Comparing and Analysis of Test and Evaluation Methods for Connected Vehicle Communication Antenna System

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Abstract—With the development of Connected Vehicle, various on-board applications and functions rely on stable, reliable and fast-response wireless connections furtherly, making it more urgent and widespread for vehicles to be equipped with relevant antenna systems such as positioning and communication. There are many types of vehicle antenna systems, together with a wide range of installation locations and a complex electronic environment which brings huge challenges to the development of antenna manufacturers and the matching of automobile OEMs. In order to carry out the R&D, matching and testing of the vehicle antenna system better, various parties have proposed a multi-dimensional test and evaluation methods, but there is still a lack of horizontal evaluation between them. This paper analyses the requirements of automotive antenna system evaluation, sorts out and compares the technical paths of various common solutions, summarizes the characteristics and differences of various solutions, and provides a research foundation for further optimizing the vehicle-level antenna system test and evaluation program.

1. Introduction
With the in-depth integration of the automotive industry, electronics industry and communications industry, consumers' demand for automobiles has evolved from a simple transportation tool to more safety, comfort, and intelligence requests. Therefore, the on-board wireless communication function has been greatly developed. As an indispensable and important conversion device for wireless communication systems, the antenna is responsible for the mutual conversion function between the guided wave of the transmission line and the electromagnetic wave in space. The various applications of the vehicle make the number of vehicle antennas reach more than a dozen, and its wireless communication function highly depends on the underlying RF performance of the vehicle antenna system. Therefore, OEMs and antenna suppliers are paying more attention to the antenna system. For R&D and testing, various parties have proposed a variety of vehicle-mounted antenna test programs from different dimensions. This article will research the technical characteristics and differences of
each solution which start from the needs of the automotive industry for antenna systems, and promote the further development of vehicle antenna system testing and evaluation programs.

2. On-board Antenna Type and Distribution

With the further deepening of vehicle intelligence and networking, the realization of its sensing and communication functions is closely related to the antenna. The on-board antennas are abundant in variety and increasing in number. The frequency distribution is shown in Figure 1.

![Antenna type and frequency distribution](image)

Fig.1 Antenna type and frequency distribution

Generally, it is installed in different positions of the vehicle according to the characteristics of the antenna function and application [1]. The installation position of the common on-board antenna is shown in Figure 2.

![Common vehicle antenna installation location](image)

Fig. 2 Common vehicle antenna installation location

According to the functional requirements realized by the vehicle antenna, the different types of vehicle antenna installation positions are:

- **Broadcast Radio Antenna**
  
  This type of antenna is used in AM, FM, DAB and other broadcast radio communications, mainly installed in: car window glass, roof short pole or shark fin, trunk or mudguard long mast, rear-view mirror, bumper, etc.[2].

- **Cellular Network Antenna**
  
  This type of antenna is used in cellular mobile communications such as GSM, GPRS, EDGE, CDMA (EV-DO), WCDMA, HSPA, LTE, 5G, etc. It is mainly installed on: roof short poles or shark fins, roof smart antennas (integrated), Dashboard, centre console, rear-view mirror, bumper, etc.

- **Direct Communication Antenna**
  
  This type of antenna is used in PC5, DSRC direct communication, and is mainly installed in: roof shark fins, rear-view mirrors, roof smart antennas (integrated), etc. [3].

- **Global Navigation Satellite System (GNSS) Antenna**
  
  This type of antenna is used in GPS, Beidou, Glonass, Galileo and other satellite positioning and positioning communications, and is mainly installed in: roof shark fins, roof smart antennas (integrated), dashboards, centre consoles, etc.

- **Infotainment and Communication antenna**
  
  This type of antenna is used in Bluetooth, WLAN and other infotainment communications, mainly installed in: dashboard, centre console, roof shark fin, rear-view mirror, etc.
Smart Entry System Antenna

This type of antenna is used in PEPS, PKE, RKE and other automotive intelligent entry systems, and is mainly installed on the roof, the rear of the car, the side of the car, etc.

Among the above types of antennas, cellular wireless communication antennas, direct communication antennas, and satellite navigation antennas are closely related to vehicle safety and are the focus of this paper.

3. Analysis of Requirements for Testing and Evaluation of Vehicle Antenna Systems

The radio frequency performance of the vehicle antenna system directly affects the performance of the vehicle's cellular wireless communication, direct communication and global satellite navigation. Therefore, the antenna system, as the necessary underlying support for vehicle perception and communication functions, has received more and more attention from OEMs and Tier 1 for its radio frequency performance.

The performance of the vehicle antenna system is affected by many factors, including:

- The configuration of the installation location, the material of the car body, and the installation angle.
- Vehicle occlusion and reflection.
- Layout of wiring harness.
- Harassment from other electronic systems of the vehicle.

The radio frequency performance of the vehicle antenna is not affected by a single component or a single factor [4]. Therefore, there is a significant difference between antenna component-level testing and vehicle-level testing. Its performance is a system problem. R&D and testing need to be comprehensively designed and investigated from the vehicle level. With the deepening of industry research, all parties have derived a variety of different technical solutions based on different foundations and ideas. However, the automotive industry does not have a unified standard to regulate the evaluation system and test methods, resulting in differences in the actual loading performance of the vehicle antenna system, which has a certain restrictive effect on the development of the industry. This article will further research the principles and characteristics of each technical programs, and explore the direction of future technical routes.

4. Research of the Test Program Technical Path

4.1. Single Antenna Passive Radio Frequency Performance Test (Test Program 1)

Due to the large size of the vehicle-level full-wave anechoic chamber and the high construction cost, some OEMs still test the circuit characteristics and the passive radio frequency performance of the single antenna (see Figure 3) supplemented by the vehicle field function verification to research and development.

![Fig.3 test of single antenna](image)

Due to the small size of the single antenna, the solution has low requirements on the size of the full-wave anechoic chamber, and the test of the antenna unit is more convenient. However, the program also has greater risks, which are mainly manifested in:
• Only use the CW signal to test the passive radiation characteristics such as the pattern, gain, polarization, etc., without considering the OBU and actual communication signal characteristics, it is difficult to evaluate the receiving sensitivity of the radiation power meter.
• Without considering factors such as actual vehicle installation and matching scenarios, vehicle electronic and electrical architecture configuration, electromagnetic compatibility, etc., only the radio frequency characteristics of the antenna can be obtained.
• Once the vehicle function verification effect is not good, it is difficult to locate the problem and analysis quantitatively, and the rectification is difficult.

Therefore, the test plan is changed to more applications and the R&D and testing of radio and infotainment antennas. As more and more antennas are involved in driving safety issues, this solution is not enough to support R&D. OEMs, testing institutions and scientific research institutions have gradually shifted the research direction to vehicle-level antenna testing (see test program 2, 3, and 4).

4.2. Passive RF Performance Test for Vehicle-level Antenna (Test Program 2)
Different from Test Plan 1, the passive radio frequency performance test program of the whole vehicle antenna considers the actual installation position of the antenna, the material of the vehicle body, the installation angle, the layout of the wiring harness, and the vehicle blocking reflection. An example of the test layout is shown in Figure 4.

Fig.4 Example of layout of passive radio frequency performance test for vehicle antenna

4.3. Integrated Test for Antenna System Active Radio Frequency Performance on the basis of Vehicle Radiation Aperture (Test Program 3)
The function of the vehicle system depends on the underlying radio frequency performance of the antenna system, so it is very necessary to test and evaluate the antenna system under the actual vehicle installation state. Due to the configuration of the antenna installation position, the vehicle body material, the installation angle, the layout of the wiring harness, the vehicle occlusion and reflection, and the disturbance of other vehicle electronic systems, there is a significant difference between the antenna component level test and the vehicle level test. So it is the most direct and effective to test the vehicle antenna system composed of OBU, wiring harness and antenna [5].

The ideal solution for the active test of the vehicle-level antenna system (OBU-Harness-Antenna) is to use the far-field or compact range solution for testing. The test items generally include the transmitting power and receiving sensitivity corresponding to the upper hemispherical surface of the car (as shown in Figure 5) or a specific angle in the upper hemispherical surface (as shown in Figure 6).

For the far-field test program, the distance between the test antenna and the vehicle under test satisfies the following relationship:

\[ r = \frac{2D^2}{\lambda} \]  

(1)
where \( r \) is the test antenna and the vehicle under test; \( D \) is the radiation size (the size of the metal shell of the vehicle connected to the antenna is the default if unknown); \( \lambda \) is the wavelength.

Taking the C-V2X antenna of a passenger car as an example, the far-field distance between the test antenna and the vehicle under test will exceed 1,000 meters.

There are strict requirements for the outdoor far field. In addition to the size of the site, in order to ensure the consistency and reproducibility of the test, it is also necessary to ensure a relatively clean electromagnetic field environment around the site to avoid co-frequency and adjacent-frequency interference. And considering the further expansion of the on-board frequency, the size of the outdoor far field still has the possibility of further expansion. Therefore, the field size factor and electromagnetic environment factor are a big challenge for the outdoor far field.

Fig. 5 Example of vehicle active test range (upper hemisphere).

Fig. 6 Example of vehicle active test range (a specific angle on the upper hemisphere).

In order to avoid electromagnetic environment interference and compress the test distance at the same time, a compact range solution with mature technology can be adopted, as shown in Figure 7. The compact range program converts spherical waves into plane waves through the reflecting surface, and reduces the size of the vehicle's darkroom to tens of meters on the premise of achieving the far-field purpose. At the same time compact range program can form a certain size of quiet zone space. After measuring the quiet zone emission level, amplitude taper, amplitude fluctuation, phase error, and cross polarization, the far-field requirement can be achieved.
4.4. Simplified test for vehicle-level active RF performance of antenna system (Test Program 4 and 5)

The tight field test program has mature applications in the communications industry, but has not yet been applied in the automotive industry. The main reasons are:

- The connected vehicles has developed rapidly in recent years, and its realized functions involve safety. The testing of communication antennas has received more and more attention from OEMs, but it is still in the initial stage of development;
- Due to the large quiet space corresponding to the size of the car, the load-bearing capacity of the turntable used by the car is relatively high, which makes the cost of the compact range higher.

Taking into account the necessity of active testing of vehicle-level antenna systems, some research institutions and program suppliers have turned to research simplified schemes for vehicle-level antenna systems.

4.4.1. Simplified plan for step-by-step testing (Test Program 4)

A simplified test program is designed based on the assumption that the electronic disturbance of the vehicle will not affect the antenna system. Firstly, the program tests the passive radio frequency performance of the vehicle antenna (Program 2), obtains the vehicle-level pattern of the antenna, and tests the receiving sensitivity of the OBU's transmit power meter by conduction. Through the mathematical derivation and combination of the directional pattern and the OBU transmit/receive characteristics, the vehicle-level active radio frequency performance is calculated.

This solution is simple to operate, but will have certain differences due to the different electromagnetic characteristics generated by the electrical and electronic components of different vehicles.

4.4.2. Simplified plan for equivalent radiation aperture (Test Program 5)

The equivalent radiation aperture program is based on the assumption that the scattered current of the antenna decays rapidly on the metal surface of the vehicle body, and the antenna radiation area is limited to a certain size around the antenna. According to the formula (1), when the radiation size D is further reduced, the test distance between the test antenna and the vehicle under test will be effectively reduced.

The program ensures the integrity of various key factors by directly testing the active radio frequency indicators of the vehicle antenna. However, since the radiation size is affected by many factors such as signal characteristics, body material, installation angle, etc., its range is difficult to determine.
5. Test Program Comparison
Through analysing the research of the above 5 kinds of antenna test program, the advantages and disadvantages can be analysed which is shown in Table 1.

Table 1: Antenna test program comparison.

| Program | Test method description | Advantages | Disadvantages |
|---------|------------------------|------------|---------------|
| 1       | Single antenna passive test | Quickly obtain antenna single circuit characteristics and passive radio frequency characteristics | Without considering factors such as actual vehicle installation and matching scenarios, vehicle electronic and electrical architecture configuration, EMC, etc., it is difficult to troubleshoot antenna matching problems |
| 2       | Passive test of vehicle antenna (Near to far field conversion) | The test distance is short, the test is easy to implement, and the passive radio frequency indicators such as the antenna pattern of the whole vehicle can be obtained | Cannot directly perform active RF index test |
| 3       | Active test of vehicle antenna (Far field, compact range) | The test distance is shortened by reflecting surface or phased array technology, and the active radio frequency index test is realized | The cost is high, and the project is difficult to realize |
| 4       | Active test of vehicle antenna (Simplified step by step) | Easy to implement | Unable to obtain the electromagnetic influence of the electronic and electrical components on the vehicle |
| 5       | Active test of vehicle antenna (Simplified equivalent radiation aperture) | The test system is simple, the test is easy to implement, and it can verify the influence of the electromagnetic characteristics of electronic and electrical components on the antenna system | Difficult to obtain equivalent radiation size |

6. Conclusion
The rapid development of vehicle intelligence and networking has made the types and numbers of antennas on vehicles increasingly abundant. The wireless communication function is highly dependent on the underlying radio frequency performance of the vehicle antenna system. It has become an industry consensus that the test and evaluation should be carried out in conjunction with the entire vehicle. In order to solve this problem, various test schemes have emerged. How to comprehensively consider test evaluation schemes from different dimensions such as test accuracy and convenience has become a key issue of industry research. This article analysed the technical characteristics and advantages and disadvantages of each program to help promote the further development and improvement of the vehicle-mounted antenna system test and evaluation program.

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