Challenges and Solutions of ADAS and Automotive Radar

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Introduction to ADAS (Advanced Driver Assistance Systems)

- ADAS are systems to help the driver in the driving process.
- The systems inform and warn the driver, provide feedback on driver actions, increase comfort and reduce the workload by actively stabilizing or manoeuvring the car.
- They assist the driver and do not take over the driving task completely, thus the responsibility always remains with the driver.
- ADAS are characterized by all of the following properties: *
  - Support the driver in the driving task
  - Provide active support for lateral and/or longitudinal control with or without warning
  - Detect and evaluate the vehicle environment
  - Use complex signal processing
  - Direct interaction between the driver and the system

* Ref: Code of Practice for the Design and Evaluation of ADAS, Response3

- **Why ADAS?** Traditionally the driver is considered to cause or partially cause of 90% of all accidents often due to a mismatch between driver – vehicle – traffic environment
Examples of ADAS

- Adaptive Cruise Control (ACC)
- Blind Spot Monitoring
- Lane Change Assist
- Rear traffic crossing alert
- and many more.....

- Adaptive light control
- Automatic braking
- Automatic parking
- Collision avoidance systems
- Driver drowsiness detection
- GPS navigation
- Hill descent control
- Intelligent speed adaptation
- Night vision
- Tire pressure monitoring
Common Sensing Technologies for ADAS

- **Ultrasonic** (Parking Assist, Blind Spot Detection)
- **Camera/Video** (Lane Change Assist, Parking Assist)
- **InfraRed (IR)** (Night Vision)
- **Ladar (Laser Detection And Ranging)** / **Lidar (Light Detection And Ranging)** (Speed Detection, Vehicle Identification, Driver Identification)
- **Radar** (Adaptive Cruise Control)
Example of ADAS Sensing in a Vehicle

- Adaptive Cruise Control
- Lane Change Assist
- Blind Spot Detection
- Side Impact
- Pre-Crash
- Advanced Emergency Braking
- Evasive Collision Avoidance
- Adaptive Cruise Control
- Pedestrian
- Stop & Go
- Front Cross Traffic Alert
- Rear Cross Traffic Alert
- Parking Assist
- Side Impact
A typical automotive radar is mounted behind the front grille of a vehicle at a height of less than 1 meter.

The radar emits millimeter waves that are not readily affected by the climate to detect the surrounding conditions.

These devices are employed in advanced cruise control systems, which can actuate a motor vehicle’s accelerator and/or brakes to control its distance separation behind another vehicle.
Automotive radar systems are capable of detecting

- Object and obstacles surrounding the vehicle (Size)
- Their position to the vehicle (Range)
- Their speed relative to the vehicle (Velocity)

There are 4 major frequency bands allocated for radar applications.

- 24.125GHz with a bandwidth of around 200MHz (short/mid-range radar)
- 24GHz with a bandwidth of 5GHz (short/mid-range radar)
- 76-77GHz (narrow-band long range radar)
- 77-81GHz (wideband radar short/mid-range range)
Automotive Radar – 24Ghz ➔ 79GHz Transition

Comparison of sensor performance showing key parameters
Range resolution, Angular resolution, Doppler resolution

Source: CEPT Report 37
Automotive Radar – 24Ghz ➔ 79GHz Transition

Target separation capability

Typ. Long Range Radar Bandwidth

Typ. High Resolution Radar Bandwidth

B = 250 MHz

B = 1500 MHz

Chassis Systems Control

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Radar Sensor Supply Chain

**Chipsets**

- Freescale SiGe chipsets
  - Continental uses Freescale SiGe chipsets for Continental demo

**1st Tier**

- Continental
  - Also supplied 79GHz SiGe proto chips for Continental demo
  - SiGe chip RXN7740 from the RASIC product family for 77GHz LRR model LRR3

**OEM’s**

- Volkswagen
  - 1x FF Dual Camera System
  - 2x FS/RS MM SRR/MRR @ 24GHz (UWB) for BSD

- Mercedes-Benz Daimler
  - 1x FF Dual Camera System
  - 1x FF MM 77GHz LRR/MRR model ARS300 for ACC / Stop&Go

- Audi
  - 2x FF 77GHz LRR model LRR3 “3rdGen” for ACC / Stop&Go used in Audi A8
  - 2x FS/RS 77GHz MRR (front/rear) for BSD/LCA/RCTA

**Multi-Purpose Camera System**

- Keysight Technologies
  - 2x PCB Modules
    - RF Module: RF MMIC, Radar-ASIC (Mod Control, Sig Processing)
    - Control Module: System-ASIC, FlexRay Transceiver, CAN Interfaces
Automotive Radar
Example of 77GHz Radar System
Automotive Radar
Example of 77GHz Radar System & Keysight Design and Test Solutions

**mmW Signal Generation with simulated signals**

- AWG
- PSG
- mmWave Source Module
- TX Antenna
- Radar Target Simulator

**mmW Signal Analysis with FMCW modulation**

- UXA
- Scope
- mmW Smart Mixer
- RX Antenna
Automotive Radar – Test Challenges

AR Sensor Technology Challenges:

• Frequencies – include 24GHz, plus 77GHz and 79GHz mmW.
• Bandwidth – from 100MHz up to 2GHz BW at mmW.
• Power – need to validate both wanted power levels plus unwanted emissions against ETSI conformance specifications (e.g. ETSI EN 302 264 for 79GHz).
• Modulation & Phase Noise – both need to be verified to ensure sensor provides required range, velocity and target identification/separation performance.
• Protocol – ensure communication bus compliance to CAN, CAN-FD, FlexRay, Ethernet (BroadR-Reach) standards.
• Complex real-world environment scenarios, includes multiple moving targets, multi-scattering RCS, unwanted clutter and interference.
Automotive Radar – T&M Solution Enablers

- Protocol Solutions
- RF Network Analysis
- Power Measurement
- RF Simulation Tools
- Signal Generation
- Signal Analysis
  - RF Power
  - Modulation
  - Phase Noise
Automotive Radar – Protocol Solutions

InfiniiVision & Infinium Scopes – Protocol Test Solutions
- Hardware-based protocol triggering and decode:
  - CAN, CAN FD, LIN, SENT, and FlexRay
- Symbolic decode and trigger:
  - CAN-dbc and LIN-ldf
- Eye-diagram mask testing
  - CAN, CAN FD and FlexRay
- Compliance Test solutions (*Infinium Scopes only*)
  - BroadR-Reach (Ethernet), MOST50/150

Key Features:
- Provides on-screen time-correlation link between protocol layer decode and physical layer analog signals
- Fast waveform update rates to capture automotive transients
- Real-time frame and error frame counters/totalizers including bus load
- Multiple bus decode triggering and time-interleaved listing
- Segmented memory acquisition – enables efficient capture of longer interval user specified decoding events
- Differential active probing, and extreme temperature probing

Examples:
- CAN eye-diagram mask test, CAN FD decoding
- CAN-dbc symbolic decode

For more information:  [www.keysight.com/find/scopes-auto](http://www.keysight.com/find/scopes-auto)
Automotive Radar – RF Network Analysis

PNA (N522xA) or PNA-X (N524xA) Series
• >67GHz Frequency Extender solution choice of either:
  • Broadband 1mm coax (10MHz-110GHz)
  • Banded waveguide (includes 60-90GHz E-Band)
• 2-port & 4-port solutions
• Optional Built-in Kelvin Bias Tees

Key Features:
• Understand design linear & non-linear behaviors,
• True differential drive, Power leveling,
• S-Parameters:
  • Gain, Return loss, Match, Isolation
• Passive and Active component test applications:
  • Amplifiers, Mixers, Frequency convertors,
  • Antenna test, Materials measurements,
• Pulse measurements,
• Gain & Phase compression, AM-AM, AM-PM,
• Group delay, Noise figure,
• Harmonic distortion (Non-Linear),
• Two-tone, Intermodulation distortion (IMD)

For more information: www.keysight.com/find/pna
Automotive Radar – Power Measurement

E8486A E-Band **
Waveguide Power Sensor

Key Features:
• Precise mmW power measurements with low SWR, mismatch and uncertainty
• Wide dynamic range option
• Frequency range: 60 to 90 GHz
• Power range:
  • Opt 100: -30 to +20 dBm
  • Opt 200: -60 to +20 dBm
• Maximum SWR:
  • Opt 100: <1.06 (>30dB RL)
  • Opt 200: <1.28
• UG-387/U Flange, EIA WR-12
• 50MHz Calibration port

Example A: 2-channel E-Band power measurement using a single dual-channel power meter.

Example B: E-Band mmW source power calibration providing traceability to US National Institute of Standards and Technology (NIST).

** Note: V-Band and W-Band sensors also available.

For more information: www.keysight.com/find/waveguidesensor
Automotive Radar – RF Simulation Tools

SystemVue - W1905EP Radar Model Library

Key Features
1. RF-DSP multi-domain electronic design
2. Antenna and Array antenna model with beamforming (linear & 2D planar)
3. Environment scenarios: moving targets (multi-scatter), clutter, interference
4. Custom DSP algorithm
5. Estimating target range and velocity (remove clutter, interference effects)
6. Advanced measurements & visualizations

Automotive Radar – Signal Generation

M8190A (optional) + PSG + mmW Source Module

- PSG supports up to 80MHz BW at PSG RF output
- PSG + M8190A AWG supports up to 2GHz BW at PSG RF output
- Phase Noise @mmW = PSG RF Phase Noise spec. + 20log(N)

Key Features:
- Download Radar FMCW signals from either:
  - Signal Studio Pulse Builder, SystemVue, Matlab, or other
- Generate ideal reference signals (replace Tx LO/VCO)
- Generate interferer, clutter, jamming test signals (Rx Test)

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**mmW Signal Generation**

** PSG **
E8257D Analog, 67GHz (I/Q Mod not req’d) or E8267D, 44GHz (if I/Q Mod not req’d, 80MHz BW) or E8267D-016 (if I/Q Mod req’d, 2GHz BW)

** mmW Source Module **
E8257DS12 (60 to 90GHz, N=6) or E8257DS10 (75 to 110GHz, N=6)

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**Note:** Could replace M8190A + PSG combination with single UXG wideband chirp signal source as alternative.

For more information:  [www.keysight.com/find/psg](http://www.keysight.com/find/psg) and [www.keysight.com/find/m8190a](http://www.keysight.com/find/m8190a)
Automotive Radar – Signal Analysis – RF Power

X-Series Spectrum Analyzers
- PXA supports 160MHz Real-Time BW up to 50GHz
- **UXA** supports 510MHz Real-Time BW up to 26.5GHz
  - Excellent phase noise (-142dBc/Hz at 1GHz, 100kHz offset)
  - Supports both FMT (freq. mask trig.) and TQT (time qualified trig.)

**mmW Smart Mixers**
- **M1970E** supports 60 to 90GHz E-Band **
  - Excellent low conversion loss (27dB) and calibration accuracy

Key Features:
- Automatic detect mixer model/serial number
- Automatic configuration of mmW frequency & LO harmonic
- Automatic amplitude correction applied through USB plug and play
- Automatic LO level alignments, supporting LO cables up to 3m (10dB insertion loss)

Key Measurements:
- RF Power
- Spectrum Emissions
- Phase Noise
- Frequency Stability
- Modulation Quality

**mmW Signal Analysis**

**Note**: V-Band and W-Band smart mixers also available.

For more information: www.keysight.com/find/uxa and www.keysight.com/find/smartmixers
Automotive Radar – Signal Analysis - Modulation

89601B VSA Option BHP - FMCW Radar Analysis

Key Features:

- Supports over 40 Keysight measurement platforms including
  - X-Series Signal Analyzers
  - Infiniium Oscilloscopes
  - Modular digitizers

- Solution is **bandwidth scalable**

- Signal **Record / Playback** support

- Visualize dynamic signal time and frequency characteristics using displays:
  - RF Spectrum
  - Spectrogram
  - Persistence
  - Cumulative History

For more information: www.keysight.com/find/89601B and 89601B Opt BHP - FMCW Radar Analysis
Automotive Radar – Signal Analysis - Modulation

89601B VSA Option BHP - FMCW Radar Analysis

Key Features:

- Automatically synchronize to FMCW radar signals comprised of multi-chirp linear FM modulation patterns.

- Synchronized Amplitude & Phase ➔

- Synchronized Frequency (FM) Modulation ➔

- FMCW Region Tabular metrics ➔
  - Power and Time
  - Best-Fit FM
  - Phase Error
  - FM Error
  - FM Slope Error

For more information: www.keysight.com/find/89601B and 89601B Opt BHP - FMCW Radar Analysis
Automotive Radar – Signal Analysis – BW Scalable

Use Case #1

Scope** (> 2GHz BW)

or

DUT

Divide by “N” Test Output
(Typ. Test RF 2 - 27GHz)

Use Case #2

Scope** (> 1GHz BW using SA IF Out) +

DUT

PLL VCO Output
(Typ. Test RF 20 - 41GHz)

Use Case #3

X-Series SA + Smart Mixer (300MHz BW) +

DUT

mmW Output
(Typ. Test RF = 76 - 81GHz)

Use Case #4

Scope** (> 2GHz BW) +

Custom Downconverter

DUT

mmW Output
(Typ. Test RF = 76 - 81GHz)

** Note: Example is 10-bit Series Scope, but 89601B VSA supports all Infiniium Oscilloscopes up to 63GHz BW maximum.

For more information: www.keysight.com/find/s-series and www.keysight.com/find/uxa
Automotive Radar – Signal Analysis – Phase Noise

E5052B Signal Source Analyzer
Key Features:
1. **Phase Noise** and **AM Noise**
   - Simple, fast and accurate
   - Uses cross-correlation (noise-cancelling) technique along with heterodyne digital discriminator

2. **Frequency / Phase / Power Transients**
   - Dual heterodyne and divided path analysis
   - Narrowband path (up to 80MHz BW)
   - Wideband path (up to 4.8GHz BW, band dependent, up to 500 MHz BW when using E5053A input port)

**Measure Phase Noise directly at mmW** using:
   - E5052B SSA + E5053A Microwave Downconvertor
   …plus 11970W 75 to 110 GHz Harmonic Mixers

For more information: www.keysight.com/find/ssa
Automotive Radar Component Testing
Analog / Microwave Component Test
Automotive Radar Component Testing

4-Port 13.5/26.5 GHz PNA-X Options 419, 423, 029

Noise source used for calibration only

RF jumpers

receivers

Mechanical switch

Pulse generators

Source 1

Source 2

Signal combiner

Pulse modulator

Pulse modulator

LO

To receivers

Source 1

OUT 1

OUT 2

Source 2

OUT 1

OUT 2

LO

To receivers

Test port 1

Test port 3

Test port 4

Test port 2

Impedance tuner for noise figure measurements

+28V

R1

R3

R2

R4

J1

J2

J3

J4

J7

J8

J9

J10

J11

A

B

C

D

Impedance tuner for noise figure measurements

10 MHz

3 GHz

3 – 13.5/26.5 GHz

Keysight Technologies
Automotive Radar Component Testing

Millimeter Wave Component Testing

Millimeter wave Devices

- Passive Devices
- Amplifiers
- Mixers
- Semiconductors
- Antennas
- Materials

Millimeter wave Measurements

- S-Parameters (N-Port, Differential)
- Absolute power
- Gain compression
- Pulsed measurements
- Material parameters
- Time domain

[Diagram showing analog and millimeter sections with components such as DAC, AMP, ADC, VCO, Xn, LNA, LPF, etc.]

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Automotive Radar Component Testing
Single Connection Multiple Measurements

Ch1: Standard S-parameters. 201 pts, 2-port cal, 1 kHz IFBW. **500 ms**
Ch6: Pulse profile (S21), 401 pts, 2-port cal, using internal pulse gens/mods, 5 MHz IFBW. **33 ms**

Ch2: Two-tone IMD using internal broadband combiner and two internal sources. 101 pts, src/rcvr cal, 100 Hz IFBW. **950 ms**

Ch3: Fastest & most accurate amplifier gain compression. 101 pts, src/rcvr/mismatch cal correction. 10 kHz IFBW. **450 ms**

Ch4: Fastest and most accurate amplifier noise figure measurement. 101 pts, source-corrected NF cal, 1 kHz IFBW. **2700 ms**

5 channel setup with full calibration. No need to connect or disconnect between measurements. S-parameters + pulse profile + IMD + gain compression + noise figure. **Total time: 5.1 s**
Previous ATE system took >186 s with less accuracy. **PNA-X result: more accurate and ~ 37x faster**
Automotive Radar Component testing
Application Example for 77 GHz Automotive Component test

80 GHz Power Amplifier

80 GHz Mixer
Basic mm-wave System Architecture

- Network Analyzer is the measurement engine.
- **Optional** Test Set Controller interfaces to modules
- THz Frequency Extenders provide frequency conversion and signal coupling
Millimeter Wave Configurations

• Two Basic families Broadband or Banded Waveguide solutions

4-port Broadband

4-port Banded
# Banded Waveguide System

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bands</td>
<td>cover 50 GHz to 1THz</td>
</tr>
<tr>
<td>Options</td>
<td>2-port &amp; 4-port options with a Test Set Controller</td>
</tr>
<tr>
<td>Options</td>
<td>2-port Option without a Test Set Controller</td>
</tr>
<tr>
<td>Interface</td>
<td>DUT Interface = waveguide</td>
</tr>
</tbody>
</table>
| Features | • Source Power leveling up to 1.1 THz  
• True differential Measurements  
• Integrated Pulse measurements  
• Mixer measurements  
• Spectral Power Measurements |

**Configuration With Test Set Controller**

**Configuration Without Test Set Controller (Direct Connect)**
mm-wave Measurements

mm-wave Devices

- Passives
- Amplifiers
- Mixers
- Semiconductors
- Antennas
- Materials

mm-wave Measurements

- S-Parameters (N-port, Differential, Translated)
- Absolute power
- Gain compression
- Pulsed measurements
- Material parameters
- Time domain
What is Radar Target Simulator (RTS)?

RTS (Distance, RCS, Speed)

Equivalent
Radar Target Simulator Functionality

The DUT radar signal is

- a) Received
- b) Manipulated
- c) Retransmitted

### RTS will apply

<table>
<thead>
<tr>
<th>RTS will apply</th>
<th>To simulate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Delay</td>
<td>Distance</td>
</tr>
<tr>
<td>Frequency Shift</td>
<td>Radial Velocity</td>
</tr>
<tr>
<td>Attenuation</td>
<td>Object Size (RCS)</td>
</tr>
</tbody>
</table>

Radar (DUT) ➔ Radar Target Simulator (Distance, RCS, Speed) ➔ Radar (DUT)
Radar Target Simulator Test Concept

Vertical Setup

Horizontal Setup
Keysight E8707A Radar Target Simulator
Scalable system configurations

<table>
<thead>
<tr>
<th>Description</th>
<th>Fixed Range</th>
<th>+ Full Range</th>
<th>+ Doppler</th>
<th>+ DUT Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Features</td>
<td>• 76-77GHz</td>
<td>• 10 – 450m with 1m resolution</td>
<td>• +/- 360 Km/h with 0.1Km/h resolution</td>
<td>• Enable DUT Tx power monitoring</td>
</tr>
<tr>
<td></td>
<td>• 1 or 2 Horns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 75 &amp; 150m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 1GHz BW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• RCS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Hardware Configuration
- Base System
- Base system internal HW upgrade
- N5183A MXG
- U2042XA Power Meter

Support & Warranty
- 3 Years Keysight Factory warranty with calibration certificate valid for 1 year
- Optional 1 or 3 years contract
  - Return to Keysight or onsite calibration
  - Spare onsite swap

Keysight Confidential
Keysight Radar Target Simulator
User Interface and controlling software

Bench Environment

Simple and Ease of use GUI

Manufacturing Environment

SW API supporting C++ & C# environment

Connection via LAN

C++ & C# programming

Keysight API

Radar Target Simulator
Keysight Radar Target Simulator Product Summary

Key Product Specifications and Features

<table>
<thead>
<tr>
<th>Specification</th>
<th>Specification Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Range</td>
<td>76 – 77 GHz</td>
</tr>
<tr>
<td>Horn Antenna Configuration</td>
<td>Single and Dual Horns Antenna</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>1 GHz</td>
</tr>
<tr>
<td>Min Target Distance</td>
<td>10m</td>
</tr>
<tr>
<td>Simulated Range</td>
<td>10m to 450m with 1m step</td>
</tr>
<tr>
<td>Doppler Shift Range</td>
<td>+/- 360km/h with 0.1km/h step</td>
</tr>
<tr>
<td>Receive Transmit Gain Control</td>
<td>-63.5dB with 0.5dB step</td>
</tr>
<tr>
<td>Dimension (H x W x D)</td>
<td>222 x 425 x 574 (mm)</td>
</tr>
</tbody>
</table>
Keysight Radar Target Simulator Product Summary

- Wide simulated range coverage with **minimum distance starting from 10m**
- **1GHz** Bandwidth support wide range of module without the need of changing center frequency
- **Scalable** for both Manufacturing and R&D test
  - Basic – Fixed range simulation (ie 75m & 150m)
  - Comprehensive – Full range, RCS, Doppler & DUT Transmit Power
- **Reliable, accurate** and **repeatable** performance
- **Ease of use GUI** and **API** where all parameters controllable in **C++ & C# programming environment**
- Designed, manufactured and **supported by single company Keysight Technologies**
- **World wide support**, calibration and warranty
  - Default 3 years factory warranty
  - Optional upgrade with onsite calibration, onsite spare and 7x24 support packages
- CE and Safety certified
Automotive Radar
Measurement Example

- E-band Signal Generation & Analysis
- 77GHz PCB Array Antenna
Car PCB Performance Verification in Taiwan
Keysight Automotive Radar Solutions
“Over Your Design and Test Lifecycle”

From Design Simulation, Wide Bandwidth mmWave Signal Generation & Analysis, Precise Power and Component Measurements to Manufacturing Tests
Automotive Radar
Radar Design and Test Software Platforms

Electronic Design Automation Software
- SystemVue
- EMPro
- Advanced Design System
- GoldenGate
- IC-CAP
- HeatWave
- Genesys

PC & Embedded Application Software
- Signal Studio
- 89600 VSA

Programming Environments

Productivity Software

Keysight Software leveraging instrument capabilities
Thank You