Bring Safety and Innovation to Autonomous Vehicles

General Manager of AES Electronics Applications
Keysight Technologies
Boon Khim Tan
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/
95% of traffic accidents are caused by human error

Source: http://www.who.int/mediacentre/factsheets/fs358/en/
Key Technologies for Autonomous Vehicles

**INNOVATIONS FOR ALL ADVANCED DRIVER SYSTEMS**

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

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

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

**System Integration**
- Sensor Fusion
- AI system training for decision making
ADAS and Autonomous Vehicle Current Situation

AV TECHNOLOGY HAS ADVANCED BUT MASS MARKET TIMELINE STILL UNCLEAR

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

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**Robo Taxi Fleet**

- **L0**: No Active Assistance System
- **L1**: Longitudinal or Transverse Guide
- **L2**: Traffic Control
- **L3**: Awareness for Take Over
- **L4**: No Driver Intervention
- **L5**: No Driver

**Level 4+ Shared Mobility**

- Robo-Taxi (Waymo)

**Level 2+ Consumer ADAS**

- Super Cruise (GM), Autopilot (Tesla), Traffic Jam Assist (Audi)

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**Timeline**

- **2016**: Consumer
- **2017**: Level 2+ Consumer ADAS
- **2018**: Super Cruise (GM), Autopilot (Tesla), Traffic Jam Assist (Audi)
- **2019**: Robo Taxi Fleet
- **2020**: Level 4+ Shared Mobility (Waymo)
- **2025**: Level 4+ Shared Mobility (Waymo)
- **2035+**: Level 5 autonomous driving
Sensors - Radar
Sensors Overview

No Industry Consensus

- 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.

Object detection
- Camera: Good, Radar: Good, Lidar: Good, Ultrasonic: Poor, LIDAR+Radar: Good

Object classification
- Camera: Good, Radar: Good, Lidar: Good, Ultrasonic: Poor, LIDAR+Radar: Good

Distance estimation
- Camera: Good, Radar: Good, Lidar: Good, Ultrasonic: Poor, LIDAR+Radar: Good

Object edge precision
- Camera: Good, Radar: Good, Lidar: Good, Ultrasonic: Poor, LIDAR+Radar: Good

Lane tracking
- Camera: Good, Radar: Good, Lidar: Good, Ultrasonic: Poor, LIDAR+Radar: Good

Range of visibility
- Camera: Good, Radar: Good, Lidar: Good, Ultrasonic: Poor, LIDAR+Radar: Good

Functionality in bad weather
- Camera: Good, Radar: Good, Lidar: Good, Ultrasonic: Poor, LIDAR+Radar: Good

Functionality in poor lighting
- Camera: Good, Radar: Good, Lidar: Good, Ultrasonic: Poor, LIDAR+Radar: 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)
Industry Challenges

**PERFORMANCE – STANDARDS – PRODUCTION**

**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.

How to test without a car on the road – Simulate the real world in your lab.
# Patchwork Of Radar Frequency Spectrum Allocation

<table>
<thead>
<tr>
<th>Region</th>
<th>Frequency Range</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>UWB 24.25 - 26.65 GHz</td>
<td></td>
</tr>
<tr>
<td>South Korea</td>
<td>UWB 22-29 GHz</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>UWB 21.65 - 26.65 GHz</td>
<td>76 - 81 GHz: LRR and SRR</td>
</tr>
<tr>
<td>Canada</td>
<td>UWB 22 - 29 GHz</td>
<td>76 - 81 GHz: LRR and SRR</td>
</tr>
<tr>
<td>EU</td>
<td>UWB 21.65 - 26.65 GHz</td>
<td>77 - 81 GHz: SRR</td>
</tr>
<tr>
<td>Worldwide</td>
<td>ISM 24.05 - 24.25 GHz</td>
<td></td>
</tr>
</tbody>
</table>

Source: CEPT / Yole

<table>
<thead>
<tr>
<th>Year</th>
<th>&lt; 2015</th>
<th>2018</th>
<th>2020</th>
<th>2022</th>
<th>2024+</th>
</tr>
</thead>
</table>

Keysight World
Radar Sensor Performance

**IMPROVED ACCURACY**

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
Automotive Application Frequency Range

**Possible Interference**

- **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**

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

By SeungChul
Test Challenge: Creating Interference Scenarios

WHAT DOES THIS MEAN FOR TESTING?

ETSI Group discussed test setup
Automotive Radar Rx / Interference Test Solution

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

Basic interference signals
- CW
- FM CW
- PSK
- CB

Moving Radar transmit signals as interferer
- 71~76GHz, 81~86GHz
- 5G mmW Backhaul

PMCW/OFDM/Coded Next Gen Automotive Radar

Any type of Noise signals

KS83200A SW

Interference Signal

Radar Echo Signal
E8740A Automotive Radar Solution

>5GHz up to 110GHz Signal Analysis and Flexible Signal Generation

Radar Target Simulator

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

Signal Analysis Solution (Tx)

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 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 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

Signal Generation Solution (Rx)

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

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

<table>
<thead>
<tr>
<th>Crash Imminent Scenario</th>
<th>Frequency</th>
<th>Cost</th>
<th>Functional Years Lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Vehicle Stopped</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Control Loss</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>Vehicle Turning</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>Straight Crossing Paths</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead Vehicle Decelerating</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>Vehicle Changing Lane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Turn Across Path</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

✔️ Denotes top five ranking for the crash category
# V2X Augments Sensing To Increase Safety

## Mapping Critical Crash Scenarios and Safety Applications

<table>
<thead>
<tr>
<th>Crash Imminent Scenario</th>
<th>Emergency Electronic Brake Light</th>
<th>Forward Crash Warning</th>
<th>Blind Spot Lane Change Warning</th>
<th>Intersection Movement Assist</th>
<th>Left Turn Assist</th>
<th>Control Loss Warning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Vehicle Stopped</td>
<td>![Checkmark]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>![Checkmark]</td>
</tr>
<tr>
<td>Control Loss</td>
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</tr>
</tbody>
</table>
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
# Global V2X Trends

## Regional V2X Policies

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

[United States](https://www.dot.gov) | [Europe](https://www.europarl.europa.eu) | [China](https://www.mot.gov.cn)
What Is Dedicated Short Range Communication (DSRC)

- 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

![Graph showing frequency bands for DSRC/WAVE and ITS-G5](image-url)
Test Challenges Of Conformance Testing

ENSURE TEST CASE COVERAGE WITH QUALIFIED TEST EQUIPMENT

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

Using the same test platform in conformance testing will reduce issues and speed up test times.
What is Cellular-Vehicle to Everything (C-V2X)

C-V2X OVERVIEW

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

UXM 5G Wireless Test Platform

Interactive 5G/ITS Stack and Tools

Common measurement science, logging, and automation

UXM 5G Wireless Test Platform
C-V2X Hardware and Software Solution Components

3 KEY BUILDING BLOCKS

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
V2X Scenario Simulation Software

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)

<table>
<thead>
<tr>
<th>Cable</th>
<th>Connector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Ethernet</td>
<td></td>
</tr>
<tr>
<td>Automotive Ethernet</td>
<td></td>
</tr>
</tbody>
</table>
Why Use Automotive Ethernet?

- 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

<table>
<thead>
<tr>
<th>IEEE Standard</th>
<th>100BASE-T1</th>
<th>1000BASE-T1</th>
<th>Multi-Gig</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.3bw-2015</td>
<td>802.3bp-2016</td>
<td>802.3ch</td>
<td>~2020</td>
</tr>
<tr>
<td>Transmissions Speeds</td>
<td>100Mb/s</td>
<td>1000Mb/s</td>
<td>2.5 Gb/s, 5 Gb/s, 10Gb/s</td>
</tr>
<tr>
<td>Cable</td>
<td>Single Balanced Twisted Pair</td>
<td>Single Balanced Twisted Pair</td>
<td>Single Balanced Twisted Pair</td>
</tr>
<tr>
<td>PHY Signal</td>
<td>PAM3 @ 66.667 Mb/s</td>
<td>PAM3 @ 750 Mb/s</td>
<td>PAM4</td>
</tr>
</tbody>
</table>
Evolution Of The Autonomous Vehicle

Computing and Data Bandwidth Requirements

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

Example Applications

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

Bandwidth

- 24Gbps
- 12Gbps
- 3Gbps
- 1Gbps
- 150Mbps

TFLOPS

- 100+
- 10
- 1
- 0.1

Gbit/s

- 20+
- 10
- 1
- 0.1

Computing & Bandwidth

ADAS Level

- 5
- 4
- 3
- 2
- 1

Self Driving

Local Computing
Behind every sensor

Keysight World
Keysight Automotive Ethernet Solutions

UNIQUE TEST COVERAGE

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 World
• 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

**Comprehensive Full Layer 1-7 Stack Test Coverage**

<table>
<thead>
<tr>
<th>Layer 1 – 7 Coverage</th>
<th>Time Tested Conformance</th>
<th>Powerful Test Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Only vendor for validation solution spanning across layer 1 to layer 7</td>
<td>• More than 1300 test cases for TCP/IP stack</td>
<td>• AVB / TSN Protocol emulation at scale</td>
</tr>
<tr>
<td>• Solution for functionality, conformance and performance validation</td>
<td>• Test cases matured over last 20 years of use by NEMs.</td>
<td>• Realistic data traffic for car workload</td>
</tr>
<tr>
<td></td>
<td>• Conformance package for Avnu automotive profile</td>
<td>• Extensive statistics for identifying and debugging failures</td>
</tr>
</tbody>
</table>

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

**Keysight World**

*Images and icons used for illustrative purposes.*
Summary

Advancement in Sensors, In-Vehicle Networks and Wireless Connectivity 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
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
Automotive & Energy Solutions
Realize Your Vision Of Mobility
Keysight.com/find/automotive

E-Mobility
Keysight.com/find/e-mobility

Autonomous Driving
Keysight.com/find/autonomous-driving

Connected Car
Keysight.com/find/connected-car