Auto radar probe test technologies for high-volume production

By Tim Cleary, Daniel Bock [FormFactor]

With multiple companies now developing single-chip radar solutions for vehicular and other motion-based technologies, autonomous vehicles (AV) are no longer a futuristic pipe dream, but are slowly becoming a reality as advanced driver assist systems (ADAS) pave the way for the eventuality of full AVs. In certain industrial sectors like mining and farming, AVs are already in use, albeit in restricted fashion and limited to private roads. By 2040, we can expect on-highway trucks to be the first to feature full AV technology on public roads. Automakers are expected to define their AV strategies in the next two to three years, but it won't likely be until the 2040s to 2050 that AVs will become the primary means of transport [1].

One of the biggest drivers for today's ADAS is the role they could play in reducing traffic fatalities. Numbers for 2013 show that fatalities dropped by 3.1% in 2013 models, which have more recent standard safety features—such as stability control and multiple airbags—than previous model years [2]. Furthermore, according to a recent study by The Boston Consulting Group, commissioned by the Motor & Equipment Manufacturers Association, currently available ADAS technologies could prevent some 9,900 fatalities and $251 billion in socioeconomic losses in the U.S. each year [3].

Beyond passive safety systems, ADAS include adaptive cruise control and collision warning systems with automatic steering and braking intervention that rely on radar millimeter wave technology. In a collision warning system, a 77GHz transmitter emits signals reflected from objects ahead, at the side and to the rear of the vehicle, and are captured by multiple receivers integrated throughout the vehicle. The radar system can detect and track objects, triggering a warning to the driver of an imminent collision, and initiating electronic stability control intervention automatically (Figure 1) [4].

Historically, millimeter-wave testing of wafers was relegated to labs and low-volume production for defense, aerospace and other somewhat-exotic applications. However, with the coming of auto radar and high-speed data, this kind of testing is moving into high volume for the first time (Figure 2). This article provides what manufacturers—and in particular, what test engineers—need to know about changes in testing for millimeter-wave wafers used in auto radar and other E-band applications. It reviews some of the changes that will be required to support wafer testing in the 40GHz-81GHz range in high-volume manufacturing (HVM), and will talk about the advancements in probe card technology that enable multi-site production-level testing for auto radar chips.

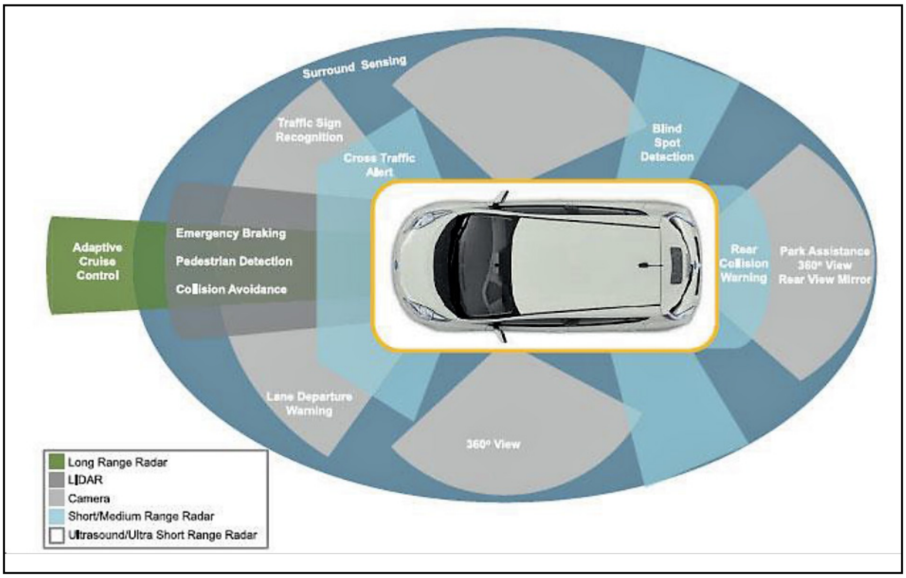


Figure 1: Vehicle safety technology sensor types include LIDAR for emergency braking, pedestrian detection and collision avoidance; and image sensors for camera technologies that provide 360° view, traffic sign recognition and traffic signal warning, park assist and rear view mirror.

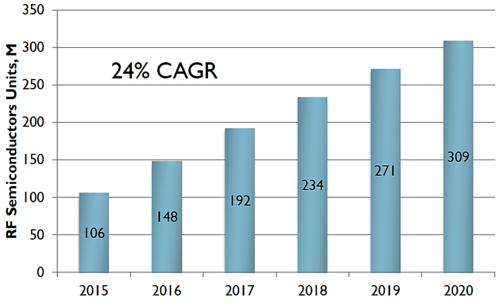


Figure 2: Estimated auto radar RF IC units. Image courtesy of Feldman Engineering.

For these technologies to be successful in reducing crashes and saving lives, it's critical that they function over the lifetime of the vehicle which can be upwards of 20 years. The radar and sensors are located on both the interior cabin and exterior of the vehicle, and can be subject to harsh conditions. Therefore, the government has issued a specific set of rules targeting auto safety, which in turn have impacted production testing requirements.

The Automotive Electronics Council (AEC) established AEC-Q-100, "Failure Mechanism Based Stress Test Qualifications for Integrated Circuits" to provide standardized test methodologies for reliable, high-quality electronic components. It includes testing to be performed at both the integrated circuit

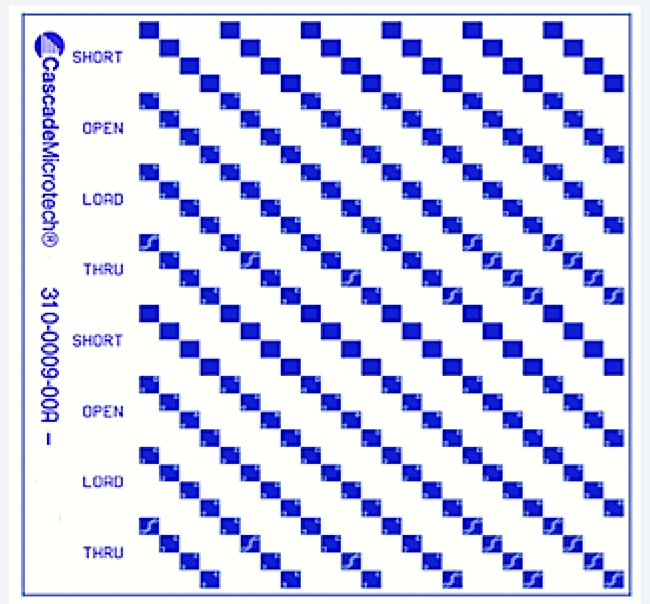
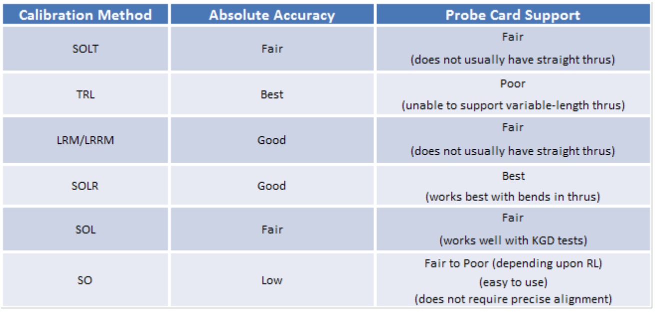


Figure 3: Example of a custom multi-DUT calibration substrate for SOLT.



Calibration Method	Absolute Accuracy	Probe Card Support
SOLT	Fair	Fair (does not usually have straight thrus)
TRL	Best	Poor (unable to support variable-length thrus)
LRM/LRRM	Good	Fair (does not usually have straight thrus)
SOLR	Good	Best (works best with bends in thrus)
SOL	Fair	Fair (works well with KGD tests)
SO	Low	Fair to Poor (depending upon RL) (easy to use) (does not require precise alignment)

Table 1: Comparison of different RF calibration methods.

(IC) supplier and the packaging house. AEC-Q-100 grades are based on the ambient operating temperature range, and range from 0-3, with Grade 0 at -40°C to 150°C, and Grade 3 at -40°C to 85°C. The ambient temperature for sensors and ICs used in ADAS varies depending on where in the automobile the sensor is mounted. They must meet at least a Grade 1, -40°C to 125°C, to meet the requirement [5].

While low-frequency testing technology is sufficient for millimeter-wave radar used in defense, aero and exotic applications, auto radar technology in high-volume production calls for a more enhanced way to test to accommodate the volumes of sensors and high-speed data. Test protocols need to handle multi-site calibration and testing with minimum crosstalk, and they must be accurate at frequencies of up to 81GHz. Essentially, testing needs to be designed specifically for multi-site production tests. Testing just became more costly for the manufacturer.

Requirements for production-level testing

Now that we've addressed the motivation and reasons for the industry's demand for higher-level testing, we need to look at what's required to ramp millimeter-wave radar test for automotive applications into volume production. The three pillars to achieve this include: multi-site testing; multi-site calibration; and automated probe card change-out.

Multi-site testing

Why is multi-site testing necessary? Once the volume of any chip has reached a certain threshold, there is significant cost pressure to move to testing multiple die in parallel using a multiple device under test (multi-DUT) approach. This approach requires investment in both the tester and the probe card. A half-step in this direction is to put in a switching matrix that keeps the tester resources to a minimum and eliminates the issue of die-to-die crosstalk. It takes longer than true multi-DUT testing, but it does reduce the step time and extend the life of the probe head. Full-on multi-DUT testing first requires a tester with sufficient resources. Several companies now offer this capability.

As production-level testing calls for multiple sites with 10+ RF channels, electrical isolation has become a challenge that needs to be considered, particularly when the chip is being tested at the wafer level. For example, if a die is designed with RF test channels on all four sides, it may be difficult to isolate two DUTs. In that case, it may be necessary to test the die one at a time, or two alternate die must be tested, skipping the one between them. Neither is desirable as it increases test time and test program complexity.

While the increased number of test channels increases capital cost, it's important to remember that the cost is spread over the lifetime of the test cell, and that this greater number allows for higher parallelism, assuming isolation can be addressed. This reduces total test time. The trick for test houses will be to keep all of this test capacity utilized as much as possible.

Multi-site calibration

The second pillar for production-level test is multi-site calibration. Measurement errors that might be considered insignificant at lower frequencies can become important at millimeter wavelengths. Using a simultaneous multi-site calibration during multi-DUT testing provides the highest electrical accuracy because all the DUT RF channels are in a known and controlled state.

RF calibration is used to move the measurement reference plane from the tester to the device in order to obtain the best device measurement and to remove the effects of the test fixture. This is done by measuring RF on a calibration substrate, like that shown in **Figure 3**. The most accurate calibration substrate is also to make it mirror the multi-site layout of your probe card in order to properly measure the effects of the test fixture.

For RF calibration, there are a number of options that use some combination of RF standards. These usually include some combination of short, open, load and thru (**Table 1**). For lower frequencies, short-open-load-thru (SOLT) is a standard calibration technique. For highest accuracy, SOLT requires good definitions of all of the standards. It is possible to use short-open-load-reciprocal (SOLR) as an alternative. In contrast to SOLT, SOLR does not need a precise definition of the thru. This is useful when there are bends in the thru that make it harder to have a strict definition of the thru length.

As the frequencies get higher, an alternative model, multi-line reflect thru (mTRL) is used. mTRL was developed by NIST, and is considered to be the gold standard in RF calibration. However, it is difficult to use with probe cards because of the fixed distance separation between the probe tips.

Cascade Microtech (a FormFactor company) developed line-reflect-reflect-match (LRRM), an algorithm that features more robust loss models, which compares favorably to mTRL. LRRM is more probe-card-compatible, because it only requires one thru (line) to be defined for it to calibrate. In some test layouts, it can still be difficult to define a good thru for calibration. In those cases, the 1-port SOL calibration method can be used. Although less accurate because of the lack of the thru, for production testing and known good die methods, it is (more than) adequate to use to determine if your device is good.

Automated probe card handling

The third pillar of production-level testing is automated probe card handling. Changing out the probe card from an RF test cell can be a labor-intensive task requiring a technician to unscrew all the cables connecting the probe card to the tester when a screw-on connector is used. This takes an hour or more and creates the risk of bending the cables in a way that would alter the RF performance or possibly damage the test setup. Implementing a probe station outfitted with blind mate connection capabilities automates the process by moving the stage in or out in the z-direction, mechanically aligning pins so that cables snap together "blindly" and are tightly held in place by pressure. Blind mating allows the RF connection between the probe card and the tester to take place without human intervention. This results in better repeatability and lowers overhead time for setup.

Blind mate connectors can be used for either coax or waveguide connectors (**Figure 4**). Coax types of connectors have a smaller connector that is easier to route, and can be better for design and setup as well as broadband performance. In contrast, the waveguide is narrow band with a larger connector. Because testers usually have waveguide outputs, staying in waveguide results in lower loss. However, some multi-DUT applications have 24 or more RF ports, and in those cases, coax is preferred, because it fits in tighter spaces.

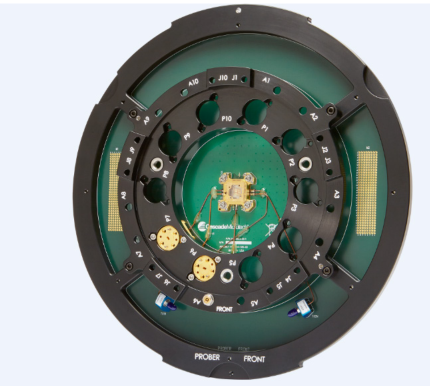


Figure 4: An example of a probe card with blind-mate connections for fast change out in the prober in a production environment. Photo courtesy of Cascade Microtech, a FormFactor company.

Cost-of-ownership for multi-site testing

As production volumes increase in this high-frequency market, companies are looking more closely at what the right choice is for them. With new consumer products at 80GHz+, they are starting to reach new conclusions.

Determining the cost-of-ownership (CoO) for a production-level millimeter-wave radar test cell can be broken down into three parts: the probe station, the tester, and the probe card. While the probe station is a fixed capital cost that isn't based on how many parallel die are being tested, it doesn't makes sense to own more than needed to reach peak capacity. This is determined by how many dies are being tested and the required throughput during a product ramp. The tester is configured with expensive racks of electronics for high-speed signal measurements. It is critical to use those resources as optimally as possible if you are investing in the ability to test a large number of RF lines. The third expense is the probe card, which is considered a consumable product with a fixed lifetime based on some number of touchdowns. It makes no difference to the probe card lifetime how many die are tested for any one touchdown.

For an x4 solution, the probe station becomes four times more efficient, the tester has a more expensive one-time cost, and the probe card will touch four times the number of die before it wears out. Alternatively, it's very costly to maintain extra tester resources and idle probe stations if the need for a particular design is small. Therefore, a variation on this model is to have a probe card set up for x4, but to only keep enough tester resources for one with a switch matrix so you can test each die one at a time. This helps the probe card touchdown life and keeps tester resources low, but it burdens the probe station with lower throughput due to longer test times.

Summary

Utilizing a multi-DUT test approach to lower costs is not a new concept. The memory market has long been masterful at getting the biggest bang out of every test touchdown, but there are specific advances required to apply that model to testing at millimeter-wave frequencies. Die isolation while under test becomes more critical, calibration strategies need to become more sensitive, and automating the test cell amid those heightened sensitivities requires advances in connecting technologies that adapt to the more rigorous electrical environment.

The promise of a safer and potentially much more efficient transportation future is alluring to say the least. It is timely that the test industry has anticipated these needs, and that leading-edge suppliers are now offering solutions that enable a cost-effective path forward. All of the requirements needed to enable cost-effective production volume testing reviewed here are now available from leading-edge companies that have worked within these frequency domains for years anticipating this opportunity to build a true production solution.

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Biographies

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