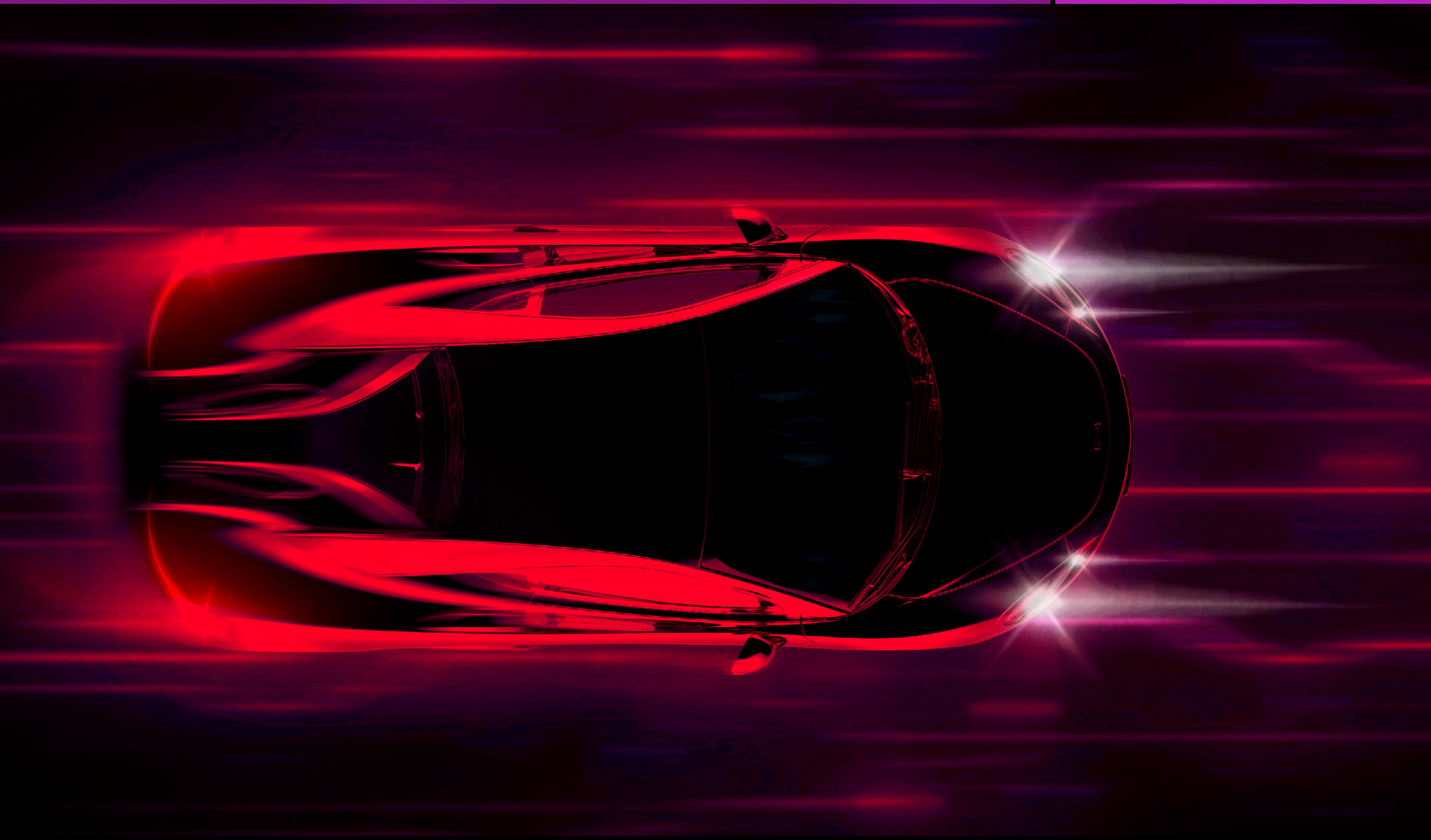
WHITE PAPER



Steer Toward Full Vehicle Autonomy with Confidence

Sharpen your ADAS radar vision with full-scene emulation

KEYSIGHT

The race is on. The vision of fully autonomous vehicles (AVs) is fast approaching. Along with improving the overall efficiency of transportation systems, driver and passenger safety is the most compelling advantage of self-driving vehicles. The most recent data shows that approximately 1.3 million people worldwide die each year as a result of road collisions[1]. According to the US National Highway Traffic Safety Administration (NHTSA), human error is the cause of 94% of serious crashes[2].

Figure 1. According to the NHTSA, 94% of road accidents are the result of human error

Level Up Your Vehicle Autonomy

What if we could increase safety and reduce the risk of accidents on the road? What if we could take driver error out of the equation? Reports suggest self-driving vehicles could reduce traffic deaths by as much as 90%[3]. In addition to saving lives, AVs would save billions in costs associated with car accidents.

Advanced driver-assistance systems (ADAS) in production vehicles have reached SAE International Level 2+ to Level 3 automation, which in most traffic situations still requires the driver to control the vehicle (Figure 2). Many original equipment manufacturers (OEMs) and industry experts believe that reaching Levels 4 and 5, where 5 represents vehicles that don't require any human interaction, will make our roadways safer. But getting there creates a unique set of challenges requiring a number of technical advancements.

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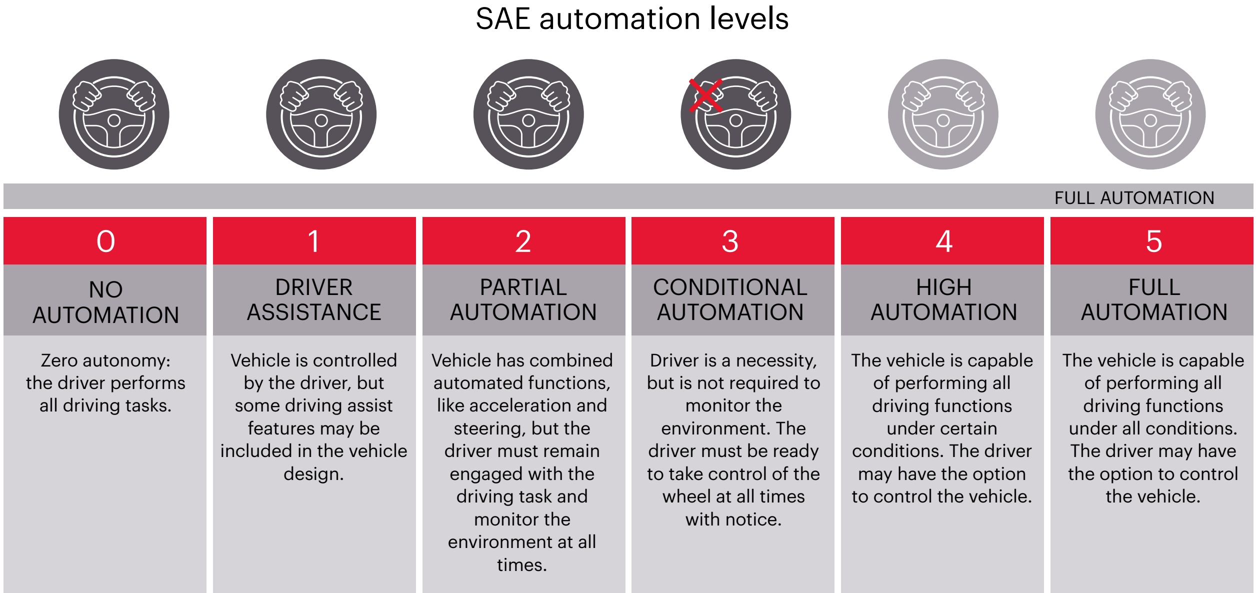
[1] *Road Traffic Injuries*. World Health Organization, June 21, 2021. https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries.

[2] *Automated Vehicles for Safety*. National Highway Traffic Safety Administration, n.d. https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety.

[3] *"7 Benefits of Autonomous Cars."* Thales Group. Last updated January 2021. https://www.thalesgroup.com/en/markets/digital-identity-and-security/iot/magazine/7-benefits-autonomous-cars.



SAE automation levels

0	1	2	3	4	5
NO AUTOMATION	DRIVER ASSISTANCE	PARTIAL AUTOMATION	CONDITIONAL AUTOMATION	HIGH AUTOMATION	FULL AUTOMATION
Zero autonomy: the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the wheel at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

Figure 2. SAE levels of vehicle autonomy *(Source: SAE International)*

To achieve the next level of vehicle autonomy, the automotive industry faces technological, social, legal, and regulatory concerns. Although many of these issues are difficult to control, technology limitation is one area the automotive community and OEMs can help advance. They can make radar, lidar, cameras, and other sensors smaller, more robust, and less expensive, while improving those sensors' detection and recognition software. Two obstacles stand in the way of improving the training of those algorithms.

The gap between roadway and software simulation testing

Today, OEMs use simulated environments with software-in-the-loop systems to test sensors and control modules. Software simulation is valuable, but it cannot fully replicate the real-world and potentially imperfect sensor response. Fully autonomous vehicles must know how to deal with those imperfections.

Road testing of the complete integrated system in a prototype or road-legal vehicle enables OEMs to validate the final product before bringing it to market. While road testing is a vital part of the development process, the cost, time required, and challenge of repeatability make relying on real-world road testing alone unrealistic. Using this approach, it would take hundreds of years for vehicles to be reliable enough to navigate urban and rural roadways safely 100% of the time.

Inability to train ADAS / AV algorithms with real-world conditions

Testing automotive radar is critical to training autonomous driving algorithms. These algorithms use the data acquired by a vehicle's radar sensors to decide how it will respond in any given driving situation. When those algorithms are not properly trained, they may make unexpected decisions that undermine driver, passenger, or pedestrian safety. To test enough use cases to validate AV functions, OEMs need to shift from a handful of targets to real-world scenes and move out of the sterile world of theory and into the practical world of applications.

A driver makes many decisions. It takes time and experience to become a good driver. Taking vehicle autonomy to the next level requires complex systems that exceed the abilities of the best human drivers. A combination of sensors, sophisticated algorithms, and powerful processors are key pieces that will make autonomous driving possible. While the sensors perceive the immediate environment, the processors and algorithms behind them must make the right decision — such as following road rules — in significantly less time than human drivers under any conditions.

Confidence in new ADAS functions is critical. With an unproven system, premature roadway testing is risky. Automotive OEMs need to emulate real-world scenarios that enable validation of actual sensors, electronic control unit code, artificial intelligence logic, and more. Testing more scenarios sooner gives OEMs a clear sense of when to stop and confidently sign off on ADAS functions.

Gaps in Autonomous Vehicle Testing and Validation

Today's test systems don't effectively address some challenges. They test against a limited number of targets, cannot emulate objects at close distances, and have difficulty distinguishing between objects.

Limited number of targets and field of view

Some systems use multiple radar target simulators (RTSs), each presenting point targets to radar sensors and emulating horizontal and vertical positions by mechanically moving antennas (Figure 3). Mechanical automation slows overall test time. In addition, each movement of the antennas introduces a change in the echo's angle of arrival (AoA), which might lead to errors and loss of accuracy in rendering targets if not recalculated or recalibrated.

Another option is to use multiple radio-frequency (RF) front ends for each RTS, where one object uses one delay line. When a scene requires multiple objects, the test setup should increase the number of RF front ends and switch between them when needed. This means it can generate an object anywhere in the scene but cannot simultaneously emulate targets on opposite sides of the scene, for example.

These two options — moving the RTS mechanically or using switched multiple RF front ends — will create gaps and missed objects within a scene, marked as X in Figure 3. Testing radar units against a limited number of objects delivers an incomplete view of driving scenarios and masks the complexity of the real world, especially in urban areas with different intersections and turning scenarios involving pedestrians, cyclists, and electric scooters.

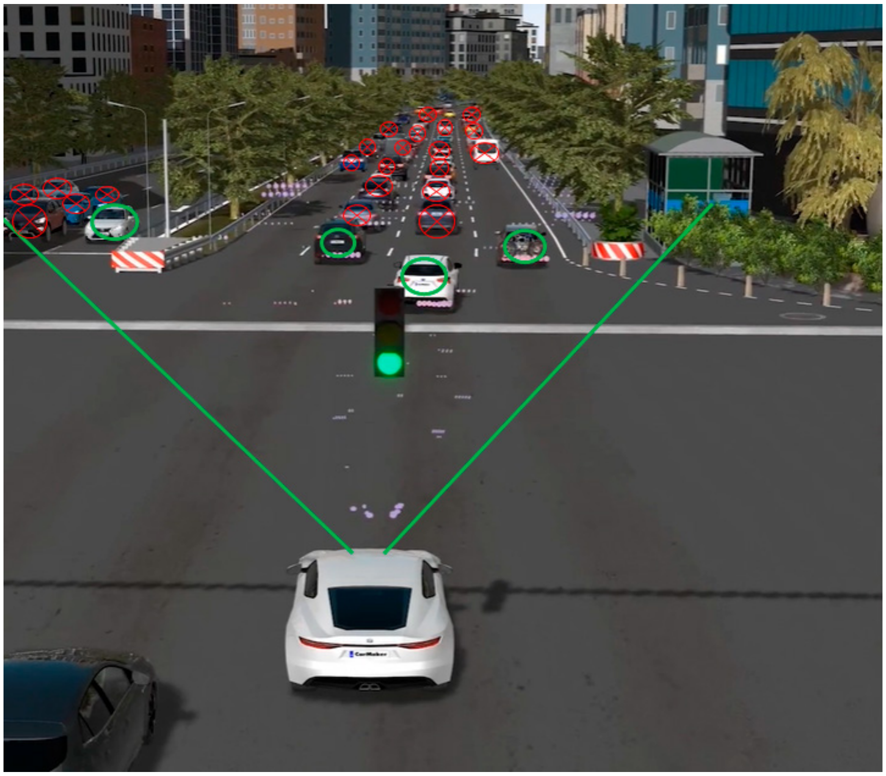


Figure 3. Example of a scene with a limited number of RTS or radar front ends

Inability to generate objects at distances of less than 4 meters

Current radar target simulator solutions cannot generate objects at distances of less than 4 meters (in some cases, even longer). That leaves a blind spot in front of the car's bumper. Many test cases, such as the New Car Assessment Program, require object emulation very close to the radar unit. Take the automated emergency braking system as an example. Obstacles on the road need to be dangerously close. Target simulation solutions on the market today can simulate only objects that are 4 or more meters away (Figure 4).

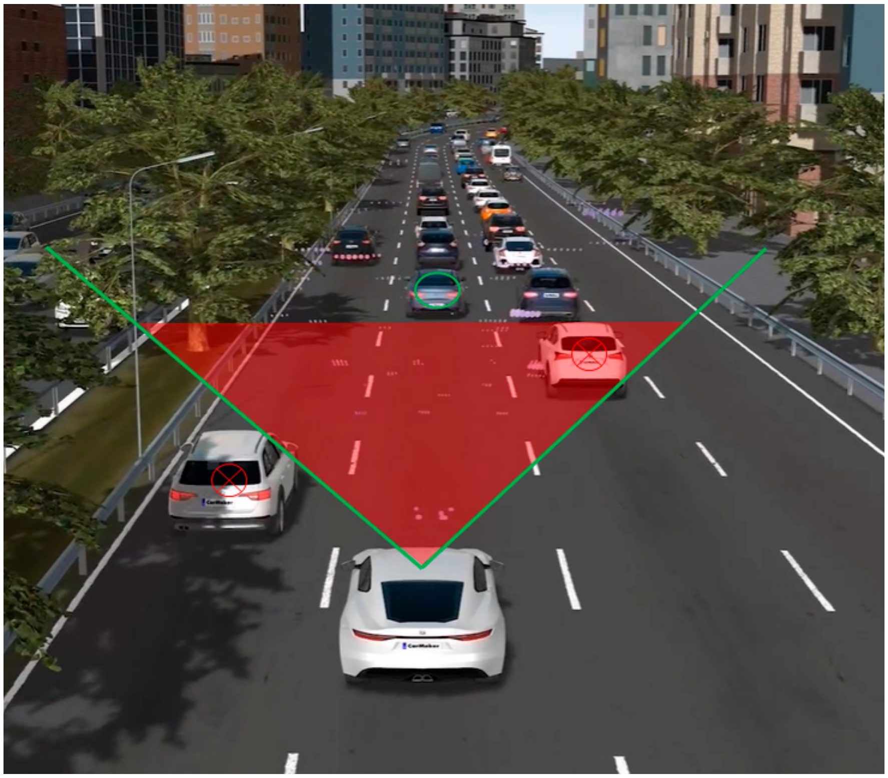


Figure 4. When there is a large amount of dead space before the first car can be emulated, it is impossible to test an emergency breaking scenario

Lower resolution between objects

Older radar technology perceived objects as point targets, meaning the radar did not take the spatial aspect of the detected object into account. Instead, it treated objects as if all the reflected energy had accumulated in a single point. Here is where the concept of radar cross section comes in. It converts the power density that hits the target into reflected power and combines spatial size, shape, and reflectivity into a single number. However, this is a valid approach only if you can treat the target as a single point. In the case of modern automotive radar, where targets are often close to each other, the radar unit must employ its high angular resolution to perceive the spatial characteristic of objects.

Target simulators on the market today cater to older radar sensors. By design, they process only one object as one radar signature, leaving gaps in the details of the scene.

Key Technology Advancement to Address the Challenges

Full-scene emulation in the lab is key to developing the robust radar sensors and algorithms needed to realize ADAS capabilities on the path to full vehicle autonomy. Keysight's first-to-market full-scene emulator combines hundreds of miniature RF front ends into a scalable emulation screen representing up to 512 objects at distances as close as 1.5 meters.

Delivering this solution required several breakthroughs:

- a single miniature RF front end (Figure 5a)
- eight RF front ends integrated on one circuit board (Figure 5b)
- 64 boards arranged in a semicircular array to form an emulation screen (Figure 6)

In addition to these RF hardware advances, there is an equal amount of innovation in the software to prevent the device under test (DUT) from detecting ghost objects less than 1 m away and connecting to the 3D imaging software that renders these images on the screen.

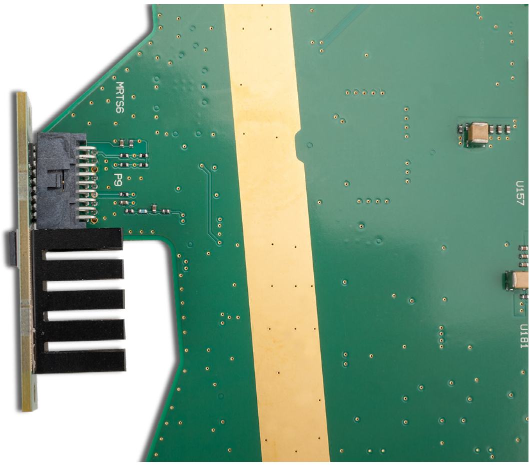


Figure 5a. Close-up view of a new RF front end using Keysight ASIC technology

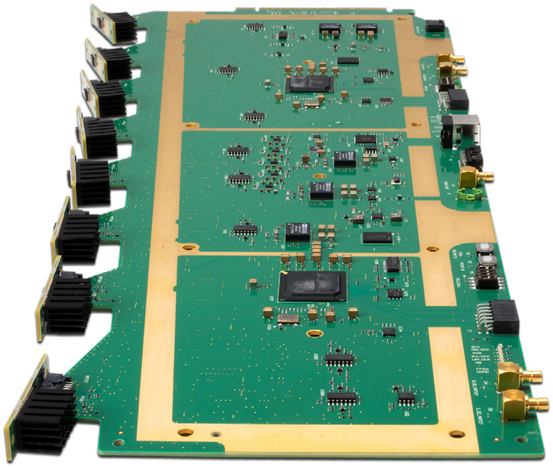


Figure 5b. A circuit board that contains 8 RF front ends

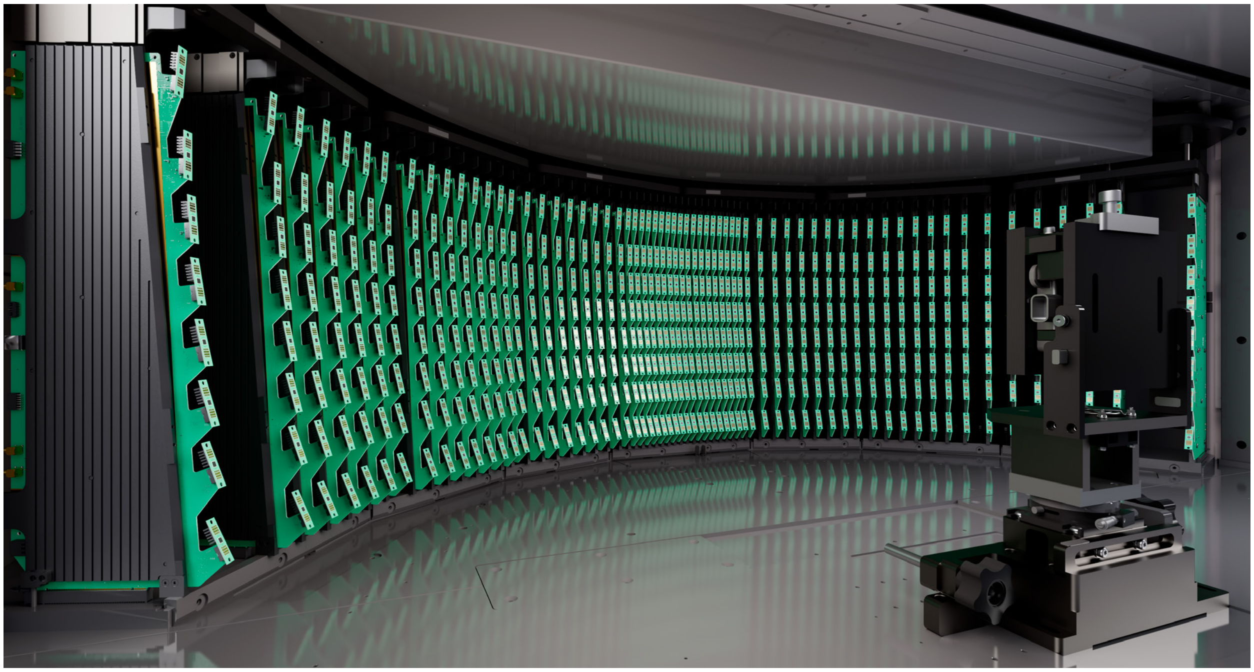


Figure 6. An animated rendering of 64 boards assembled into a screen of RF front ends

More objects to create a scene

The Keysight Radar Scene Emulator employs innovative technology that shifts from an approach centered on object detection via target simulation to traffic scene emulation (Figure 7).

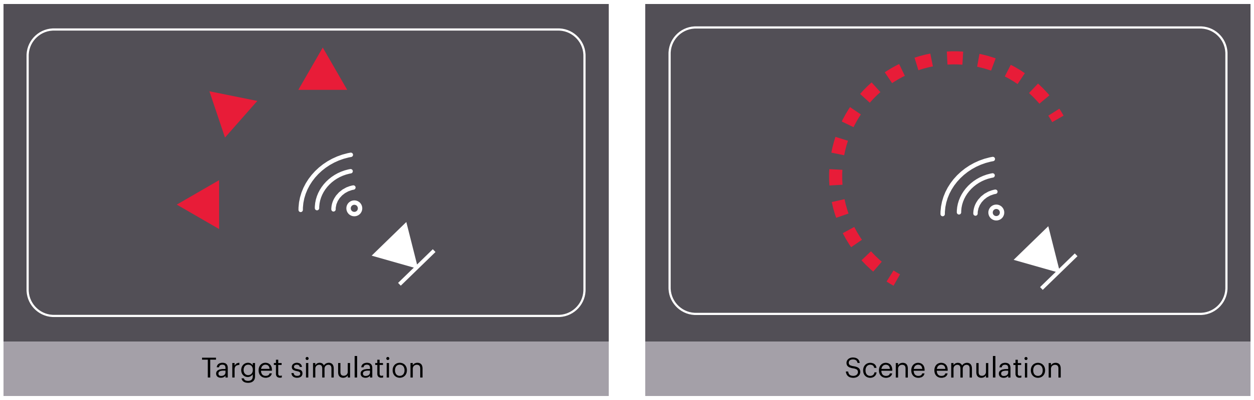


Figure 7. Comparison of target simulation and scene emulation

The solution emulates complex scenarios, including coexisting high-resolution objects, with a wide field of view and unparalleled minimum object distance. It accomplishes this through compact RF front ends densely packed into a small space.

These miniaturized "pixels" are invisible to the radar sensor by design and activated by 3D simulation software, replacing mechanical movement altogether. Each pixel in the array emulates an object's distance and echo strength (Figure 8).

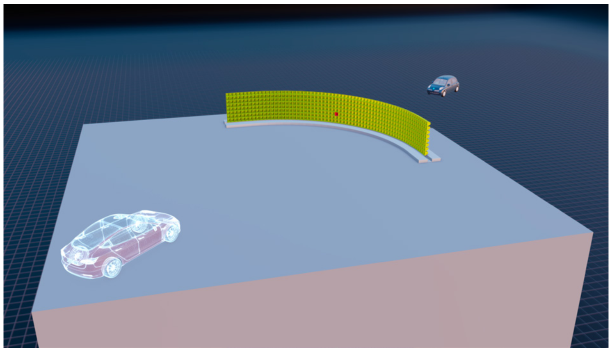


Figure 8. Each pixel on the wall represents an object's distance, speed, and echo strength

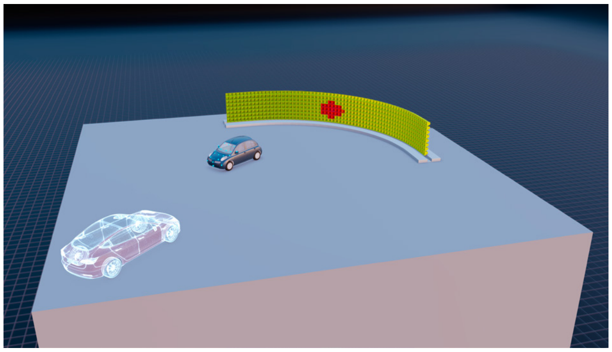


Figure 9. Multiple pixels can represent an object, depending on the distance from the DUT — showing more resolution and more points per object

Multiple pixels can represent an object according to its size and distance from the DUT (Figure 9). Multiple objects close to each other at a longer distance will be resolved as they get closer.

Wider contiguous field of view

The Keysight Radar Scene Emulator helps radar sensors see more with a wider, contiguous field of view (FOV) and support for near and far targets. This capability eliminates the gaps in radar's vision and enables better training of algorithms to detect and differentiate multiple objects in dense, complex scenes. As a result, AV decisions are based on the complete picture, not just what the test equipment allows.

Keysight's technology covers the sensor's entire FOV to achieve higher test coverage and run more comprehensive and sophisticated test scenarios than any other solution on the market. Exercise the radar sensors' detection software thoroughly with up to 512-pixel objects and with a contiguous FOV of ± 70° azimuth and ± 15° elevation. The 512 RF front ends are static in space, allowing for reproducible and accurate AoA validation.

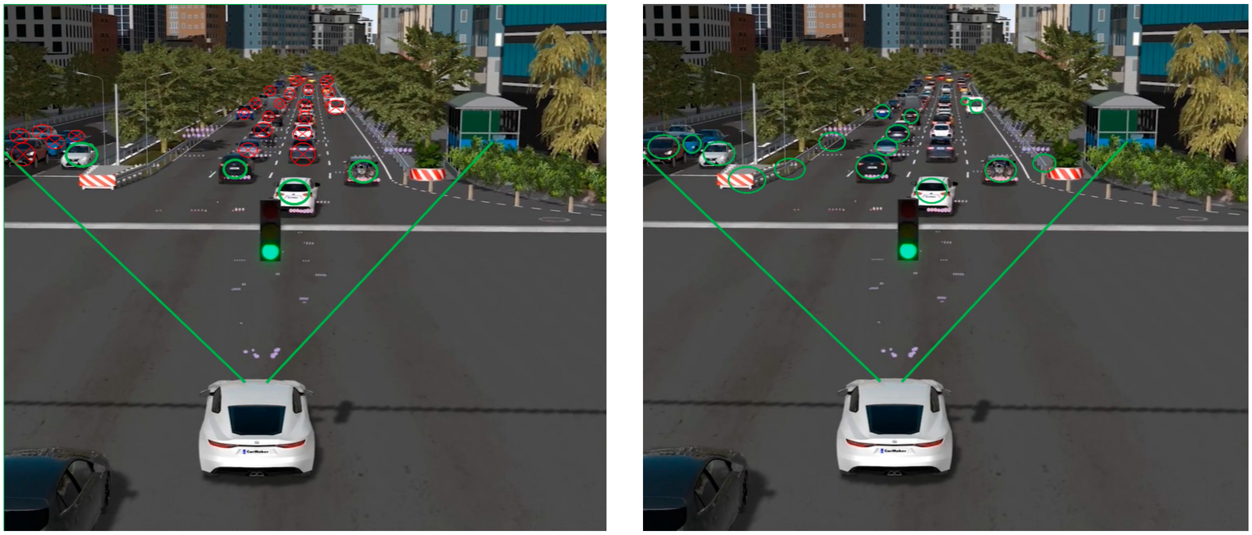


Figure 10. The scene on the right shows what complete FOV looks like from the Radar Scene Emulator vehicle

Shorter minimum distance

Realistic traffic scenes require the emulation of objects very close to the radar unit. For example, at a stoplight where cars will be no more than 2 m apart, bikes might move into the lane or pedestrians might suddenly cross the road. Passing this test is critical for the safety features of an ADAS / AV. Keysight's Radar Scene Emulator has an emulation range of 1.5 m to 300 m with velocities of 0 to 400 kph.

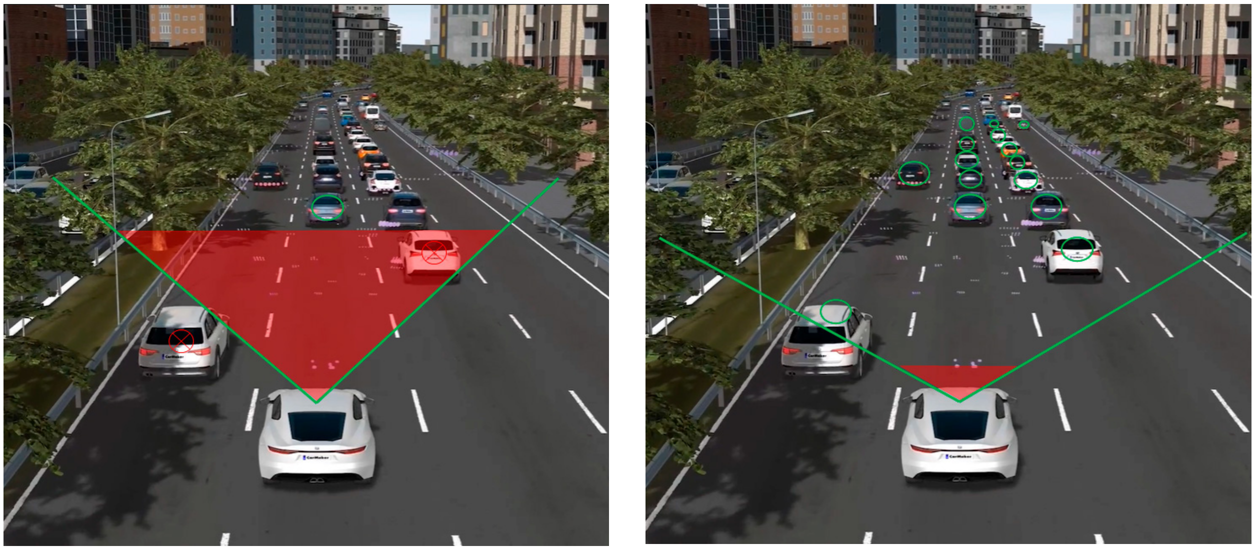


Figure 11. The minimum distance to the first object detected is much closer in the scene on the right, making it safer. Reducing the size of the blind spot in front radar sensors opens a world of possibilities for ADAS function validation testing.

Better resolution for each object

Object separation — the ability to distinguish between obstacles on the road — is another focus of testing for a smoother and faster transition to Level 4 and 5 vehicles. For example, a radar detection algorithm will need to differentiate between a guard rail and a pedestrian while the car is driving on a highway.

Figure 12. Multiple points per object adds useful information to the scene

Keysight addresses this with the point cloud concept, which brings more resolution for each object. This approach adds details to the scene and gives automotive OEMs the confidence to know that the algorithm they are testing can distinguish between two objects that are close together. Whereas a traditional RTS will return one reflection independent of distance, the Radar Scene Emulator increases the number of reflections as the vehicle gets closer, also known as dynamic resolution. This means that the number of objects varies with the distance of the object.

Test More Scenarios, Sooner

The Radar Scene Emulator allows OEMs to readily detect gaps or misbehavior in ADAS software via rendering based on dynamic resolution adaptation and use the realism provided by the representation of nearby objects as multiple distinct targets. It lets OEMs build complex, real-world scenarios in the lab — including those with large planar objects. The solution covers a wide range of scenarios, including dangerous situations and risky corner cases, to help OEMs discover more potential issues sooner, reducing the likelihood of post-release failures.

Test real-world complexity

Testing radar sensors against a limited number of targets provides an incomplete view of driving scenarios and masks the complexity of the real world. The Radar Scene Emulator allows OEMs to emulate real-world driving scenarios with every variation of environmental condition, traffic density, speed, distance, and total number of targets. Complete testing earlier and for common to corner case scenes while minimizing risk.

Accelerate learning

The Radar Scene Emulator provides a deterministic real-world environment for lab testing complex scenes that today require road testing. Its industry-first test approach allows OEMs to significantly accelerate ADAS / AV algorithm learning by testing scenarios earlier with complex repeatable scenes, high density of objects (stationary or in motion), environmental characteristics, or any mix of these while eliminating inefficiencies from manual or robotic automation.

Achieve Greater Confidence in ADAS Functionality

Automotive companies understand how complex it is to test autonomous driving algorithms — and the safety issues at stake. The Radar Scene Emulator is ideal for autonomous driving developers who value safety first. It allows faster testing of automotive radar sensors, with highly complex multitarget scenes and full-scene rendering that emulates near and far targets across a wide continuous FOV.

The Radar Scene Emulator is part of Keysight's Autonomous Drive Emulation (ADE) platform, created through a multiyear collaboration with IPG Automotive and Nordsys. The ADE platform emulates synchronized connections to all relevant sensors in a car, such as the global navigation satellite system, vehicle-to-everything camera, and radar, in a single system. As an open platform, ADE enables automotive OEMs and their partners to focus on developing and testing ADAS systems and algorithms, including sensor fusion and decision-making algorithms. Automotive OEMs can integrate the platform with commercial 3D modeling, hardware-in-the-loop systems, and existing test and simulation environments.

Keysight's Radar Scene Emulator and the ADE platform offer automotive OEMs the ideal solution to realize new ADAS functionality on the path to full vehicle autonomy.

Figure 13. Keysight AD1012A Radar Scene Emulator

Realize Your Vision of Mobility

At Keysight, we believe that bridging the gap between simulation and road testing with an integrated real environment emulator is necessary to approach higher levels of autonomy. You need to make AV and ADAS software decisions based on the complete picture, not on what your test equipment allows you to see. Keysight's Radar Scene Emulator solution helps you achieve your vision of ADAS and next-generation vehicle autonomy sooner and with less risk.

To learn more, please visit www.keysight.com/find/DiscoverRSE.

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