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Challenges and Solutions for Automotive OTA Testing

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***Abstract*—OTA (over-the-air) testing is essential for developing assisted and autonomous driving systems in vehicles, as it plays a crucial role in the localization, perception, and intelligent driving capabilities of ICVs (intelligent connected vehicles). Automotive antennas, typically much smaller in size than the vehicle itself and can be located in various positions, require spherical near-field measurement for OTA testing. While there are established standards for OTA testing methods and uncertainties for mobile devices, base stations, and satellite components, there are still many challenges in the OTA testing of automotive systems. These challenges, specifically in SISO (single input single output) and MIMO (multiple input multiple output) configurations, are discussed along with potential solutions in this article.**

Keywords—OTA test, automotive antennas, intelligent connected vehicles

I. INTRODUCTION

Electronic systems within vehicles have become increasingly important with the rise of assisted and autonomous driving technologies. The automotive electronic system enables these advanced driving capabilities, providing Vehicle to everything (V2X) connectivity , driving and inside cabin passenger safety related sensor integration, and cooperative vehicle infrastructure system (CVIS). The key elements of these systems are the onboard radio frequency (RF) sensor systems, which collects data to generate a real-time map of the surroundings and inform the control systems on how to navigate the road safely. This system's performance, stability, and reliability are critical for the vehicle's and pedestrian safety. As such, these systems must be thoroughly tested and validated to ensure their proper functionality and performance to minimize the risk of accidents or other incidents.

GPS navigation and real-time kinematic techniques are essential for providing highly accurate localization for Intelligent connected vehicles (ICVs) [1]. These technologies can enable ICVs to locate themselves with high precision, ranging from meter-level to centimeter-level accuracy. In addition, millimeter wave radar can help ICVs to detect surrounding targets, while V2X communication allows ICVs to exchange information with other vehicles and infrastructure in real time. This can enhance the performance of CVIS and provide additional information beyond what is available from onboard sensors. Together, these technologies can enable ICVs to achieve cooperative localization and perception and access cloud-based intelligent driving capabilities.

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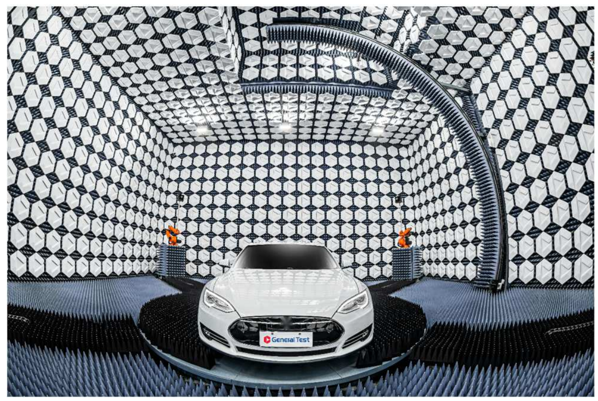

Fig. 1 An automotive OTA test systems

OTA testing is an essential method for evaluating the performance of an integrated RF system, it is systematic evaluation method for final products. OTA is particularly important for the mission critical automotive applications. This testing considers a range of factors that can impact the system's performance, including the influence of common mode current on the antenna, changes in radio radiation sensitivity after integration, and interference from other system noise on the transmitter and receiver [2]. Additionally, OTA testing considers changes in boundary conditions after the system has been integrated into the vehicle. Considering all these factors, OTA testing provides a comprehensive and realistic assessment of the system's performance after integration.

OTA testing has been widely applied in testing mobile terminals, base stations, and satellite antennas. Existing the cellular telecommunications and internet association (CTIA) standards [3] and the third generation partnership project (3GPP) [4] have defined standard test methods and test uncertainties for OTA. The current standard OTA test method in 3GPP and CTIA standards are developed and verified based on mobile user equipment automotive devices under test are a lot bigger with relatively small RF systems. The current standard OTA methods need to be investigated for automobile applications.

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Fig. 2 The EPP absorbers

In this paper, we provide a comprehensive analysis of the challenges and potential solutions in OTA testing for automotives, specifically focusing on Sigle-input and Single-output (SISO) and Multiple-input and Multiple-output (MIMO) measurements. By integrating some novel techniques, our approach contributes to the advancement of wireless communication systems in the automotive industry, leading to improved designs, better end-user experiences, and increased road safety.

II. CHARACTERISTICS OF AUTOMOTIVE TESTING

Automotive testing presents several challenges due to the unique characteristics of vehicles. One of the main challenges is the size and placement of the car's antenna. In most cases, the car's antenna is much smaller than its body, making it difficult to position the antenna within the test system properly. There are quite a few RF systems in a vehicle, the antennas of those RF systems are located in different part of the vehicle, which may not always in the middle of the vehicle. It can be challenging to position every antenna under test in the center of the a turntable, as the limited size of the turntable makes it difficult to place the antenna at the center of rotation. This off-centered positioning of the device under test can impact the measurement methodology, algorithms, hardware innovation, accuracy and reliability of the test results. Therefore, it is essential to use appropriate techniques to address these issues to ensure accurate and reliable results.

The automobile testing facilities needs to fit large DUT into controlled environment, which generally is an anechoic chamber. An automobile a much bigger DUT, the test environment is also very big in terms of physical dimensions. To build a large chamber is not only a big financial investment, it also need to find a large available real estate site. Electromagnetic compatibility (EMC) chambers are a fundament test facility available in most automobile companies, sharing the OTA test with EMC test chamber is a cost-effective concept. The EMC test chamber generally works for lower frequency range and OTS is performed at high frequency bands. The EMC absorber need to be redesigned for work for low and high frequency bands, which is usually very challenge to achieve.

Absorbers play a crucial role in automotive OTA testing, as they help create an accurate and controlled test environment by minimizing reflections and interference caused by electromagnetic waves [5]. Traditional microwave absorbers used for anechoic chambers are made from a combination of polyurethane (PU) foam and carbon black (CB) or graphite powder. These absorbers, however, often exhibit nonuniform performance and poor quality due to the handcraft process and the use of large-sized carbon particles.

To address these limitations, a new generation of absorbers has been developed using expanded polypropylene (EPP) or PP foam mixed with nanometer-sized CB particles. EPP absorbers, prepared using a molding process, offer smooth surfaces, precise dimensions, and an extremely uniform distribution of absorbent nanoparticles. The improved electromagnetic performance provided by these absorbers contribute to a more controlled and stable test environment. This ultimately leads to better assessment and development of intelligent connected vehicles, ensuring accurate and reliable test results for both SISO and MIMO configurations. Determining the location of the antenna under test (AUT) phase center is another challenge related to near-field to far-field transformation (NF-FF) and the location where the calibration antenna is positioned. One of the most critical part of conducting accurate SISO and MIMO measurement is the accurate calibration of the system pathloss based on standard dipole or loop antennas. The location of the AUT for SISO is where the standard antenna should be located, and for MIMO each receiving antenna location must be identified because those antennas might be far apart for automobile applications. The location of the AUT can be determined if the antenna is physically known, otherwise it can be identified by phase center measurement.

Standard antenna calibration is a crucial step in absolute antenna testing, as it allows the antenna's performance to be compared to a known reference. To ensure accurate and reliable test results, carefully considering the placement of the calibration antenna and using appropriate techniques to ensure precise calibration is essential. The standard antenna measurement is to be carry out in free space with turn table and ground covered by proper absorbers.

Although the physical size of a car antenna is not large, the antenna current may be spread over a large area of the car's body. Due to the large physical size of the car's body, most car testing is done in a near-field test environment. So NF-FF transformation is generally used for automobile testing.

III. SISO TESTING

One challenge in conducting automotive OTA SISO testing is proper use of a spherical wave expansion (SWE) method for NF-FF transformation, which requires the application of the SWE method for larger test objects.

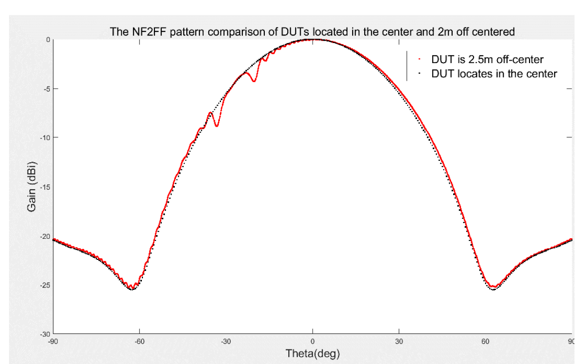

Fig. 3 The deviation between centered and off-centered DUT in spherical near-field measurement

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Accurate calculation of higher-order special functions and efficiently handling a large amount of data are also important practical considerations. Additionally, there is a challenge in addressing the eccentricity problem in spherical near-field testing. This occurs when the DUT is not correctly centered on the turntable during near-field testing. When the test object is of significant eccentricity in a spherical near-field test environment, using SWE with the center of rotation as the expansion center may lead to deviations in the test results (see Fig. 3).

To address these challenges, new algorithms, range antenna and mechanical scanning method need to be implemented. A Translated SWE (TSWE), high-performance test probes, and techniques to ensure that the test probe is consistently pointed at the phase center of the DUT. In spherical near-field testing, Translated SWE is used to address the issue of large-scale eccentricity. In traditional spherical near-far field transformations, the order of expansion of SWE is determined by the minimum measurable sphere that contains the DUT. However, in automotive OTA testing, the phase center of the DUT is often eccentric, which leads to a large minimum measurable sphere and a correspondingly large order of expansion for SWE. This reduces test efficiency and accuracy. Translated SWE addresses this issue by mathematically moving the minimum measurable sphere to the phase center of the DUT, which reduces the radius of the minimum measurable sphere and the order of expansion of SWE, leading to fewer required sampling points and improved test efficiency.

Fig. 4 dipole and loop calibration antennas.

During OTA testing for automotive, the phase center of the DUT within the vehicle can be determined through passive or active measurement, and the operating frequency band determines the potential spread of the antenna current. As a reference, the order of TSWE's expansion coefficient need to be investigated based on antenna type and the associated ground plane. As long as significant antenna current influenced area is included in the TSWE source of expansion sphere, the accuracy of the TSWE can be expected. For example, if the AUT is inverted-F antenna, then the simulation shows that the current of the antenna can be set at 2λ, which is much smaller than the minimum sphere of the traditional spherical near-field method for the full vehicle size.

The test probe plays a significant role in spherical near-field testing. By designing probes with high pattern symmetry, high cross-polarized purity in wide beam width, and a beam that effectively covers the entire vehicle, the measurement accuracy can be improved for the large DUT with high eccentricity. Due to the size of the vehicle and the antenna current spreading effects, the range antenna beamwidth needs to be wide enough to cover whole antenna area. In traditional TSWE, the range antenna beam is pointing towards the center of the turn table, then it is perforable that the antenna beam is symmetrical with low cross polarization in a wide angle to avoid measurement uncertainty caused by the range antenna.

The effective isotropic sensitivity (EIS) and total isotropic sensitivity measurement (TIS) of a RF system are very challenging as well. It not only requires having all of the other electronic systems working at the same time turn on to evaluate radio radiated sensitivity, but also have to make the range antenna pointing towards AUT and all pathloss calibrated at deferent angle with proper polarization. The calibration and range antenna pointing arrangements are necessary for effective radiated power (ERP) and total isotropic radiated power (TRP) measurements.

IV. MIMO Testing

As wireless communications technology advances, the importance of MIMO systems in automotive OTA tests has grown, leading to the need for effective testing methods. The Radiated Two-Stage (RTS) method, an improvement on the conventional two-stage method, is a valuable tool for evaluating MIMO system performance in automotive OTA testing.

In MIMO automotive testing [6], the position of each receiving antenna must be determined and calibrated to obtain the antenna's gain and phase characteristics accurately. This is like the SISO system calibration and antenna gain measurement. The MIMO system, in addition, a detailed uncertainty analysis of the phase characteristics of each antenna is required. In testing MIMO antennas for vehicles, the MPAC and RTS are two standard test methods defined by 3GPP and CTIA. However, the MPAC method cannot control the signal quality due to the large size, difficulty in flipping, and complexity of the reflections of vehicles. In the testing of the RTS method, the accurate testing of each antenna, including calibration and gain and radiation pattern testing, also presents the same challenges as for SISO antennas.

The conventional two-stage method requires a direct cable connection to the device under test (DUT), which prevents the evaluation of self-interference in the DUT. Self-interference, a significant factor in receiver sensitivity, can adversely affect the test results, making it crucial to address this issue for

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accurate automotive OTA testing. The RTS method improves upon this approach by measuring complex antenna patterns in the first stage and throughput through over-the-air (OTA) radiated means in the second stage. This improvement ensures that self-interference in the DUT is taken into account, providing more accurate test results.

The RTS method offers several advantages for automotive OTA testing. Firstly, it can be executed in a standard single-input-single-output (SISO) anechoic chamber, which reduces the overall system cost and simplifies maintenance. Secondly, it offers high reliability and repeatability in measurements, ensuring consistent performance evaluation across different vehicles and devices. Lastly, it provides extensive subcomponent-level performance information, making it an ideal solution for both research and development (R&D) and certification tests in the automotive industry.

By overcoming the limitations of the conventional two-stage method, the RTS method allows for a more accurate evaluation of MIMO system performance in automotive OTA testing. This ensures that the performance of MIMO user equipment in vehicles can be effectively assessed, leading to improved designs, better end-user experiences, and enhanced safety on the road. The integration of the RTS method in automotive OTA testing is a significant step forward in the development and evaluation of advanced wireless communication systems in the automotive industry.

V. CONCLUSON

OTA testing is an essential method for evaluating the performance of integrated RF systems in vehicles, and it plays a critical role in the localization, perception, and intelligent driving capabilities of ICVs. The testing of automotive antennas is particularly challenging due to their smaller size and various locations in the vehicle. This paper has discussed the challenges and potential solutions for OTA testing of automotive systems, specifically in SISO and MIMO configurations.

The size and placement of the car's antenna, as well as the location of other RF systems, make it difficult to position the antenna within the test system correctly. This off-centered positioning of the device under test can impact the measurement methodology, algorithms, hardware innovation, accuracy, and reliability of the test results. However, the implementation of TSWE, high-performance test probes, and techniques to ensure that the test probe is consistently pointed at the phase center of the DUT can address these challenges in SISO testing.

In MIMO automotive testing, the RTS method is a valuable tool for evaluating system performance. The RTS method improves upon the conventional two-stage method by measuring complex antenna patterns in the first stage and throughput through OTA radiated means in the second stage. This improvement ensures that self-interference in the DUT is taken into account, providing more accurate test results.

The implementation of the discussed methods in automotive OTA testing can lead to improved designs, better end-user experiences, and enhanced safety on the road. Despite the challenges, the testing and validation of electronic systems in vehicles are critical for minimizing the risk of accidents or other incidents. With further research and development, the challenges of automotive OTA testing can be effectively addressed, providing a comprehensive and realistic assessment of the system's performance after integration.

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