# SAFELY NAVIGATING ON ROADS

Vehicles see the world through sensors. A new test system sharpens their vision.

**Without highly advanced sensors, autonomous driving is only a dream. But sensor development is making rapid progress. Radar sensors can now deliver image-like resolution, but only if they are calibrated. A compact test system from Rohde & Schwarz accomplishes this very quickly.**

## ADAS increases road safety

The EU has a relatively good record when it comes to traffic safety. Nevertheless, according to a publication of the European Parliament, there are still more than 25,000 fatalities every year on roads in the EU, and another 135,000 persons suffer severe injuries. The socioeconomic consequences alone are estimated at EUR 120 billion annually.

These figures could be reduced by improving the safety systems in vehicles. Advanced driver assistance systems (ADAS), such as blind spot warning and braking assistants, have been state of the art for many years. In February 2019, forty countries under the leadership of Japan and the European Union agreed to require new passenger vehicles and light commercial vehicles to be equipped with automatic emergency braking (AEB) systems from 2022 onward. In addition, the European New Car Assessment Program (NCAP) evaluates vehicles on the basis of safety features to increase user awareness and push ADAS deployment by vehicle manufacturers.

## Radar is essential for autonomy

Even without legislative requirements, the ADAS development trend is being explicitly promoted because autonomous vehicles (the ultimate goal of all development efforts) are otherwise simply not feasible. The sensor frontend, which is intended to replace the driver's eyes and ears, is making especially rapid progress. Vehicles at autonomy levels 4 and 5 will presumably make use of an extensive sensor set consisting of cameras, ultrasonic sensors, lidar and radar sensors. Along with functional aspects, the costs of these components are decisive for their use. Lidar sensors, which are based on laser technology, are lagging a bit behind radar sensors and are still relatively expensive. They feature higher spatial resolution capability, but their reliance on optical systems impairs their capability under poor weather conditions. Radars are not bothered by this, and since their performance has improved dramatically in recent years and they are relatively low-cost, they form the backbone of current ADAS.

The latest 77 GHz/79 GHz radar sensors have bandwidths of up to 4 GHz, compared to 200 MHz with traditional 24 GHz sensors. The higher frequency band allows smaller antennas while significantly improving resolution capability and accuracy. The increasingly high levels of sensor integration are another contributing factor. The radar-on-chip (RoC) module from Uhnder (Fig. 4), which combines all analog and digital frontend and backend components on a single chip, leads the development trend.

## Tricky test conditions

R&D, optimization, validation and calibration of automotive radar sensors must be be subjected to accurate tests because road safety is directly dependent on precision. In addition to measuring the RF parameters, target simulation must be used to evaluate whether a sensor can determine the positions and speeds of objects in its field of view (FoV) within the required resolution.

This is a demanding task due to the high frequency band and the need to make measurements under far-field conditions in order to achieve accurate results. The Fraunhofer formula shows that measuring a 77 GHz radar with a 15 cm aperture requires a target distance of at least 11.5 meters (Fig. 1) to obtain the necessary electromagnetic field uniformity (quiet zone, Fig. 2). The industry is striving for higher and higher angular resolution, so the trend is to integrate more antennas per module, leading to the deployment of antenna arrays with larger apertures. Aperture sizes of more than 20 cm are not unusual, especially in the prototype phase. Far-field test chambers are impractical for these conditions, so near-field to far-field transformation methods can be used instead. These lead to compact antenna test ranges (CATR) that are small enough to easily fit in relatively small labs and are especially beneficial in production environments (Fig. 3).

Radar sensors are in the category of automotive devices that have to be individually tested. Each and every sensor has to be verified, both for safety reasons and because the RF features make individual calibration necessary. This

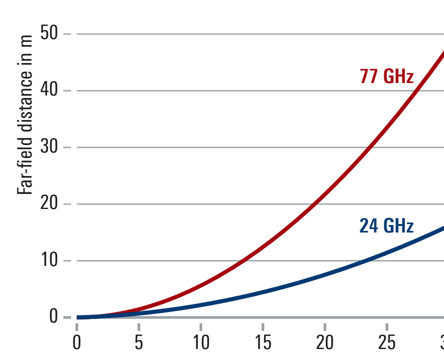


Fig. 1: The large far-field distance of a 77 GHz automotive radar compels T&M manufacturers to come up with innovative solutions to keep measurement setups compact.

is done by simulating a target with a known position, size and speed. The gain, phase and coupling of the antenna path are calibrated for this target, which means that unique calibration data is assigned to them and stored in the module.

The industry is independently trying to do everything necessary to make radars reliable, and now the competent standardization bodies are also tackling this issue. For example, the European Telecommunications Standards

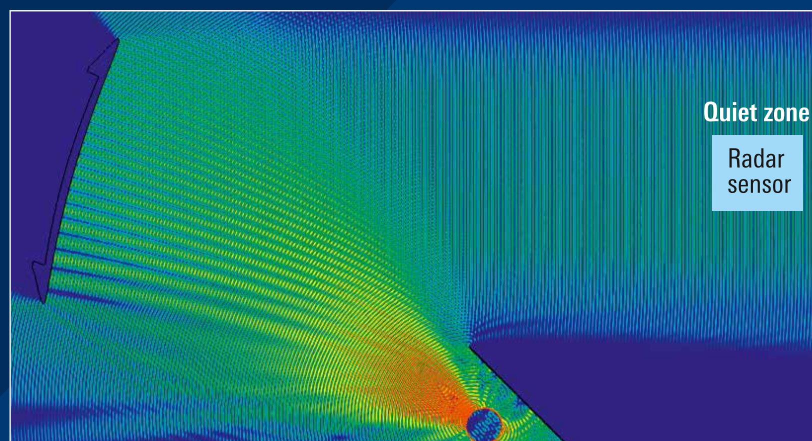


Fig. 2: The precision parabolic reflector in the test chamber transforms the spherical near-field waves from the feed antenna into planar far-field waves, resulting in a quiet zone with a diameter of 30 cm at the positioner location where the radar under test is placed.

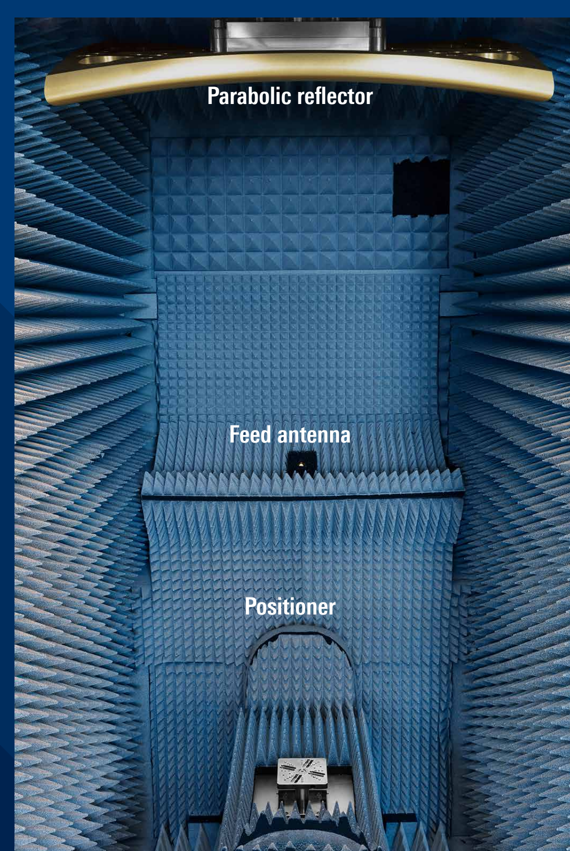


Fig. 3: The test solution for automotive radar sensors, consisting of the R&S®ATS1500C shielded test chamber and the R&S®AREG100A radar echo generator. For operation, the remotely controlled echo generator is mounted on the rear wall of the chamber.

Institute (ETSI) has published automotive radar standards that are applicable within the EU and specify measurements under far-field conditions. Given the importance of radars for future road traffic, similar standards can be expected for other regions.

## Precise tests in a very small space

Rohde & Schwarz is the first company to develop a comprehensive solution for testing automotive radar sensors. It consists of the R&S®ATS1500C test chamber with a footprint of only 1.3 $m^2$ and the R&S®AREG100A radar echo generator (Fig. 3).

The echo generator simulates up to four targets with customer-specific distance, speed and size. The chamber's 3D positioner features high positioning speed and an angular resolution of 0.03°. Specifically developed for radar applications, it automatically varies the angle of incidence (in azimuth and elevation) of the echo hitting the radar sensor. It can maintain a constant polarization orientation between the radar and the measuring system. This avoids the motion-dependent errors that occur with simple positioning systems.


Fig. 4: It is hard to believe that this small chip is a complete multi-channel radar with all signal processing circuitry. All that is missing are the antennas.

Like all devices that transmit and receive signals, radar sensors must be certified in line with the legal regulations for EMI. The limit values in Europe are specified by the Radio Equipment Directive (RED) and the associated ETSI standards. The FCC has issued similar standards for the USA. The R&S®AREG100A allows test equipment such as signal generators and signal analyzers to be connected to the IF input to fully process the relevant test cases. Key parameters such as occupied bandwidth, chirp linearity and chip duration can be measured at the same time.

## A new generation of automotive radars

Uhnder, a high-tech startup based in Austin, Texas, has developed a revolutionary imaging radar system and integrated it into a radar-on-chip (RoC) module the size of a fingernail (Fig. 4). Unlike conventional automotive radars, the Uhnder RoC works with digital code modulation (DCM) instead of FMCW chirps with analog modulation (see page 25).

The RoC is also unique because it is the first to combine the analog frontend, baseband processing, digital frontend, digital backend, memory and interfaces on a single CMOS chip. Two CPUs and two DSPs handle digital signal processing. The baseband section alone has a processing capacity of 20 teraOPS. All that computational power is needed to make a complete radar system with an antenna array consisting of 12 transmit antennas and 16 receive antennas. The RoC creates 192 virtual transceivers by utilizing the code diversity of the signals. All this results in a variety of advantages, including extreme compactness, very low power consumption, high processing power and unprecedented spatial resolution.

The Uhnder RoC is classified as a 4D radar because it provides azimuth, elevation, distance and velocity values for each target. Thanks to the high spatial resolution, an Uhnder RoC based sensor can be used to obtain a detailed environment model that is comparable to optical sensors (Fig. 5).

## Win-win cooperation

Sensors based on the Uhnder RoC require precise calibration to realize their full potential, and the test solution from Rohde & Schwarz is the answer to this task. The two companies have been cooperating closely for a good while to optimize their products. This has enabled Uhnder to not only improve the sensitivity and accuracy of its sensors, but also develop a fast production-ready calibration algorithm that helps its customers (the sensor manufacturers) perform verification at the end of the production line. And Rohde & Schwarz has gained insight on how to further improve its test chambers. In a joint demo at CES 2020 in Las Vegas, the partners showed how a radar sensor based on the Uhnder RoC could be calibrated in less than a minute. Fig. 6 illustrates the process.

## Summary

Radar sensors are the most import source of information about the vehicle environment. Advanced imaging sensors (4D imaging radars) already provide sufficiently high resolution to allow complex environment models to be generated from the data and used as the basis for making vehicle driving decisions. The sensors, which use ever larger antenna arrays and MIMO transceivers, achieve this performance only after precise calibration, which must be performed for each unit on the production line. The compact test system developed by Rohde & Schwarz, which consists of a shielded test chamber and a radar target simulator, allows even the latest generation of complex sensors to be calibrated in less than a minute. The 30 cm diameter quiet zone in the chamber, where far-field conditions prevail, provides enough space for large-aperture sensors, making it suitable for future sensor generations.

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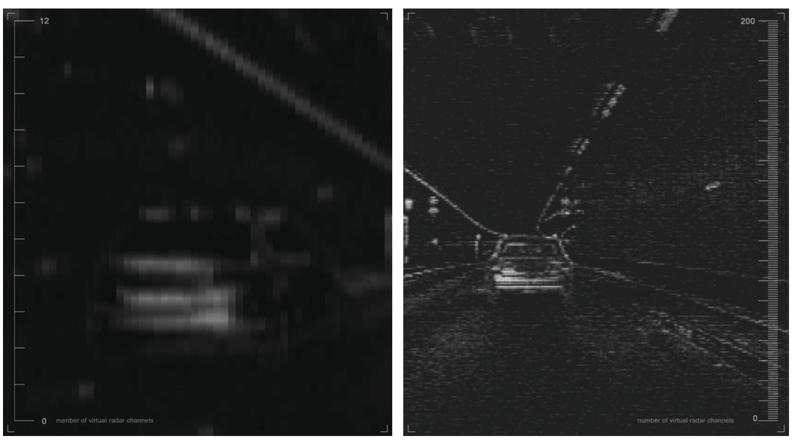


Fig. 5: This simulation gives an impression of the difference between an imaging radar and a conventional automotive radar. Its resolution is so high that it can detect and separate objects that are close together, such as a pedestrian next to a cyclist, and process their individual 4D coordinates.

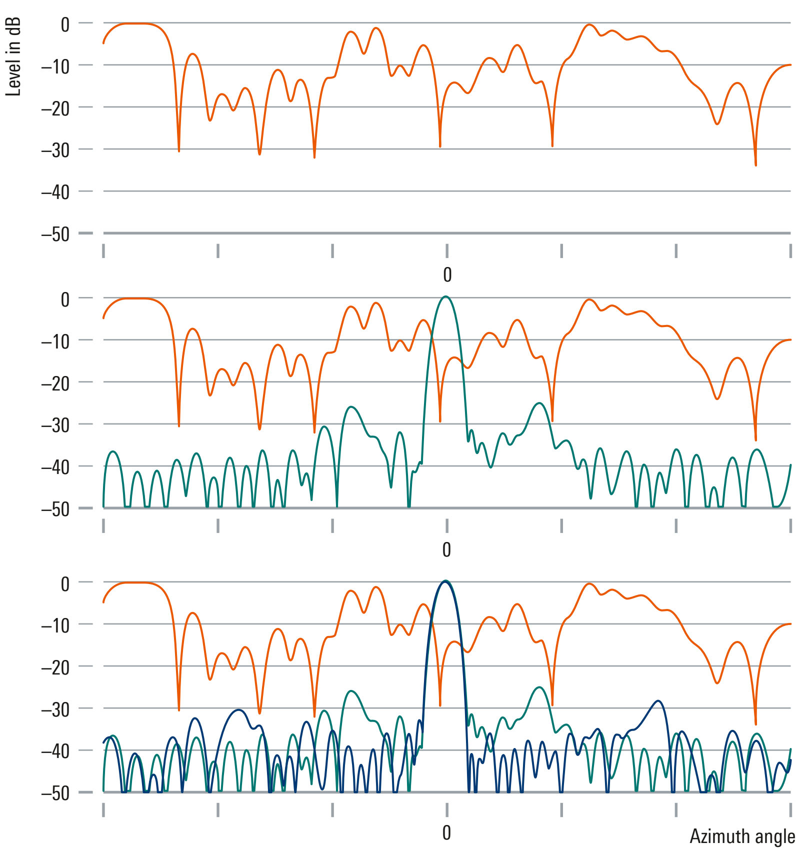


Fig. 6: Calibration of a sensor based on the Uhnder RoC in the R&S®ATS1500C test chamber with the R&S®AREG100A radar echo generator.

Top: The uncalibrated sensor does not detect the target.

Middle: The first calibration step takes place with the sensor stationary and directly facing the target (center axis oriented to the target). This calibration compensates for individual antenna differences in terms of phase and amplitude due to different path lengths. Now the target is clearly distinguishable with a peak to side lobe ratio (PSLR) of 25 dB. The sidelobes are due to the cross-coupling of the antennas.

Bottom: In the second step, the azimuth angle between the sensor's central axis and the target is varied from –45° to +45° by continuously rotating the positioner. This allows correction for cross-coupling, resulting in a 10 dB improvement in the PSLR. This sweep calibration takes less than 25 seconds. At the end, the sensor is calibrated.