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# Semi-virtual Test for ICVs in Automotive EMC Laboratary

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*Abstract*— **Functional test is critical to the deployment of intelligent connected vehicle (ICV). Both industry and academia devote to create a testing framework, which could provide a reliable, quick, safe, low cost and reproducible method and accelerate the development of ICV. However, currently mainstream testing method, such as virtual test and on-road field test are sometimes difficult to satisfy the needs. In this paper, a semi-virtual test method, which employ semi anechoic chamber to construct operating environment of ICV, is proposed. Corresponding tests are done in semi-chamber of China Automotive Engineering Research Institute Co., Ltd (CAERI) to verify the effectiveness of proposed method. Test results show that proposed method is helpful for ICV function evaluation.**

## I. INTRODUCTION

The intelligent connected vehicle (ICV) is an emerging paradigm aimed at deploying and developing a fully intelligent transportation system that utilizes environmental information, enhances safety, improves mobility and reduces the adverse environmental impacts of the transportation systems[1]. By means of sensors, communication units and intelligent control units, ICV can collect real-time data through multiple ways and play a fundamental role towards the Internet of things[2]. However, the fast and vast growing demands on ICV results in a huge number of test problems to vehicle manufacturers and corresponding test facilities.

The core technologies of ICV can be concluded into three categories:

The first one is the automated driving (AD) system which controls vehicles to drive automatically without human interventions. Depending on the degree of driver's intervention, AD can be divided into 6 levels, according to The Society of Automotive Engineers (SAE)[3].

The next one is the Internet of Vehicles (IoV) technologies which can assist vehicles to communicate with the outside world, by means of onboard infotainment, telematics, vehicle-to-vehicle communication (V2V), or vehicle-to-infrastructure communication[4].

The last one is the onboard artificial intelligence which provides drivers and passengers with non-driving tasks, such as speech recognition and gesture recognition[5].

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Most of these core technologies are relatively new in automotive industry. Some of them are new technologies even in the consumer electronics industry. Since automotive industry has a far higher demand on reliability of electronics than consumer electronics industry, the applications of these technologies bring a huge challenge to automobile manufacturers: How to verify the functionality, performance and reliability of these technologies on the vehicle level? [6].

Nowadays, both industry and academia believe that ICV test should include two parts: on-road field test and in-lab virtual test [7].

No one doubts the necessity of field tests as the final and the most important way of verification for ICV as a whole system. Actually many test centers have been designed and built all around the world for ICV tests in recent years, like M-City in Michigan, USA and i-VISTA in Chongqing, China [8]. However, all of these test centers, including those already built and under construction, may be not adequate, judging from the growth momentum of ICV. This will lead to either more investment in test center building or prolonged test period caused by the long test queues. In any case, high test cost is inevitable.

Except for this, road test can be quite hard to control. Not only because environmental parameter varies moment by moment, but it is not the experimenter who decides which weather would be in the next several hours, days or weeks. For instance, in order to test sensor's performance under snowy environment, experimenters have to wait for a snowy day or travel hundreds and thousands of miles to complete the test, it is either time-consuming or money-costing.

In-lab virtual test, on the other hand, are mostly focusing on functionality and performance verification of control algorithm, signal processing algorithm and corresponding hardware. Test methods include software in the loop (SIL), hardware in the loop (HIL) and vehicle in the loop (VIL). SIL and HIL tests can be conducted in the early design stage, so it's mostly used by designers for verification of components or systems, while the reliability of test result is highly dependent on model accuracy of the simulated parts, e.g. the processors or the powertrain [9].

VIL test is a method that is very close to field test. It tests actual vehicles under simulated traffic scenarios. But with more sensors like communication antennas, cameras, ultrasonic radars, millimeter wave radars and laser radars are introduced into ICV, surrounding environment became a relatively important factor for ICV tests, both in road tests and virtual tests. Unpredictable environmental variations like rain [10, 11] can lead to unpredictable test deviation,

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degrading the repeatability and credibility of ICV tests.

In order to make the ICV test more accurate, controllable and reproducible, a new test method is needed, which can provide a well-controlled test environment in terms of weather (performance under different weather), temperature (temperature-drift characteristics), and electromagnetic background (environmental noise), while simulating the traffic and communication scenario for ICV tests.

Research in [12] proposed an in-lab test strategy which is called road test simulator (RTS). By means of RTS, road tests can be done inside the laboratory, which is time-saving and repeatable. However, test environment mentioned in this paper focused on parameters like noise, vibration and harshness (NVH) rather than vehicular sensors. Meanwhile, little research focus on vehicle-level sensors performances under an in-lab test environment. So it is essential and reasonable to design an in-lab virtual test environment dedicated for vehicle-level sensor test.

In this paper, a semi-virtual test method is proposed, which uses the vehicle-level electromagnetic compatibility (EMC) test lab (a 10-meter semi-anechoic chamber) to construct both the well-controlled environment and the test scenario for ICV.

The rest of this paper is organized as follows: Section II analyses ICV test requirements and the functionalities, systems of an ICV were divided into two parts according to their operating mechanism. Test designs dedicated for those two systems were explained respectively in section III, including instrument configurations and vehicle condition setup. Note that all the vehicles under test (VUT) in this article were bought from domestic market in China. Test conductions and test results were described and analyzed in section IV. Finally, section V draw a conclusion.

## II. Test Requirements

Aside from traditional vehicle tests, ICVs need verification on two additional kinds of systems: the intelligent driving system and the connected system. Meanwhile, to inspect ICV's performance under complex electromagnetic environment, EMC tests are also considered.

### A. Test requirements for the intelligent driving system

Intelligent driving system is composed by information collecting sensors along with their corresponding processors. Sensors are normally located on and along the outline of the vehicle, aiming at detecting potential danger and providing assistant information to drivers. Sensors deployed on ICVs nowadays are normally millimeter radar and cameras. Some high-end autonomous driving vehicles are equipped with Lidar. Different sensors as well as processor systems have different characteristics, so the test requirements are normally different.

*1) Millimeter radar:* Millimeter radar stands for radar that could transmit or receive microwaves with a frequency range from 30GHz to 300GHz. Millimeter radars deployed on ICVs normally utilize 24GHz frequency band for Blind Spot Detection (BSD) and 77 frequency band for Adaptive Cruise Control (ACC), Autonomous Emergency Braking (AEB) and Forward Collision Warning (FCW).

Tests for millimeter radars focus on verification of the ability to identify target size, velocity and distance. Usually tests on millimeter radar module can be done inside a lab with a small anechoic chamber, while tests on vehicle-level radar system is done on the road in field tests.

In the lab tests, limited by the lab size, it's almost impossible to form a long enough simulated road in front of or around the evaluated radar system for the radar target to move in order to trigger the radar functionality. So radar target simulator is introduced to produce a radar target signal. It receives radar signal generated from the radar under test, imitates the reflected signal with a frequency and power transformation just the same as the signal reflected by a target. Radar-Cross Section (RCS) is applied to imitate target of different shapes and sizes. In this way, the radar is cheated by the target simulator, believing there is a target in the direction where the reflection signal comes from, while there is actually nothing but the simulator.

The target simulator can also be used in the vehicle-level millimeter radar system test in the same way.

Once the refection signal is simulated, its power and frequency can be set by test engineers to simulate targets from different distance away with different relative velocity.

As the feature of millimeter wave signal, transmission lose need to be considered and simulated since obstacles and air attenuations are non-ignorable.

*2) Camera:* Camera can provide a full vision of image around vehicle and, with the help of image process, a human-like way of identifying objects can be realized and makes a great contribution to the realization of autonomous driving.

Tests of the camera system focus on verifying the ability to recognize particular objects. First is the recognition of lane markings and traffic signs, including different kinds of lane lines, pedestrian crossing, stop line, lane instructions, speed limits, residential area, no entrance sign, highway entrance/exit sign, traffic lights and so on. Second is awareness of pedestrian and other vehicles. The recognition of pedestrian and vehicle, especially their movements (including distance, speed and acceleration against VUT), along with signal lights of other vehicles, needs to be checked comprehensively. Except for all the things above, basic performances of camera, including the number of pixels, signal-noise ratio (SNR), distortion, sharpness and transmitting speed, are crucial factors to camera, too.

*3) Lidar:* Lidar is another important kind of sensor in intelligent driving systems, which uses laser to detect objects near or far away from the vehicle. Comparing to millimeter wave radars, Lidar has the additional ability of 2D imaging. Comparing to cameras, Lidar is all day applicable with a much higher resolution. However, conditions like heavy rain or dense fog and haze can bring great attenuations into laser transmission.

In-lab test of Lidar requires an experimental infra-structure that can provide Lidar system with a stable and correct response. Nevertheless, currently there is no unified technology on Lidar system, which means the deployment of corresponding test laboratory must satisfy different requirements presented by different Lidar technologies. So test requirements of Lidar system may be discussed in the further research process.

### *B. Test requirements for the connected system*

Intelligent Connected Vehicle is a high-tech synthesis, which integrates environmental awareness, decision-making and multi-level driving assistance technologies into one single unity, by means of computer, modern sensing, information fusion, pattern recognition, communication network and automatic control technologies.

Aside from the direct environmental awareness and decision making technologies, which has been covered in the previous section, ICV also need information which is imperceptible by onboard sensors, such as traffic in the third crossroad in front of vehicles. In this case, long range communication such as V2X is needed.

Sometimes when a wireless device needs to access the internet through the Access Point (AP) onboard, intra-vehicle communication such as Bluetooth or Wi-Fi is needed.

Some applications may need vehicle location information, such as Emergency call (E-call). In this way, satellite receiving is needed.

These three kinds of communication technologies, long range communication, intra-vehicle communication and satellite receiving, work together to ensure the connectivity of the ICV.

*1) Long range communication:* The long range communication can be voice-oriented or data-oriented.

In voice communication, the voice delay and voice quality are concerned.

In data communication, the most concerned parameters are data rate, transmission delay, Bit Error Rate (BER) and Packet Loss Rate (PLR) on varies of roads, under different weather & traffic conditions. The data rate defines how much information can be sent out or received in a certain period of time. The transmission delay defines how fast the information can pass on among vehicles, thus defines how fast one vehicle can respond to the warning of other vehicles. BER and PLR, on the other hand, define the reliability of information transmission.

*2) Intra-vehicle communication:* Tests for intra-vehicle communication focus on Bluetooth and Wi-Fi connectivity, stability and anti-jamming characteristics. What's more, compatibility with other communication systems like V2X and cellular network system is another key parameter.

*3) Satellite receiving:* Satellite system has become an important system in vehicle systems ever since Global Positioning System (GPS) was widely used. With the help of satellite system, applications like positioning and navigation can function well and provide tremendous help to drivers. Moreover, the high precision positioning service, which can provide drivers with high resolution and real-time position information, has been taken into consideration during the vehicle developing process.

However, satellite signal is normally quite weak when arriving at the receiving antenna. Any shading around or above the vehicle, or bad weather, can lead to great signal degradation. And as the vehicle moves on the road, signal varies in a large dynamic range.

Tests for satellite receiving focus on the positioning and navigation ability in the worst case, key parameter of the test including satellite searching time, response time, positioning accuracy, and so on.

### *C. Test requirements for EMC*

EMC test normally refers to the Electromagnetic Interference (EMI) test and Electromagnetic Susceptibility (EMS) test. EMI test aims at finding out how much interference the device will produce during operation, while EMS test aims to find out how much interference the device can endure before malfunction happens.

For ICVs, EMS test are more concerned than EMI since ICV contains more wireless communication units than normal vehicles. Besides, EMS test shows the reliability of ICVs under severe electromagnetic environments, where wireless units are normally sensitive to.

Noted that before doing the EMS test, one need to make sure that normal ICV systems function well, e.g. the EMS test resides in the last part of the whole test process.

## III. Test Design

The core idea of semi-virtual test is constructing a controllable and repeatable test environment in EMC test lab to fulfill road scene emulation.

Test system and test procedure are designed according to the test requirements stated in section II. The basic set is given as follows:

1) A vehicle level EMC test lab, 10m semi-anechoic chamber, is selected as a basic test enviorment;

2) Both humidity and temperature inside the chamber are controllable;

3) Electromagnetic interferences inside the chamber are controllable.

Since different systems introduced above propose different test demands, it is necessary and reasonable to design the basic test scenes dedicated for each subsystem respectively. Then corresponding comprehensive tests are designed based on all these subsystem test schedules.

Limited by the length of the paper, here we select millimeter wave radar test as an example to explain test method for intelligent driving system tests. Meanwhile, the long-range communication test design is also selected as an example to explain the test schedule for connected system.

As mentioned earlier, EMS test is considered as an additional test using the same test scene and test configuration. So EMS test is integrated into every system test and will not be explained separately.

## A. *Test design for the millimeter wave radar*

Test configuration for the millimeter wave radar test is shown in Fig.1.

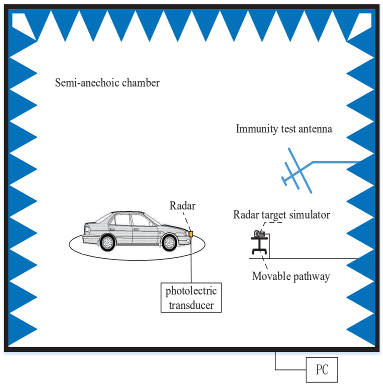


Fig. 1. Test scene of radar system

As shown in Fig.1, radar under test is mounted in the middle of the vehicle front face in order to detect target in front of vehicle. In the EMC lab, the ICV is tied to the drum dynamometer, and a radar target simulator, which is used to generate target reflection signal, is placed on a fan-shaped rail 0.8-1.0 meters in front of the vehicle. According to the simulator specification, the deployment height of target simulator is the same as that of radar under test. Radar target simulator travels along fan-shaped rail to control the direction of arrival (DOA) of target signal. A computer outside the chamber controls the target simulator through photoelectric transducers. Moreover, an EMS test antenna is employed here to verify the radar system's immunity feature under strong interference condition. The deployment of EMS test antenna follows ISO11451-2 standard.

This set could satisfy test demand of cut in (another vehicle in the front moves from the side lane into the same lane as the VUT) and cut out (vehicle in the front moves from the same lane as the VUT into the side lane) scenario.

## B. *Test design for long range communication*

The EMC lab shields electromagnetic interferes out, but at the same time, cellular network signal, which is necessary for the onboard long range communication system, is shielded either. However, with the help of communication tester as well as necessary cables and antennas, a local cellular coverage can be achieved in the chamber.

Test configuration is shown in Fig.2.

A communication tester is employed as a simulated base station to generate signal, which is used to establish communicate link with onboard communication units.

The wireless channel feature of real road condition, such as shading, attenuation and etc., is simulated by channel simulator and used to provide real road channel condition. In addition, the interference environment is constructed by an EMS test antenna, which is used to introduce strong interference, and then to verify system's immunity feature.

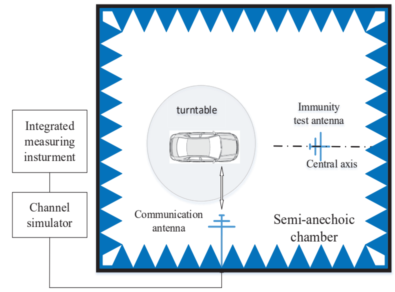


Fig. 2. Test scene of cellular network system

Note here, in EMS test scenario, communication antenna must be placed far away from the strong field area to protect the communication tester.

## IV. Test Conduction And Test Results

In this section, a vehicle-level semi-virtual millimeter radar test and communication test are described and corresponding test results are analyzed. All related tests are done in EMC lab of CAERI.

## A. *Vehicle-level millimeter wave radar test*

Millimeter wave radars are widely used in Forward Collision Warning (FCW) systems, which can be simply interpreted as collision warning and automatic braking systems.

In this test, a vehicle equipped with ACC and AEB systems could be used as the VUT.

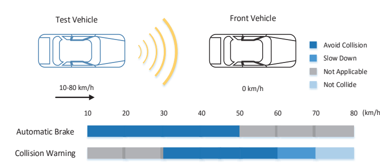


Fig. 3. Early warning model

Fig. 3 shows the test procedure of typical FCW systems. In this procedure, test vehicle approaches a stationary front vehicle at a certain speed (10-80km/h). The test protocol-AEB system of Euro-NCAP [13] is taken as a reference when deciding the range of speed. When the radar recognizes the front target, it will take actions to slow down the vehicle until the target is out of the dangerous distance range. If distance between radar and target is longer than safe distance and speed of VUT is slower than its predefined speed, the ACC activated vehicle will automatically speed up.

*1) ACC Test:* ACC test focus on the cruise control system, which could adjust the vehicle speed to maintain a safe distance from vehicles ahead automatically. The settings for ACC test under semi-virtual test manner is given as follow:

**Step1: Basic setting**

In this step, both initial speed of the vehicle and the target simulator are set.

The VUT runs on the drum in the speed of 30km/h, while simulated distance between target simulator and VUT is 100m with a relative speed of 0km/h.

**Step2: Settings of ACC system**

The parameters of ACC system are set in this step. Here we set ACC deceleration progress initiating when distance between VUT and virtual target is less than 25m. When this distance is up to 25m, the vehicle speed maintains 30km/h, which is configured by ACC system.

**Step3: Settings of target simulator**

Reset target simulator, change the relative speed between vehicle and target simulator into -10km/ h. Keep it until distance between vehicle and target simulator reaches 10m. Then, change relative speed into +10km/h. Keep it until simulated distance between vehicle and target simulator is longer than 100m.

The target simulator configuration is shown in TABLE 1 and Fig.4, while the radar-mounted vehicle configuration is shown in TABLE 2. Related test scene is shown in Fig. 5.

TABLE I
RADAR TARGET SIMULATOR PARAMETER SETTING

| RTS parameter | The maximum distance | The minimum distance | Relative velocity $\nabla V$ | RCS |
|---|---|---|---|---|
| Value | 100m | 10m | 10km/h | 10dBsm |

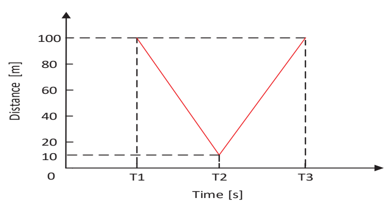


Fig. 4. The distance between two cars varies with time

TABLE II
VEHICLE PARAMETER SETTING

| Vehicle parameter | The maximum relative speed | The minimum relative distance |
|---|---|---|
| Value | 30km/h | 25m |

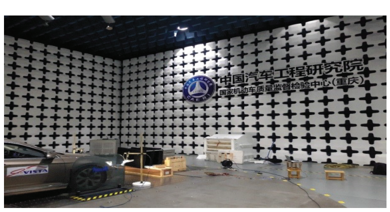

Fig. 5. Test scene

As shown in Fig.4, the distance between vehicle and target simulator reduces to 10m in the moment T2, and then, the virtual target starts to accelerate and get away from the vehicle. And if the test procedure does work, the speed of vehicle changes accordingly.

If vehicle response time matches the demand of setting parameter, test should be considered successful.

The vehicle instrument displays in the test are shown in Fig.6, and related test results illustrate that proposed method is effective in ACC function verification.

Fig. 6. Dashboard display of VUT

*2) AEB Test:* AEB test focus on the verification of brake function. Hence, corresponding semi-virtual setting is different from that of ACC, and is given as follows:

**Step1: Basic setting**

The basic setting is same as that of ACC test.

**Step2: Settings of AEB system**

The parameters of AEB system are set in this step. Here we set AEB deceleration progress initiating when distance between vehicle and virtual target is less than 25m. When this distance is less than 5m, the vehicle brakes to 0km/h.

**Settings of target simulator**

Reset target simulator, change the relative speed between simulator and under-test vehicle to -10km/ h.

Here the target simulator is configured as TABLE 3 and Fig.7, while the radar-mounted vehicle configuration is shown in TABLE 4.

TABLE III
RADAR TARGET SIMULATOR PARAMETER SETTING

| RTS parameter | The maximum distance | The minimum distance | Relative velocity $\nabla V$ | RCS |
|---|---|---|---|---|
| Value | 50m | 5m | 0km/h | 10dBsm |

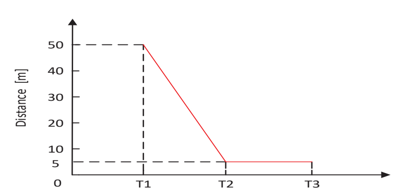


Fig. 7. The distance between two cars varies with time

TABLE IV

VEHICLE PARAMETER SETTING

| Vehicle parameter | The maximum relative speed | The minimum relative distance/ AEB triggering distance |
|---|---|---|
| Value | 30km/h | 25m |

All above is just a brief introduction of a sample millimeter wave radar test. More complicated tests can be done on the basis of this, including EMC test.

### *B. Communication test*

According to the semi-virtual test design for the long-range communication described above, a test is conducted in the EMC lab of CAREI. The onboard communication module (T-BOX) supports LTE/WCDMA.

R&S CMW500 communication tester together with a communication antenna is used as a simulated base station.

After the link is built between the onboard T-BOX and the CMW500, EMS test is conducted from 1000MHz to 2000MHz. The polarization of the EMS test antenna is set to horizontal, the modulation mode is CW, the field strength is 100V / m. System throughput and BER are monitored and recorded in Fig.8 and Fig.9.

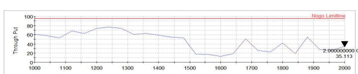

Fig. 8. 1-2GHz system throughput

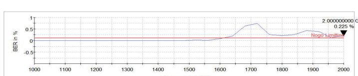

Fig. 9. The BER of AM&PM modulation

It can be seen from the test result that below 1500MHz, system throughput is normal and BER is very small. Above 1500MHz, when there’s strong outside interference, BER goes up obviously and system throughput degrades greatly.

Mentioned that test shown above is just one of the potential tests that can be done under these configurations. Actually, with controllable transmitting power and coverage area of communication tester as well as appropriate selection on channel simulator, quite a lot of communication environment can be simulated and evaluated in laboratories.

## V. CONCLUSIONS

ICV is a vehicle that has access to the Internet or other devices, with the ability to sense the outside world and use all the information to decide how to drive or how to help the driver drive. However, due to the variability of road and field environment, test consistency and repeatability can’t be assured. To solve the problem, this paper put forward a semi-virtual test method for ICV using the vehicle-level 10m semi-anechoic chamber to provide a well-controlled environment. Test design is explained, and corresponding tests are conducted in the EMC lab of China Automotive Engineering research institute. Test results show that it can simulate some of the traffic scenarios well. In terms of communication environment, channel model need to be studied further to form better channel simulators for more accurate traffic simulation.

## ACKNOWLEDGMENT

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