車用雷達測試面面觀

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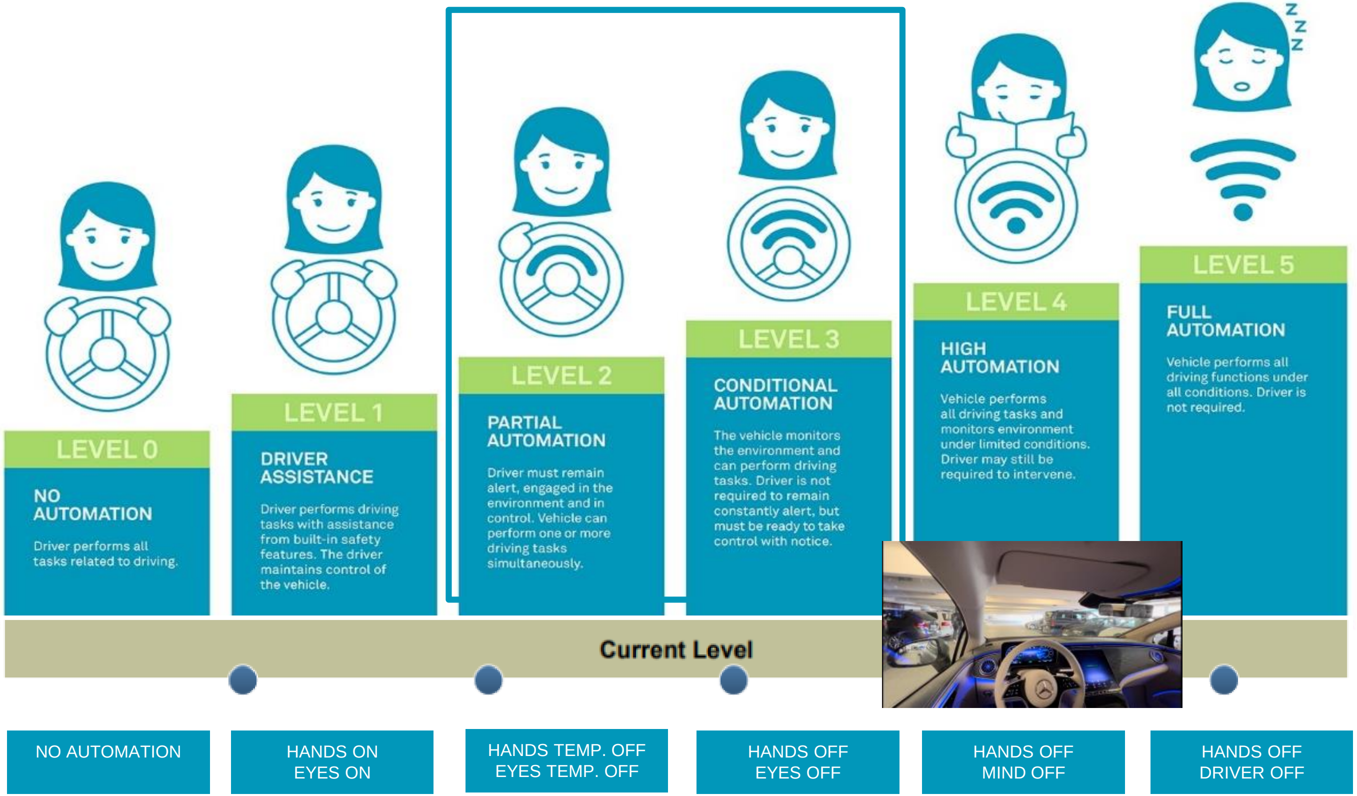
ROHDE&SCHWARZ
Make ideas real

OUTLINE

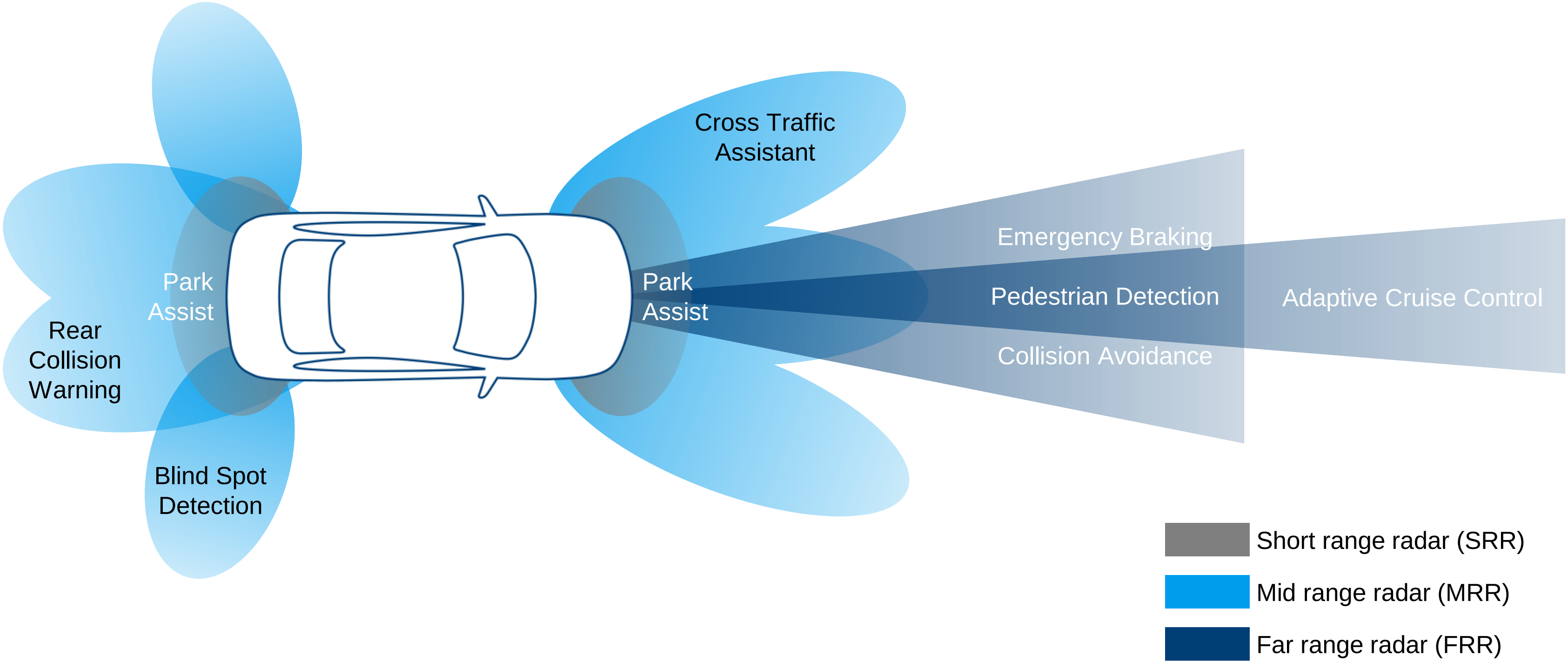
- ► ADAS Technology
- ► FMCW Theory
- ► Test Challenges
- ► Test and Measurement Solutions

LEVELS OF DRIVING AUTOMATION (SAE J3016™)

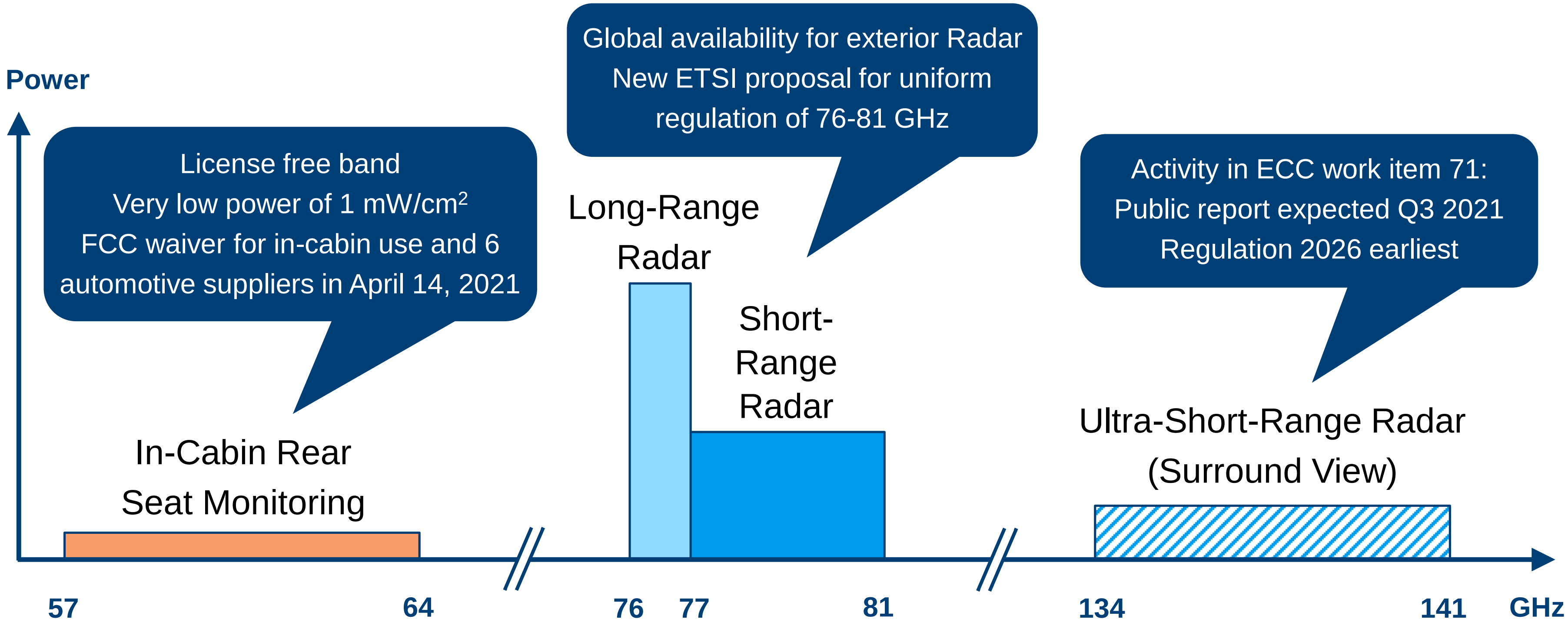


- **L2+** introduced by OEMs
- L3-like functions with restrictions to comply with missing legal framework
- Today's sensor maturity is sufficient for L2

RADAR BASED AUTONOMOUS DRIVING
THE SITUATION



AUTOMOTIVE RADAR FREQUENCY MAP
76-81 GHZ GLOBALLY AVAILABLE

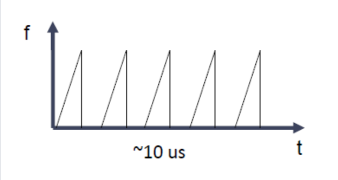
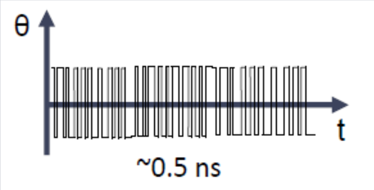
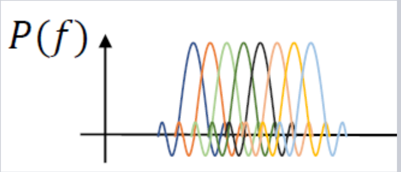


COMPANY RESTRICTED

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

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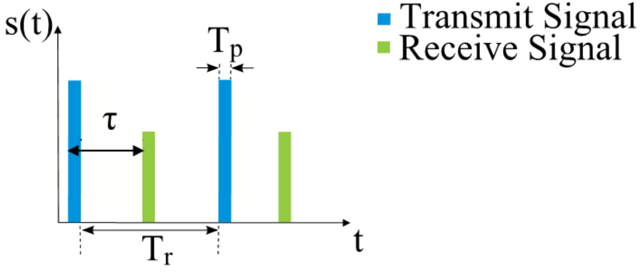
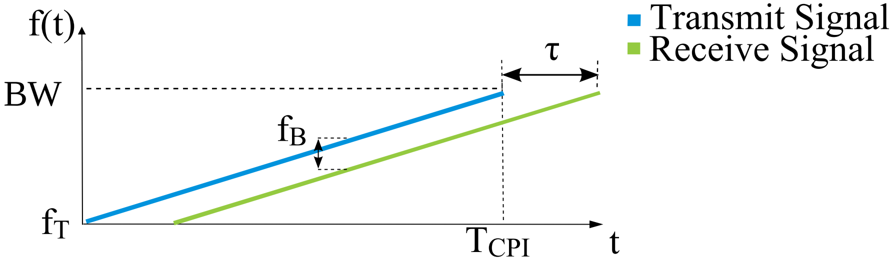
- ADAS Technology
- **FMCW Theory**
- Test Challenges
- Test and Measurement Solutions

FMCW RADAR – RANGE MEASUREMENT





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

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

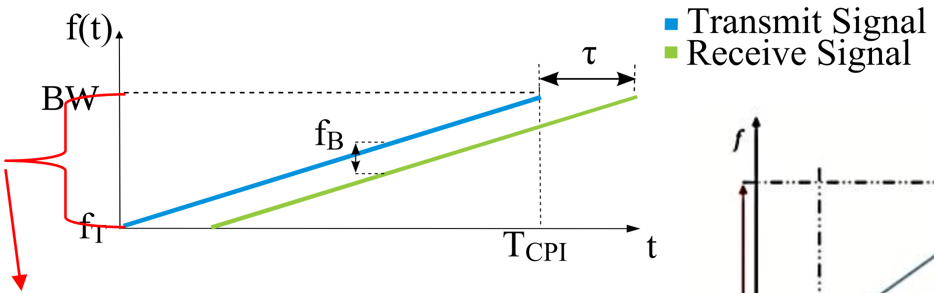
Plug τ into pulsed range equation

Solving for τ

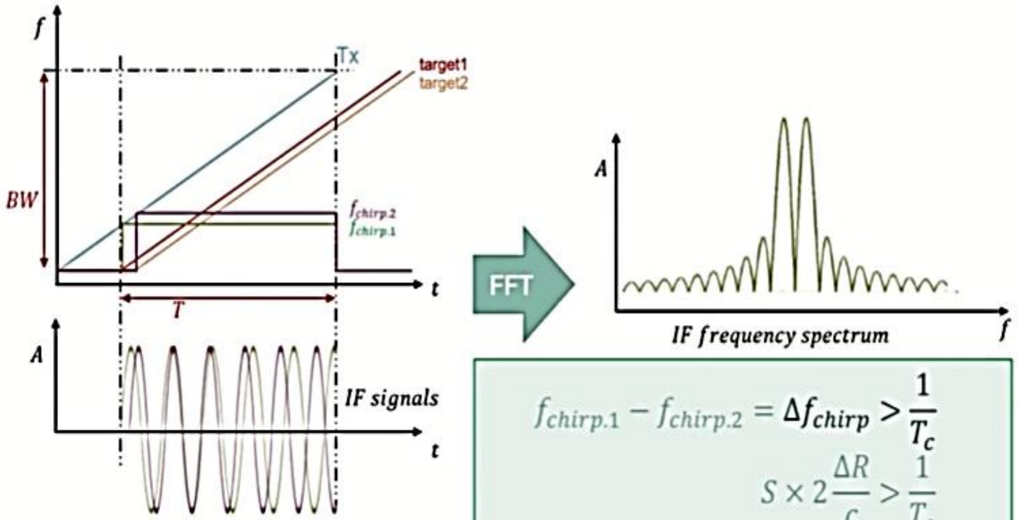
$$\tau = \frac{f_B}{B_w} * TCPI$$

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

FMCW RADAR – RANGE RESOLUTION



BW (Mhz)	△Range (m)	△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

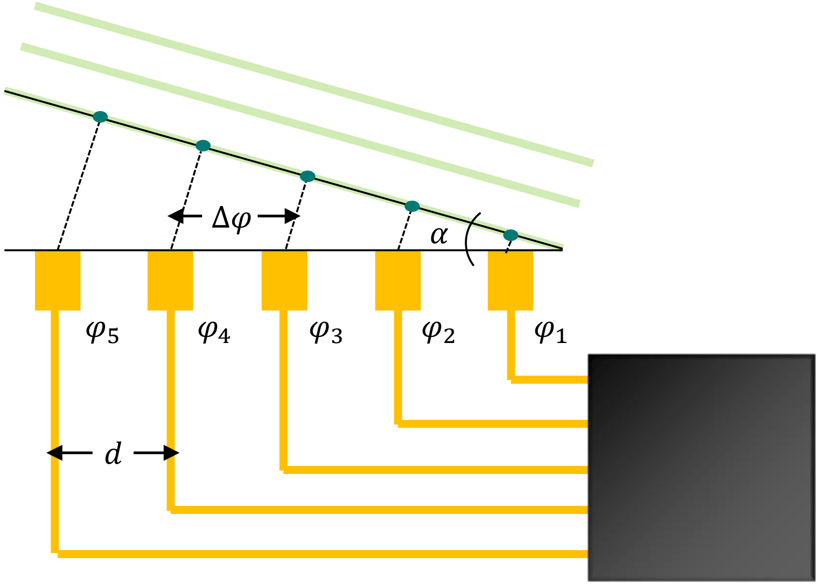


$$f_{chirp.1} - f_{chirp.2} = \Delta f_{chirp} > \frac{1}{T_c}$$

$$S \times 2\frac{\Delta R}{c} > \frac{1}{T_c}$$

$$\Delta R = \frac{c}{2 \times BW}$$

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)

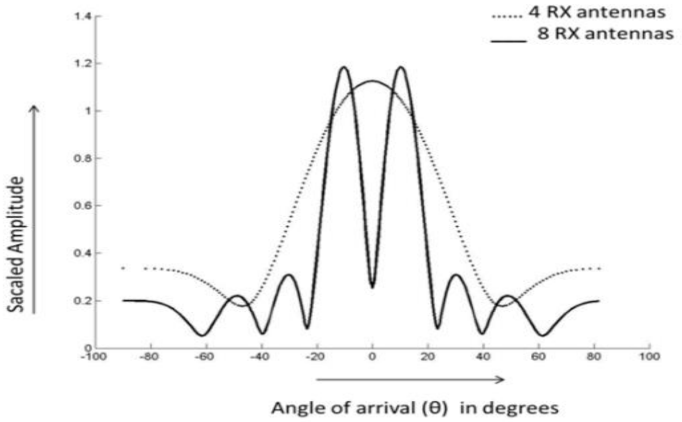
- ► Angular resolution with 8 Rx antennas

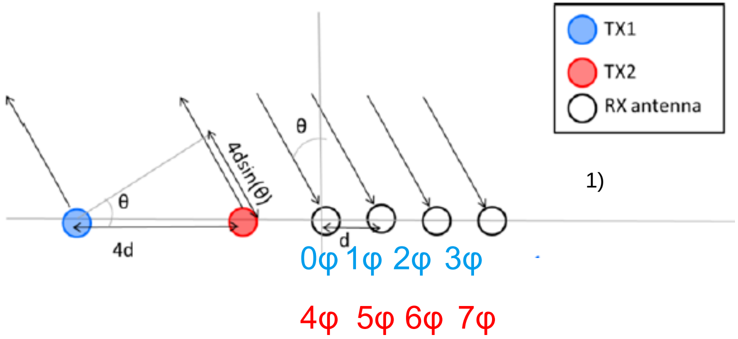
- ► MIMO approach with 4 Rx and 2 Tx

  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

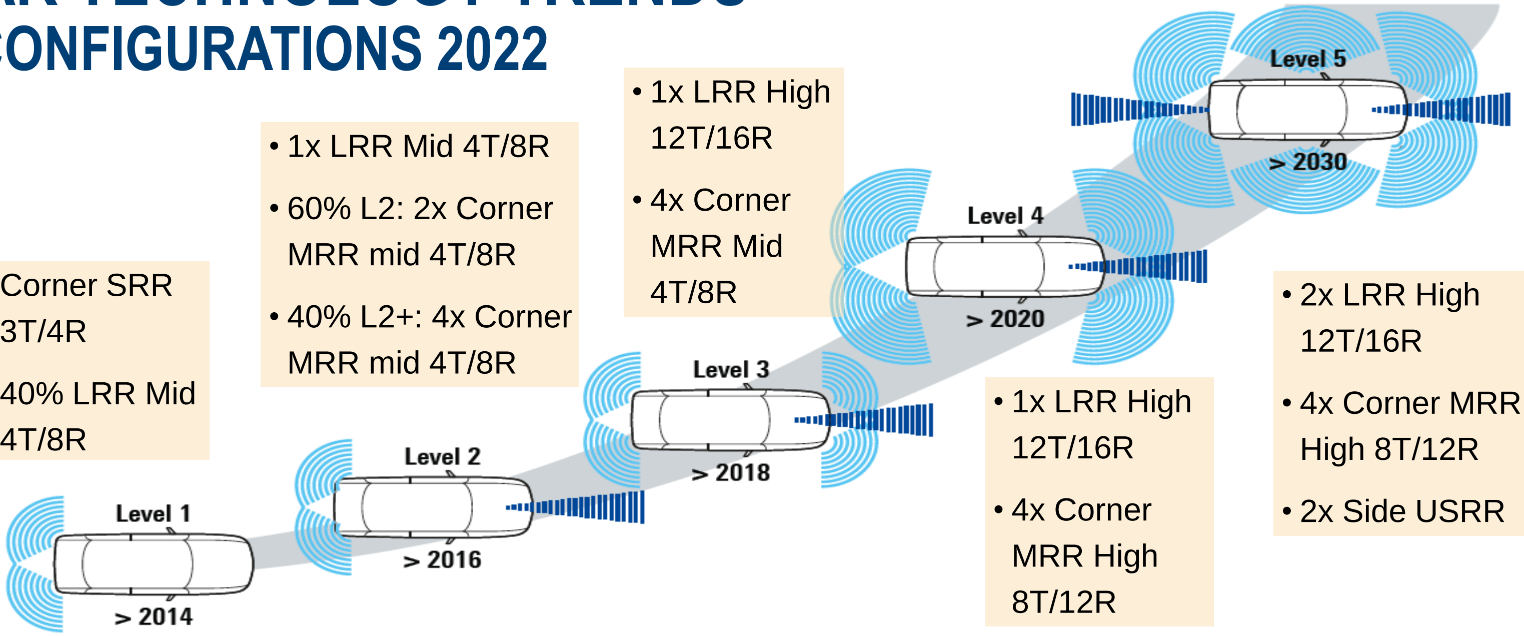




1)

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

RADAR TECHNOLOGY TRENDS
CAR CONFIGURATIONS 2022



- Corner SRR 3T/4R
- 40% LRR Mid 4T/8R

- 1x LRR Mid 4T/8R
- 60% L2: 2x Corner MRR mid 4T/8R
- 40% L2+: 4x Corner MRR mid 4T/8R

- 1x LRR High 12T/16R
- 4x Corner MRR Mid 4T/8R

- 1x LRR High 12T/16R
- 4x Corner MRR High 8T/12R

- 2x LRR High 12T/16R
- 4x Corner MRR High 8T/12R
- 2x Side USRR

Object detection
Features
SRR mode BSD, LCA

Object detection
Features
SRR mode BSD, RCW, LCA,
LRR mode ACC, AEB

High-resolution target separation
Features
SRR mode BSD, FCW, RCW, RCTA
LRR mode ACC, AEB

3D detection
Features
SRR mode BSD, RCTA
MRR mode AEB pedestrian
LRR mode ACC, AEB

360° object recognition
Features
USRR mode AVP, PA
SRR mode BSD, RCTA
MRR mode AEB pedestrian
LRR mode ACC, AEB

OUTLINE

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- FMCW Theory
- **Test Challenges**
- Test and Measurement Solutions

TEST IMPLICATIONS OF TECHNOLOGY DEVELOPMENTS

- New frequency bands, modulation schemes, higher bandwidths and complex modulation schemes and MIMO
- L3 and beyond systems requires Virtual Integration and Vehicle-in-the-Loop validation
- Advanced tests during R&D of automotive radar sensors and testing of ADAS features require multiple dynamic artificial objects
- These artificial objects must be dynamic in terms of:
  - Distance
  - Size (Radar Cross Section – RCS)
  - Radial velocity (Doppler frequency shift)
  - Angular direction
- Higher levels of autonomous driving require multiple radar sensors in a single vehicle which have to be stimulated simultaneously

RADAR OBJECT SIMULATION CHALLENGES

Limitation of current laboratory test options
- OTA sensor stimulation required
- Limited scenario testing capabilities
- Azimuthal moving targets challenging to simulate

Reproducible and standardized testing
- Millions of test kilometers on test track
- Increased ADAS capabilities

Complex and time critical driving tests
- Limited test capability on public roads
- A roadworthy prototype is required

→ Historically bulky, expensive & inflexible test systems

OUTLINE

- ADAS Technology
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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

R&S®QAT100
FRONTENDS VERSIONS

R&S®QAT100 with QAT-B11 (SIMO) frontend

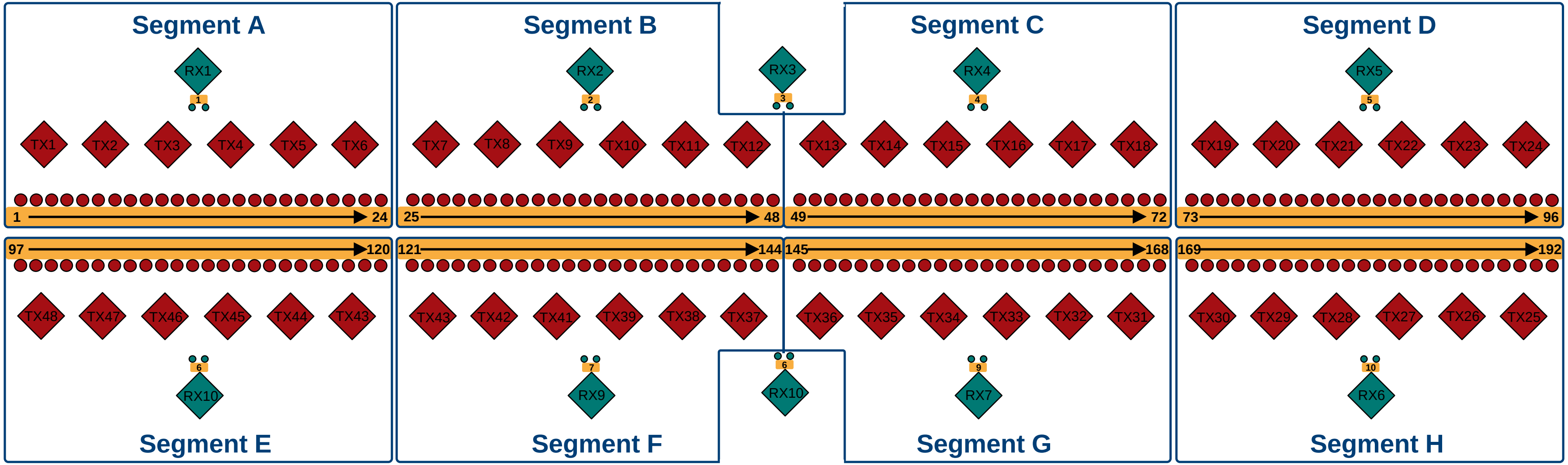
- 96 transmit & 5 receive antennas
- Optional second independent TRX line
- Simulation of up to 8 echoes from different directions

R&S®QAT100 with QAT-B21 (MIMO) frontend

- 96 transmit / receive antenna pairs
- Optimized for MIMO technology
- Simulation of up to 4 echoes from different directions

R&S®QAT100

QAT-B11 / -B2 ANTENNA NUMBERING

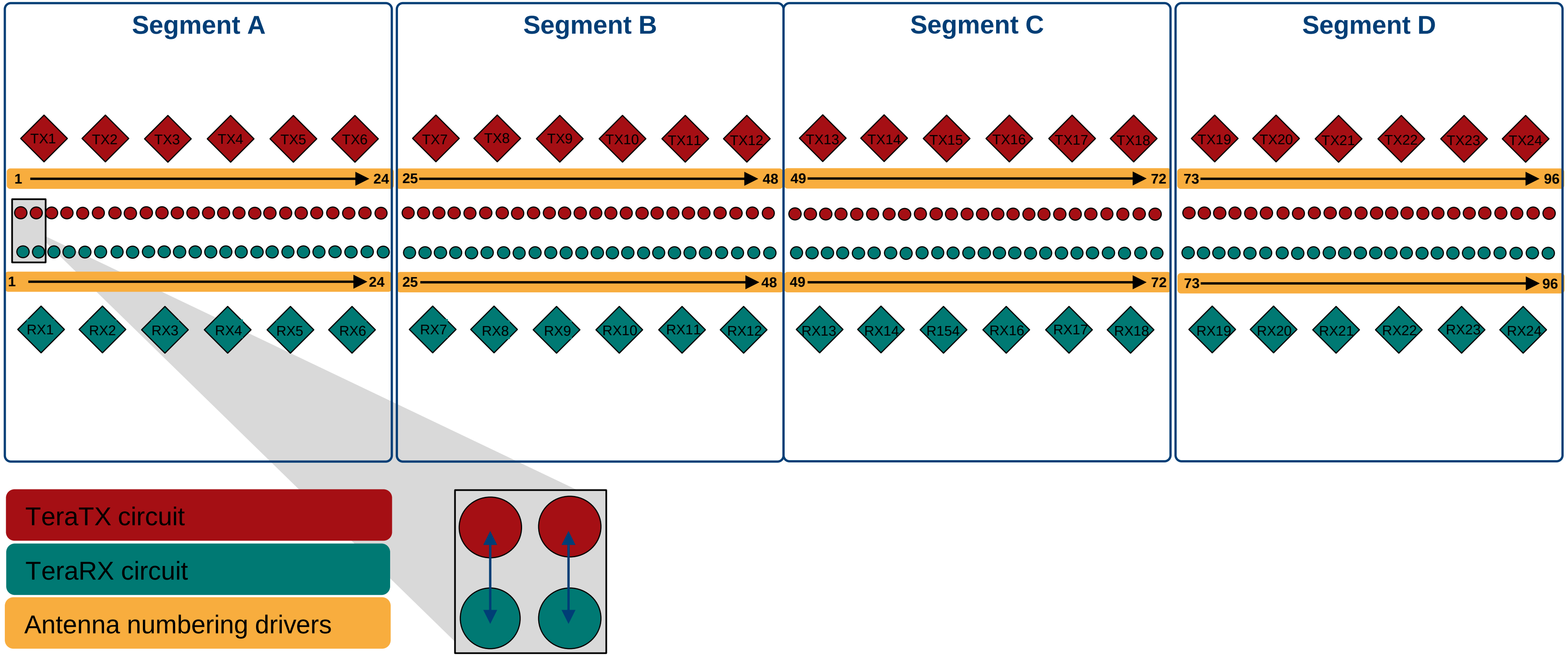


TeraTX circuit

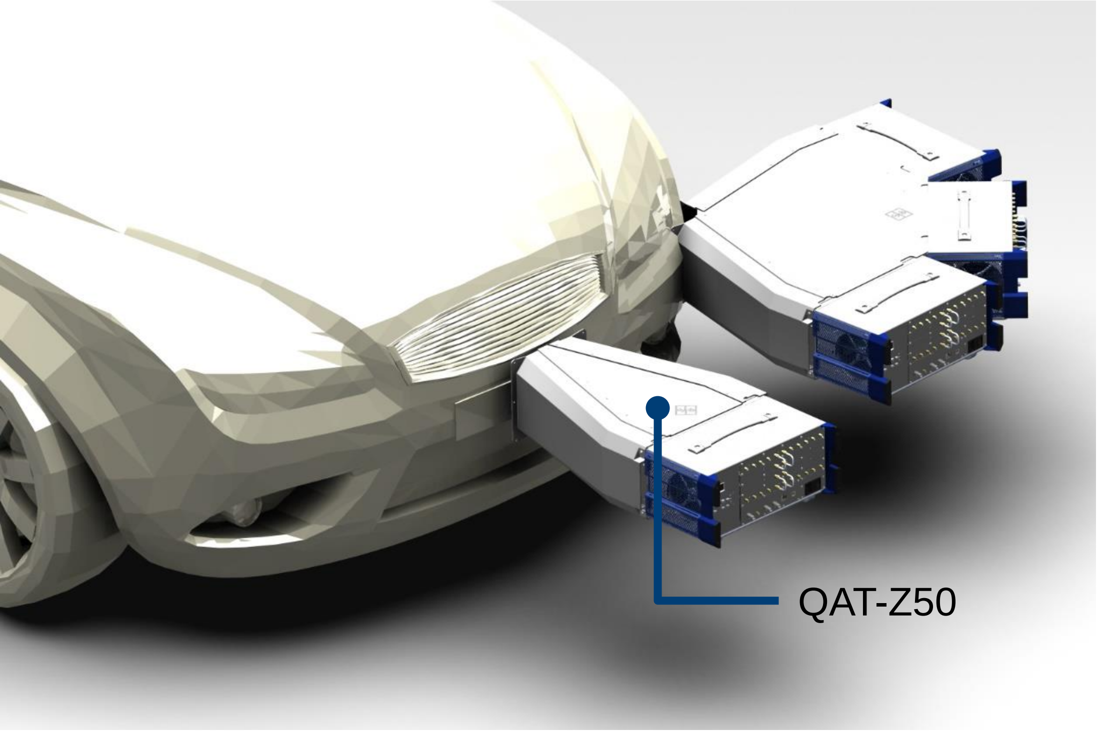
TeraRX circuit

Antenna numbering drivers

R&S®QAT100
QAT-B21 ANTENNA NUMBERING



QAT100 ADVANCED ANTENNA ARRAY
QAT-Z50 SHIELDING SYSTEM



- **QAT-Z50 shielding system**
  - 50 cm long, 10° opening
  - Direct mounting kit for QAT
- **Challenges**
  - Car mounting kit respectively QAT stand in front of car
  - Customization based on e.g. CAD required

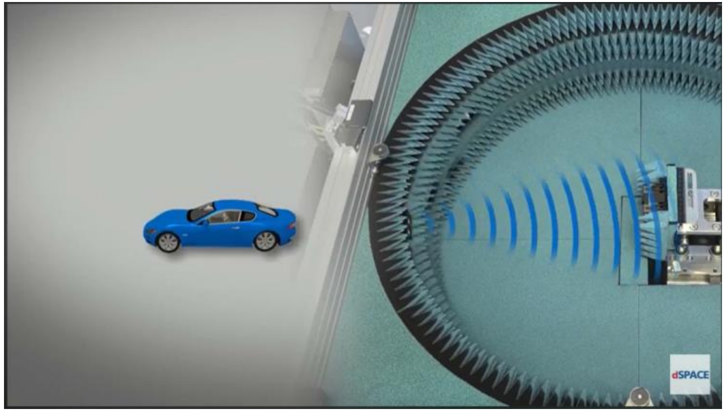
ANGULAR RESOLUTION & FIELD-OF-VIEW

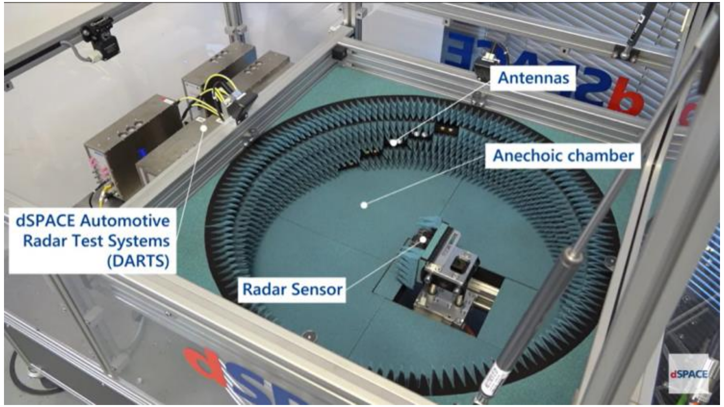
Distance (d)	Field-of-view (α)	resolution ($\Delta\alpha$)
500 mm	38,7°	0,42°
700 mm	28,1°	0,30°
1000 mm	19,9°	0,21°
1500 mm	13,34°	0,14°
2100 mm	10,0°	0,10°

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

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

HARDWARE-IN-THE-LOOP – BEFORE

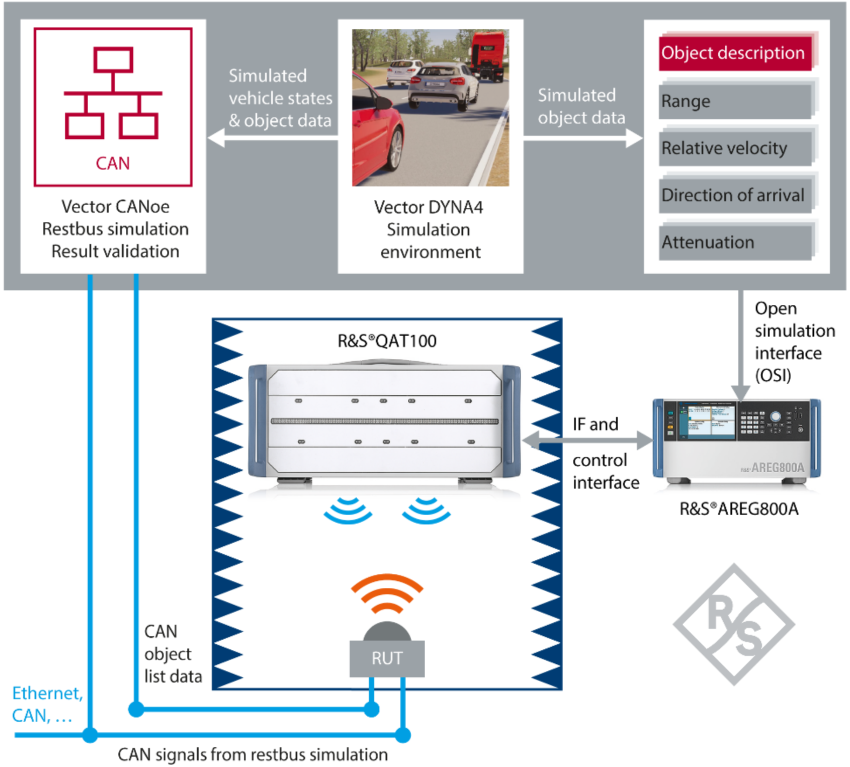




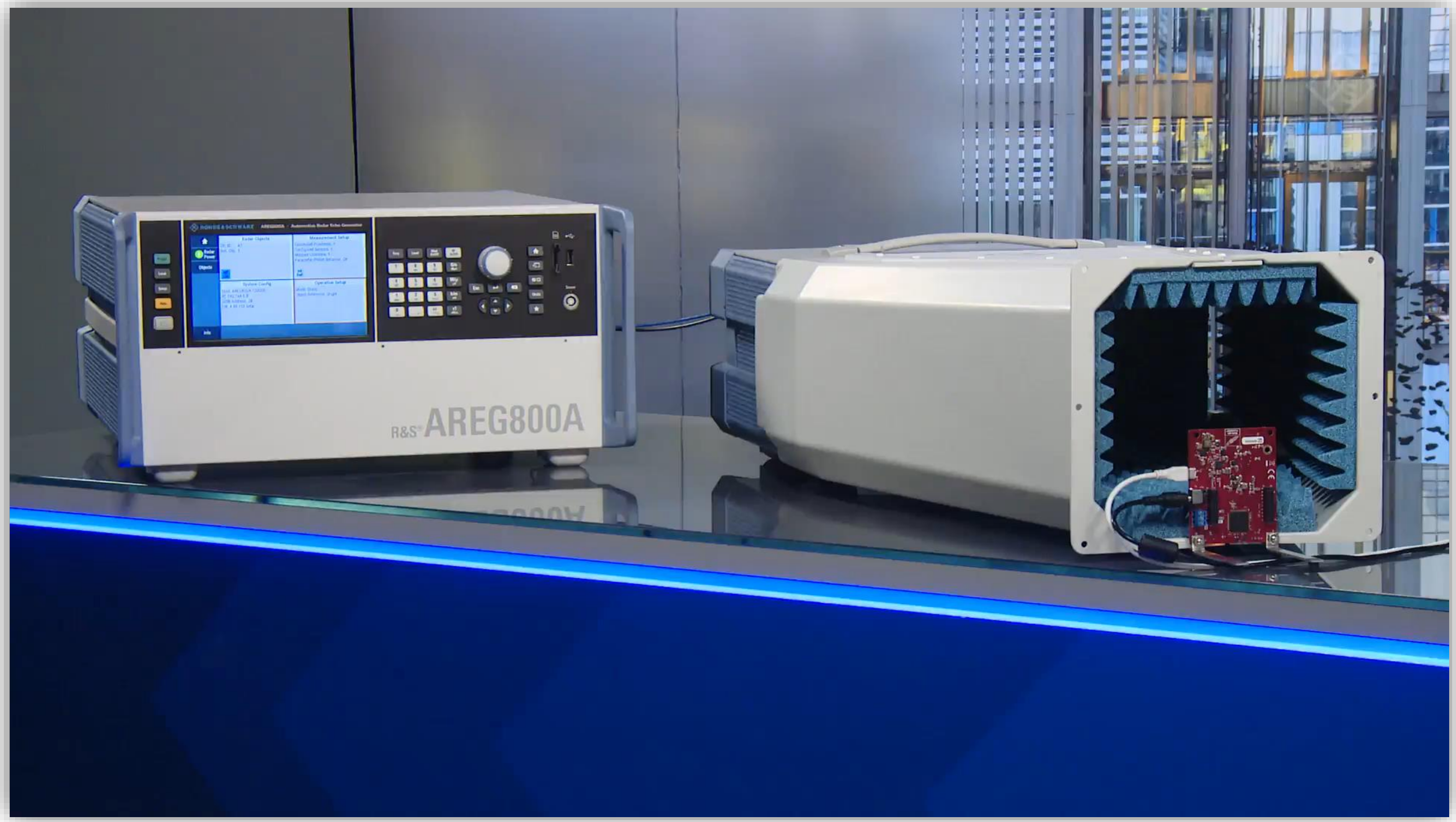
https://youtu.be/t0noOLYGPDw

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



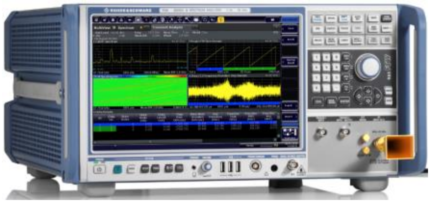
HARDWARE-IN-THE-LOOP – DEMONSTRATION



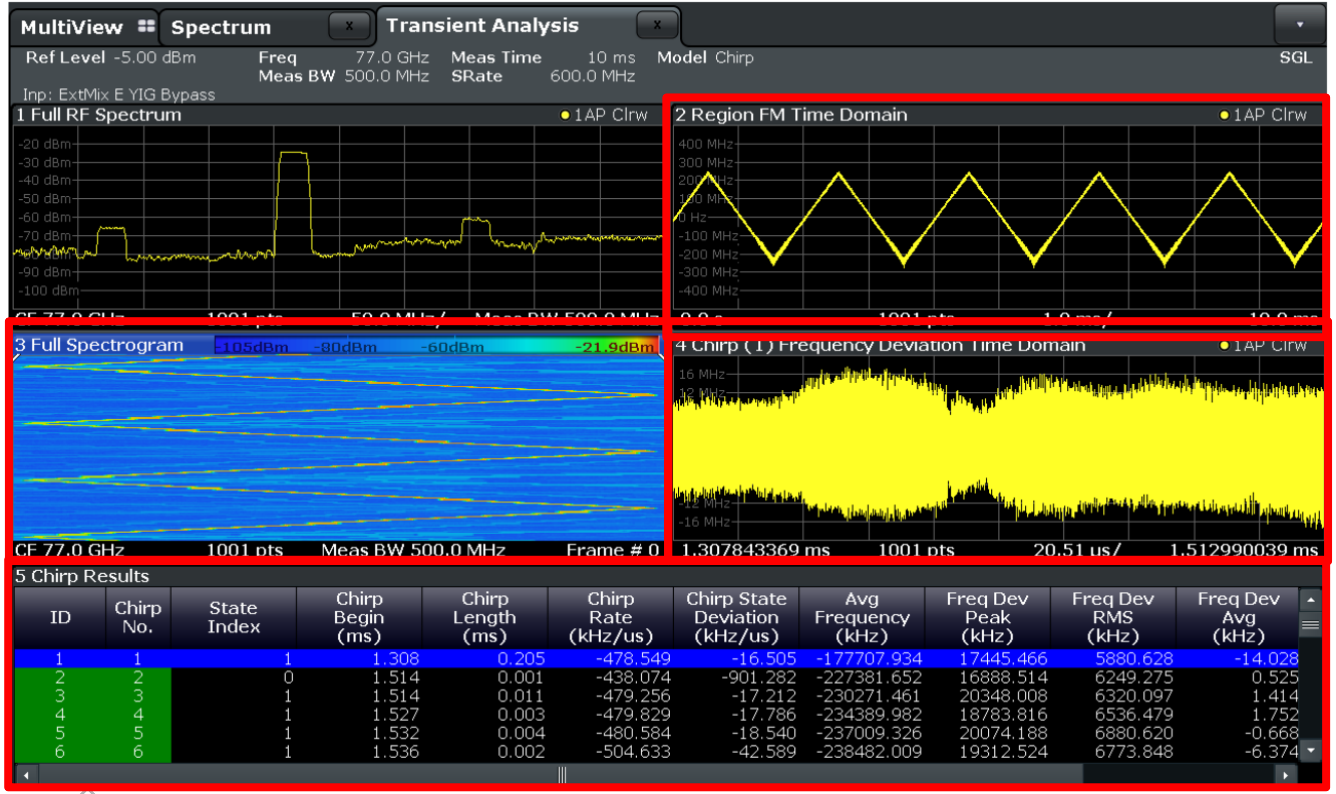
RADAR SIGNAL ANALYSIS
SPECTRUM ANALYZERS AND OSCILLOSCOPES

- **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



RADAR SIGNAL ANALYSIS
CHIRP SIGNAL ANALYSIS WITH R&S SOFTWARE



ID	Chirp No.	State Index	Chirp Begin (ms)	Chirp Length (ms)	Chirp Rate (kHz/us)	Chirp State Deviation (kHz/us)	Avg Frequency (kHz)	Freq Dev Peak (kHz)	Freq Dev RMS (kHz)	Freq Dev Avg (kHz)
1	1	1	1.308	0.205	-478.549	-16.505	-177707.934	17445.466	5880.628	-14.028
2	2	0	1.514	0.001	-438.074	-901.282	-227381.652	16888.514	6249.275	0.525
3	3	1	1.514	0.011	-479.256	-17.212	-230271.461	20348.008	6320.097	1.414
4	4	1	1.527	0.003	-479.829	-17.786	-234389.982	18783.816	6536.479	1.752
5	5	1	1.532	0.004	-480.584	-18.540	-237009.326	20074.188	6880.620	-0.668
6	6	1	1.536	0.002	-504.633	-42.589	-238482.009	19312.524	6773.848	-6.374

Analyze the Full spectrogram of the signal in waterfall view.

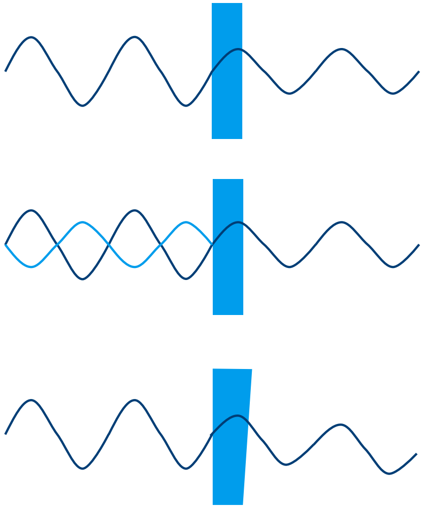
Analyze the chirp in an intuitive time-frequency plot.

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

A table summarizing all important chirp specifications.

RADAR MEASUREMENT PRINCIPLE

cause	effect
High attenuation	decreased range
High reflection	Sensor blindness
Inhomogeneities	Angular inaccuracy



Transmitted signal — Received signal — Radome / bumper

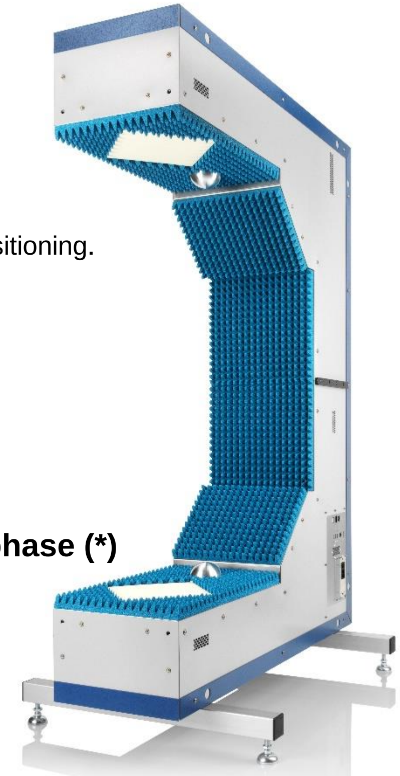
QAR50
TECHNICAL SUPERIORITY …

Both polarization
Available with horizontal and vertical polarization.

Traceable Tx loss and reflection
Results traceable to (inter)national standards.

Precise reflection
Ensures radar compatibility and correct positioning.

High resolution reflection image (*)
Enables enhanced homogeneity analysis.



Precise Transmission loss
Ensures radar compatibility.

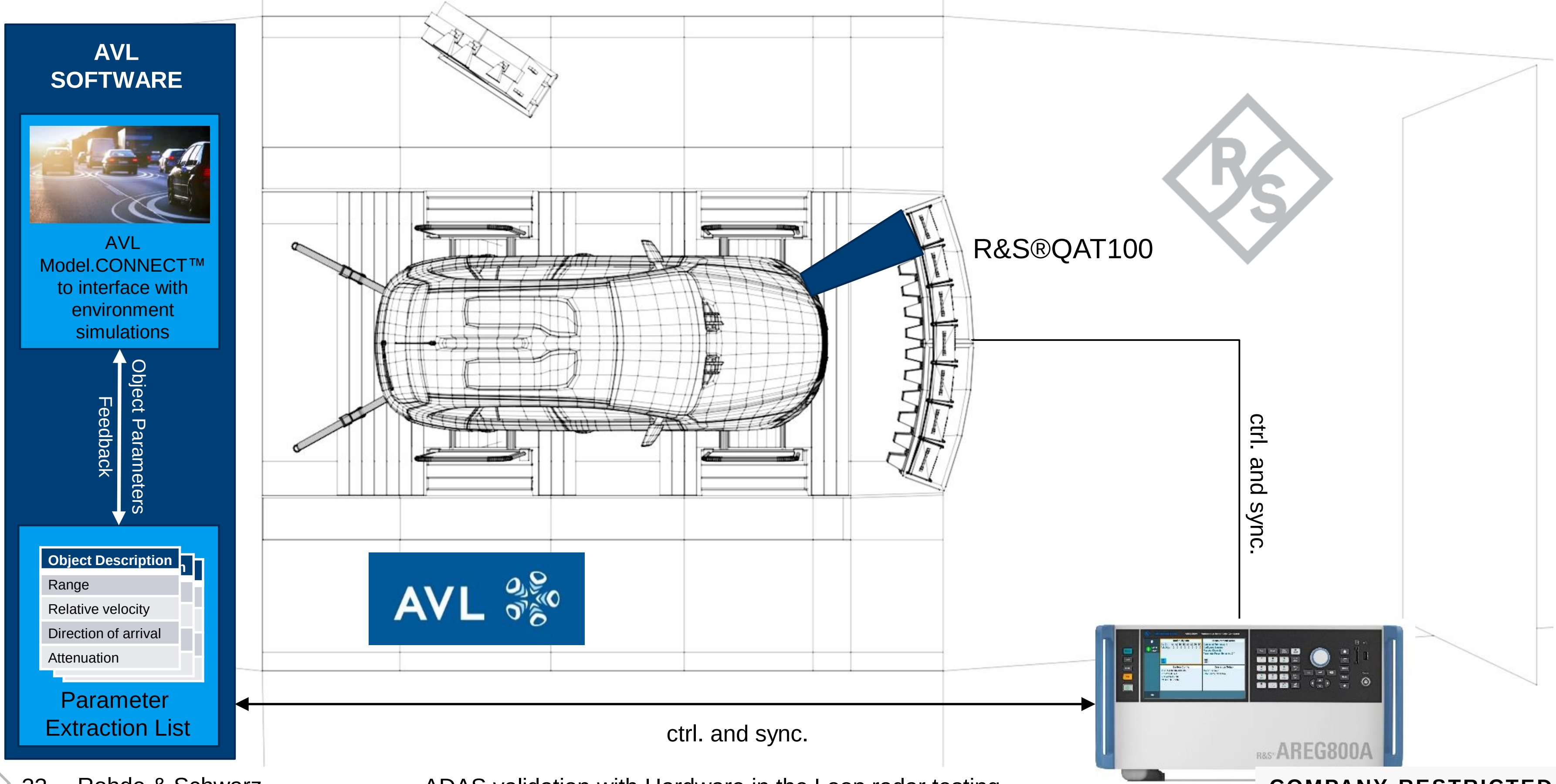
Reflection frequency response (*)
Helps identifying thickness and other mismatches.

Spatially resolved transmission phase (*)
Enables homogeneity checks.

Transmission loss frequency response (*)
Ensures radar compatibility.

(*) optional items

VEHICLE-IN-THE-LOOP TESTING



VEHICLE-IN-THE-LOOP DEMONSTRATION

THANK YOU FOR YOUR ATTENTION