ELECTRONICALLY STEERABLE FRONTEND FOR QUALIFYING AUTOMOTIVE RADAR

World's first fully electronically steerable antenna array

YOUR TASK

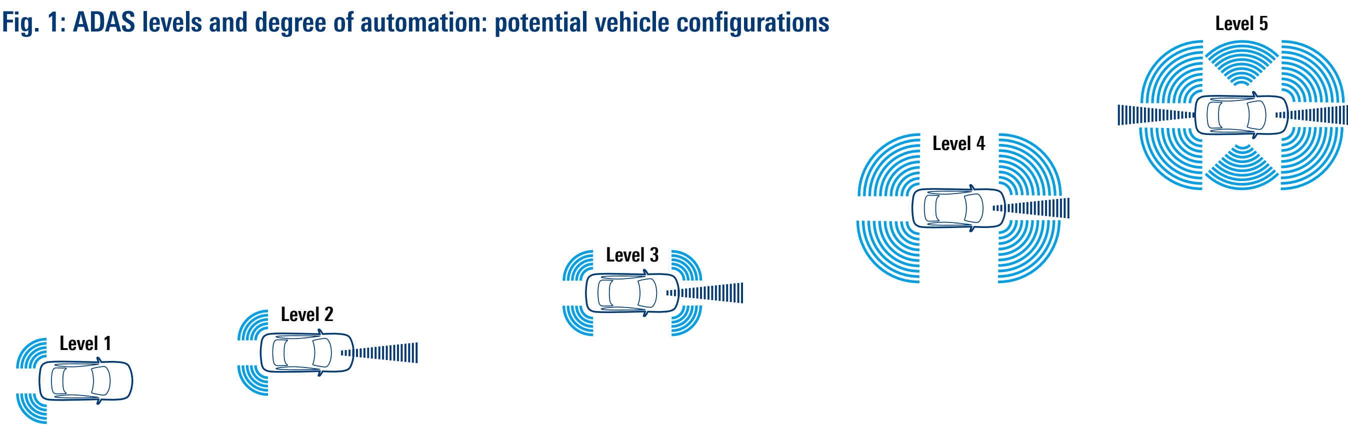
Autonomous driving (AD) and advanced driver assistance systems (ADAS) are a major driver of innovation in the automotive industry. Radar sensors are one of the key technologies for AD and ADAS and they need to be tested for different scenarios, such as pedestrians (an object crossing in front of the car), driving in the city (driving towards a stationary or slower vehicle) and inter-urban travel (similar to city travel where the centerline of the test vehicle is not in line with the center of the target).

Hardware-in-the-loop (HIL) and vehicle-in-the-loop (VIL) test scenarios with more complex target simulation capabilities are needed to reach ADAS levels 4 and 5. Demand is also increasing for benchtop radar simulation and functional tests to speed up the validation process (Fig. 1).

Today, OEMs and engineering service providers use simulated environments with software-in-the-loop systems to test sensors and control modules. Software simulations are valuable, but they cannot replicate the real-world and potentially imperfect sensor responses. Fully autonomous vehicles must deal with these irregularities. Road testing an entire integrated system in a prototype or road-legal vehicle is necessary since it allows OEMs to validate a final product before a market launch. Road testing is important to the development process but road tests alone are not enough: they are costly, time consuming and difficult to replicate.

Further testing is needed across the whole sensor development value chain and simple use cases such as testing single radar sensor components and testing complex scenarios with multiple sensors must be integrated. The goal is to test autonomous driving functions such as adaptive cruise control or emergency breaking systems under various lab conditions (see Fig. 2).

Fig. 1: ADAS levels and degree of automation: potential vehicle configurations



Level 1
- Corner SRR 3T/4R
- 40 % LRR mid 4T/8R

Object detection
Features
SRR mode: BSD, LCA

Level 2
- 1 × LRR mid 4T/8R
- 60 % L2: 2 × corner MRR mid 4T/8R
- 40 % L2: 4 × corner MRR mid 4T/8R

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

Level 3
- 1 × LRR high 12T/16R
- 4 × corner MRR mid 4T/8R

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

Level 4
- 1 × LRR high 12T/16R
- 4 × corner MRR high 8T/12R

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

Level 5
- 2 × LRR high 12T/16R
- 4 × corner MRR high 8T/12R
- 2 × side USRR

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

Realistic and repeatable radar sensor testing is challenging in the sensor value chain:

- The radar sensor is a black box. A test system must stimulate the radar sensor plus its response without knowing the internal processes.
- The system must prevent undesired reflections from the environment or test setup, such as horn antennas. It must reduce the influence of test and measurement equipment and external disturbances[1] on the radar signal. It must keep a system independent from all this interference as much as possible and ensure reliable operation.
- A flexible and scalable system is needed to cover the complete chain of sensor and ADAS testing. Having a system that can be used and deployed across the entire value chain helps.

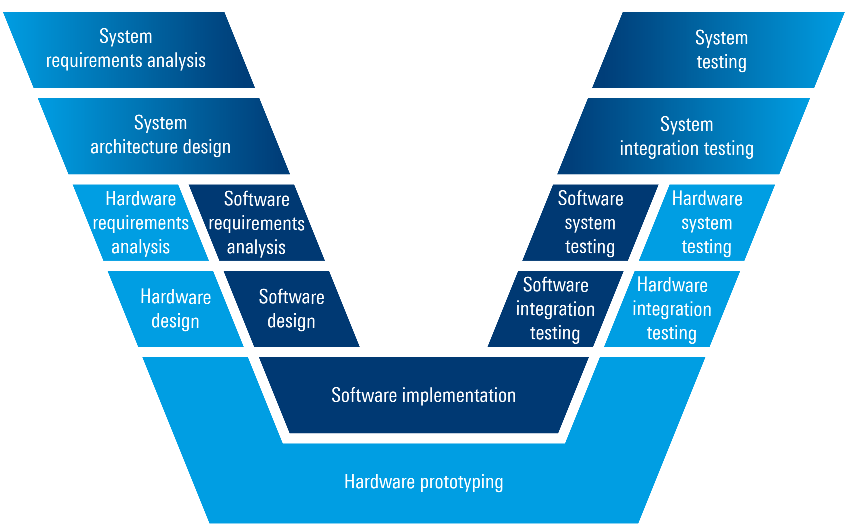
[1] Reduction of sensor noise floor as well as suppression of close range targets and potential multipath reflections.

ROHDE & SCHWARZ SOLUTION

Current target simulators use horn antennas as frontends, where each point targets radar sensors and emulates horizontal and vertical positions by mechanically moving the antenna. Mechanical automation slows overall test times. Each antenna movement changes the echo's angle of arrival (AoA), leading to errors and loss of accuracy when rendering targets when the antennas are not recalculated or recalibrated.

To overcome current system limitations and address the growing importance of HIL and VIL, Rohde & Schwarz has developed the R&S®QAT100 advanced antenna array – the world's first electronically steerable antenna array. The R&S®QAT100 simulates azimuth and elevation by activating small patch antennas. The switching time between the antennas is about 2 ms to simulate quickly moving azimuthal targets (e.g. cross traffic at an intersection or passing scenarios).

Fig. 2: ADAS sensor development process



Overview of radar sensors

Radar module parameters[1]	Radar types					
	Short-range	**Standard mid-range**	**Premium mid-range**	**Standard long-range**	**Premium long-range**	**Imaging**
Frequency range	76 GHz to 77 GHz, 77 GHz to 81 GHz	76 GHz to 77 GHz	77 GHz to 81 GHz	76 GHz to 77 GHz	76 GHz to 77 GHz	76 GHz to 81 GHz
Typical bandwidth	200/1000/ 4000 MHz	1000 MHz	2000 MHz	500 MHz	1000 MHz	2000 MHz
Range	80 m	150 m	150 m	250 m	300 m	300 m
Range resolution	300/30/3.5 cm	30 cm	7.5 cm	75 cm	30 cm	60 cm/9.5 cm
FOV[2] azimuth/elevation	±60°/±0°	±30°/±0°	±50°/±15°	±15°/±5°	±15°/±10°	±50°/±15°
Typical channel number (transmit/receive)	3/4	4/8	8/12	4/8	12/16	48/48

[1] Data sheet values of commercially available sensors from various suppliers.
[2] Field of view.

Fig. 3: The R&S®QAT100 is available in two different models

R&S®QAT-B11 standard frontend
- ▶ 96 transmit and 5 receive antennas
- ▶ Optional second independent TX/RX line
- ▶ Simulation of up to 8 echoes from different directions

R&S®QAT-B21 single-line MIMO frontend
- ▶ 96 transmit/receive antenna pairs
- ▶ Optimized for MIMO technology
- ▶ Simulation of up to 4 echoes from different directions

R&S®QAT100 advantages over the mechanical approach

OTA radar stimulation in elevation and azimuth without physically moving antennas
- ▶ Switchable transmit antennas give the R&S®QAT100 high resolution, high speed, high repeatability and better RF performance
- ▶ Electronic antenna switching does not produce any wear and tear on RF cables or other moving parts
- ▶ No mechanical handover required

Clean RF: no reflections from FE

The PCB antennas have a much lower RCS than the standard gain horns used in other systems. The R&S®QAT-B50 shielding system ensures a shielded RF environment.
- ▶ Reliable operation
- ▶ Reduced influence from other test and measurement equipment, external disturbance factors (reduced sensor noise floor, suppressing close range targets and potential multipath reflections)
- ▶ No test bed mode required for the radar

Scalable solution

Several frontends can be combined to simulate up to 360° of radar environment:
- ▶ Highly flexible and ready for expansion
- ▶ Radar FOV [1] of several sensors can be simulated by one or multiple frontends
- ▶ Usage standalone or as a one-box solution with the R&S®AREG800A automotive radar echo generator

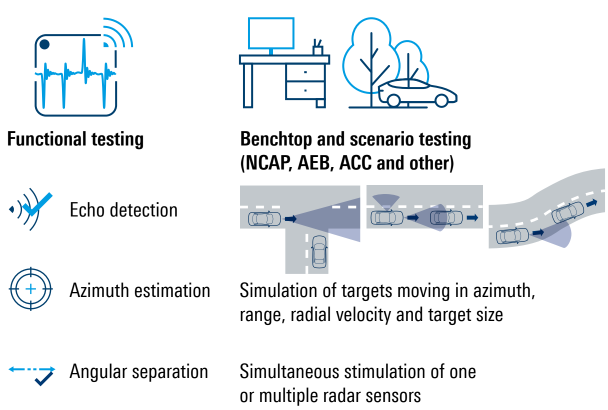
Immune to vibration: perfectly fitted for VIL testbed mounting
- ▶ Reduced amount of RF connections
- ▶ Reliable due to vibration robust design
- ▶ Suitable for test beds

[1] Field of view.

Use cases

The modular setup of the R&S®QAT100 can be used in various different applications for radar target simulations.

Fig. 4: Radar target simulation with R&S®QAT100 use cases



Component or functional testing

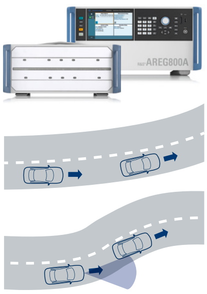
It starts with very simple use cases such as component testing for a single radar sensor. To test if a radar sensor correctly detects an echo, distinguishes between two targets at a given distance or a given angle and the angular resolution of your radar sensor.

Scenario testing

Secondary use cases include scenario testing, such as traffic scenarios with multiple cars, emergency breaking systems or adaptive cruise control. The goal is to simulate moving targets in azimuth, range, radial velocity and target size. Depending on the scenario, one or several sensors can be simulated.

Fig. 5: ADAS sensor tests

Basic ADAS sensor tests



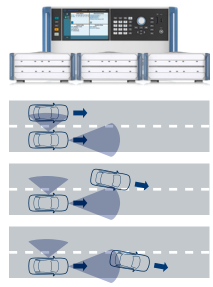
Consists of:

- ► One R&S®QAT100 advanced antenna array
- ► R&S®AREG800A automotive radar echo generator

Key features:

- ► 4 GHz bandwidth with the R&S®QAT100A advanced antenna array
- ► Dynamic artificial objects with individual distance, RCS and radial velocity and azimuth
- ► Dynamic objects: one to eight objects in the range from the air gap of the R&S®QAT100 to the sensor up to 3000 m
- ► IF input, IF output and HIL interface

Advanced ADAS sensor tests



Consists of:

- ► Three R&S®QAT100 advanced antenna arrays (up to eight possible)
- ► R&S®AREG800A automotive radar echo generator

Key features:

- ► 4 GHz bandwidth with the R&S®QAT100A advanced antenna array
- ► Dynamic artificial objects with individual distance, RCS and radial velocity and azimuth
- ► Dynamic objects: one to eight objects in the range from the air gap of the R&S®QAT100 to the sensor up to 3000 m
- ► IF input, IF output and HIL interface
- ► Can stimulate multiple radar sensors in parallel

The R&S®QAT100 has the versatility and capability to support the entire process along the radar sensor chain.

Starting with the R&S®QAT100 as a standalone device for radar sensor performance evaluation in the early stages with classical benchtop setups, to HIL and VIL applications (with target simulator as backend) at the radar sensor module level when adapting a sensor to OEM specifications(Fig. 6).

SIMO frontend

The R&S®QAT-B11 standard frontend has 96 transmit and 5 receive antennas, divided into 4 independent segments. The configuration meets SIMO sensor requirements. The R&S®QAT100 can be operated in line mode or in segment mode, depending on what is required. Segment mode divides each line into four segments, where each has an individual RF connector and can simulate up to four targets from different directions. The R&S®QAT-B11 can come with an additional TX/RX line (R&S®QAT-B2) to add another 96 transmit and 5 receive antennas to simulate up to 8 targets from different directions or two objects across the complete array.

Fig. 6: ADAS sensor development process with use cases for the R&S®QAT100 marked in orange

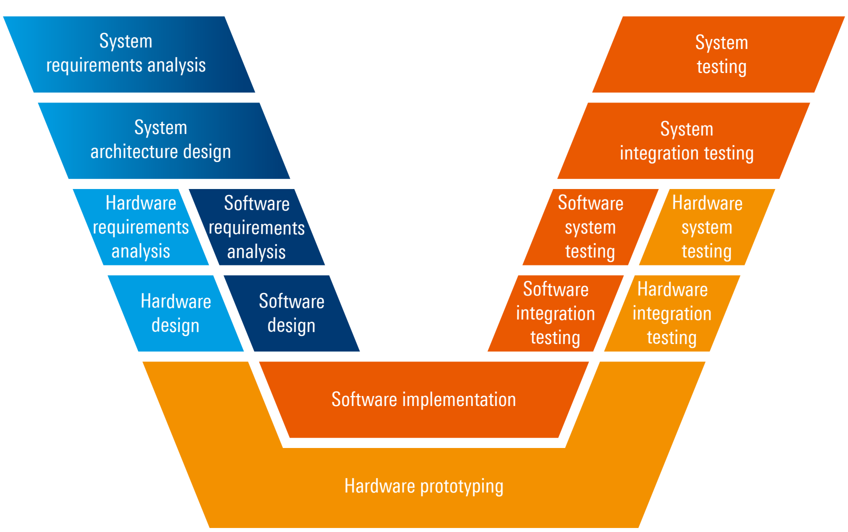
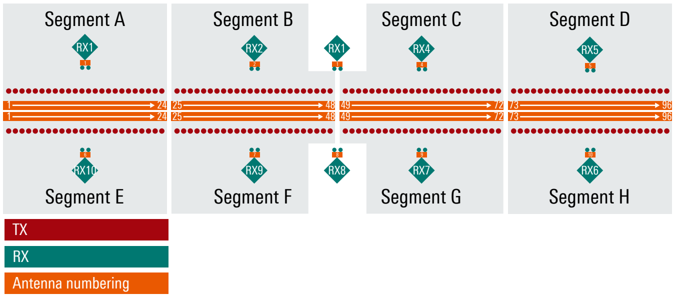


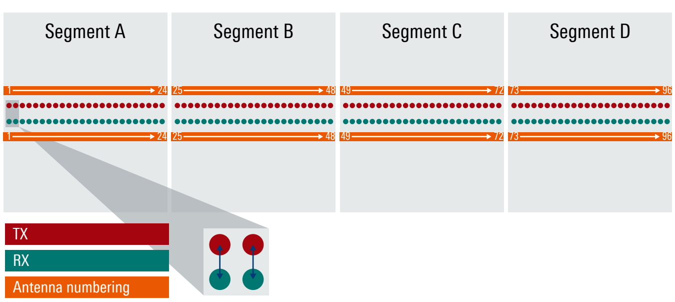
Fig. 7: R&S®QAT-B11 standard frontend and R&S®QAT-B2 second line with 96 transmit antennas



MIMO frontend

The larger offset between RX and TX antennas means the R&S®QAT-B11 does not fully meet MIMO requirements since it can be jumped at different angles. The R&S®QAT-B21 single-line MIMO frontend has one line of receive and one line of transmit antennas. Every transmit antenna is paired with a receive antenna to meet MIMO requirements. 96 receive and 96 transmit antennas are now available to minimize phase errors and enable easy validation of MIMO radars with improved spatial echo resolution in three dimensions.

Fig. 8: R&S®QAT-B21 single-line MIMO frontend

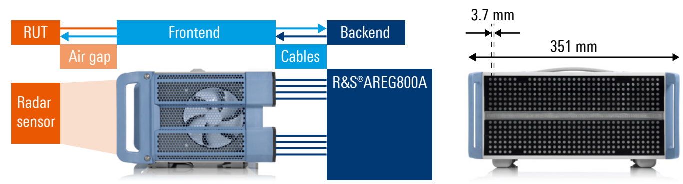


MEASUREMENT SETUP

Define the physical distance from the sensor to the R&S®QAT100

The individual antennas are 3.7 mm (0.146 in) apart, while the total unit width is 351 mm (13.818 in). The setup can be tailored to the sensor. The R&S®QAT100 is designed for typical ADAS radar transmission power.

Fig. 9: Sensor placement and R&S®QAT100 dimensions



The field of view (FOV) and achievable angular resolution for the R&S®QAT100 are based on the setup and are calculated as follows:

Field of view:

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

Angular resolution:

$$\Delta\alpha = tan^{-1}\left(\frac{3.7\ mm}{d}\right)$$

The values for FOV and angular resolution result from varying distances

Distance (d)	Field-of-view (α)	Angular resolution (Δα)
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°

The free-field attenuation can be determined with:

$$10log10 = \left[\frac{4 \cdot \pi \cdot d \cdot f \cdot 10^{9}}{c_0}\right]^2$$

π: = 3.1415...
d: = distance from radar under test to the R&S®QAT100
f: = frequency
c_0: = 299 792 458 m/s (speed of light)

Depending on distance and frequency range, the following values apply:

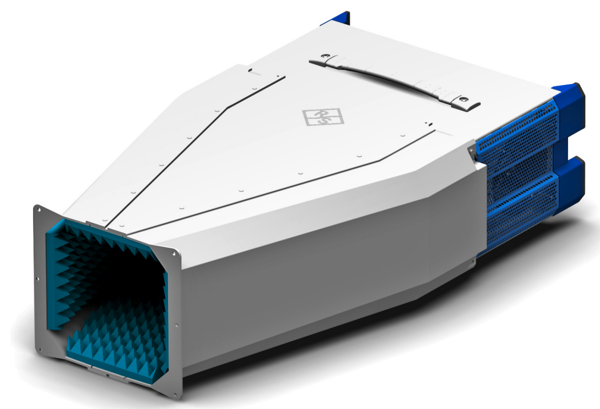
Open-field attenuation	76 GHz	77 GHz	78 GHz	79 GHz	80 GHz	81 GHz
0.5 m	64.0 dB	64.2 dB	64.3 dB	64.4 dB	64.5 dB	64.6 dB
1 m	70.1 dB	70.2 dB	70.3 dB	70.4 dB	70.5 dB	70.6 dB
1.5 m	73.6 dB	73.7 dB	73.8 dB	73.9 dB	74.0 dB	74.1 dB
2 m	76.1 dB	76.2 dB	76.3 dB	76.4 dB	76.5 dB	76.6 dB
2.5 m	78.0 dB	78.1 dB	78.2 dB	78.4 dB	78.5 dB	78.6 dB
3 m	79.6 dB	79.7 dB	79.8 dB	79.9 dB	80.1 dB	80.2 dB
3.5 m	80.9 dB	81.1 dB	81.2 dB	81.3 dB	81.4 dB	81.5 dB
4 m	82.1 dB	82.2 dB	82.3 dB	82.4 dB	82.6 dB	82.7 dB
4.5 m	83.1 dB	83.2 dB	83.4 dB	83.5 dB	83.6 dB	83.7 dB
5 m	84.0 dB	84.2 dB	84.3 dB	84.4 dB	84.5 dB	84.6 dB

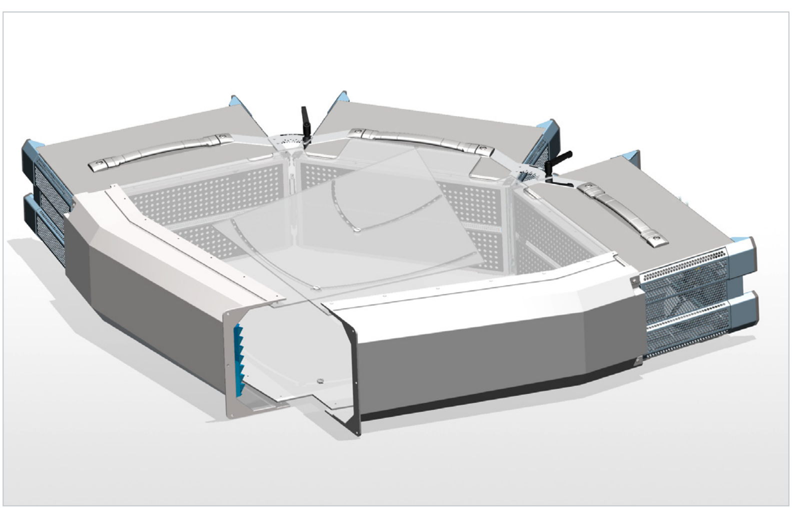
Minimize external interference

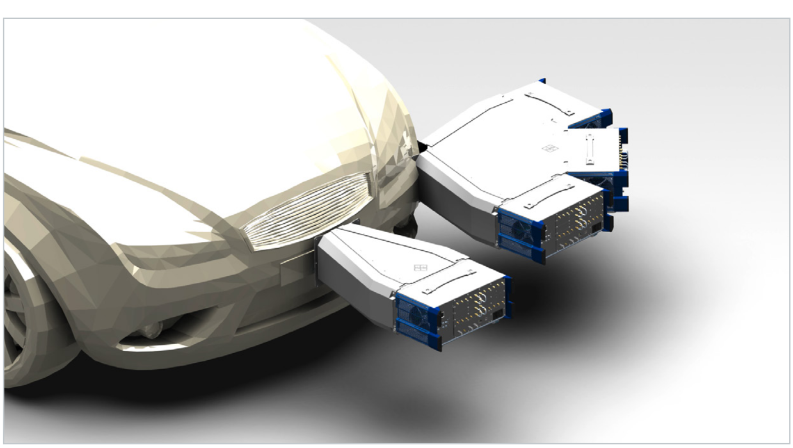
To minimize the influence of external interference, an additional shielding system provides a nearly interference-free RF environment perfectly suited to the R&S®QAT100. The shielding system can be used in laboratories on benchtops or in vehicle test stands. The shielding provides a multipath and reflection-free environment for the radar under test. When combined with the R&S®QAT100, small patch antennas with an absorber covered surface provide a clean RF frontend and suppress close-range targets as well as potential multipath reflections (see Fig. 10).

Fig. 10: Shielding and mounting set

The shielding system connects with the R&S®QAT100 and shields radars from external signals. It is available in different sizes depending on the number of connected R&S®QAT100 advanced antenna arrays (e.g. R&S®QAT-Z50 shielding system, R&S®QAT-Z53 shielding trio).







Instrument setup and connection to a radar echo generator

The number and types of connections to a radar echo generator depend on the complexity of the test setup. The setup complexity depends on the number of simulated radar objects, the number of R&S®QAT100 advanced antenna arrays or the number of receive antennas (receive antennas always receive, but can only forward a signal when connected to a backend).

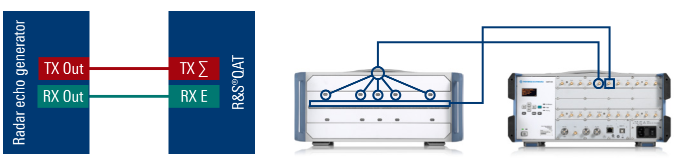
Depending on the number of individually controlled antenna segments, a radar echo generator must have a certain number of inputs:

- Connect the R&S®QAT to an LAN
- Connect the TX connectors to the “TX IF Out” for the radar echo generator. TX connectors can be used in two ways:

Fig. 11: TX connector use

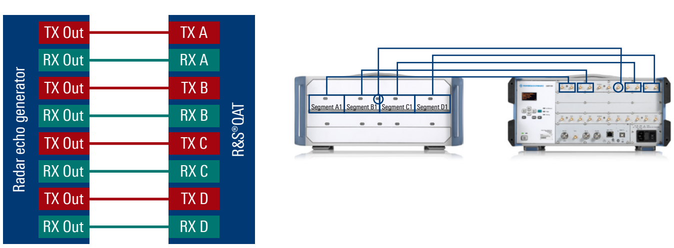
Variant 1

Connect the transmit signal to the “TX ∑” connector. All transmit antennas share the same signal now.



Variant 2

Connect the transmit signal from “TX A” to “TX D” connector. Each antenna segment can transmit a different signal now, enabling up to four targets per TX line. Connect the RX antennas to the “RX IF In” on the radar echo generator. If you want just a single receive signal from the radar echo generator, connect the “RX Select” to one “RX IF In”. To connect other external devices such as a spectrum analyzer, use the “RX Select” connector.



To synchronize reference frequencies, connect the frequency reference (input or output) to the radar echo generator.

When equipped with the R&S®QAT-B2 second line of 96 transmit antennas, the R&S®QAT100 has two lines with four independent segments each, enabling a single instrument to connect to eight individually controllable IF paths. This combines perfectly with the eight completely independent artificial objects simulated by a fully equipped R&S®AREG800A automotive radar echo generator. Each IF path can be freely steered within an R&S®QAT100 segment.

To simulate targets at a shorter range, the R&S®QAT100 can be equipped with an analog stepped delay line (ASDL) to reduce the minimum delay line. This line can simulate radar objects at very short distances of 1.8 m to 12.9 m that are challenging for radar echo generators. It also enables the standalone use of the R&S®QAT100. To test the angular resolution of your radar sensor, the radar sensor distinguishes between two targets at a given distance or a given angle.

In combination with a target simulator, the R&S®AREG800A can emulate moving targets.

Total number of generated echoes		1 (adjustable)
Distance	minimum	< 1.8 m [2]
	maximum	12.9 m [2]
	resolution	0.1 m
Attenuation	range	60 dB
	resolution	1 dB

[2] Without air gap.

SUMMARY

Autonomous driver assistance systems urgently need reliable and high-quality data from various radar sensors that detect objects in the environment. Automotive companies and suppliers know how complicated testing these sensors in autonomous driving scenarios can be.

The R&S®QAT100 is the first fully electronically steerable antenna array that stimulates automotive radar sensors in the range from 76 GHz to 81 GHz. The modular R&S®QAT100 concept lets automotive OEMs and partners focus on developing and testing ADAS systems.

Open architecture OEMs let suppliers and service providers easily integrate the R&S®QAT100 platform into commercial 3D modeling, hardware-in-the-loop systems and existing test and simulation environments. Faster testing of automotive radar sensors across the whole value chain is possible from simple functional component validation to highly complex multitarget scenario testing.

Summarized benefits

Benefit	Description
No mechanical movement, immune to vibration results in precise and repeatable measurements	The switchable transmit antennas in the R&S®QAT100 ensure high resolution, high speed and high repeatability. Electronic antenna switching produces no wear and tear on RF cables or other moving parts. 4 GHz of instantaneous bandwidth supports state-of-the-art automotive radar sensors in the frequency range of 76 GHz to 81 GHz.
Support of advanced scenarios and scalable solution	Antenna spacing of just 3.7 mm ensures high angular resolution for realistic simulation of complex radar scenarios. Several R&S®QAT100 units can be combined to increase the field of view. A target simulator for complex ADAS scenarios ensures synchronization of all R&S®QAT100 arrays in multi-instrument advanced antenna arrays.
Shielded environment as well as reduced reflections and multipath effects	The R&S®QAT-Z50 shielding system and R&S®QAT-Z53 shielding trio ensure a nearly interference-free RF environment ideal for the R&S®QAT100. The small patch antennas together with the absorber covered surface provide a clean RF frontend with very low RCS to reduce the sensor noise floor and suppress close range targets and potential multipath reflections
Quickly perform functional tests in standalone mode	An R&S®QAT-B5 analog stepped delay line (ASDL) lets the R&S®QAT100 be operated in standalone mode. In this mode, the R&S®QAT100 can simulate close range echoes within the delay range for quick and space-saving functional tests.

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