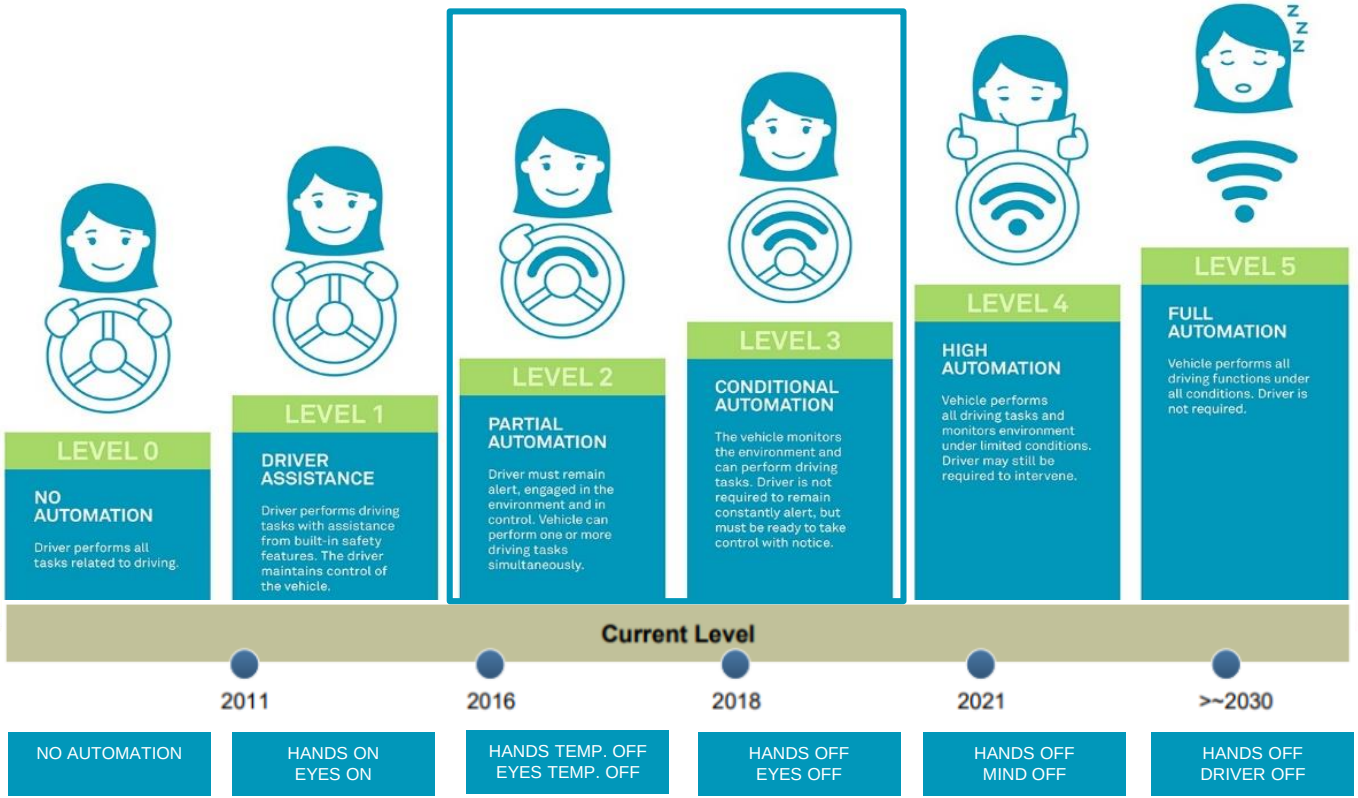
車用雷達測試面面觀

Arsene Chen 陳震華
Application Engineering Manager

ROHDE&SCHWARZ
Make ideas real

ADAS TECHNOLOGY AND TEST CHALLENGES

LEVELS OF DRIVING AUTOMATION (SAE J3016™)



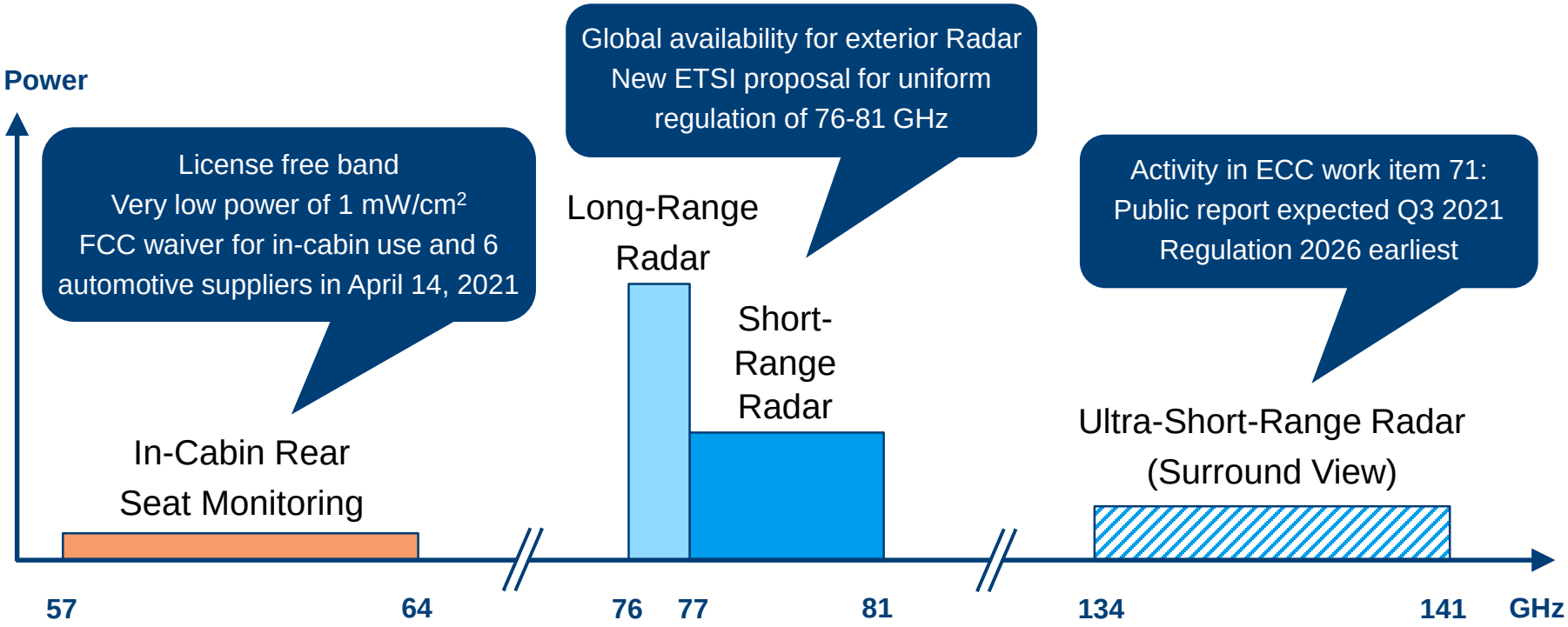
L2+ introduced by OEMs:

L3 like functions with restrictions to comply with missing legal framework

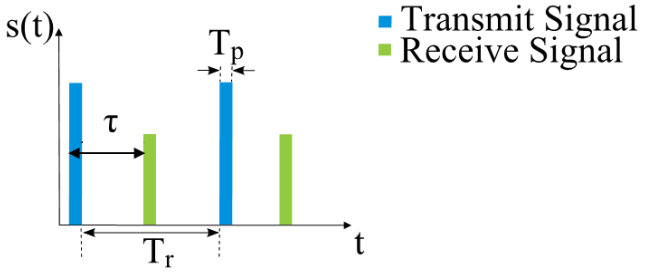
AUTONOMOUS DRIVING REQUIRES TECHNOLOGY INNOVATION IN MANY AREAS

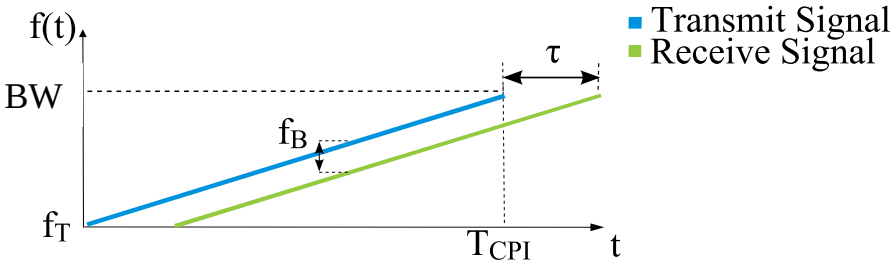
- **Sensor performance and robustness**
  - Radar has potential for reaching Lidar like resolution
  - Lidar not yet meeting cost/performance sweet spot
- **V2X** deployment and infrastructure required
- Road testing needs to be replaced to large extend by improved **Virtual Integration/Validation** and **Vehicle-in-the-Loop** approaches
- **Standardization** required for mastering system complexity

AUTOMOTIVE RADAR FREQUENCY MAP
76-81 GHZ GLOBALLY AVAILABLE



FMCW RADAR – RANGE MEASUREMENT





$$\frac{f_B}{B_w} = \frac{\tau}{T_{CPI}}$$

$$Range = \frac{c}{2} * \tau$$

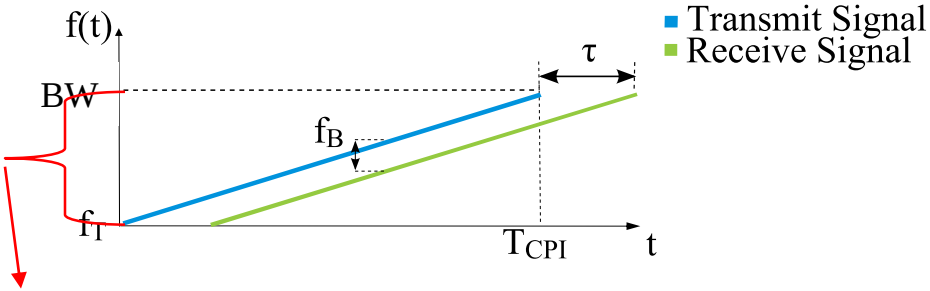
Plug τ into pulsed range equation

Solving for τ

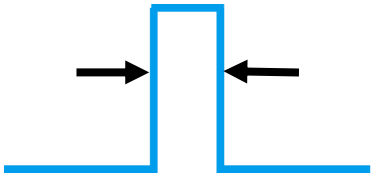
$$\tau = \frac{f_B}{B_w} * TCPI$$

$$R = \frac{c}{2} * \frac{f_B}{B_w} T_{CPI}$$

FMCW RADAR – RANGE RESOLUTION



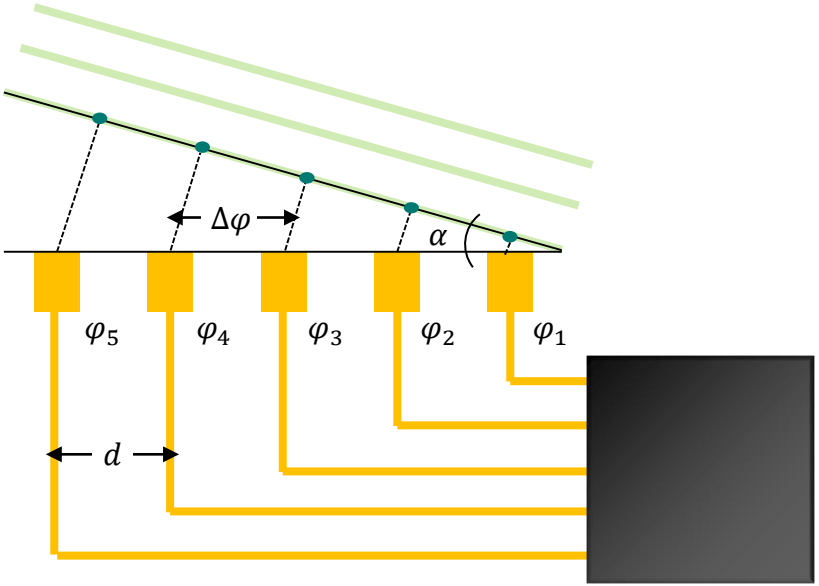
BW (Mhz)	Δ Range (m)	Δ Range (cm)
150	1.00	99.93
250	0.60	59.96
400	0.37	37.47
500	0.30	29.98
750	0.20	19.99
1000	0.15	14.99
2000	0.07	7.49
4000	0.04	3.75
5000	0.03	3.00



The chirp bandwidth determines the range resolution. It is the FMCW equivalent to pulse width in pulsed radar.

$$R = \frac{c}{2} \cdot \frac{f_B}{B_w} T_{CPI}$$

FMCW RADAR – ANGULAR MEASUREMENT



d	Physical distance between antennas
$\Delta\varphi$	Phase difference
α	Angle of arrival
λ	wavelength

$$\alpha = \sin^{-1}\left(\frac{\lambda \cdot \Delta\varphi}{2\pi d}\right)$$

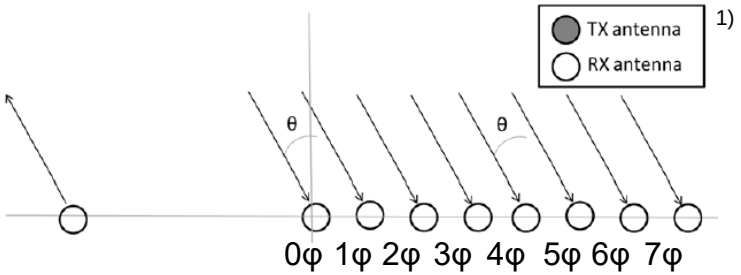
Estimate azimuth / elevation angles from phase differences / amplitudes at the receive antennas of the phased array

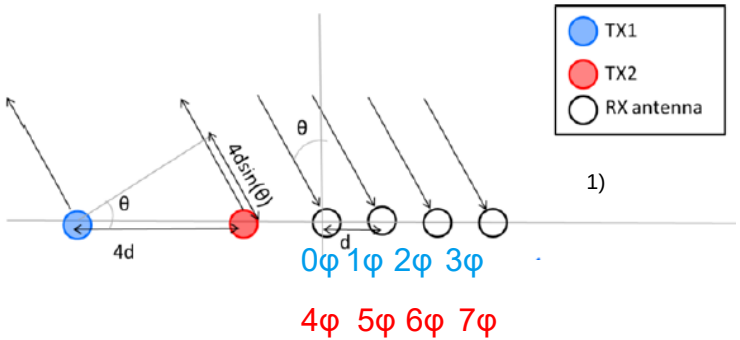
FMCW RADAR – MIMO FOR ANGULAR RESOLUTION

- Requirement: Angular resolution
  Phase difference φ from antenna to antenna
  (Object is far away – plane wave approach)

- Angular resolution with 8 Rx antennas

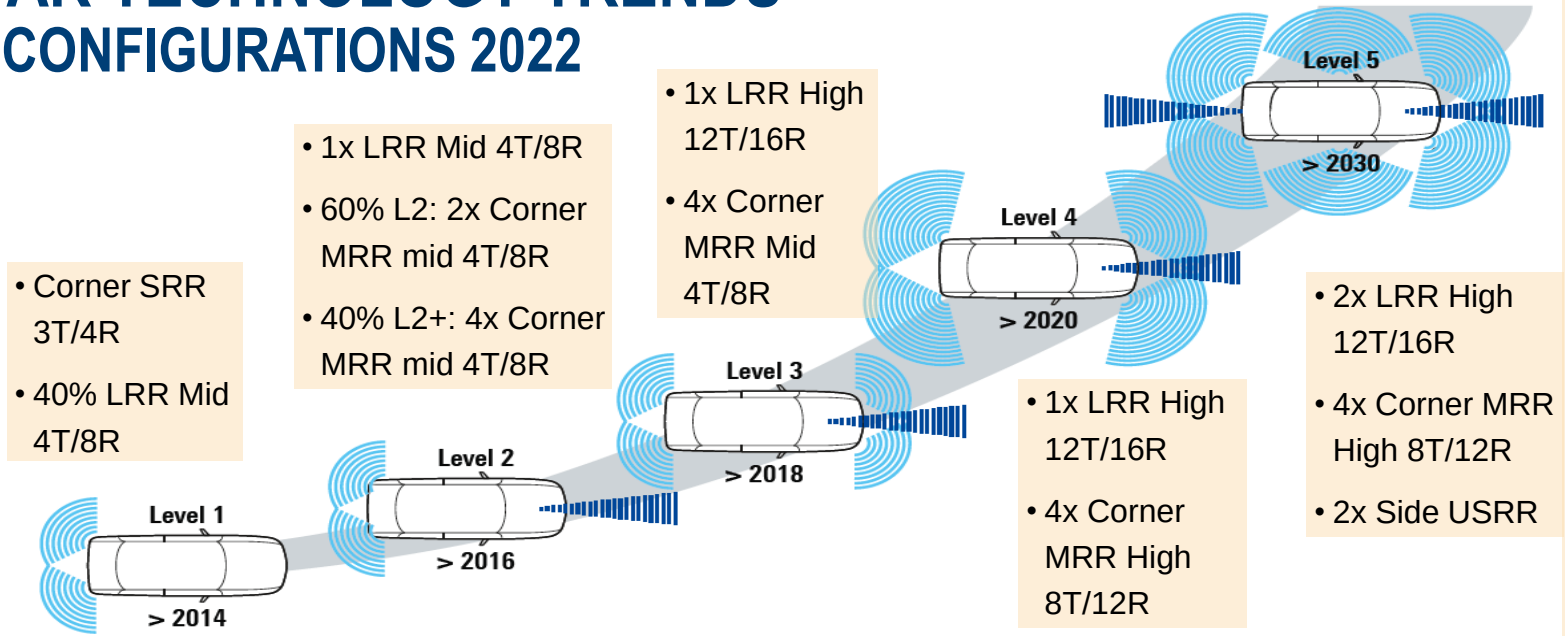
- MIMO approach with 4 Rx and 2 Tx
  Tx1 is seperated by 4d from Tx2
  Wave emanating from Tx2 traverses an additional path of length 4dsin(θ) compared to Tx1
  → 6 antennas vs. 9





1) http://www.ti.com/lit/an/swra554a/swra554a.pdf

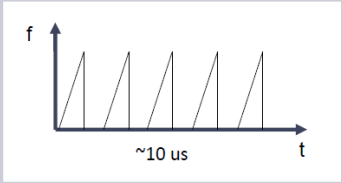
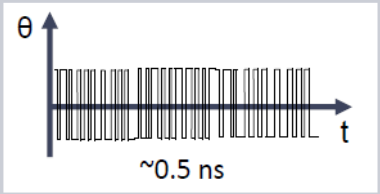
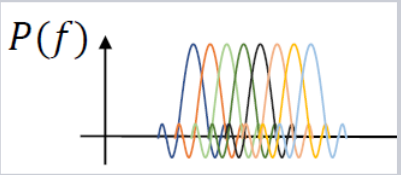
RADAR TECHNOLOGY TRENDS
CAR CONFIGURATIONS 2022



RADAR TECHNOLOGY TRENDS
TYPICAL SENSOR PARAMETERS

Radar Module Parameters	Short-Range Radar	Standard Mid-Range Radar	Premium Mid-Range Radar	Standard Long-Range Radar	Premium Long-Range Radar
Frequency Range [GHz]	24,76-77,77-81	76-77	77-81	76-77	76-77
Typical Bandwidth [MHz]	200, 1000, 4000	1000	2000	500	1000
Range [m]	80	150	150	250	300
Range Resolution [cm]	300, 30, 3.5	30	7.5	75	30
FOV Azimuth / Elevation [°]	±60 / ±0	±30 / ±0	±50 / ±15	±15 / ±5	±15 / ±10
Typical Channel Number [Transmit / Receive]	3 TX / 4 RX	4 TX / 8 RX	8 TX / 12 RX	4 TX / 8 RX	12 TX / 16 RX

RADAR TECHNOLOGY TRENDS
NEW MODULATION SCHEMES FOR BETTER INTERFERER ROBUSTNESS

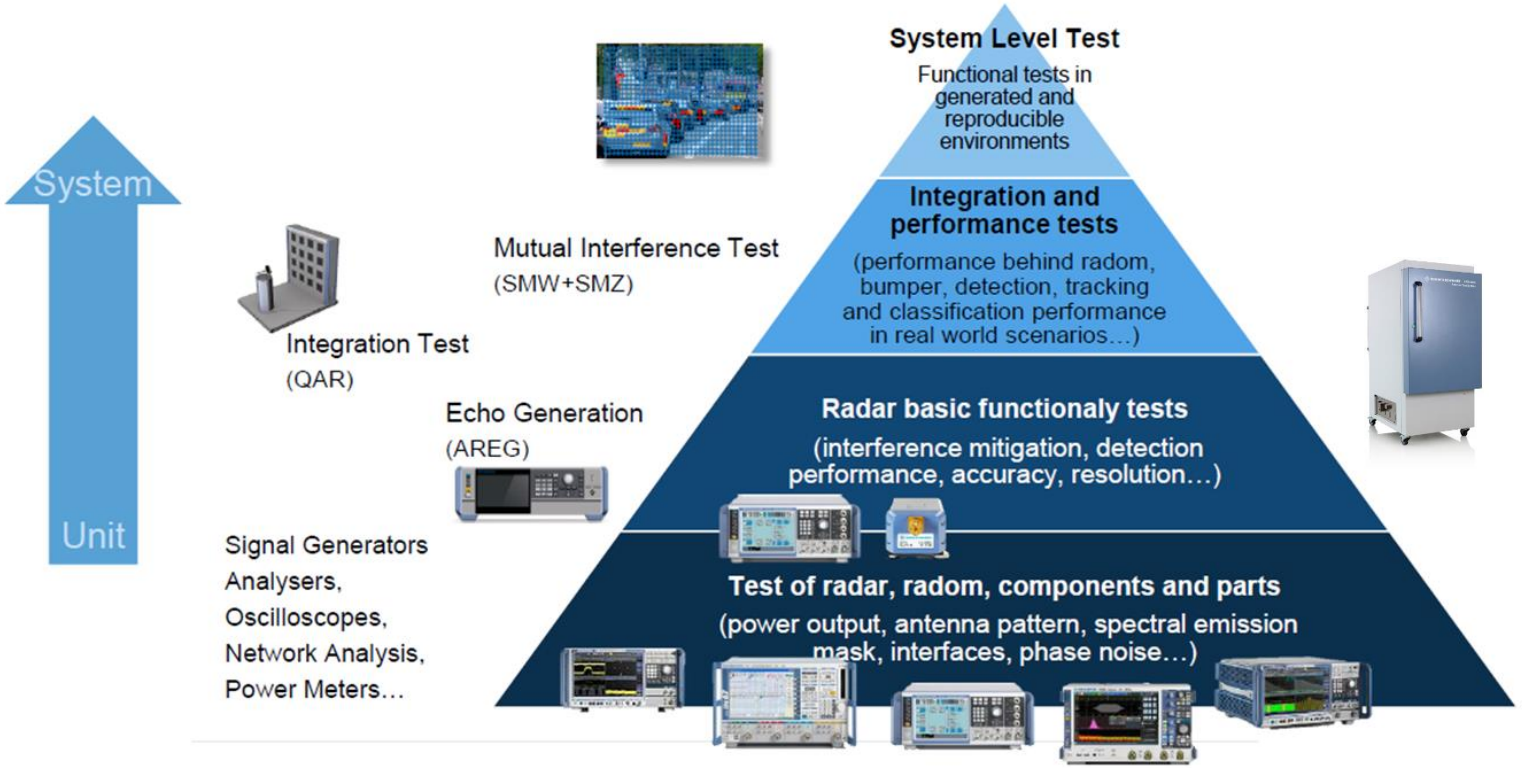
Modulation Technique	Today: FMCW	Near Future: PMCW	Long term: OFDM
Waveform			
Waveform Duration	~10 µs	~1 µs	~1 µs
ADC Sample Rate	~50 MSample/s IQ	>1 GSample/s IQ	>1 GSample/s IQ
Interferer Robustness	Good	High	High
Massive MIMO	Multi-Phase, Chirp Coded	Phase Coded	Orthogonal Sub-Carrier

MARKET TRENDS AND TEST CHALLENGES

- **New legislations and OEMs** require improved module **quality assurance**
  - RF compliance testing up to 231 GHz (e.g. ETSI, FCC)
  - **Virtual integration** and **Hardware-in-the-Loop** testing for type approval
- **134 GHz to 141 GHz** regulation in early stage (2026 earliest)
- **60 GHz** in-cabin radar for rear seat **passenger monitoring**
- High penetration requires **cost reduction** of car production and maintenance:
  Yield improvement by **active calibration** and lower **mounting tolerances**
- **High performance** radars continue to push the limits:
  E.g. bandwidth up to 5 GHz, MIMO, more channels, new modulation schemes
- **L3 and beyond** systems requires **Virtual Integration** and **Vehicle-in-the-Loop validation**

TEST AND MEASUREMENT SOLUTIONS

RADAR MARKET TEST REQUIREMENT OVERVIEW



RADAR SIGNAL AND MATERIAL ANALYSIS
VECTOR NETWORK ANALYZER

- **Vector Network Analyzer** for precision measurements
  - Antenna matching (S11)
  - Conversion loss from 77GHz input to IF output (R&D)
  - Power level test (saturation, compression) by power sweeps
  - RF component test like mixers, filters, power amplifiers or LNAs
  - On-wafer test of MMIC
  - Free-space material characterization

- **ZNA67EXT**
  - Single Sweep solution for **10 MHz to 110 GHz** Meas.
  - Two port and Four port systems

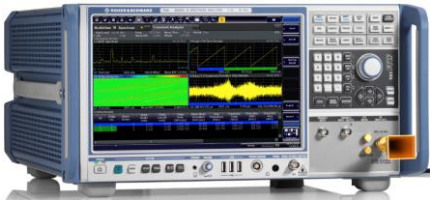
ZNA*xx* Vector Network Analyzer

ZNA67EXT

RADAR SIGNAL ANALYSIS
SPECTRUM ANALYZERS AND OSCILLOSCOPES

- **Spectrum Analyzers** for high sensitivity measurements
  - Signal analysis for up to **90 GHz** frequency and **8.3 GHz bandwidth**
  - Measuring **chirp** frequency linearity, length, long-term stability and power in order to improve accuracy and fulfill regulatory requirements
  - Measuring **chirp phase noise** to increase sensitivity

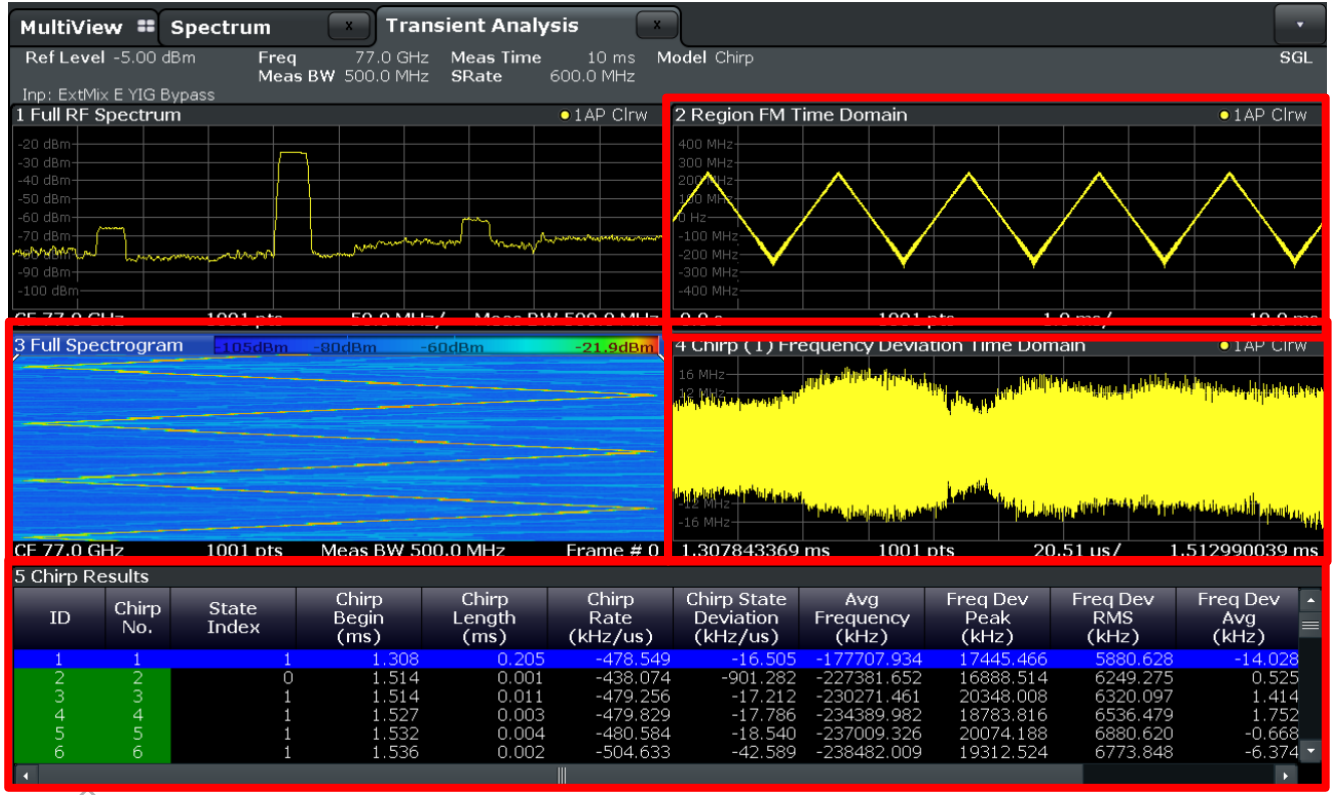
FSW85 Spectrum Analyzer



- **Oscilloscopes** for low latency & phase-coherent multi-channel measurements
  - Up to **16 GHz** bandwidth @ 40 GSample/s and 2 GSample storage
  - Triggering on complex radar signals after real-time de-embedding
  - Comprehensive signal analysis with **VSE** software

RTP0x4 Oscilloscope

RADAR SIGNAL ANALYSIS
CHIRP SIGNAL ANALYSIS WITH R&S SOFTWARE



Analyze the Full spectrogram of the signal in waterfall view.

Analyze the chirp in an intuitive time-frequency plot.

Check the frequency deviation of the chirp at each time instant.

A table summarizing all important chirp specifications.

RADAR SIGNAL ANALYSIS
D-BAND CONVERTORS FOR RADAR/B5G RESEARCHES

- FE170ST and FE170SR frontends extend the supported frequency range of **SMW200A, FSW** and **RTP** to **110-170 GHz**
- Integrated to UI of base units
- Calibrated solution as correction data of IF cables and frontend is considered by base units
- Smart accessories (Bandpass filter and Tx PA)
- Excellent signal performance

RTP with FE170SR

SMW with FE170ST

FSW with FE170SR

RADAR TARGET SIMULATION
MOST SCALABLE AND VERSATILE SOLUTION IN THE MARKET

Extremely short distances

Generation of dynamic objects

Precise and repeatable

One stop shop solution

Multiple independent objects

Worldwide service and support

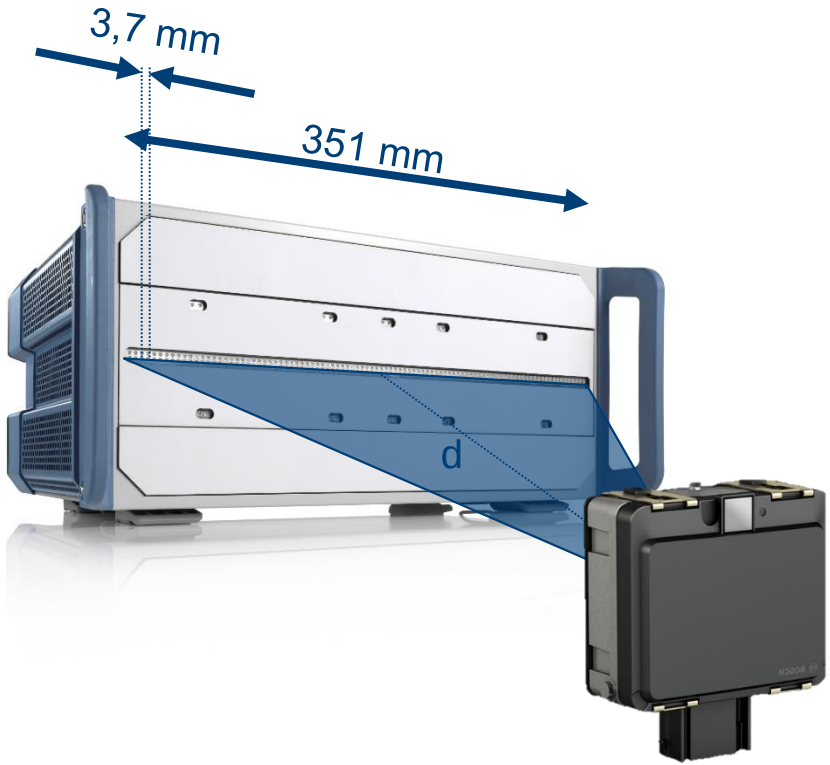
High instantaneous bandwidth

Standardized OSI HIL Interface

Highly scalable solution

No mechanical movement

RADAR TARGET SIMULATION
ANGULAR RESOLUTION & FIELD-OF-VIEW WITH QAT100



The field-of-view (FOV) and angular resolution achievable with the R&S®QAT100 are dependent on the setup but can be calculated as follows:

Field-of-view:

$$\alpha = 2 \cdot \tan^{-1}\left(\frac{351mm}{d}\right)$$

Angular resolution:

$$\Delta\alpha = \tan^{-1}\left(\frac{3{,}7mm}{d}\right)$$

RADAR TARGET SIMULATION
MOST SCALABLE AND VERSATILE SOLUTION IN THE MARKET

Research and Development

R&S®AREG800A with various frontends

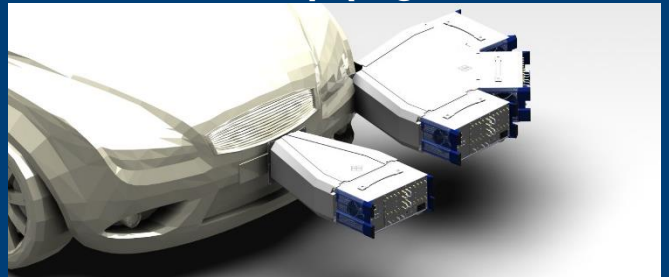
EOL Production Test

R&S®AREG100A or R&S®AREG800A

Hardware-in-the-Loop

R&S®AREG800A and R&S®QAT100

Vehicle-in-the-Loop (together with AVL)



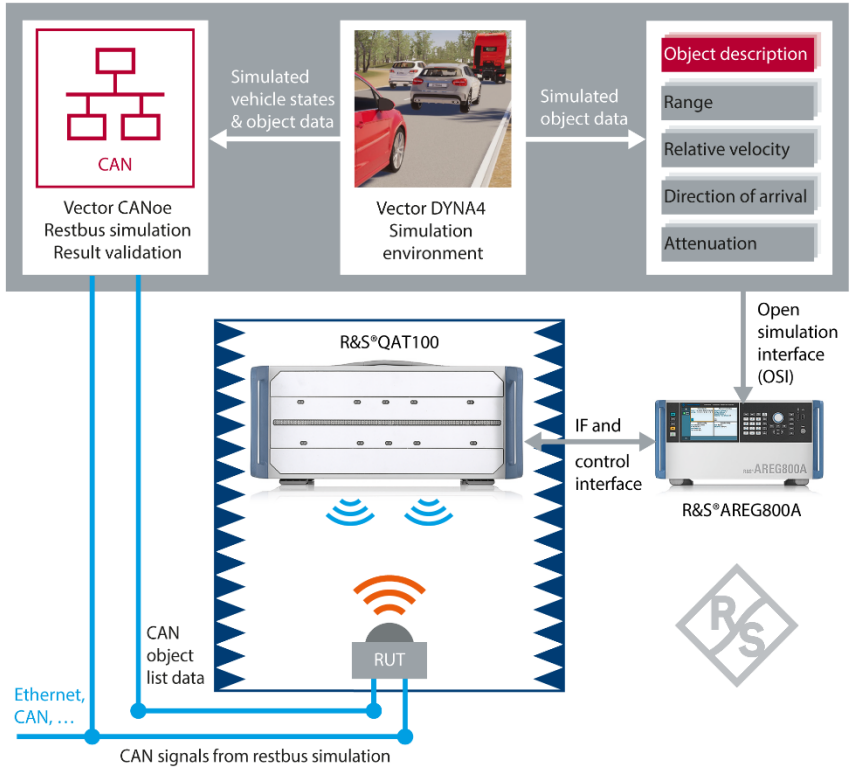
R&S®AREG800A and R&S®QAT100

HARDWARE-IN-THE-LOOP VALIDATION
COLLABORATION WITH VECTOR

Closed-loop radar module validation using realistic road scenarios or artificial test cases

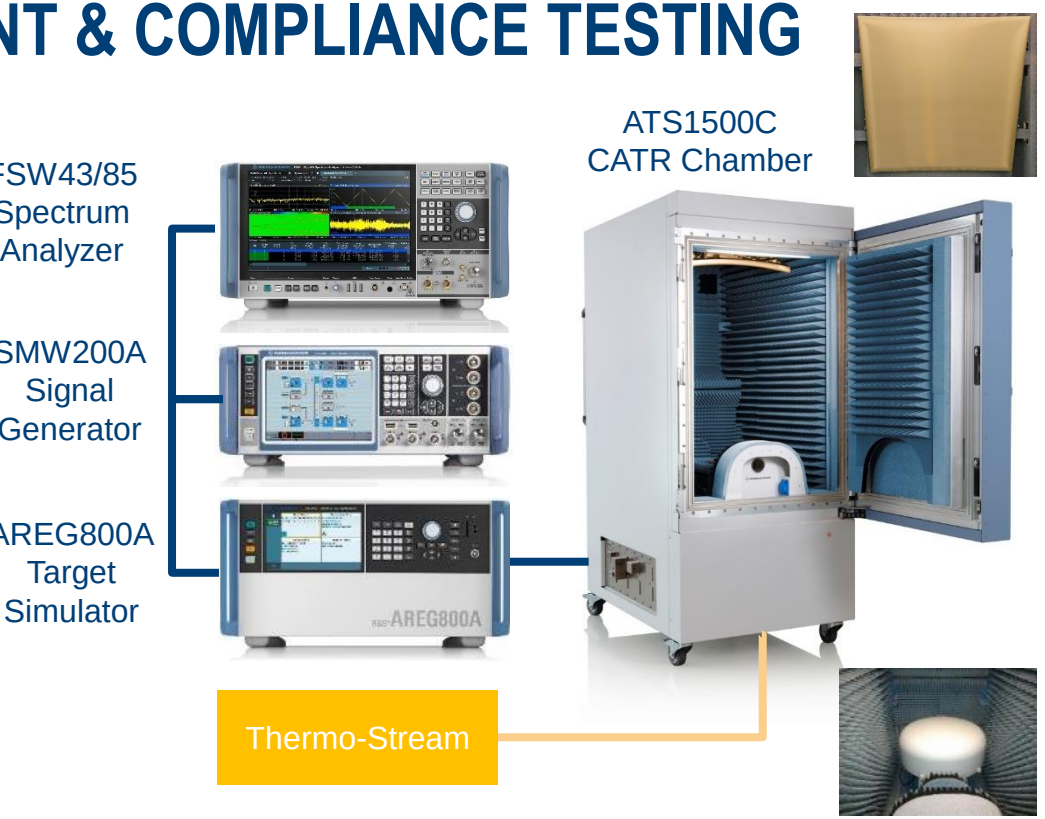
Open Simulation Interface (OSI) ensures future-proof and smooth software integration

Vector CANoe for rest-bus simulation via CAN or Ethernet connectivity in real-time



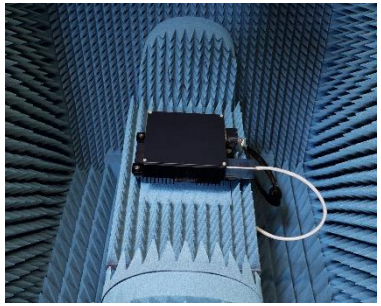
FUTURE-PROOF REFERENCE SOLUTION FOR RESEARCH, DEVELOPMENT & COMPLIANCE TESTING

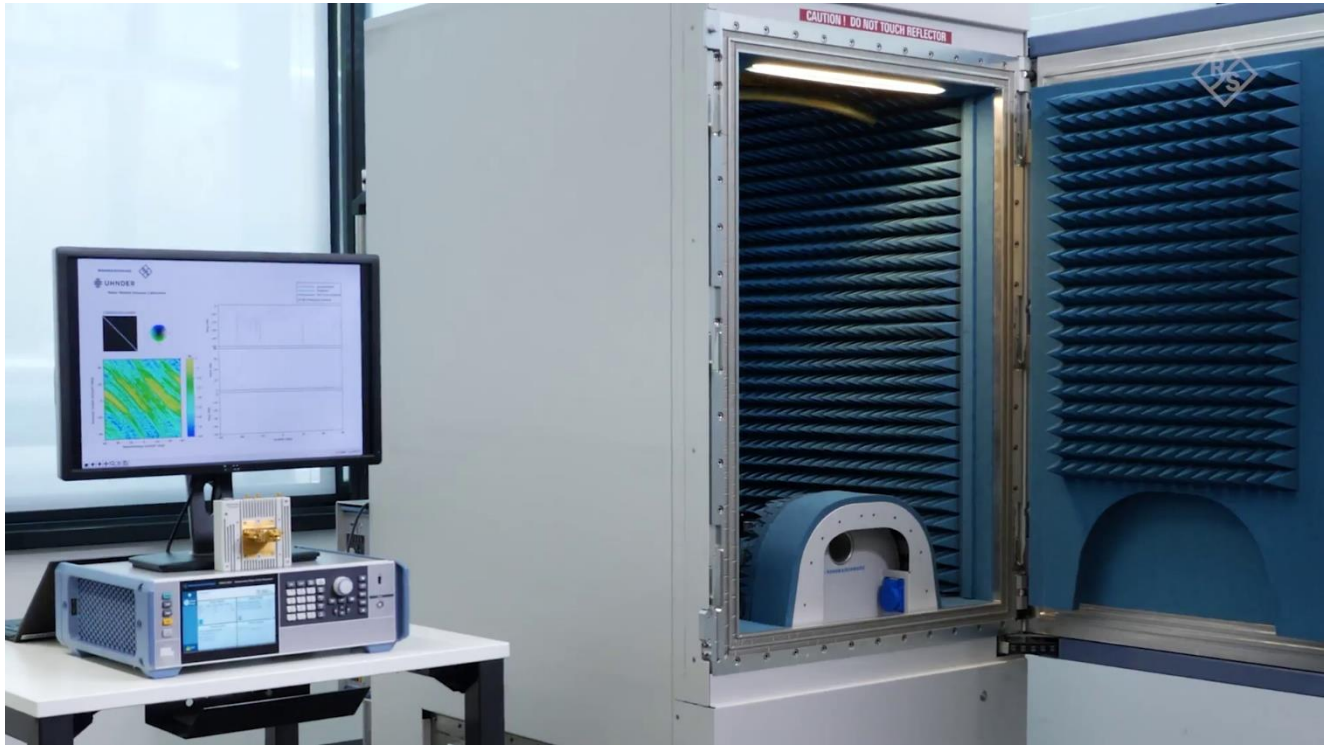
- Future-proof CATR reflector technology for growing antenna apertures
- Unique turn-key solution based on best-in-class components
- Performance confirmed by customers working on leading edge radar



PRE-PRODUCTION CALIBRATION BENCHMARK
COLLABORATION WITH UHNDER

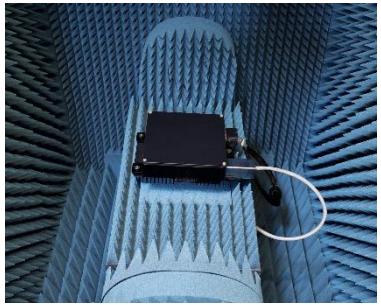
- Calibration of PMWC radar with large number of antennas is demanding
- R&S and Uhnder started collaboration mid of 2019

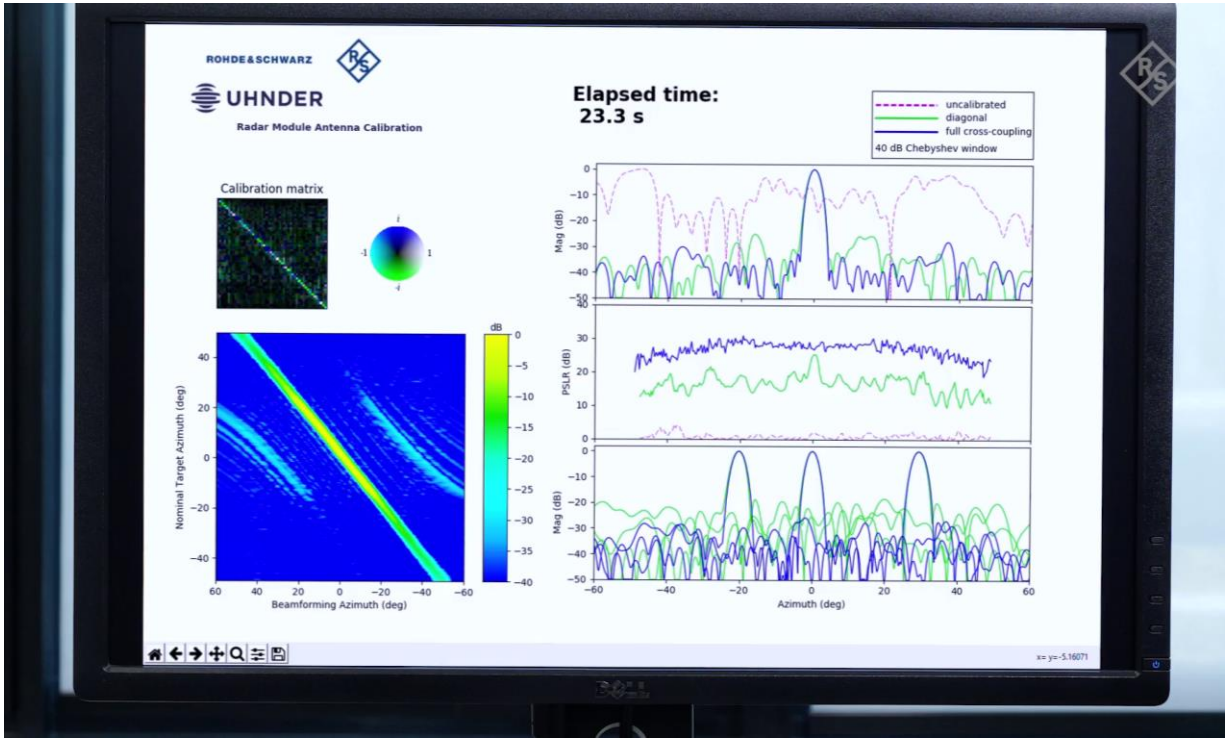




PRE-PRODUCTION CALIBRATION BENCHMARK
COLLABORATION WITH UHNDER

- Successful calibration with ATS1500C and AREG100A demonstrated at CES 2020

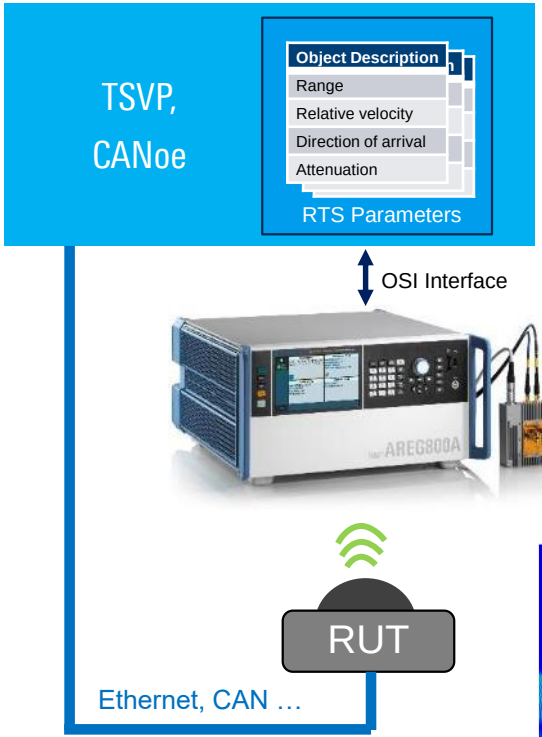


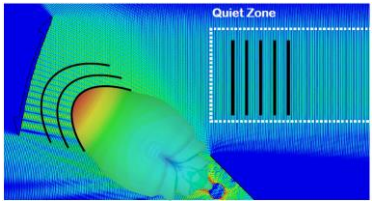


RADAR MODULE PRODUCTION TESTER
PARTNERSHIP WITH NOFFZ TECHNOLOGIES

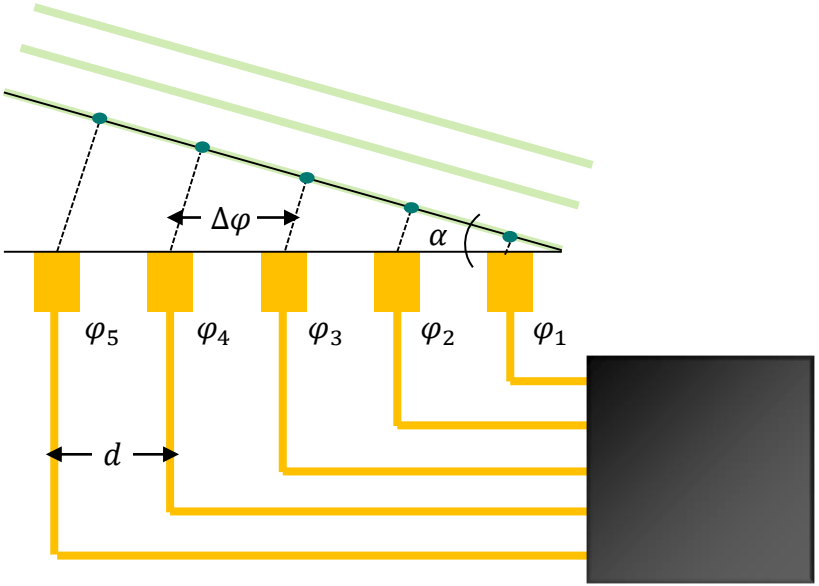
NOFFZ TECHNOLOGIES

- Future-proof CATR reflector technology for growing antenna apertures
- Seamless CATR production tester solution for customers developing radar in ATS1500C
- Bundle CATR and AREG ensures best quiet zone
- Joined Go-to-Market





RADAR ANGULAR MEASUREMENT TECHNOLOGY

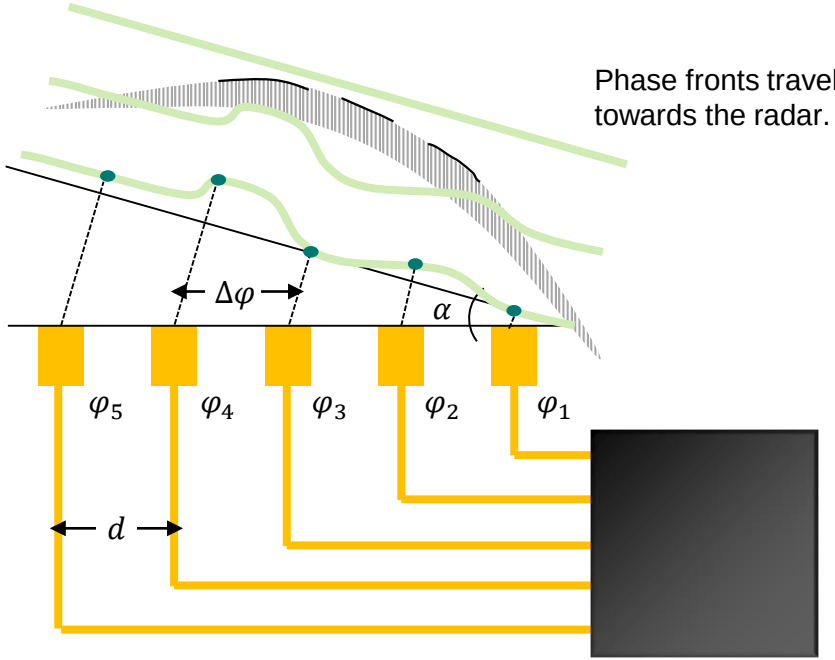


d	Physical distance between antennas
$\Delta\varphi$	Phase difference
α	Angle of arrival
λ	wavelength

$$\alpha = \sin^{-1}\left(\frac{\lambda \cdot \Delta\varphi}{2\pi d}\right)$$

Estimate azimuth / elevation angles from phase differences / amplitudes at the receive antennas of the phased array

RADAR ANGULAR MEASUREMENT TECHNOLOGY



Phase fronts traveling towards the radar.

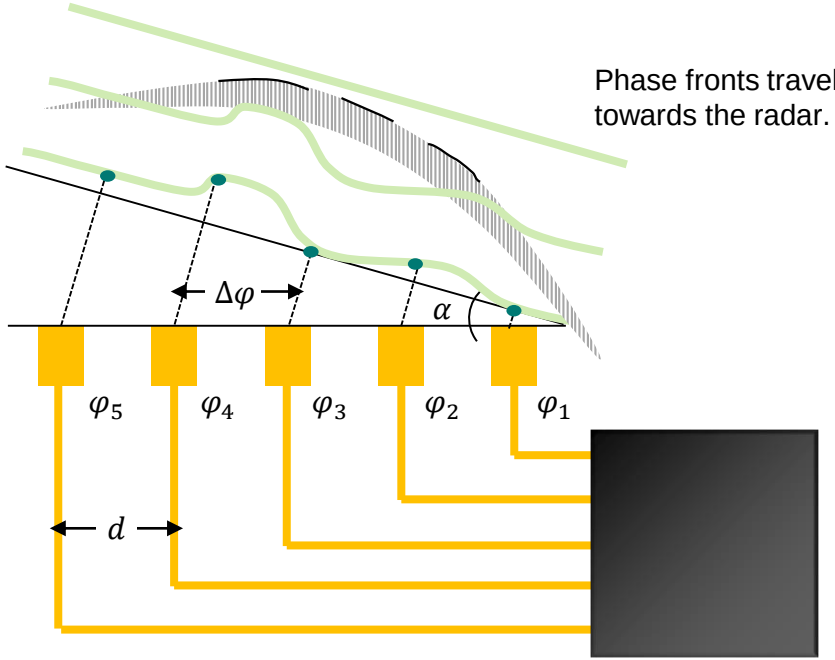
d	Physical distance between antennas
$\Delta\varphi$	Phase difference
α	Angle of arrival
λ	wavelength

$$\alpha = \sin^{-1}\left(\frac{\lambda \cdot \Delta\varphi}{2\pi d}\right)$$

$$\Delta\varphi_1 \neq \Delta\varphi_2 \neq \Delta\varphi_3 \neq \Delta\varphi_4 \neq \Delta\varphi_5$$

Phase estimation is wrong

RADAR ANGULAR MEASUREMENT TECHNOLOGY



Measuring the angle error does not lead to useful results, if:

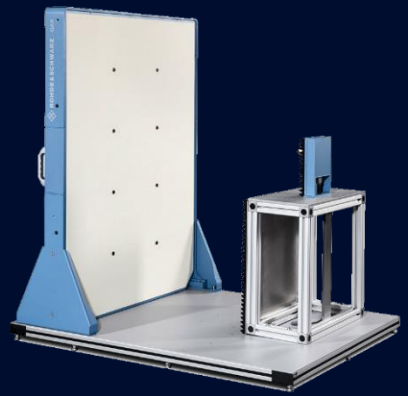
- The radar is slightly moved.
- The distance between the antennas is changed.
- Another algorithm is used for angle of arrival estimation during post processing.

Or, more general, if:

- Another radar / radome combination is used.

An alternative method has to be used.

R&S®QAR – Quality Automotive Radome Tester



R&S®QAR

R&S®QPS201
(Denver Airport)

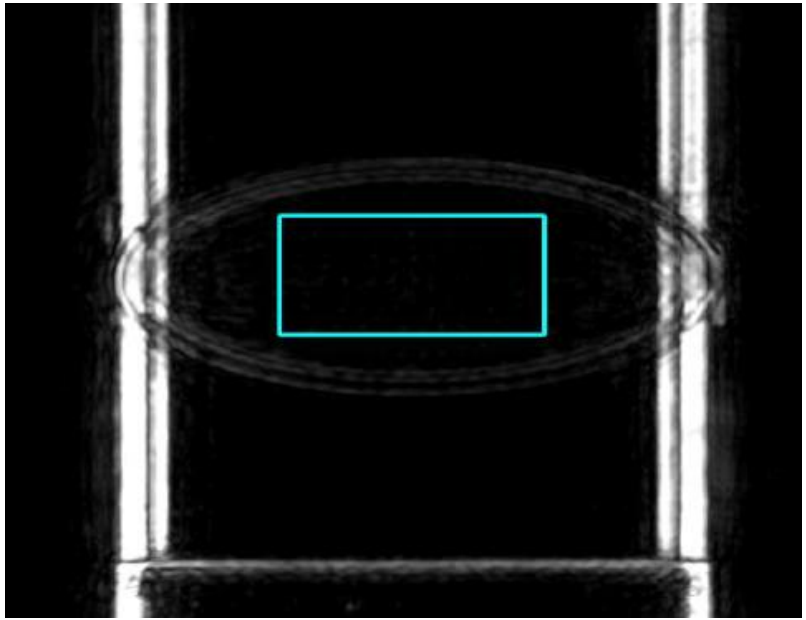
QUICK COMPARISON OF RADOME SUPPLIER QUALITY

► Ford Radome Supplier 1

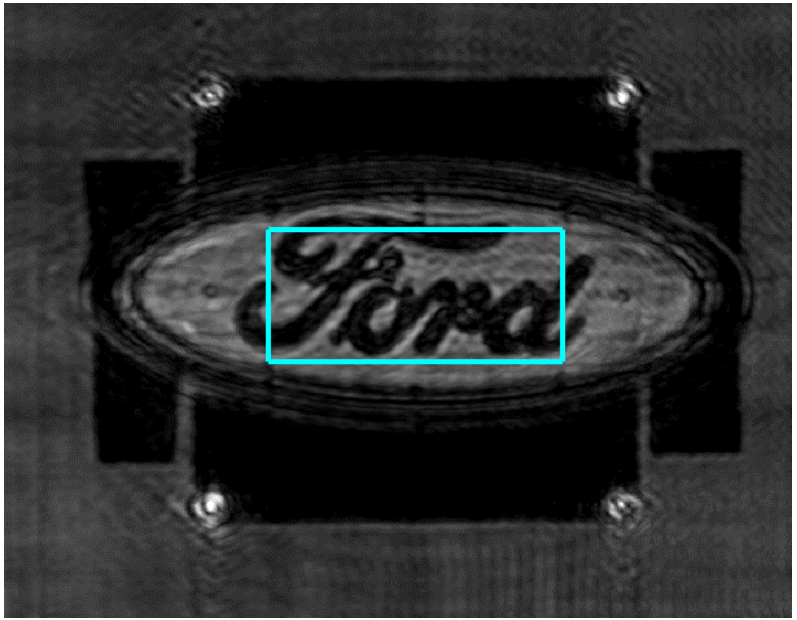
► Ford Radome Supplier 2

QUICK COMPARISON OF RADOME SUPPLIER QUALITY

► Ford Radome Supplier 1



► Ford Radome Supplier 2

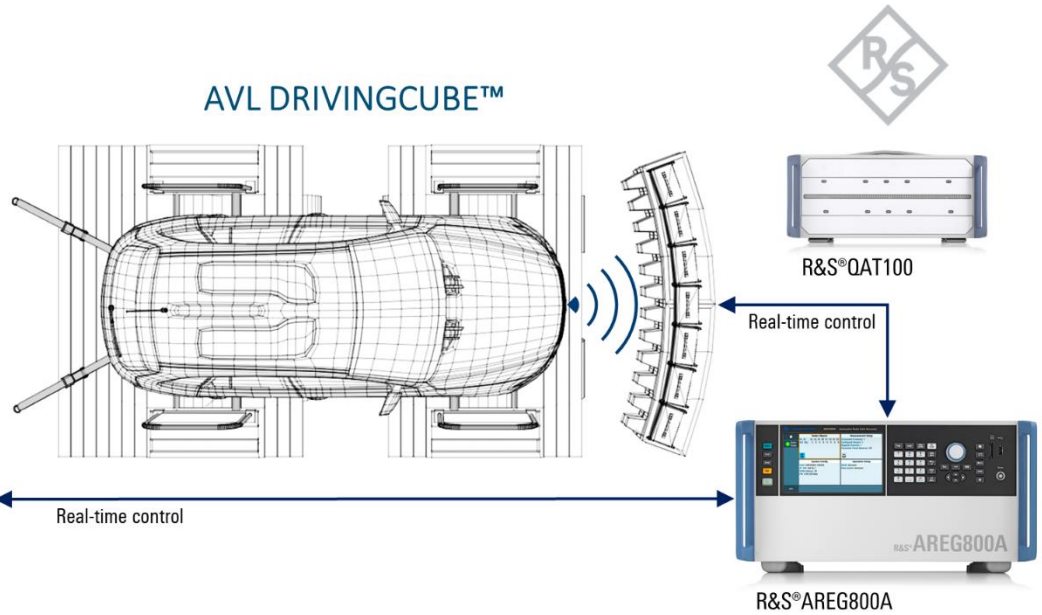


VEHICLE-IN-THE-LOOP TESTING BRINGS THE ROAD INTO THE LAB – PARTNERSHIP WITH AVL

Scalable solution

No mechanical movement

Multiple independent objects



Seamless integration

Precise and repeatable

Performance optimized

THANK YOU FOR YOUR ATTENTION