Overview of Electromagnetic Compatibility in Automotive Integrated Circuits

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Abstract. This article summarizes the current development situation of automotive integrated circuits, the origin of relevant domestic and foreign standards AEC Q100, IEC 61967, IEC 62132. In addition, this article introduces in detail the test methods of IEC 61967 and IEC 62132 standards, that is radiated emissions, radiated immunity, conducted emissions, conducted immunity, and gives a test block diagram of the relevant test methods. Finally, this article summarizes the status of domestic integrated circuit electromagnetic compatibility testing and standards

1. Preface
With the advent of artificial intelligence and the internet of things, consumer demand for cars has gradually turned to intelligence, self-driving, safety, interconnection and other directions. Therefore, traditional automotive manufacturers have turned to smart car manufacturing\cite{1}. At the same time, the mobile communication industry is becoming saturated, semiconductor manufacturers are opening up new continents, and integrated circuits (chips) are the key to smart cars. Therefore, various enterprises have begun to lay out the automotive integrated circuit business.

With the continuous improvement of manufacturing processes, integrated circuits have gone from sub-micron level to nano-level\cite{2}. At the same time, the voltage of integrated circuits is getting lower and lower, the frequency is higher and higher, the number of integrated transistors is also increasing, and the problem of electromagnetic compatibility (EMC) is becoming more and more serious. If the chip is in the electromagnetic environment for a long time and suffers electromagnetic interference, its performance will be reduced to a certain extent\cite{3}. It will affect the normal operation of the device at a slight level or the chip is damaged. In addition, the layout between chips in the system is getting closer and closer, and the electromagnetic interference generated by the chips on the system cannot be ignored\cite{4}.

2. Automobile Electromagnetic Compatibility Standards
2.1. Automotive system-level electromagnetic compatibility standards
At present, domestic and foreign standards for automotive system-level electromagnetic compatibility (EMC) are relatively mature\cite{5}. There are mainly standards listed in Table 1.
2.2. **Automotive integrated circuit-level electromagnetic compatibility standards**

At present, there are no standards related to automotive integrated circuits in China. According to the survey, the standards adopted by companies such as NXP Semiconductors and Infineon are the IEC61967, IEC62132, IEC62215, and IEC61000 series, while domestic companies such as Huawei and Horizon do AEC-Q100 standards. However, AEC-Q100 only covers emission and static content in terms of electromagnetic compatibility.

2.2.1. **AEC-Q100**

AEC-Q100 was developed by the American Automotive Electronics Council (AEC). At present, AEC mainly implements standard specifications for automotive applications, automotive components and automotive electronics. AEC standards include AEC-Q100-(001~012), AEC-Q101, and AEC-Q200. Among them, AEC-Q100 is the first standard of AEC, which was first published in June 1994 and has now become a general standard for automotive electronic systems. AEC-Q100 is the most common stress test certification standard for automotive chips. It specifies a series of tests, and defines the minimum requirements for stress test-driven certification and the reference test conditions for IC certification. AEC-Q100 includes tests of environmental stress acceleration, life simulation, package assembly integration, chip wafer reliability, electrical characteristics confirmation, defect screening monitoring, and package depression integration\(^6\). Regarding electromagnetic compatibility testing, AEC-Q100 only stipulates electrostatic discharge (human body model / mechanical mode) and radiated emission of integrated circuits. For the radiated emission test method of integrated circuits, refer to SAE J1752-3.

| International Standard | Corresponding National Standards | Standard Name |
|------------------------|----------------------------------|---------------|
| IEC 60050:1990         | GB/T 4365-2003, GB/T 17624.1-1998 | EMC terms |
|                        |                                  | Application and interpretation of basic EMC terms and definitions |
| Test Standards for     | CISPR 25:2016, GB/T 18655-2018   | Limits and measurement methods for protecting radio disturbance characteristics of vehicle-mounted receivers |
| Automotive Electronic  | ISO 7637, GB/T 21437             | Road vehicles Electrical harassment caused by conduction and coupling |
| Components             | ISO 11452, GB/T 33014            | Road vehicles. Test methods for immunity of electrical / electronic components to narrow-band radiated electromagnetic energy |
| Test Standard of the   | ISO 10605 2008, GB/T 19951-2005  | Road vehicles Test method for electrical disturbance caused by electrostatic discharge |
| Whole Vehicle          | CISPR 12:2009, GB 14023-2011     | Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers |
| ISO 11451, GB/T 33012  |                                  | Road vehicles Vehicle immunity to narrow-band radiated electromagnetic energy |
| ISO 7637, GB/T 21437   |                                  | Road vehicles Electrical harassment caused by conduction and coupling |
| ISO 10605 2008, GB/T 19951-2005 |                    | Road vehicles Test method for electrical disturbance caused by electrostatic discharge |

2.2.2. **Electromagnetic emission of integrated circuits IEC 61967**

In October 1997, the Ninth Working Group (WG9) of the 47A Technical Sub-Committee of the International Electro-technical Commission (IEC) was established. The working group is specifically responsible for analyzing the various test methods that have been proposed to develop standards for
evaluating the electromagnetic compatibility of integrated circuits. Finally published a collection of toolbox-style test methods for electromagnetic interference (EMI) and electromagnetic sensitivity (EMS)-IEC 61967 series and IEC 62132 series. IEC 62215 has also been published, which is complementary to IEC 62132 and more comprehensively considers the electromagnetic interference situation suffered by integrated circuits.

The IEC 61967 standard[7] is applicable to the test of the electromagnetic emission part of integrated circuits with the frequency of 150kHz to 1GHz, which includes the following six parts:

The first part, IEC 61967-1, mainly introduces the general conditions and definitions of the electromagnetic radiation emission of integrated circuits (refer to SAE J1752.1). This part introduces the scope of application of the IEC 61967 standard, the definition of terms and the reference literature used. The test generally includes test conditions, required equipment, test configuration, test report and other related content. In addition, this part also introduces the jig-test board used to test the chip. The standard specifies the test board schematic and layout requirements to the greatest extent, so as to ensure the consistency with test boards from different designs and production.

The second part, IEC 61967-2, mainly introduces the method of radiation emission measurement-TEM cell (refer to SAE J1752.3). The TEM cell can be used as a coaxial cable with an equivalent cross-sectional impedance of 50Ω. One end is connected to a 50Ω coaxial cable, and the other end is connected to a 50Ω matching load, including tapered absorbing material and a resistor at the end of the core plate for impedance matching. The top of the outer conductor of the cell has a square opening for mounting the test circuit board. One side of the integrated circuit is installed on the inside of the cell, and the interconnection line and the peripheral circuit side are outward, so the measured radiation emission mainly comes from the integrated circuit under test. This method requires good cell tightness. Any gaps and leaks may affect the cell's indicators such as reflection, absorption, impedance, and field uniformity, resulting in measurement errors. The connection diagram is shown in Figure 1.

![Figure 1. Schematic diagram of TEM cell test connection](image1)

The third part, IEC 61967-3, mainly introduces the method of radiation emission measurement-surface scanning (refer to SAE J1752.2). This method measures the radiation field of the chip casing and the chip surface by a near-field probe, thereby obtaining the radiation emission field strength of the chip. The test schematic is shown in Figure 2.

![Figure 2. Schematic diagram of the surface scanning method test connection](image2)

The fourth part, IEC 61967-4, conducted emission measurement method-1Ω / 150Ω direct coupling method[8]. The 1Ω test method is mainly used to test the total disturbance current on the ground pin of the chip. Because the current of the chip will eventually be aggregated to the ground pin, this method can reflect the intensity of the electromagnetic disturbance of the chip well. Using a 1Ω resistor in series with the ground loop, on the one hand, it can be used to obtain the current of the ground loop, on the other hand, it can also achieve impedance matching between the ground pin terminal and the test equipment. The 150Ω test method is mainly used to test the disturbance voltage of the output port.
This method can test the disturbance voltage of single or multiple output signal lines. The 150Ω impedance represents the statistical average value of the common mode impedance of the harness. In order to achieve the impedance matching of 150Ω common mode impedance and 50Ω test system, this method must use an impedance matching network. The schematic diagram is shown in Figure 3.

Figure 3. Schematic diagram of 1Ω / 150Ω direct coupling method test connection diagram

The fifth part, IEC 61967-5, conducted emission measurement method-Faraday cage method (WFC). This method measures the conducted electromagnetic emission at the specified common touch point, thereby estimating the electromagnetic emission intensity from the connecting cable. The chip test board used in this method is limited by the size of the Faraday cage. However, according to research, this method is rarely used in chip EMC testing.

The sixth part, IEC 61967-6, conducted emission measurement method-magnetic field probe method. This method uses a magnetic field probe to measure the magnetic field associated with the PCB trace. The recommended test arrangement is to install the chip to be tested on the test board, so as to maximize the repeatability and reduce the direct coupling of the probe with other circuits. This method and Faraday cage method are rarely used in practice.

The comparison of each test method of IEC 61967 is shown in Table 2.

| Item | IEC 61967-2 | IEC 61967-3 | IEC 61967-4 | IEC 61967-5 | IEC 61967-6 |
|------|-------------|-------------|-------------|-------------|-------------|
| Method | TEM cell | Surface scanning | 1Ω / 150Ω | Faraday cage | Magnetic field probe |
| Frequency Range | 150kHz-1GHz | | | | |
| Objects | Radiated electromagnetic field | Radiated electric field / magnetic field component | Conducted voltage | Conducted voltage | Conducted current |
| Characteristics | Proportional to the square of the RF current | The electric field / magnetic field is separated, the phase information can be measured | Easy to measure differential mode transmission lines | Measure common mode disturbances | Differential mode voltage, Common mode current |
| Whether to use standard PCB | Yes | Yes | Yes | Yes | Yes |
| Whether to use application PCB | No | Yes | Yes | Yes | Yes |
| Number of single pins | No | No | Yes | No | Yes |
| Correspondence with device level | None | None | None | Corresponds to radiated emissions | None |
2.2.3. Electromagnetic immunity of integrated circuits IEC 62132

The IEC 62132 standard\cite{9} is an electromagnetic immunity test standard for integrated circuits with a frequency of 150 kHz to 1 GHz. It includes the following five parts:

The first part, IEC 62132-1, general conditions and definitions. It mainly introduces the evaluation method of integrated circuit conduction and radiation immunity. This part introduces the scope of application of the IEC 623132 standard, the definition of terms in it and the reference literature used. The test generally includes test conditions, required equipment, test configuration and test report related content. In addition, the standard specifies the level that characterizes the immunity performance of integrated circuits and the PCB test fixture used for the chip under test. The test fixture is the same as the IEC61967 standard, but mainly for the immunity test. The standard requires that the design of the PCB and supporting circuit used in the immunity test should ensure that the test and the device itself are not affected by the test.

The second part, IEC 62132-2, radiation immunity measurement method-TEM cell method, the standard specifies the method of measuring the chip radiation immunity. This method requires an integrated circuit electromagnetic compatibility test board. As shown in figure 4, this method specifies that the chip to be tested is to be installed on a test board, and the test board is installed to a matching port connected to the top or bottom of the TEM cell. The test requires that the chip to be tested is tested in at least two directions to ensure that the chip can be fully exposed to the generated electric field\cite{10}.

![Figure 4. Schematic diagram of TEM cell test connection](image)

The third part, IEC 62132-3, the measurement method of conducted immunity-large current injection method (BCI). The standard specifies the method for measuring the electromagnetic immunity of the chip. This method is mainly aimed at the noise current from the cable connected to the chip pins. This method needs to install the chip to be tested on the integrated circuit electromagnetic compatibility test board or application board. The test connection diagram is shown in Figure 5.

![Figure 5. Connection diagram of big current injection method](image)

The fourth part, IEC 62132-4, measurement method of conducted immunity—direct radio frequency power injection (DPI). This standard, like IEC 62132-3, specifies the method for measuring chip immunity. However, this method is to inject the RF signal directly to a single pin or a group of pins of the chip. In this method, the chip can be installed on the electromagnetic compatibility test board or application board of the integrated circuit. As shown in figure 6. The coupling capacitor plays a DC blocking role here to prevent the direct voltage from being directly applied to the output end of
the power amplifier.

![Diagram of direct RF power injection method](image)

Figure 6. Connection diagram of direct RF power injection method

The fifth part, IEC 62132-5, measurement method of conducted immunity-Faraday cage method (WFC). The standard stipulates the method of injecting the noise signal at the designated common touch point to simulate the cable exposure to electromagnetic radiation environment in actual application, so as to test the conducted immunity of the chip. In this method, the chip to be tested needs to be installed on the integrated circuit electromagnetic compatibility test board or application board. The test board and application board are limited by the size of the Faraday cage. Like IEC 61967-5, this method is rarely used in actual use. The comparison of IEC62132 test methods is shown in Table 3:

| Item                        | IEC 62132-2          | IEC 62132-3          | IEC 62132-4          | IEC 62132-5          |
|-----------------------------|----------------------|----------------------|----------------------|----------------------|
| Method                      | TEM cell             | BCI                  | DPI                  | Faraday cage         |
| Frequency Range             | TEM cell             | BCI                  | DPI                  | Faraday cage         |
| Objects                     | Radiated electromagnetic field | Induced conduction current | Injected forward power | Conducted voltage |
| Characteristics             | /                    | Both common mode and differential mode can be applied | Both common mode and differential mode can be applied | Inflicting common mode harassment |
| Whether to use standard PCB | Yes                  | Yes                  | Yes                  | Yes                  |
| Whether to use application PCB | No                  | Yes                  | Yes                  | Yes                  |
| Single pin measurement      | No                   | Yes                  | Yes                  | No                   |

3. Conclusion

Since the automobile is closely related to human life safety, the automobile industry is an industry that requires extremely high safety performance. Any factors that may affect the reliability of the automotive system should be given sufficient attention. Nowadays, domestic cars are accelerating towards intelligentization, network connection, electrification and sharing. The requirements of automobiles for electronic functions are more and more and higher, which will inevitably introduce more electronic and electrical components and more functionally complex chips. The more electronic and electrical components in the same space, the more electromagnetic compatibility problems are bound to be. Similarly, the electromagnetic compatibility problem of the chip must be more and more serious. At present, There are no relevant standards for electromagnetic compatibility of automobile integrated circuits in China. Therefore, we should promote the electromagnetic compatibility standards and test progress of automotive electronic integrated circuits vigorously and do a good job in the protection work behind research and development.
References

[1] Xu Chenxi. Development of new energy vehicles under the internet innovative thinking [J]. China’s Strategic Emerging Industries, 2015, 000(021):P.40-42.

[2] Wu Jianfei. Research on the Electromagnetic Compatibility Sensitivity Mechanism of Integrated Circuit LDO Regulators [D]. National University of Defense Technology, 2013.

[3] Ren Shangzong, Li Shaohua. Signal Integrity Analysis and EMC Simulation Technology in PCB Circuits [J]. Information Communication, 2012, 000(002):42-44.

[4] He Yi. Research on EMI and integration scheme of RF system-in-package [D]. 2016.

[5] Yan Wei 1, Xiong Shengjiang 2, Chen Chu 3. Research on EMC Test Standards for Automotive Electronic Chips [J]. Safety and Electromagnetic Compatibility, 2012 (2): 39-41.

[6] AEC-Q100-Rev-H September 11, 2014 Failure mechanism based stress test qualification for integrated circuits.

[7] IEC 61967-2006 Integrated circuits, Measurement of electromagnetic emissions. 150kHz to 1GHz[S]. 2003.

[8] Bernd Deutschmann, Gunter Winkler. Characterization of IC Electromagnetic Emission with IEC 61967-4 Characterization of Integrated Circuits Electromagnetic Emission with IEC 61967-4[J]. 2008.

[9] IEC 62132-2006 Integrated circuits, Measurement of electromagnetic immunity. 150kHz to 1GHz[S]. 2003.

[10] Cai Shaoying 1, Fan Wenqi 2, Overview of Electromagnetic Compatibility Standards for Integrated Circuits [J]. Reliability and Environmental Testing of Electronic Products, 2005, 023 (002): 47-52.