Analysis and design of precise testing instrument chassis considering electromagnetic shielding

Xuwei Hou\textsuperscript{1*}, Li You\textsuperscript{1}, Jingjing Li\textsuperscript{1} and Huiyuan Wang\textsuperscript{1}

\textsuperscript{1}Beijing Orient Institute of Measurement and Test, Beijing 100086
*Corresponding author’s e-mail: houxw_work@163.com

Abstract. In this work, the issues regarding the mechanism and structural design of electromagnetic shielding technology are introduced. In accordance with the use requirements of precise testing instruments, the precautions in the chassis design with respect to electromagnetic shielding are determined. Moreover, the approach to improve the chassis through experiments is proposed, and the test shows that the improved chassis can meet the requirements of shielding.

1. Introduction
Precise testing instruments are the basic instruments and equipment in the fields of measurement and testing, industrial production and measurement industry. At present, such products have been monopolized by the manufacturers abroad for a long time, while the market in China has an urgent demand for the localization of multi-functional products in terms of standard sources. Beijing Orient Institute of Measurement and Test has gathered the backbone of technical staff to handle the key technologies and transform technologies into products, which can produce such products.

As a precise testing instrument and equipment, besides the precision design of each functional module, the structure should also be accurately and comprehensively designed, including structural design, electromagnetic compatibility (EMC), thermal design and so on\cite{1}. Structural design is the basis of the whole standard source design, which involves the strength, stiffness, reliability, miniaturization, appearance, etc., to ensure the normal operation of the equipment to meet the requirements of interchangeability, maintainability, safety and reliability. EMC design is to ensure that each module and the whole system of the standard source are free of interference and can normally work in a compatible manner under a complex electromagnetic environment. Moreover, the impact of the internal electromagnetic environment on the external environment should meet relevant standards. Thermal design is to realize the high-density design with the consideration of coupled mechanical, electricity and thermal by field analysis method\cite{2}, aiming to reduce the internal temperature unevenness of the whole machine as possible for improved stability, reliability and service life of the product by means of the reasonable layout of heat source and airflow dredging. This work will focus on the EMC design in the design of precise testing instrument chassis.
2. EMC analysis of chassis

2.1. Chassis structure composition

![Figure 1 Schematic diagram of the chassis structure](image1)

![Figure 2 Schematic diagram of the module](image2)

Taking the precise testing instrument of the standard source as an example, it can output five standard signals such as DC voltage, DC, AC voltage, AC and DC resistance. To facilitate production, commissioning and maintenance, the equipment adopts a modular structure, including the five output modules of DC voltage, DC, AC voltage, AC and DC resistance, together with the modules of voltage and current conversion, power supply and intelligent center. Among them, the five standard signal output modules of the product are assembled in the front of the chassis, and the remaining modules are in the rear, as shown in Figure 1. The structural schematic of the five output modules is displayed in Figure 2, and each module is separately provided with an electromagnetic shielding structure.

2.2. EMC analysis

The electromagnetic compatibility of the chassis is one of the essential aspects to be considered in product design. The generation, transmission and receiving of electromagnetic energy inside the product constitute the basic framework of EMC design, in which the following three ways to prevent interference are adopted:
(1) **Suppression of source emission.**
When the internal power-frequency transformers and multiple precise high-speed circuit boards work, low-frequency electromagnetic signals will be generated with coupled characteristics to cause interference, resulting in impure standard signals output by the equipment. In light of this, it is necessary to design the electromagnetic compatibility for the low-frequency electromagnetic signal source producing interference (i.e., the main source is from the power-frequency transformer) to reduce the interference emission by itself.

(2) **Control of the coupling path.**
The generated internal interference signals will lead to external interference, which is mainly emitted through the transmission of the chassis space and the conduction by cables/connectors. The transmission and emission of electromagnetic interference signals can be reduced by improving connector filtering and among others.

(3) **Reduction of the sensitivity of key modules inside the product.**
In the initial product design, the electromagnetic performance of the system should be fully considered, and the design scheme should be improved in time to reduce the modification in the following stage. Thus, problems that may be encountered in the subsequent test process can be avoided without the increased rectification cost.

3. **Design of polar electromagnetic shielding**
The electromagnetic compatibility of the chassis design should meet the requirements of Electromagnetic emission and susceptibility requirements and measurements for military equipment and subsystems (GJB151B) and can pass the testing items of electromagnetic compatibilities, such as 10kHz~18GHz electric field radiation emission, with the frequency band of 30MHz~100MHz lower than 24dB µV/m.

Electromagnetic interference (EMI) energy inside the chassis can be transmitted through conduction coupling and radiation coupling. The main method applied to the chassis is shielding, namely, shielding the noise source to prevent noise coupling to the external equipment, which can shield the receiver to prevent noise intrusion. The shielding effect of the chassis is mainly affected by gaps, openings and wire penetration; therefore, a number of factors, for instance, ventilation holes, indicator window of the measurement instrument, display window, indicator light, fuse, switch, power line and signal line connectors [3], should be comprehensively taken into consideration in the integrity design of shielding. The integrity design of shielding can have the following four approaches, i.e., electrostatic shielding, electromagnetic shielding, gap shielding and chassis grounding design.

3.1. **Electrostatic shielding.**
The shell and plate used in the chassis are made up of aluminum. Theoretically, the 0.5 mm thick aluminum plate can shield the plane wave in most frequency bands with a performance of more than 120 dB. An aluminum alloy plate is selected by considering the stiffness, strength and other conditions of the chassis (tempering) as the basic material to fabricate the main body of the chassis. In addition, the shielding box of each modular circuit sub-board also adopts an aluminum alloy plate. Besides, to suppress the coupling of parasitic capacitance, low-resistivity material is used as the shielding body, and a metal partition screen, cover or box with good contact with the chassis is added between the induction source and the sensor.

The surface of the metal structure in the chassis is treated as electric conduction. The upper and lower cover plates, handles, side plates and other structural parts located on the inner side of the chassis and are subject to conductive treatment, while the outer is subject to insulation treatment. The strength is enhanced through sheet metal bending to fabricate the mainframe of the chassis, which is connected and assembled with rivets or screws.
3.2. Electromagnetic shielding.
For the design of low-impedance sources in the chassis, ferromagnetic materials are adopted, such as transformers, coils, some oscilloscopes, displays, etc. As the shielding material, the iron-nickel alloy has good low-frequency shielding performance due to its suitable conductivity and high permeability.

3.3. Gap shielding.
To ensure the stability of the whole product chassis, to guarantee all the contact places conductive, and the side plates, upper and lower cover plates of the product (inner side), U-groove, front and rear panels, and U-groove cover plate are selected conductive treatment on surface, which can provide good contact resistance. In the design of structural parts, the electromagnetic continuity should be paid attention to reduce the impedance of the gap, including reduced contact resistance and increased capacitance. In addition, to improve the stability, the methods adopted in the product design include the increasing number of fasteners (i.e., screws, rivets) between the two connecting parts and the use of electromagnetic sealing gasket, etc. The electromagnetic sealing gasket is made up of beryllium copper reed, which has a long service life that cannot be burnt readily, and it will not be affected by rays, ultraviolet rays or ozone, with good elasticity, mechanical performance, compatibility between the coating and the contact surface of the metal chassis, together with small bonding pressure, lightweight, fast and reliable installation. The metal reed is with a circumference compression of 15% ~ 60%, and the compression resistance is very small, with trivial fluctuation. The fan window of the chassis adopts the method of gold screen cover box and hollow metal mesh to ensure the overall electrical connection.

3.4. Grounding design of chassis.
The bonding/grounding aims to form a low-impedance loop and equipotential connection inside the product. Good grounding can effectively suppress noise to prevent interference, thus improving the electromagnetic compatibility of the product [4]. Grounding is one of the main methods to minimize unknown noise and produce a safe system. A well-designed grounding system can usually protect against unknown interference and emission without any additional cost for products [5]. An incorrect grounding system will be the main source of interference and emission; thus, it is beneficial to design an appropriate grounding system. The grounding inside the chassis mainly includes grounding design of circuit board module, circuit board shielding structure, power module, and the overall chassis.

In addition, to improve the internals common-mode rejection ratio (CMRR) of the precision instrument, the sub-board is installed in the U-shaped slot inside the chassis with an additional cover to ensure the conductivity of the whole U-shaped slot. High-insulation materials are installed between the U-shaped slot and the chassis shell to ensure high CMRR, which can ensure the insulation performance requirements and suppress the coupling of parasitic capacitance in the structural design of insulating materials.

4. Chassis shielding test

4.1. Test content
A comparative study of the shielding effectiveness of the chassis before and after rectification is carried out. According to the use requirements of precise testing instruments, the test is implemented with 30MHz ~ 1GHz in a dark room without external interference. The signal source is placed in the chassis, and the tests are carried out with two cases of opening and closing the outer cover, wherein the shielding performance will be compared. The experimental setup is depicted in Figure 3.
4.2. Testing device
The main testing devices include standard transmitting source, biconical receiving antenna with 30MHz ~ 200MHz, double ridge horn antenna with 200MHz ~ 1GHz, radio-frequency (RF) line, EMI receiver (model ESR26) and computer.

4.3. Darkroom test
Environment signal testing. The signal in the darkroom by the standard emission source switching off is tested as the reference, with the result shown in Figure 4.

The testing results with the opened standard emission source placed on the test table are shown in Figure 5.
4.4. Test result

4.4.1. 30MHz-200MHz frequency band test

(1) Testing with U-shaped groove cover (inner cover) closed
Prior to the chassis rectification, the standard transmitting source is placed in the chassis, to adjust the position of the receiving antenna to make its height consistent with the height of the standard transmitting source. The test distance between the biconical antenna and the standard transmitting source is 1m. Moreover, the standard transmitting source is open, and the inner cover of the chassis is installed. The test results are shown in Figure 6 with axes of amplitude (dBμV/m) and frequency (Hz).

![Figure 6 Testing before chassis rectification with the inner cover closed](image)

(2) Testing with the outer cover closed
Before the chassis rectification, without changing the position of the antenna and standard transmitting source, the chassis cover is installed with screws for the test. The test results are shown in Figure 7:

![Figure 7 Test results before the chassis rectification with the outer cover closed](image)

It can be seen from the test results that the expected overall shielding effect of the chassis is not realized, exceeding the frequency band 100m ~ 200m, up to 40 dBμV/m, which cannot meet the requirements of product design.

(3) Testing after chassis rectification
According to the foregoing test results, it is known that the chassis cannot meet the requirements in most frequency ranges. Through the analysis of the overall structure and chassis conductivity, the connection mode among various structural parts of the chassis, the main display window and the signal output interface of the box are redesigned for improvement. Testing with frequency 30 MHz ~ 200 MHz is carried out, with the testing results shown in Figure 8. It can be seen that the shielding effect of the rectified chassis has increased by about 15 dB compared with the chassis without rectification, with most areas lower than the level of the national military standard.
Figure 8 Testing after chassis rectification with the inner cover closed (chassis B)

The test results after the installation of the chassis outer cover are shown in Figure 9. The shielding of the chassis after rectification almost does not exceed the limitation, which can fully meet the requirements of the product for electromagnetic shielding.

Figure 9 Testing after chassis rectification with the outer cover closed

4.4.2. Test after rectification with frequency band 200MHz ~ 1GHz

(1) Testing with the inner cover closed
The rectified chassis is tested with a frequency band 200 MHz-1 GHz, and the test results are shown in Figure 10:

Figure 10 Testing with frequency band 200MHz ~ 1GHz and the inner cover closed
(2) Test with the outer cover closed
Without changing the position of the antenna and the chassis, the chassis cover is installed with screws, and the test with frequency band 200 MHz ~ 1 GHz is carried out to generate the results shown in Figure 11. Since the leakage of the chassis hole with the frequency band 200 MHz ~ 1 GHz is lower than that of 30 MHz ~ 200 MHz, the test is not carried out before rectification with the frequency band 200 MHz ~ 1 GHz.

![Figure 11 Testing with frequency band 200 MHz ~ 1 GHz and the outer cover closed](chart)

4.5. Testing conclusion
According to the test before chassis rectification, the electromagnetic signal transmitted by the standard signal source can be detected no matter whether the external cover is closed or opened, particularly with the frequency band 100 MHz ~ 200 MHz. In this case, the received signal is relatively strong, and the shielding effect of the chassis is not very significant, as shown in Figure 12.

![Figure 12 Testing before chassis rectification with inner/outer cover closed](chart)

The testing results show the shielding effect of chassis after rectification is better than before. In particular, after closing the outer cover, it can be observed that the testing signal is close to the lower-limitation noise signal in the darkroom environment. When the inner cover is closed, although the signal information transmitted by the standard signal source can still be detected, the received signal is below the limits required by the standard, which means that the shielding effect has been significantly improved, and the test results can fully meet the product requirements. The corresponding test results are displayed in Figure 13.
After the chassis rectification, the test is carried out with a frequency band 200 MHz ~ 1 GHz to examine the shielding effect. The shielding effect with the outer cover closed is better than that with the inner cover closed. When the inner cover is closed, the signal with the frequency band 200 MHz ~ 400 MHz exceeds the standard limitation. After the outer cover is closed, the signal can still be detected, but the signal amplitude decreases significantly, which is below the standard limitation, as depicted in Figure 14.

5. Conclusions
After the rectification, the overall shielding effect of the chassis can be improved significantly, particularly in the frequency band 30MHz–100MHz. After the installation of the outer cover, it decreases from 40 dBµV/m to 20 dBµV/M, and the shielding with frequency band 200MHz ~ 1GHz can reach 15 dBµV/M–20 dBµV/m, where the received signal is almost close to the signal in a darkroom. The shielding effect can meet the requirements of precise testing instruments and can be adopted as a reference for the following research and production of such instruments.

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