Bring Safety and Innovation to Autonomous Vehicles

General Manager of AES Electronics Applications
Keysight Technologies
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Traffic Accident Statistics

1,300,000

deaths every year

20,000,000

injuries every year

#1

cause of death among young adults aged 15-29

Source: http://www.who.int/mediacentre/factsheets/fs358/en/

Traffic Accident Statistics

95%
of traffic accidents are
caused by human error

Source: http://www.who.int/mediacentre/factsheets/fs358/en/

KEYSIGHT
TECHNOLOGIES
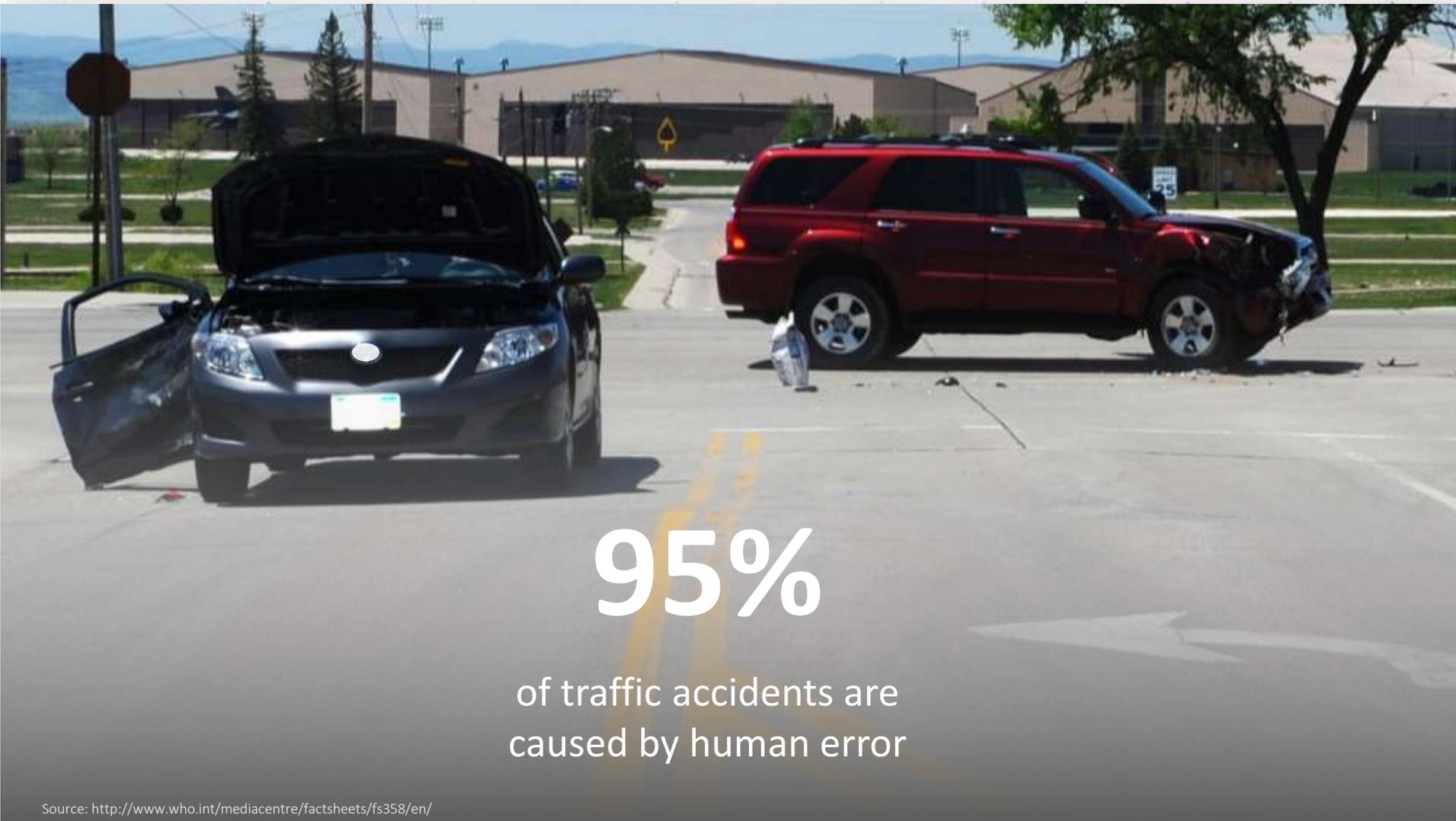
Key Technologies for Autonomous Vehicles

INNOVATIONS FOR ALL ADVANCED DRIVER SYSTEMS

Sensors (Advance Driver Assistance Systems)
- Short and long-range Radar
- Lidar
- Camera Systems

In-Vehicle Network
- CAN/LIN/SENT/MOST
- Automotive Ethernet
- MIPI A-PHY

Wireless Connectivity
- Cellular (4G / 5G + eCall)
- GPS/GNNS
- V2X (DSRC / ITS-G5 & C-V2X)

System Integration
- Sensor Fusion
- AI system training for decision making

Keysight World
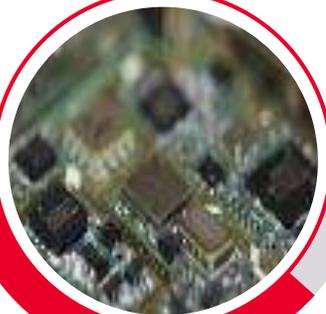
ADAS and Autonomous Vehicle Current Situation

Technology exists today but has limitations

Key Challenges

- Sensors
  - Performance and Coverage vs Cost
  - Interference (Radar vs Radar vs other wireless signals)
  - Non-Line-Of-Sight sensing

- In-Vehicle Network
  - Bandwidth Requirements
  - Latency

- Wireless Connectivity
  - Conformance to Global & Regional Standards
  - Cyber-Security

- Development Cost

L0	L1	L2	L3	L4	L5

Robo Taxi Fleet				2019	2025+
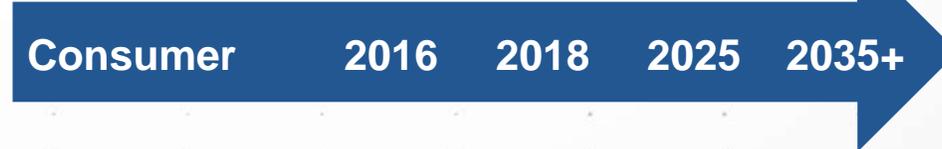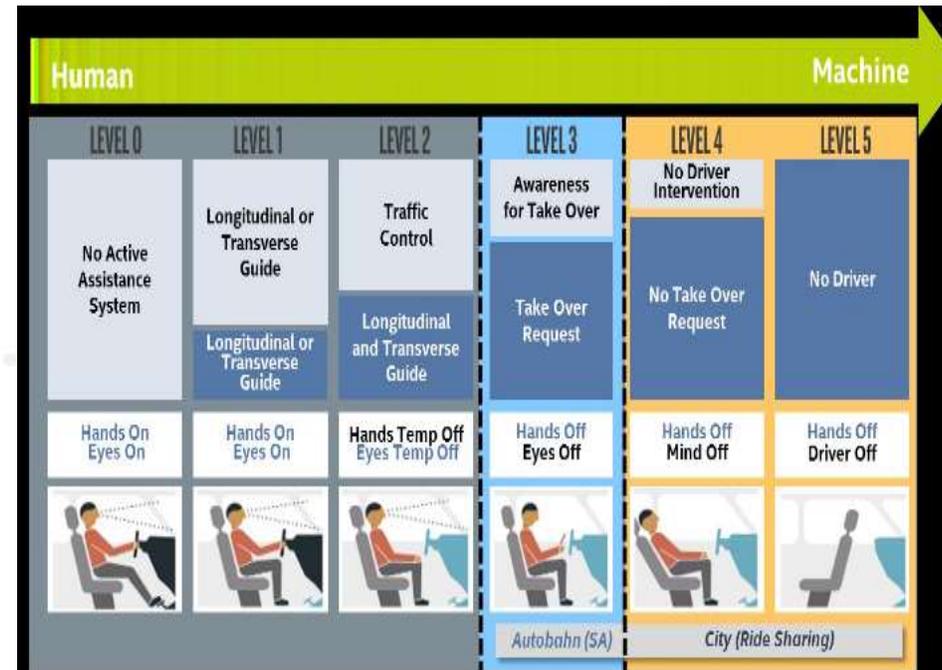
Level 4+ Shared Mobility
Robo -Taxi (Waymo)

Consumer	2016	2018	2025	2035+

Level 2+ Consumer ADAS
Super Cruise (GM), Autopilot (Tesla), Traffic Jam Assist (Audi)

Sensors - Radar

Sensors Overview

- No consensus on types of sensors needed to meet high levels of autonomy. Some believe LiDAR is required, others do not.
  - Tesla is pursuing higher levels of autonomy without LiDAR

- Individual Sensors
  - Different sensors good for different functions and environment
  - Radar vs Lidar vs Camera : Redundancy needed
  - Issues : All sensors depend on line-of-sight (➡ V2X)

- Sensor Fusion – more than just the sum of its parts!
  - Better and safer decisions than independent systems could do
  - Requires centralized processing architecture with high bandwidth In-Vehicle Networks (➡ Automotive Ethernet)

No sensor type works well for all tasks and in all conditions, so sensor fusion will be necessary to provide redundancy for autonomous functions

Most likely used fusion solution in future   ● Good   ● Fair   ● Poor

	Camera	Radar	LiDAR	Ultrasonic	LiDAR+Radar+Camera
Object detection	Fair	Good	Good	Good	Good
Object classification	Good	Poor	Fair	Poor	Good
Distance estimation	Fair	Good	Good	Good	Good
Object edge precision	Good	Poor	Good	Good	Good
Lane tracking	Good	Poor	Poor	Poor	Good
Range of visibility	Fair	Good	Fair	Poor	Good
Functionality in bad weather	Poor	Good	Fair	Good	Good
Functionality in poor lighting	Fair	Good	Good	Good	Good

"Sensor fusion is key because the more complex features get, the more redundancy you need. Every autonomous vehicle is going to have some combination of LiDAR, Radar and camera."
– ADAS engineer at a prominent OEM

Source: WCP 2016

Radar Sensor Capabilities

- Automotive radar implementation is driven by safety requirements by NCAP and NHTSA (AEB) as most car manufacturer uses radar for front obstacle detection and some for blind spot detection

- Remains the best available sensing technology to measure distance and speed, and continuously improving its angular resolution, its weakest point. Unable to classify objects.

- Radar sensors price and size meets automotive requirements, although there is still room for improvements, and has the best performance among the sensors suites when operating in harsh environment conditions.

- Most investment is going into increasing aperture size (improves angular resolution) and moving to 4GHz bandwidth (improves range resolution)

Radar   Echo

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Industry Challenges

Performance
Frequency and BW increase
24GHz, 76 GHz, 77 GHz
RF → Microwave → mmWave
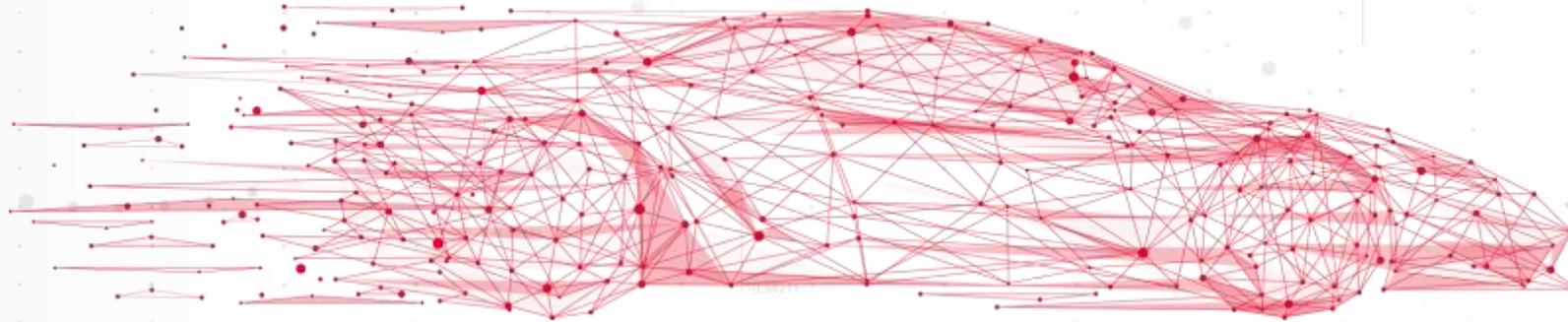
Interference standards
Changing, evolving and different
everywhere in the world

Testing – manufacturing
How to test without a car on the road –
Simulate the real world in your lab.

KEYSIGHT
TECHNOLOGIES

Patchwork Of Radar Frequency Spectrum Allocation

? | 76 - 81 GHz: LRR and SRR | ?

UWB 24.25 - 26.65 GHz | ?

76 - 77 GHz : LRR

UWB 22-29 GHz | ?

76 - 81 GHz : LRR

UWB 22 - 29 GHz

76 - 81 GHz: LRR and SRR

76 - 77 GHz : LRR

UWB 21.65 - 26.65 GHz

77 - 81 GHz: SRR

76 - 77 GHz: LRR

Worldwide | ISM 24.05 - 24.25 GHz

< 2015   2018   2020   2022   2024+
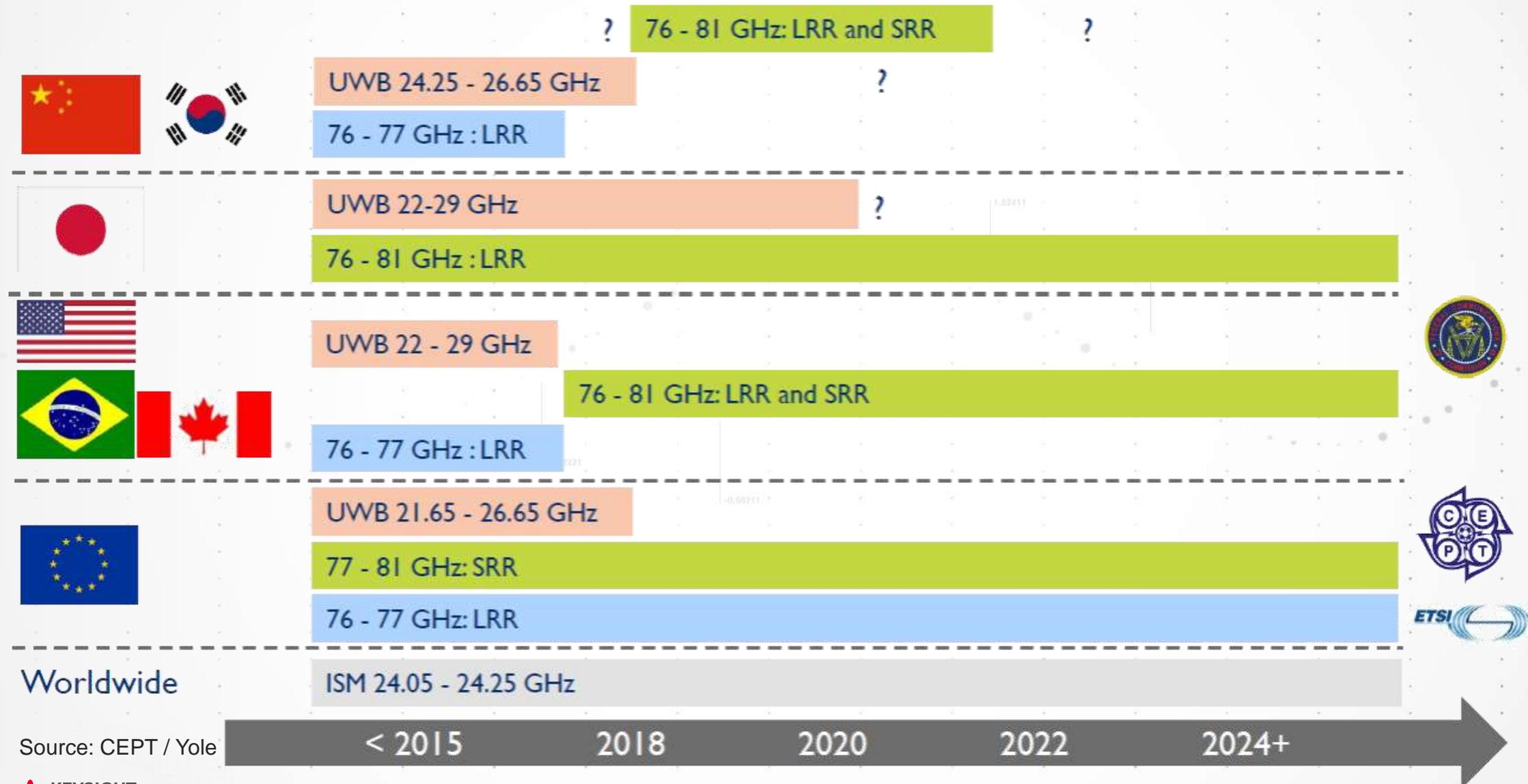
Source: CEPT / Yole

Radar Sensor Performance

The smaller the cubic the better the performance

- Smaller wavelength, doppler, and range resolution
- Smaller and lighter sensor
- Improved interference mitigation
- Higher spectrum sharing
- Less emission power
- Higher range

24 GHz
Narrow-Band
BW 200MHz max

24/26 GHz
UWB 5 GHz BW

77 GHz
1 GHz BW

79 GHz
4 GHz BW

Sensor Performance
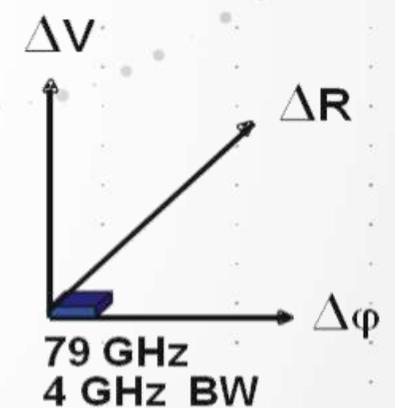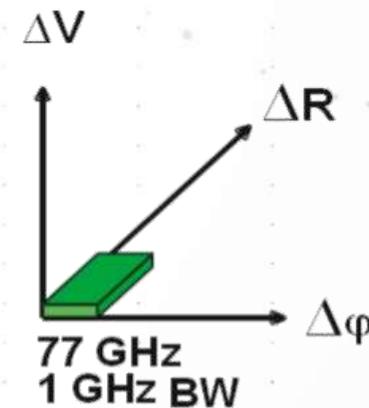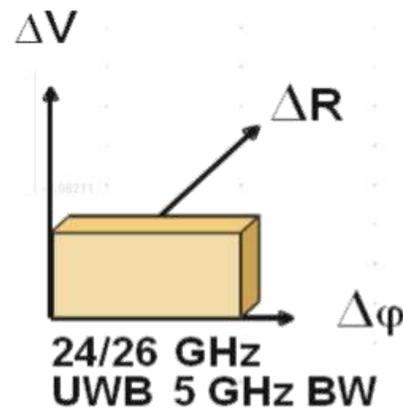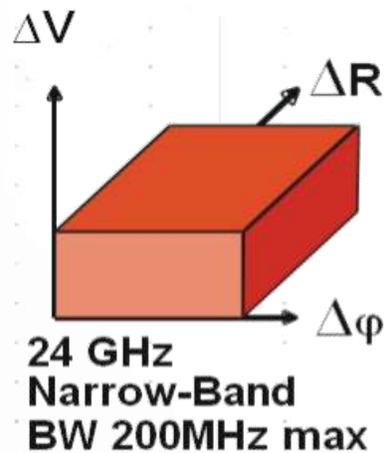
Automotive Application Frequency Range

POSSIBLE INTERFERENCE

>140 GHz Radar

77~81 GHz SRR (77~81GHz)

76~77 GHz LRR (76~77GHz)

60 GHz Motion Gesture Detection Radar

5G backhaul (81~86 GHz)

24GHz ISM NB (24.05~24.5GHz)

5G backhaul (71~76 GHz)

5GAA

5G (37~40 GHz)

LTE-V PC5 V2V,V2I (5.9 GHz)

LTE-V V2X (~3.8 GHz)

DSRC (11p) (5.9 GHz)

5G (24~30 GHz)

Bluetooth (2.4 GHz)

Cellular (850 MHz~2.1 GHz)

WIFI (2.4~5.8GHz)

WiMAX (2.3, 2.5GHz)

RKE/TMPS (315, 413, 434 MHz)

GPS (1.575 GHz)

DAB (100~400 MHz)

FM Radio (88~108 MHz)

AM Radio (1MHz)

Possible Interference

By SeungChul

| 1 MHz, 88~108 MHz | 100~434 MHz | 850 MHz~2.3 GHz | 2.4GHz~3.8 GHz | 5.9 GHz | 24GHz | 60 GHz | 76~81 GHz | 122 GHz | **Frequency** |

In-Vehicle High Speed Digital Communications : Automotive Ethernet, BroadR-Reach, 100 / 1000 BASE-T, MIPI A-PHY

Test Challenge: Creating Interference Scenarios

ETSI Group discussed test setup

D: distance to object

object with RCS (dBsm)

D$_{block}$: distance between EUT and Interference Source

Interference Source = Source for "blocking signal"

CW
Noise
FMCW
Fast Chirps
OFDM
....

Radar Target Simulator

Wideband AWG
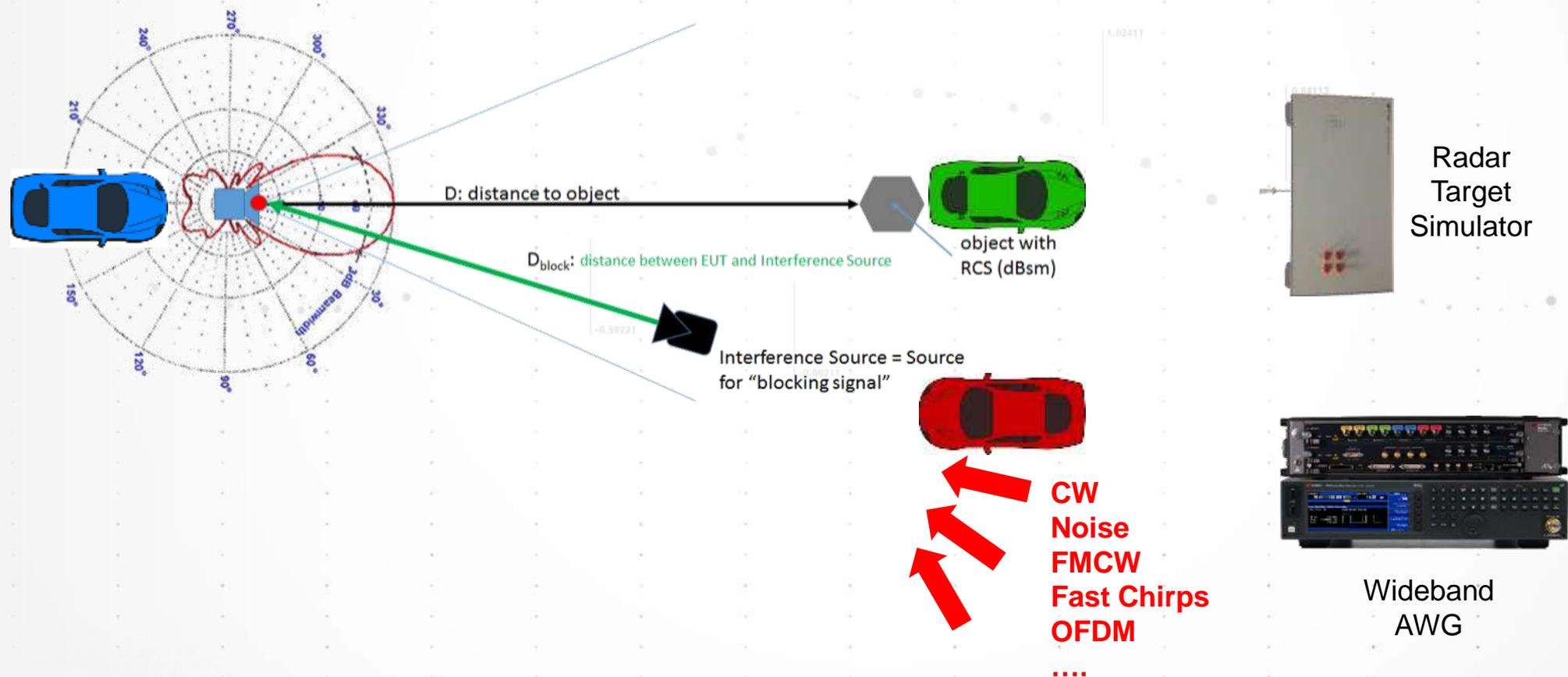
Automotive Radar Rx / Interference Test Solution

INTERFERENCE SIGNAL CREATION UP TO 8GHZ B/W ACROSS E-BAND

Basic interference signals
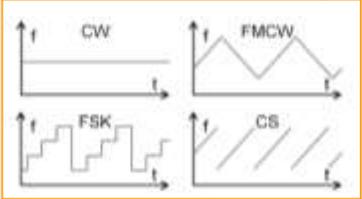
Moving Radar transmit signals as interferer
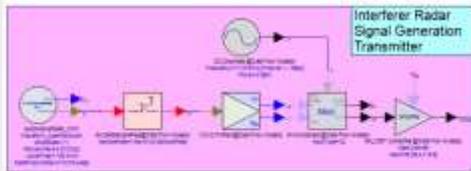
71~76GHz, 81~86GHz 5G mmW Backhaul
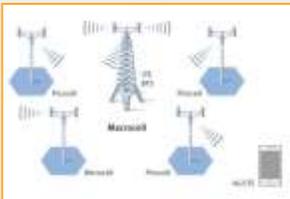
PMCW/OFDM/Coded Next Gen Automotive Radar
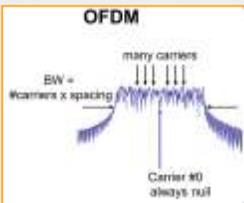
CW
Any type of Noise signals

KS83200A SW

M8195A arbitrary waveform generator
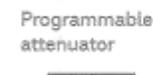
N5183B MXG X-series signal generator

E8708A Radar target simulator

High power mixer with upconverter

IF

LO

Programmable attenuator

Coupler

Power Meter

Power Sensor

Interference Signal

Radar Echo Signal

DUT

E8740A Automotive Radar Solution

>5GHZ UP TO 110GHZ SIGNAL ANALYSIS AND FLEXIBLE SIGNAL GENERATION

Radar Target Simulator

Signal Analysis Solution (Tx)

Signal Generation Solution (Rx)

24GHz | 76/79GHz

E8708A – 79 GHz w/ 4GHz BW

Radar Target simulator for Automotive radar functional test

- 4 GHz Bandwidth
- Range from 5m to 450m, 1m step
- 4 static targets
- Options for OBW and PWR
- Options for dual or single antenna

E8740A-010 Radar RF SA

Leading cost effective Auto Radar RF test tool

- 10 Hz to 26.5 GHz, 60 GHz to 90 GHz
- FMCW RF analysis

E8740A-020, 030 Basic SA

Optimum choice for Auto radar signal quality test

- 60 GHz to 90 GHz,
- 2.5 GHz BW, >5GHz BW FMCW Quality analysis

E8740A-040, 050 Advanced SA

Benchmark for demanding applications

- 10 Hz to 26.5 GHz, 60 GHz to 90 GHz
- 2.5 GHz BW , >5GHz BW FMCW Quality analysis

E8740A-060 Performance SA

Wide-open performance

- 3 Hz to 110 GHz
- >5 GHz BW for FMCW Quality analysis
- DANL-171dBm/Hz@1GHz, -150dBm/Hz up to 110GHz
- 2.4 mm, 1 mm input

- Spurious Emissions tests

E8740A-090 Emissions test solution

Conformance test

- 0 to 330 GHz
- Operating frequency range, peak power, unwanted emission, mean power, and more
- 2.4 mm, 1 mm input

E8740A-070 Performance SG

Wide-open performance

- 60 GHz to 90 GHz
- >5 GHz 3dB BW
- FM, PM, FMCW, pulse sequence, MFSK, custom OFDM

E8740A-080 Interference solution

Flexible wideband interference signal generation

- Full test set-up for ETSI interference test
- 60 GHz to 90 GHz
- >5 GHz 3dB BW
- CW, FMCW, pulse, MFSK, custom OFDM, 5G backhaul,….

OBW and Power measurement

89600 VSA software
Comprehensive demodulation & vector signal analysis
X-Series applications
Ready-to-use RF measurements
FMCW X-App for RF testing
Pre-defined RF test setting for standard
Integrated S/W platform for automotive radar testing

SystemVue
  W1908 Auto radar library measurements
Signal Studio
  N7608C Pulse/FCM/FMCW/MFSK signal creation
Integrated S/W platform for RX/interference test sequence
KS83RX0A Automation platform for automotive radar

Wireless Connectivity – V2X

Crash Avoidance Metrics Partnership (CAMP)

CRITICAL CRASH SCENARIOS

Crash Imminent Scenario	Frequency	Cost	Functional Years Lost
Lead Vehicle Stopped	✓	✓	✓
Control Loss	✓	✓	✓
Vehicle Turning	✓	✓	✓
Straight Crossing Paths			
Lead Vehicle Decelerating	✓	✓	
Vehicle Changing Lane	✓		
Left Turn Across Path			

✓ Denotes top five ranking for the crash category

V2X Augments Sensing To Increase Safety

MAPPING CRITICAL CRASH SCENARIOS AND SAFETY APPLICATIONS

Crash Imminent Scenario	Emergency Electronic Brake Light	Forward Crash Warning	Blind Spot Lane Change Warning	Intersection Movement Assist	Left Turn Assist	Control Loss Warning
Lead Vehicle Stopped		✓				
Control Loss						✓
Vehicle Turning				✓	✓	
Straight Crossing Paths				✓		
Lead Vehicle Decelerating	✓	✓				
Vehicle Changing Lane			✓			
Left Turn Across Path					✓	

KEYSIGHT TECHNOLOGIES

V2X Technologies Overview

- Vehicle-to-X (V2X) refers to an intelligent transport system where vehicles, infrastructure, networks and vulnerable road users are interconnected with each other.

- V2X augments existing sensors though non-line-of-sight (NLOS) and extended range capabilities.

- Two wireless technologies are currently being proposed
  - Cellular-V2X (also called LTE-V or 3GPP Rel14/15 C-V2X)
  - DSRC (based on IEEE 802.11p)

- Secure V2X is considered necessary for safer high level of automation

Source: Qualcomm

Global V2X Trends

| United States 🇺🇸	Europe 🇪🇺	China 🇨🇳
• 5.9Ghz band in 1999 • IEEE 802.11p based system • After 2017 NPRM, no follow up from US authorities • OmniAir certification for OBUs, RSUs, based upon IEEE & SAE standards • 5GAA and other SDOs lobbying DOT on behalf of cellular community	• 5.9Ghz band in 2008 • ETSI standards & conformance regime • European Commission recently approved the "**Delegated Act**" with final vote late May 2019 • 5GAA lobbying EC for C-V2X emphasizing roadmap to 5G	• 5.9Ghz band approved • In favor of LTE based C-V2X • Government driven (9 pilot areas, 6 directions) • Major driving force for 3GPP V2X • Large field trials under way

KEYSIGHT TECHNOLOGIES

What Is Dedicated Short Range Communication (DSRC)

IEEE 802.11P

- DSRC is an approved amendment to 802.11 for wireless access in vehicular environments (WAVE)

- ITS-G5 is the term used in Europe

- V2X communications such as vehicles and infrastructure (V2I) or vehicle to vehicle (V2V)
  - Vehicle safety services
  - Commerce transactions via cars
 - Toll collection
  - Traffic management
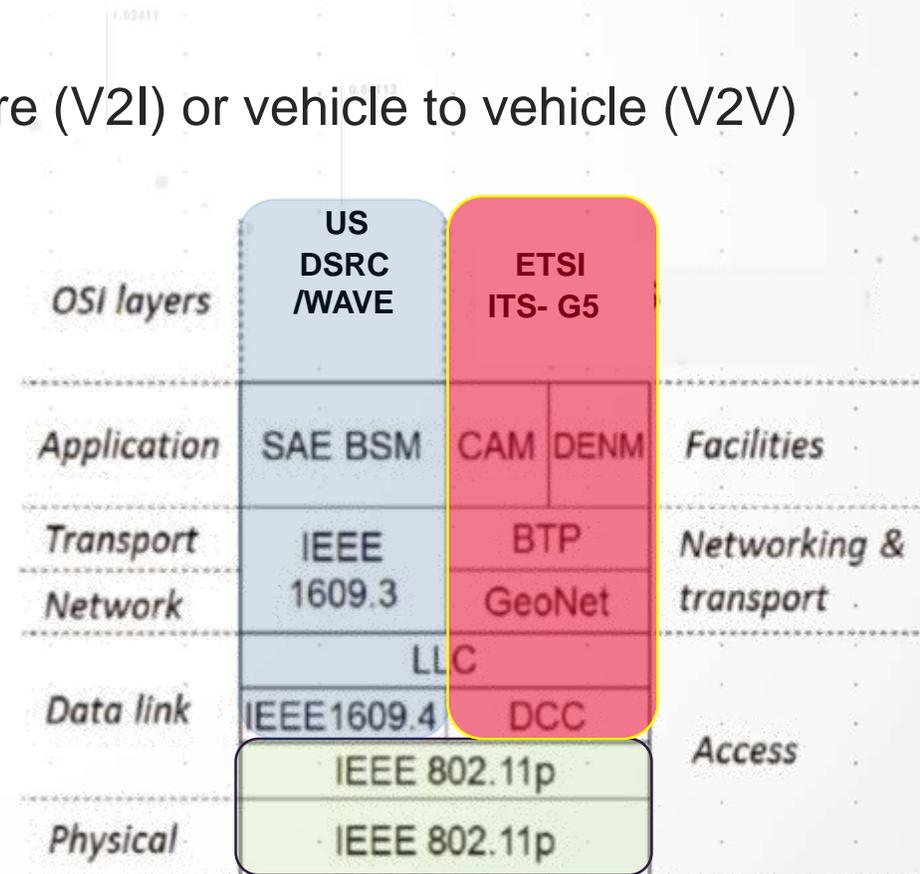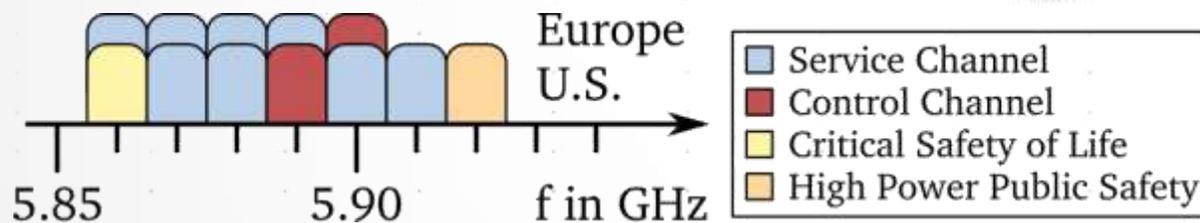
Test Challenges Of Conformance Testing

E6953A V2X Test Solution with 802.11p and DSRC

- Cover OmniAir DSRC Certification Test
  - RF Measurements + Protocol Tests
  - TAP-based Test Cases for OmniAir Certification Test
  - 802.11p 'inband' tests, IEEE1609.2,1609.3, 1609.4
  - SAEJ2945/1
- Solution Components
  - PXIe based HW
  - VXT + DSRC Signaling module
  - Cables and adapters
  - TAP-based Software
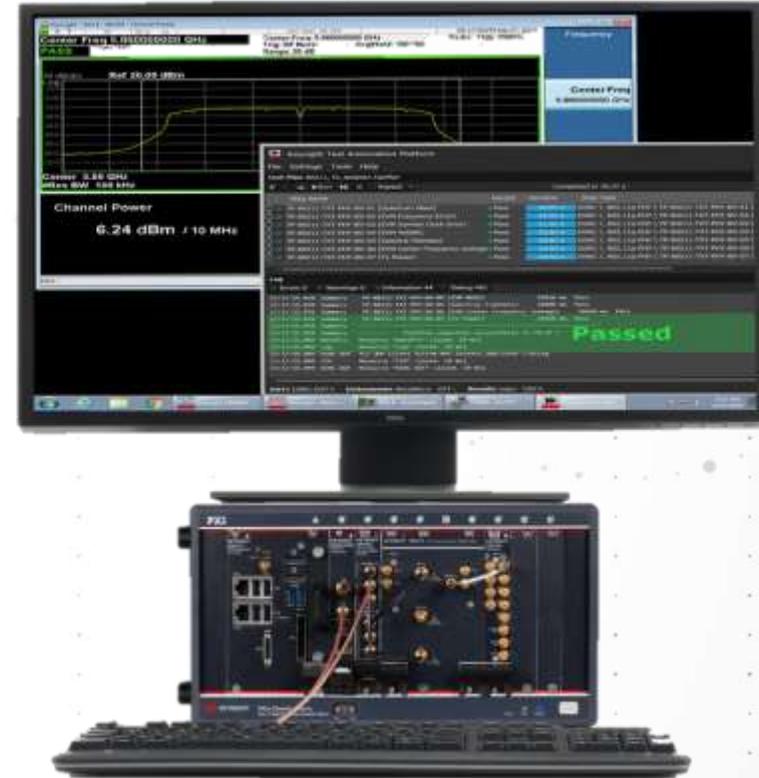
Protocol Conformance
IEEE 1609 2/3/4
SAE J2945

➡

RF Conformance
IEEE 802.11p

➡

Device Certification
OmniAir Device Certification

OMNIAIR ™
CERTIFIED
OQTE DSRC-V2X
2019011401

Using the same test platform in conformance testing will reduce issues and speed up test times.

What is Cellular-Vehicle to Everything (C-V2X)

V2X using Cellular technologies with or without network service

- Band 47 (5.9GHz) for Sidelink Communications (PC5)
- LTE-A 3GPP Rel.14 & 15
- 5G NR 3GPP Rel.16+

Benefits

- Cost Effective
- Evolution to 5G
- Better Security
- Improved Range
- Enhanced Reliability
- VRU Use Cases

- Large and Growing global C-V2X Eco-System
  - Cellular Chipset Vendors / Wireless Service Providers / Automotive OEMs & Suppliers / Road Operators

Mobile LTE / Cellular Network

ITS apps

Edge cloud (MEC) + Core network

OEM backend

Vehicle mgt

NB-IoT

Roadside Infra (eNB-type RSU)

Parking or House

LTE eMBMS

LTE V2N

LTE V2N2I

LTE V2N2P

LTE V2N2I

LTE V2N2I

LTE V2V

LTE V2V

LTE V2V

LTE V2V

local sensors

local sensors
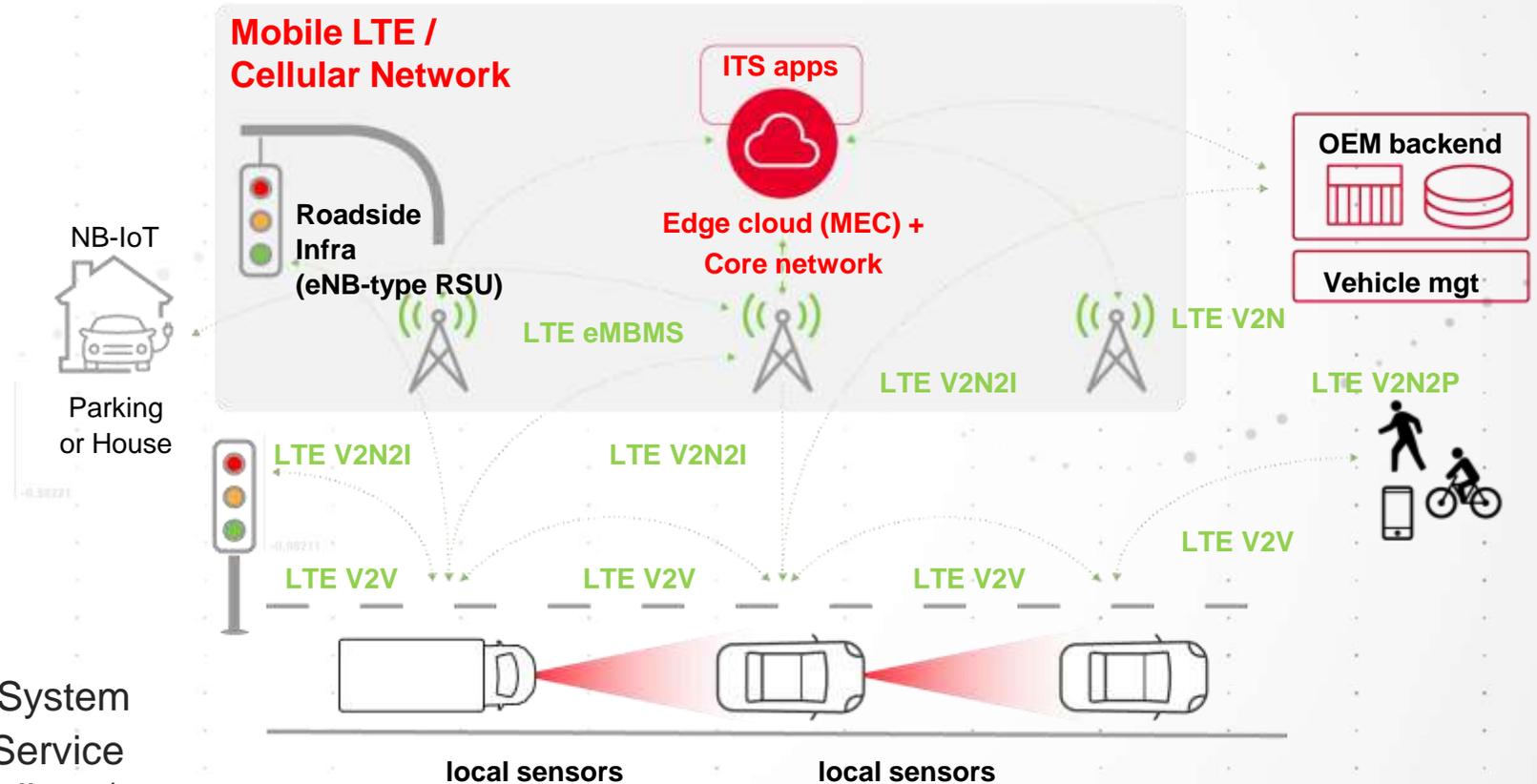
# C-V2X Evolution to 5G New Radio (NR)

Source: 5GAA
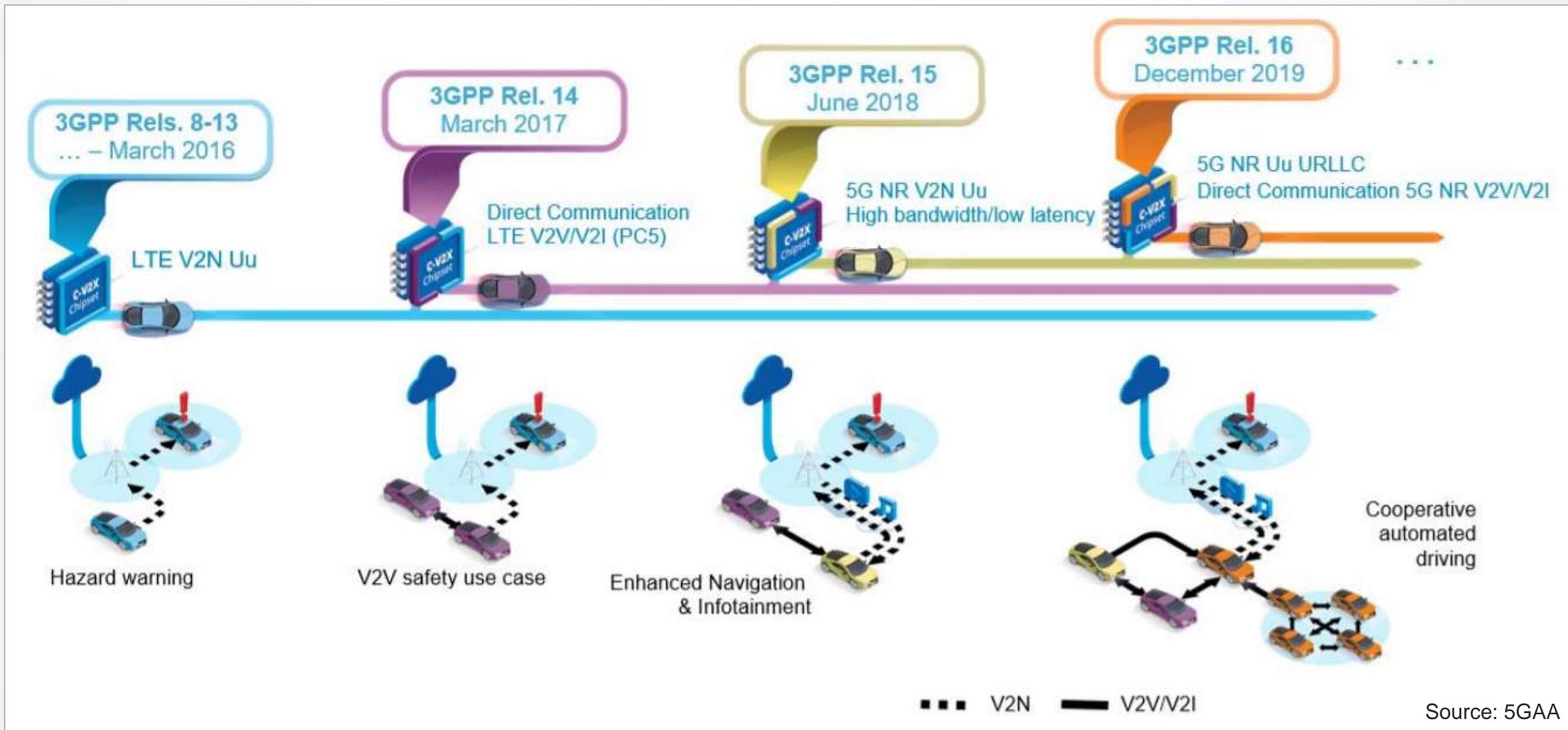
Keysight 5G & C-V2X Emulation Solutions

SUPPORTING OUR CUSTOMERS WORKFLOW

Keysight 1st Solutions across the entire device R&D workflow

5G/C-V2X Interactive R&D Solutions

- **Protocol R&D**
- **RF DVT**
- **Functional & ITS Layer**
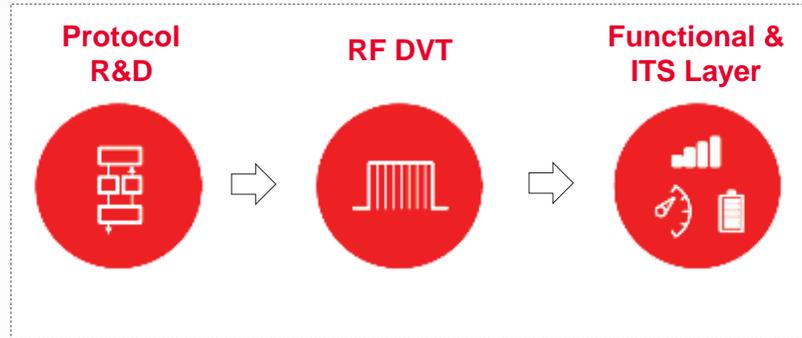
5G/C-V2X Device Acceptance Solutions

- **Protocol Conformance**
- **RF / RRM Conformance**
- **Carrier Acceptance**

Interactive 5G/ITS Stack and Tools

Common measurement science, logging, and automation

UXM 5G Wireless Test Platform

KEYSIGHT TECHNOLOGIES

C-V2X Hardware and Software Solution Components

UXM 5G Wireless Test Platform (E7515B)
- <6GHz Frequency range
- Supports both 4G and 5G in one box
- Integrated RFIO + Internal fading

MXG GNSS Emulator (N5182B)
- 6GHz Freq Range
- Real-time creation of multi-satellite signals for GPS, GLONASS constellations (L1 with C/A code), Beidou (Compass), SBAS/QZSS with up to 40 channels, and Galileo (E1) with up to 16 channels for line-of-sight and multipath signals
- Add impairments such as multipath, pseudo-range error, and CW interference signals in real-time while the signal is playing

Emulation and Verification via C-V2X Test App, X-Apps & ITS Stack Applications
- Uu and PC5 interfaces
- Multiple UE emulation
- Functional & Protocol Test (L1/L2/L3) and modem bring-up
- RF Measurements: EVM, ACLR, OBW, SEM, Chan Power, Tx On/Off Mask
- Optional ITS Stack (ETSI, IEEE) Emulation, Scenario Generation and Monitoring App

KEYSIGHT TECHNOLOGIES

V2X Scenario Simulation Software

WAVEBEE CREATOR : V2X SCENARIO SIMULATION

Create Scenario

- Easy-to-access and quick visual scenario creation via touch-gestures
- All types of V2X messages supported (traffic and infrastructure)
- Multiple entities (cars, traffic lights, etc.) and events in a single scenario
- Easy integration of DUT into scenario
- No need for auxiliary car system modulation (e.g. CAN-bus)
- Pre-defined set of day-1 scenarios included
- Seamless scenario execution

Execute Scenario

- One-touch execution of reproducible scenarios
- Live-simulation and generation of V2X-messages (no pre-encoded messages)
- Real, secured V2X-communication for realistic scenarios
- Included network and physical layer simulation (by Keysight)
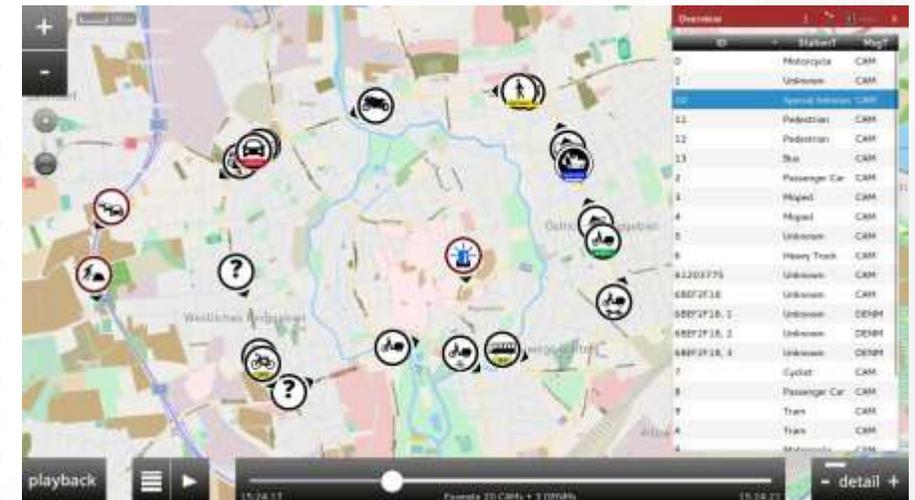
In-Vehicle Network – Automotive Ethernet

What is Automotive Ethernet?

- **Ethernet optimized for vehicular use**
  - Single unshielded-twisted pair cable
  - EMC (CISPR25 Class 5 and PAM3 for noise immunity)
  - Cost and weight
  - Temperature (-40ºC to +125º)
  - Acceleration (up to 4G)
  - Proven technology

- Originally developed by Broadcom as BroadR-Reach/Open Alliance BroadR-Reach (OABR) and later standardized by IEEE as **100Base-T1** (IEEE802.3bw)

|	Cable	Connector
Standard Ethernet		
Automotive Ethernet		
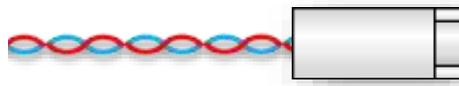
Why Use Automotive Ethernet?

Source: Molex

- Cabling is the 3rd highest cost component in a car (Engine – 1st, Chassis – 2nd)

- Harness are built ONE at a time with 50% of the cost in labor

- Cabling is the 3rd heaviest component in a car (Engine – 1st, Chassis – 2nd)

- Reducing cable weight has a direct impact on fuel economy

- ADAS and Autonomous Systems are driving the need for much greater bandwidth with low latency

|	100BASE-T1	1000BASE-T1	Multi-Gig
IEEE Standard	802.3bw-2015	802.3bp-2016	802.3ch ~2020
Transmissions Speeds	100Mb/s	1000Mb/s	2.5 Gb/s, 5 Gb/s, 10Gb/s
Cable	Single Balanced Twisted Pair	Single Balanced Twisted Pair	Single Balanced Twisted Pair
PHY Signal	PAM3 @ 66.667 Mb/s	PAM3 @ 750 Mb/s	PAM4

Evolution Of The Autonomous Vehicle

Centralized Computing
Integrates inputs from all sensors similar to a human driver's brain

TFLOPS

Gbit/s

100+

20+

ADAS Level

5

4

3

2

1
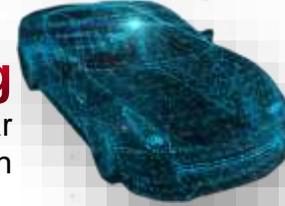
Example Applications

Bandwidth

Uncompressed ADAS Sensor Data (Level 3-4 Autonomy)	📹	24Gbps
Advanced Infotainment/Uncompressed ADAS Sensor Data (e.g. 4K video, Camera Connectivity)	📹 🎵	12Gbps
Infotainment (e.g. full HD video)	🎵	3Gbps
Legacy Entertainment Systems/ Dashboard/ Touch Screens	🎵 🔲	1Gbps
In-vehicle Networks (e.g. Apps, Traffic, Vehicle Health Report)	🔲	150Mbps

10

10

1

1

0.1

0.1

Local Computing
Behind every sensor

Self Driving

📹 Safety   🎵 Infotainment   🔲 In-vehicle networks

Computing & Bandwidth

KEYSIGHT TECHNOLOGIES
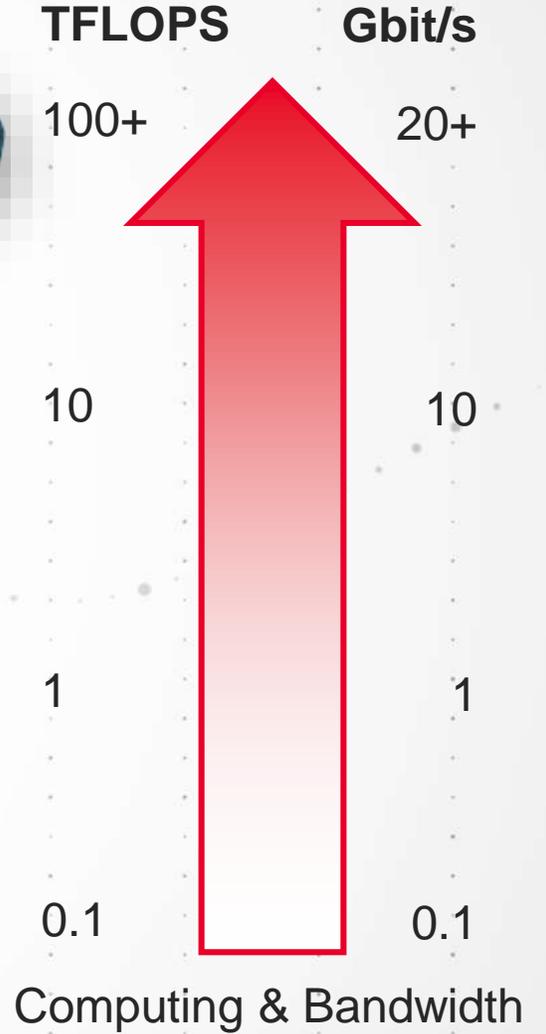
Keysight Automotive Ethernet Solutions
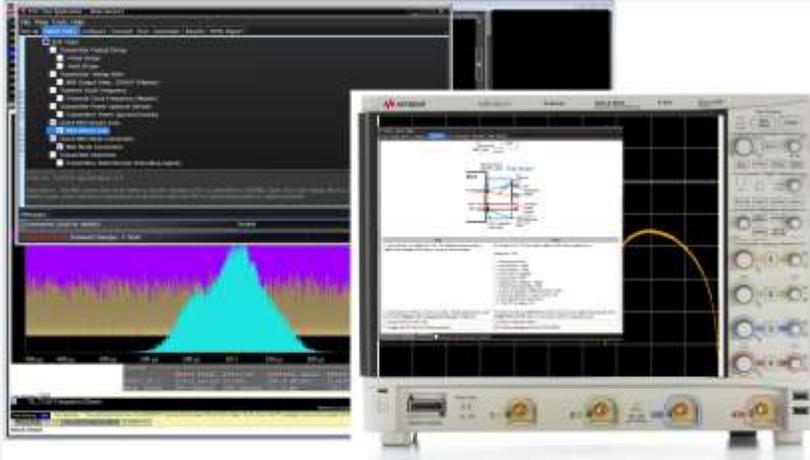
Transmitter

- **Complete 1000BASE-T1 & 100BASE-T1 compliance**
- **Protocol trigger & decode**
- **MDI S-parameter test**

Solution Components

- Oscilloscope, ENA, AWG
- Fixtures, cables, adapters
- Software

Link Segment

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

Solution Components

- ENA Vector Network Analyzer
- Cables and adapters
- Software

Receiver

- **Bit Error Rate verification**
- **Easy-to-follow setup and pass/fail report generation**

Solution Components

- PXIe mainframe, controller, digitizer and AWG
- Cables and adapters
- Software

KEYSIGHT TECHNOLOGIES

Keysight IXIA Automotive Ethernet Solutions

- Addresses the various technical issues around streaming audio and video (AV) over best effort or queued Ethernet

- Audio Video Bridging(AVB) and Time Sensitive Network (TSN)

- IEEE TSN scheduled traffic (802.1Qbv) and multiple time domains (IEEE gPTP-rev)

- OPEN Alliance Automotive Ethernet ECU Test Specifications

# Keysight Automotive Ethernet Solutions

Layer 1 – 7 Coverage

- Only vendor for validation solution spanning across layer 1 to layer 7

- Solution for functionality, conformance and performance validation
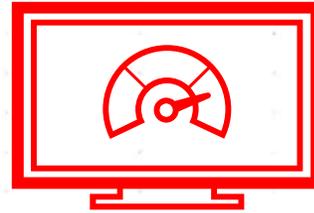
Time Tested Conformance

- 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
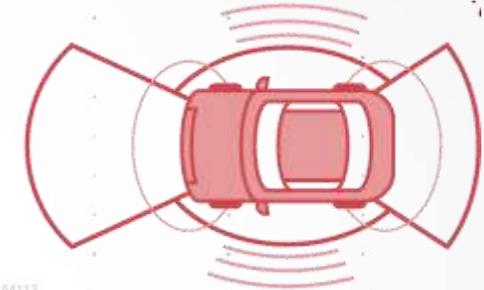
Powerful Test Platform

- AVB / TSN Protocol emulation at scale

- Realistic data traffic for car workload

- Extensive statistics for identifying and debugging failures

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Summary

Advancement in Sensors, In-Vehicle Networks and Wireless Connectivy is on-going and is needed to make autonomous vehicles a reality

Keysight provides solutions covering simulation, design and manufacturing test in all the key technology areas

Let's partner to master the current and future technological challenges and bring your innovations to market first

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TECHNOLOGIES

Automotive & Energy Track Demos

SEE AND HEAR THE LATEST AND GREATEST FROM INDUSTRY EXPERTS

E-Mobility

Scienlab EV Test Solutions

Battery Test Systems

HEV/EV Power Converter

Autonomous Driving

Radar Signal Analysis

Radar Signal Generation

Radar Target Simulator

SystemVue Radar Simulation Library

Automotive Ethernet

Transceiver (Tx) Compliance

Receiver (Rx) Compliance

Link Segment (Lx) Solution

Ixia Level 2-7 Network and Application Testing

V2X Connected Car

Dedicated Short-Range Communications (DSRC)

5G/Cellular V2X (C-V2X)

e-Call

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Automotive & Energy Solutions

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