AUTOMATED ADAS TEST SYSTEM TRIAL WITH RADAR SENSORS AND ELECTROMAGNETIC INTERFERENCE

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1 ABSTRACT

A full-vehicles test was conducted to demonstrate the automated ADAS test system, consisting of a radar echo generator, a dynamic target positioning system and an EMS test system.

The goal was to prove that simulated scenarios would be effective in activating the VUT ADAS functions and intended responses in an EMC test chamber. This is essential in assessing ADAS functions under electromagnetic interference in EMS testing.

2 BACKGROUND

Back in the 20th century, automobiles became a crucial mode of transportation. As the technologies advances, sophisticated functions and autonomous features have quickly found their way into modern vehicles. These have multiple car components communicating with each other and making complex computations to control the car as needed. Electrical cabling is the third largest factor for total vehicle cost and weight, making ADAS systems susceptible to electromagnetic interference from both the environment and the vehicle itself.

Most of the advanced driver assistance system (ADAS) functions in modern autonomous vehicles such as adaptive cruise control (ACC) and autonomous emergency braking (AEB) need radar sensors. Modern vehicles have multiple radar sensors integrated at different positions to detect targets both far away and up close. Some of these ADAS features help to prevent accidents when the driver cannot react in time.

For example, the AEB function activates when one vehicle suddenly cuts in front of another. To prevent a collision, ADAS overrides the driver controls and activates the AEB to engage the brakes.

Since radars are critical to vehicles, manufacturers need to ensure that they do not malfunction or become non-responsive in critical situations. Stringent EMS testing in line with ISO 11451-2 is carried out for vehicle level testing. However, one of the key challenges is replicating real life scenarios where the ADAS car radar functions are activated during EMS testing.

3 TEST SYSTEM AND EQUIPMENT

The ADAS test system consisting of a radar echo generator, target positioning system and EMS test system.

The R&S®AREG100A automotive radar echo generator simulates a lead vehicle that is seen by the VUT at predefined distances and variable speeds. The target positioning system (R&S®TA-RDS) simulates a lane change from left to right and vice versa. These two subsystems can generate scenarios to verify VUT automatic speed change performance in ACC mode and emergency braking performance in AEB mode.

The R&S®TS9982 EMS test system introduces electromagnetic interference to the VUT to check for performance degradation.

The following section has a brief description of the three subsystems: the R&S®AREG100A, the R&S®TA-RDS and the R&S®TS9982 EMS test system.

3.1 R&S®AREG100A automotive radar echo generator

R&S®AREG100A simulates a lead vehicle ahead of the VUT by receiving and processing the VUT radar signals before transmitting it back as an echo. The detection of simulated targets in the generated scenarios enables ACC and AEB testing.

The R&S®AREG100A provides four simulated targets with each having a defined distance. Appropriate radar cross section (RCS) settings in the R&S®AREG100A are required for the VUT to identify the simulated target as a vehicle. In the scenario settings, distance and Doppler are set to simulate a change in target position and velocity relative to the VUT, providing a realistic target simulation.

Fig. 1: R&S®AREG100 automotive radar echo generator

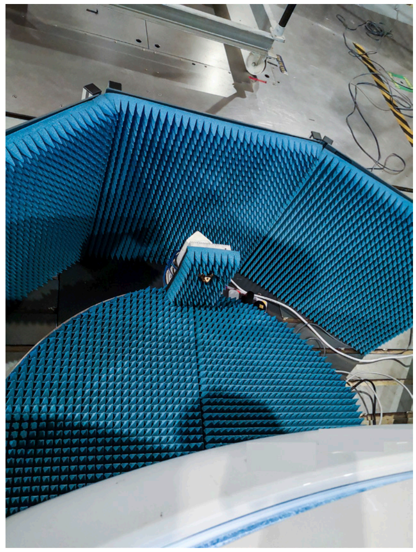
Key facts:

- Supports common 24 GHz, 77 GHz and 79 GHz automotive radar bands
- Maximum instantaneous bandwidth up to 4 GHz for testing the latest generation of E band radar sensors at 79 GHz
- User-defined test cases with up to four individually switchable distances of the object, controllable Doppler offset and radar cross section (RCS)

3.2 R&S®TA-RDS target positioning system

The R&S®TA-RDS creates angular movement for an R&S®AREG100A simulated target for cut-in scenarios that emulate real road situations, increasing car radar test coverage and reliability in different scenarios.

Fig. 2: R&S®TA-RDS target positioning system

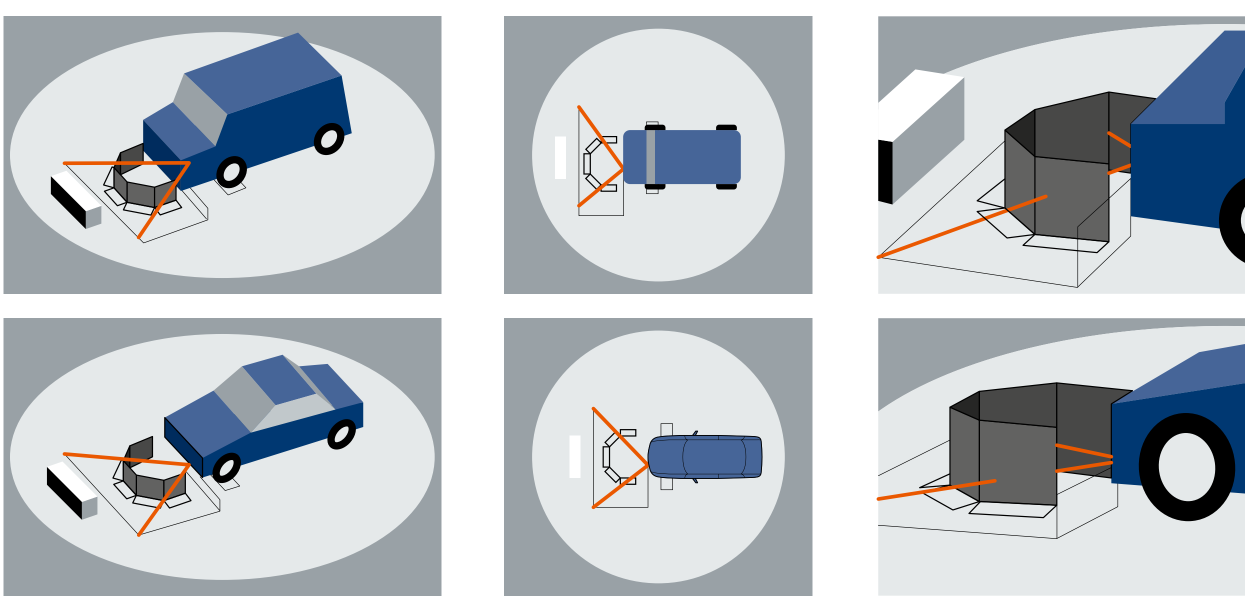


Key facts:

- ±55° range of motion to allow dynamic movement of the target during testing; center position is 0°
- Software control is integrable with R&S®EMC32
- Absorber walls prevent the radar from detecting unwanted targets

Absorber walls surrounding the driver assistance system and radar target echo antenna remove unwanted reflections that could interfere with testing by appearing as reflected targets. Additional absorbers walls are set up to prevent the VUT from receiving reflections from test antennas and the chamber walls and floor. See diagram below for various vehicle setups with the ADAS test system in an anechoic chamber.

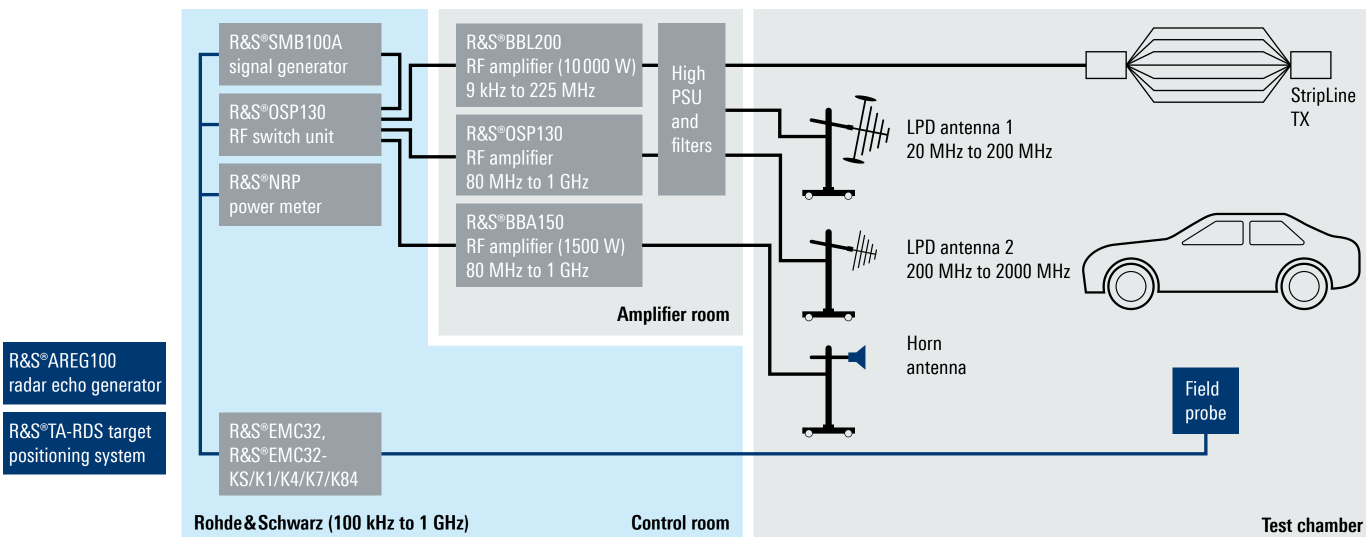
Fig. 3: Different types of car setup with movable wall absorbers in anechoic chamber



3.3 R&S®TS9982 EMS test system

The R&S®TS9982 EMS test system is the base system for conducted and radiated EMS measurements in line with ISO 114511-2. It consists of a signal generator with several amplifiers and antennas covering different frequency ranges to produce the required field strength for testing a vehicle's electromagnetic susceptibility. The figure below is a sample block diagram of an R&S®TS9982 test system covering 9 kHz to 3.2 GHz. Switching units are included to automate the selection of a different amplifier to connect to the signal generator output. High-power switching units (PSU) enable different power amplifier outputs to be switched to different connection points in the test chamber. R&S®EMC32 is the EMC test software that enables automatic EMS testing and EUT monitoring with test system instruments. R&S®EMC32 can also be configured to control the R&S®AREG100A and the R&S®TA-RDS when setting up the required ADAS testing scenarios.

Fig. 4: R&S®TS9982 EMS test system (in gray blocks)



4 TEST METHODS

This section focuses on test methods for assessing VUT ADAS functions. It introduces the VUT test setup in an anechoic chamber and describes ACC and AEB test scenarios.

The first phase of testing verifies whether the ADAS works as intended in the simulated environment using the R&S®AREG100A and the R&S®TA-RDS. No electromagnetic interference is introduced during this phase.

In the second phase, electromagnetic interference is introduced using the R&S®TS9982 EMS test system and R&S®EMC32 software that will also control the R&S®AREG100A and the R&S®TA-RDS functions for full test automation.

4.1 Vehicle under test (VUT) setup in EMC chamber

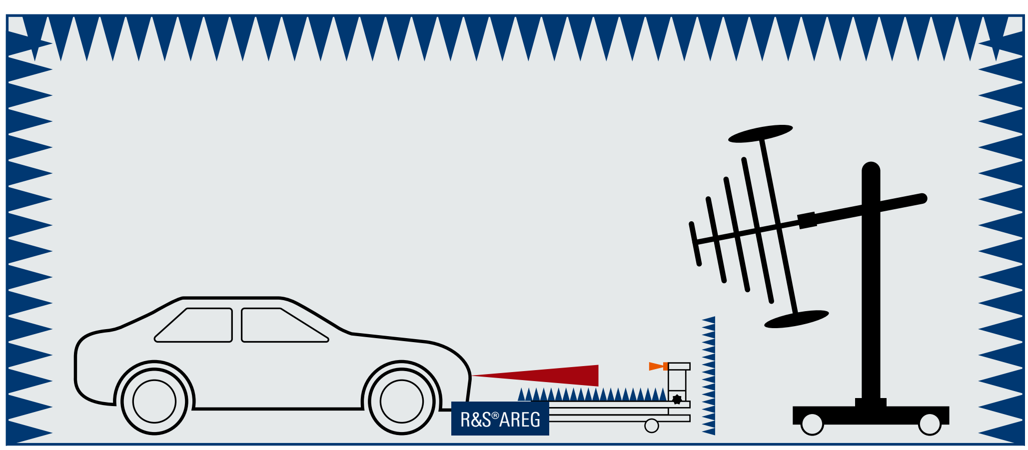
For the full vehicle EMS test, methods are assessed for testing ACC and AEB functions. These ADAS functions are activated while the VUT runs on the dynamometer. Records are kept of ADAS abnormalities or malfunctions when subjected to electromagnetic interference.

The VUT front radar sensors are tested in the EMC chamber.

The VUT responses are recorded using wheel speed on the dynamometer, brake lights and any indications on the dashboard using the EMC camera.

The scenarios below were run and tested for at least ten seconds without electromagnetic interference to check for any unforeseen problems and ensure that the ACC and AEB functions are working as intended before the EMS test.

Fig. 5: Sample setup for ISO 11451-2 testing with the R&S®TA-RDS and the R&S®AREG100A.



4.1.1 ACC test plan

The VUT cruises at a steady speed and maintains a defined minimum distance from the detected target. A dynamic driving environment uses the R&S®AREG100A to simulate the lead vehicle and the R&S®TA-RDS for cut-in scenarios. The lead vehicle will cut in at a slower relative velocity. The VUT detects the car at a close distance and tries to decelerate and maintain the defined minimum distance while under EMS testing. Another scenario involves the VUT detecting the lead vehicle at a distance and trying to maintain the distance when the lead vehicle decelerates. VUT monitoring is set up to observe the VUT response on the dynamometer, brake lights and dashboard warning lights for both scenarios.

The following three scenarios are performed sequentially.

4.1.1.1 ACC test procedure – lead vehicle at equal speed

1. Set the VUT to cruise at 40 km/h, then switch on ACC mode.

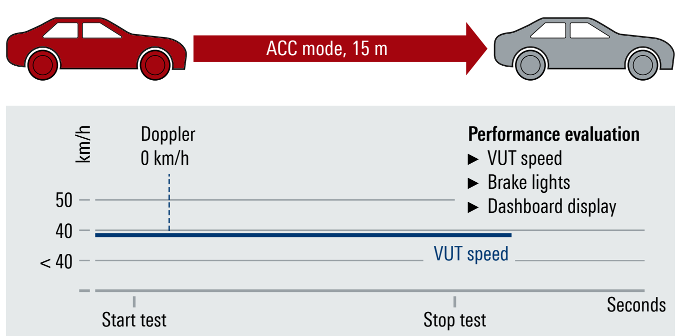
2. Set the R&S®AREG100A to:15 m target, Doppler 0 km/h and RCS 10 dBsm.

3. Set the R&S®TA-RDS to move from –40° to 0° at 1°/s speed (optional, for lead vehicle cut-in scenario only).

4. The VUT is expected to detect a lead vehicle as shown on the VUT's dashboard.

5. The VUT is expected to detect the lead vehicle traveling at the same speed as the VUT and the VUT maintains the cruising speed of 40 km/h. The constant VUT speed can be monitored on the dynamometer.

Fig. 6: VUT speed illustration for lead vehicle at equal speed



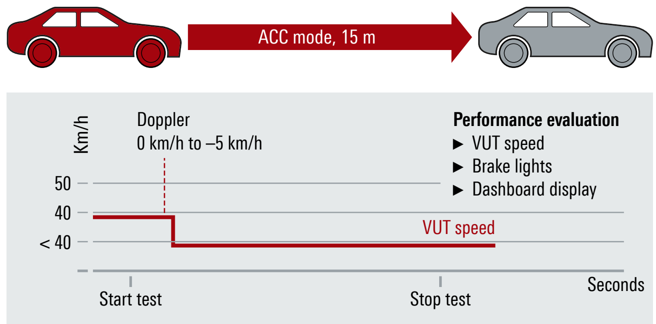
4.1.1.2 ACC test procedure – lead vehicle decelerating

1. Continuing from previous scenario in 4.1.1.1

2. Set the R&S®AREG100A to: Doppler –5 km/h.

3. The VUT is expected to detect the lead vehicle decelerating and the VUT should decelerate in response. The VUT deceleration can be observed on the dynamometer.

Fig. 7: VUT speed illustration for lead vehicle decelerating



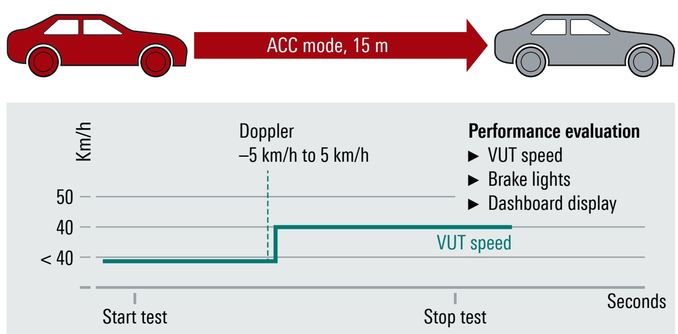
4.1.1.3 ACC testing – lead vehicle accelerating

4. Continuing from previous scenario in 4.1.1.2.

5. Set the R&S®AREG100A to: Doppler 5 km/h.

6. The VUT is expected to detect the lead vehicle accelerating and the VUT would accelerate in response until it reaches the preset ACC cruising speed of 40 km/h. The VUT acceleration can be observed on the dynamometer.

Fig. 8: VUT speed illustration for lead vehicle accelerating



4.1.2 AEB test plan

The AEB in this section is the AEB vehicle mode, not the AEB pedestrian mode. AEB vehicle and AEB pedestrian prioritize different sensors. The VUT will travel at a steady speed during the test until the lead vehicle suddenly slows down. In response, the AEB function will be triggered and the VUT will brake. Two simulation scenarios are available, in one the lead vehicle is always in the same lane and in the other the lead vehicle cuts in from an adjacent lane and brakes. The R&S®AREG100A simulates the lead vehicle and the R&S®TA-RDS cuts in for the latter scenario. The VUT response is monitored on the dynamometer, brake lights and the dashboard warning lights for both scenarios.

4.1.2.1 AEB testing – lead vehicle brakes

1. Set the VUT to cruise at 50 km/h then switch on AEB mode.

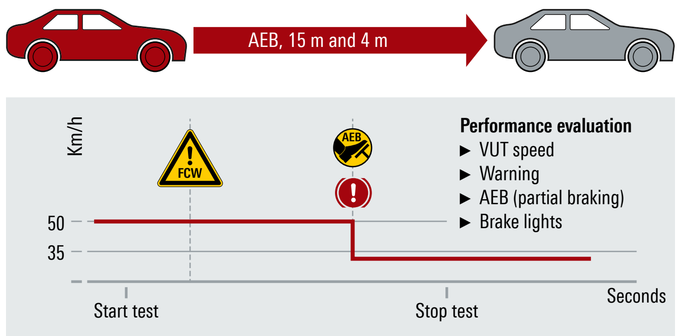
2. Set the R&S®AREG100A to: 15 m target, relative velocity 10 km/h, RCS 10 dBsm.

3. Set the R&S®TA-RDS to move from –40° to 0° at 1°/s speed (optional, for lead vehicle cut-in scenario only).

4. Set the R&S®AREG100A relative velocity: –30 km/h and 4 m target.

5. The VUT is expected to show a forward collision warning (FCW) and activate the AEB in response, as seen on the VUT dashboard AEB indicator and brake lights.

Fig. 9: VUT speed illustration due to lead vehicle braking



5 OBSERVATIONS AND CHALLENGES

5.1 Observing VUT response during trial

Following the test plan in section 4, both the ACC and AEB were activated as intended with the observations recorded in this section.

5.1.1 Observations of VUT responses without electromagnetic interference

Prior to the test, the carmaker-specified VUT response was observed without applying any electromagnetic interference.

Table 1: ACC activation scenarios and observations (1)

ACC activation scenarios	Observations
VUT accelerates from 0 km/h to 40 km/h, ACC in operation when car speed reaches 40 km/h	Passed
VUT detects and identifies target simulated by the R&S®AREG100A	Passed
VUT responses subject to the R&S®AREG100A distance and modified Doppler settings	
1. R&S®AREG100A Doppler 0 km/h, speed maintained at 40 km/h	Passed
2. R&S®AREG100A Doppler –5 km/h, speed decelerated to 30 km/h	Passed
3. R&S®AREG100A Doppler 5 km/h, speed accelerated to 40 km/h	Passed

The VUT AEB system engaged the brakes, reducing its speed from 50 km/h to 35 km/h. The VUT performed braking deceleration.

Table 2: ACC activation scenarios and observations (2)

ACC activation scenarios	Observations
Car from 0 km/h to 50 km/h	Passed
The R&S®AREG reduces distance from 15 m to 4 m and Doppler to –30 km/h, AEB is activated	Passed

5.1.2 Observing VUT response and the influence of electromagnetic interference

Electromagnetic interference is generated with the R&S®TS9982 EMS test system using R&S®EMC32 software. R&S®EMC32 is the main control software for R&S®TA-RDS and R&S®AREG100A settings.

During the trial, a total of ten different ACC scenarios and four different AEB scenarios were performed in the chamber. A field strength of 30 V/m AM was applied as the EMS test signal and no VUT failure from applied field strength was observed.

Table 3: ADAS system test scenarios

Scenario	ADAS function	AREG settings for lead vehicle simulation	Test frequency	Field strength
1	ACC	relative velocity at 0 km/h, then change to –5 km/h	20 MHz to 2 GHz	30 V/m
2	ACC	relative velocity at –5 km/h, then change to 10 km/h	20 MHz to 2 GHz	30 V/m
3	ACC	relative velocity at 10 km/h, then change to 0 km/h	20 MHz to 2 GHz	30 V/m
4	ACC	relative velocity at 5 km/h, then change to –10 km/h	20 MHz to 2 GHz	30 V/m
5	ACC	relative velocity at 10 km/h, then change to –5 km/h	20 MHz to 2 GHz	30 V/m
6	ACC	relative velocity at 10 km/h, then change to 0 km/h	20 MHz to 2 GHz	30 V/m
7	ACC	relative velocity at 3 km/h, then change to 0 km/h	20 MHz to 2 GHz	30 V/m
8	ACC	relative velocity at –5 km/h, then change to 10 km/h	20 MHz to 2 GHz	30 V/m
9	ACC	relative velocity at 10 km/h, then decrease to –5 km/h	20 MHz to 2 GHz	30 V/m
10	AEB–CCRB	15 m target relative velocity at 10 km/h, then change to –30 km/h and turn on 4 m	NIL	NIL
11	AEB–CCRB	15 m target relative velocity at 10 km/h, then change to –30 km/h and turn on 4 m	NIL	NIL
12	AEB–CCRB	15 m target relative velocity at 10 km/h, then change to –30 km/h and turn on 4 m	20 MHz to 140 MHz	30 V/m
13	AEB–CCRB	15 m target relative velocity at 10 km/h, then change to –30 km/h and turn on 4 m	30 MHz	30 V/m
14	ACC	relative velocity at 5 km/h, then change to 2 km/h, target will cut in front of the VUT	NIL	NIL

Note: The research objective is to prove that simulated scenarios can be set up in the EMC chamber to activate the VUT ADAS functions and responses and not to test VUT susceptibility. Complete EMS testing across the ISO 11451-2 frequency range of 10 kHz to 18 GHz and typical test level of 200 V/m was not conducted due to time constraints.

5.2 Test challenges

Some challenges arose during the actual test.

5.2.1 Radar requires to sense some objects for ECU to function

Absorber walls placed in front of the VUT helped remove reflections (unwanted targets) in the test environment. When the absorber walls blocked the radar's view entirely, the radar was presented with a clean environment without any targets. However, this is not a realistic scenario and the electronic control unit (ECU) would assume that the results are unreliable and that the receiver port of the radar sensor is faulty and disable the radar sensor.

To resolve this, the left and right side absorber walls were adjusted so that the radar could still detect objects from the sides, enabling the radar sensor to continue functioning in the test setup.

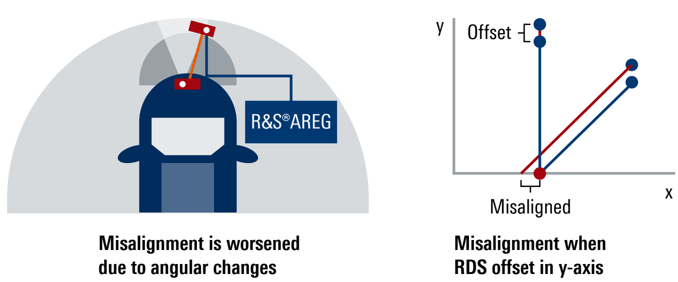
5.2.2 Absorber coverage improved for antenna holder

Absorbers remove unwanted targets detected by the radar sensor during testing. The R&S®TA-RDS antenna holder needed to be considered as it was moved from +55° to –55°. Close proximity detection occurs when the antenna holder was at –35°. The sides of the antenna holder were not covered with absorbers, so the radar saw them as a close proximity object 0.5 m in front of the VUT. The result was unintended VUT braking. (At a distance of 3 m to 4 m, an object detected at ±35° would be in the adjacent lane and should not affect the VUT radar. However at close proximity of 0.5 m, the VUT rightfully identified the risk of collision with the detected object and reacted accordingly.)

5.2.3 Wrong angle information due to misalignment of the R&S®TA-RDS and radar

The position of the internal car radar is not always visible externally. The car radar and the R&S®TA-RDS may be misaligned. This will result in the incorrect effective angle for the radar target. A laser pointer was used to indicate the position of the front radar and improve the alignment of the R&S®TA-RDS.

Fig. 10: VUT to frontend alignment



5.3 ACC and AEB performance observations

The following section documents the behavior of the VUT in ACC and AEB modes. These observations only apply to the vehicle model tested and behavior could differ for other vehicle models.

5.3.1 ACC mode behavior

1. In ACC mode the car cruised at the set speed. When a close proximity target was detected, the braking system would activate and ACC mode would deactivate. These close proximity targets could be caused by the objects in the test set up, for example, the target simulating antenna on the R&S®TA-RDS, or RF cables connecting to the antenna. Therefore it is critical that absorbers adequately remove unintended reflections from the front.

2. The car would maintain different minimum distance depending on the ACC mode. In ACC mode 1, the minimum distance between the lead vehicle and the VUT was 10 m. If the simulated lead vehicle was less than the minimum distance, the VUT decelerated to maintain the minimum distance from the lead vehicle, even though the lead vehicle had the same set speed as the VUT.

3. The dashboard of the car showed a target if it was between +20° and –20° from the radar. Even though the radar can detect a much wider angle, the ECU determined that only objects located between +20° and –20° were in front of the VUT.

4. When the target Doppler changed more than 5 km/h, the VUT detected a close proximity target and activated the brakes. This change also disabled the ACC mode. The manufacturer has indicated that the ACC function has acceleration and deceleration limits for reasons of safety and comfort. If VUT velocity changes exceed these limits, the ACC will deactivate.

5.3.2 AEB mode behavior

1. VUT velocity needed to be at least 30 km/h for AEB to activate.

2. Sudden reductions in relative velocity from 0 km/h to –30 km/h alone were not sufficient to activate the AEB. The target distance needed to be closer, e.g. simulating an additional 4 m target. In this scenario, the AEB brakes to decelerate but does not stop completely. The AEB is designed to help reduce and avoid collision damage, so the AEB adjusts to the dynamic target. In collisions, the AEB can only decelerate to reduce collision damage.

3. The ACC must be in mode 1 so that the allowable distance between the lead vehicle and the VUT is kept to a minimum. The ACC did not need to be activated for minimum distance to be effective.

6 CONCLUSION

By incorporating the ADAS test system into the existing EMS system, we can replicate multiple realistic scenarios inside the anechoic chamber and subject the VUT to EMS testing. Automated testing was possible with the successful control of the R&S®TA-RDS and the R&S®AREG100A during EMS testing.

Based on our trial assessment results, the VUT reacted as intended to our simulated target. Some improvised solutions were implemented during the trial, such as changing the frontend polarization of the R&S®AREG100A and these will be considered in future improvements to the R&S®TA-RDS.

In conclusion, the trial was successful with the customer's VUT. Since different vehicles have different ECU and radar behaviors, results with other vehicle models may deviate from our findings. Future investigations should include testing of other ADAS functions, such as camera and V2X communications and also perform full vehicle EMS testing with higher field strengths.

Test automation with R&S®TA-RDS and R&S®AREG100A

7 REFERENCES

[1] ISO 11451-1:2015, ISO document, Road vehicles — Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 1: General principles and terminology

[2] ISO 11451-2:2015, ISO document, Road vehicles — Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 2: Off-vehicle radiation sources

8 PRODUCTS FROM ROHDE & SCHWARZ

Type	Designation	Description
R&S®AREG100A	Automotive radar echo generator	The R&S®AREG100A automotive radar echo generator simulates a target object at a defined distance, radar cross section and Doppler as part of automotive radar testing.
R&S®EMC32	EMC measurement software	The R&S®EMC32 EMC measurement software is a proprietary software that automates test instruments to run electromagnetic compatibility tests.
R&S®TS9982	EMS test system	The R&S®TS9982 EMS test system is the base system for conducted and radiated EMS measurements.

9 LIST OF ABBREVIATIONS

Term	Explanation	Description
ACC	Adaptive cruise control	Adaptive cruise control operates by adjusting vehicle speed automatically to maintain a fixed safe distance to the lead car. The radar allows the vehicle to gauge the distance of the lead car and reacts accordingly by accelerating or decelerating.
ADAS	Advanced driver assistance system	Advanced driver assistance systems are electronic automotive systems that help the driver when parking or driving. They automate, adapt and enhance safety and improve driving by integrating safety features such as ACC, AEB and AESS. It helps avoid collision by taking over control of the vehicle.
AEB – CCRb	Autonomous emergency braking – car-to-car rear braking	Autonomous emergency braking assists drivers when emergency braking and is a car safety features. Car-to-car rear braking is used when a moving car detects the lead car braking. This triggers the AEB and prevents a collision.
AM	Amplitude modulation	Amplitude modulation is the modulation of a wave by varying its amplitude in proportion to that of the message signal being transmitted.
CAN	Controller area network protocol	CAN protocol is a robust vehicle bus standard that allows communications protocols to communicate between microcontrollers without a host computer acting as a medium.
CW	Continuous wave	Continuous wave is an unmodulated electromagnetic waveform that consist of constant frequency and amplitude which is typically a sine wave.
E band		E band is a frequency band in an electromagnetic spectrum that has a range of 60 GHz to 90 GHz.
ECU	Electronic control unit	The electronic control unit is an embedded system which controls one or more systems or subsystems. Each unit is modular and controls certain aspect of the modern vehicle. It is referred to as the car's computer and a modern vehicle can consist up to 80 ECUs.
EMC	Electromagnetic compatibility	Electromagnetic compatibility refers to the ability of an electrical or electronic equipment to function under electromagnetic interference and does not interfere other components with its own electromagnetic generation.
EMS	Electromagnetic susceptibility	Electromagnetic susceptibility is the tendency of electrical equipment to malfunction or break down in the presence of unwanted electromagnetic emissions. EMS testing is a vulnerability test of electronic components, subsystems or complete systems under electromagnetic interferences.
RCS	Radar cross section	Radar cross section is a measure of the radar target's ability to reflect radar signals in the direction of the radar receiver.
RDS	Radar drive system	The radar drive system is a positioner to simulate movement of the radar target.
RF	Radio frequency	Radio frequency refers to the oscillation of an alternating electric current or voltage of a magnetic, electric or electromagnetic field and is represented by the unit "Hz".
V2X	Vehicle-to-everything	Vehicle-to-everything communications is the passing of information from a vehicle to any entity that may affect the vehicle, and vice versa.
VUT	Vehicle under test	A vehicle under test refers to the automotive vehicle undergoing testing.

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