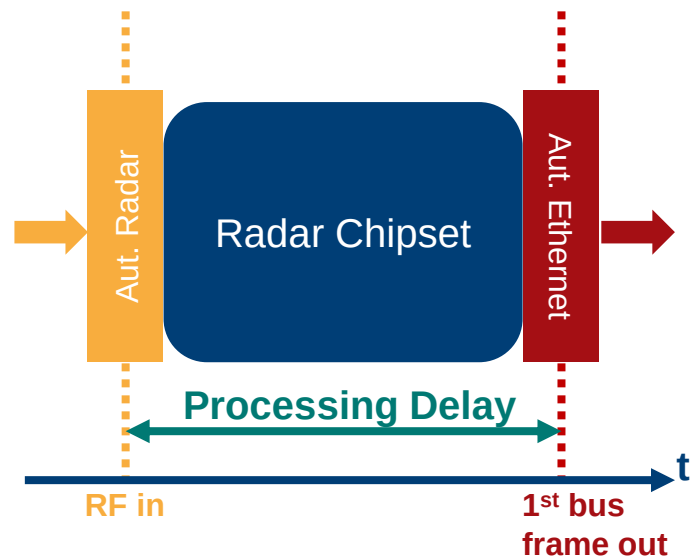


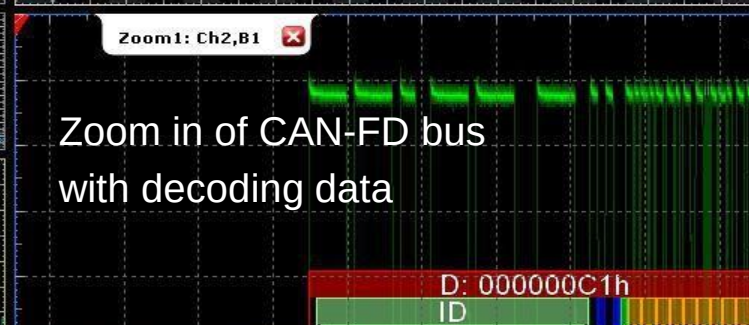
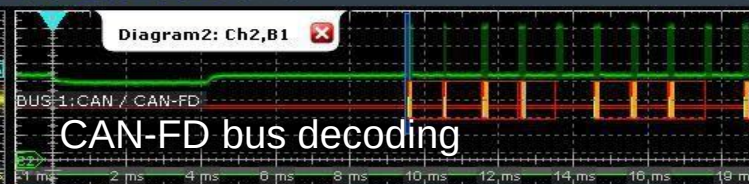
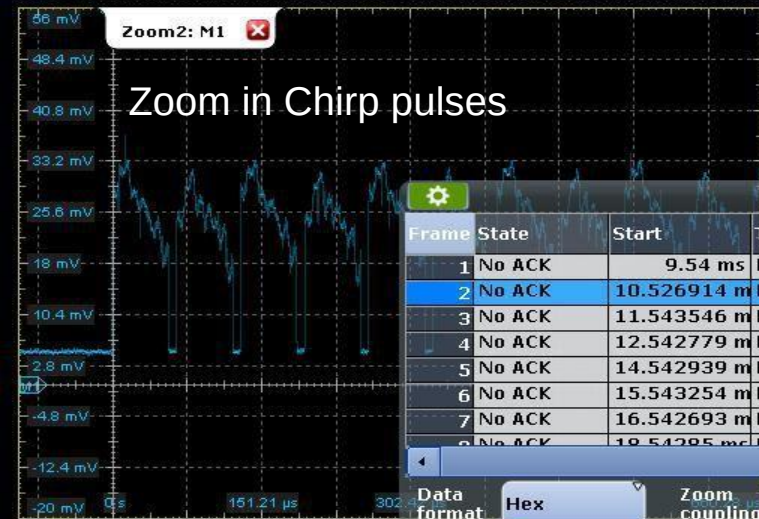
100/1000BASE-T1 TRIGGER & DECODE APPLICATIONS

EXAMPLE: ADAS SENSOR LATENCY

- ▶ Safety-critical applications (e.g. self-driving vehicles) have **strict latency** requirements
- ▶ Oscilloscope multi-domain capabilities allow measuring system delay of single components and verifying if latency requirements are met

Mode	Interleave	Bit times	Pause Quanta	Delay (ns)
2.5GBASE-T1	1x	10 240	20	4096
5GBASE-T1	1x	10 240	20	2048
5GBASE-T1	2x	13 824	27	2764.8
10GBASE-T1	1x	10 240	20	1024
10GBASE-T1	2x	13 824	27	1382.4
10GBASE-T1	4x	20 480	40	2048





Decode results B 1

Frame	State	Start	Type	ID type	ID value [hex]	Standard	DLC	NDB [dec]	Values	Sym
1	No ACK	9.54 ms	Data	29 bit	C1	CAN-FD	14	48	[hex] 02 01 04 03 0	---
2	No ACK	10.526914 m	Data	29 bit	D1	CAN-FD	8	8	[hex] 01 00 00 00 7	---
3	No ACK	11.543546 m	Data	29 bit	D1	CAN-FD	15	64	[hex] 34 00 09 00 0	---
4	No ACK	12.542779 m	Data	29 bit	D1	CAN-FD	15	64	[hex] 32 00 00 00 9	---
5	No ACK	14.542939 m	Data	29 bit	D1	CAN-FD	15	64	[hex] F8 00 00 00 2	---
6	No ACK	15.543254 m	Data	29 bit	D1	CAN-FD	15	64	[hex] C5 00 01 00 F	---
7	No ACK	16.542693 m	Data	29 bit	D1	CAN-FD	15	64	[hex] 4D 00 8F FE EE	---
8	No ACK	18.54285 m	Data	29 bit	D1	CAN-FD	15	64	[hex] 12 00 FF FF 0	---

Horizontal

1 ns 1 GSa/s
20 MSa RT
2 ms/div
0 s

Trigger Normal

A: Width Ch1
Level: 33.621 mV

Ch1Wfm1

20 mV/div
0 div 0 V
DC 50Ω BW: 8 GHz
Sample

Ch2Wfm1

500 mV/div
0 div 1.68 V
DC 50Ω BW: 1.5 GHz
Sample

Math1

Scale: 20 mV/div
Max: 180 mV
FIR(lowpass,abs(Ch1),1e6...

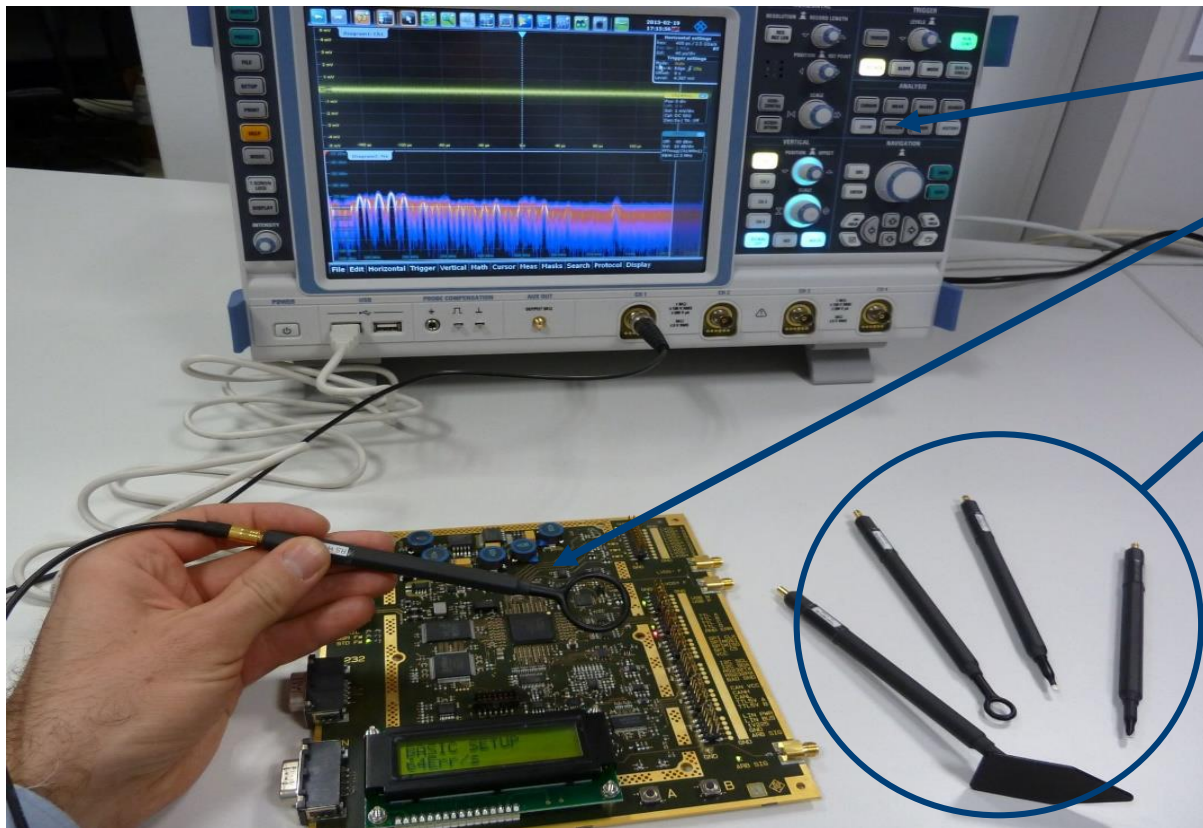
SerBus1

Type: CAN / CAN-FD
Data: C2W1

Meas Group 1	Meas Group 2
Frame to frame 986.91 μs	Pulse count 64
Triq to frame 9.54 ms	Pulse train 4.1459 ms
Bus idle 62.782 %	

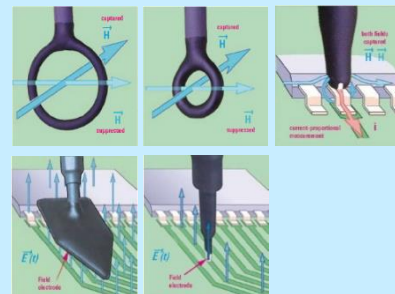
From start of 1st chirp until start of 1st CAN-FD frame

EMI DEBUGGING: EQUIPMENT



R&S ® RTO

**Near-field sniffer
Probes R&S ® HZ-15**
E- and H-field



30 MHz – 1 GHz
Can be used down to 100 kHz

*Optional:
R&S ® HZ-16
Preamplifier*

OA COMPLIANCE TESTING PHY LAYER SUMMARY



R&S®RTP

Max freq. 16GHz

OA TC8 & OA TC15
Supports speeds up to 10GBASE-T1



R&S®RTO6

Max freq. 6GHz

OA TC8 & OA TC15
Supports speeds up to 2.5GBASE-T1



R&S®ZNB

4-port VNA
9kHz – 40GHz

OA TC9, OA TC8 & OA TC15
8GHz VNA sufficient for 10GBASE-T1



Test it! Trust it!