

# Design and Implementation of EMC System Layout for Rail Trains

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**Abstract.** Nowadays, China's urbanization process is rapid, and the rail transit system has become a good solution for the traffic congestion problem. The electromagnetic compatibility (EMC) of rail transit system is an important guarantee for the safe and reliable operation of rail trains. To this end, this paper proposes an EMC layout scheme for rail trains, and designs their electrical equipment layout and electrical wiring layout. In addition, according to the distribution of the train body equipment, the rail trains are divided into three parts, i.e. the roof, the interior and the bottom, and their associated EMC partition layouts are given. Finally, the layout scheme is tested by taking the Shanghai Metro Line 6 as a test rail train. The test results show that the proposed scheme can greatly improve the EMC performance of the rail trains and achieve the expected design goals.

## 1. Introduction

As a travel mode with less land occupation, large traffic volume, less environmental pollution, safety and comfort, urban rail trains have sprung up in China's major cities with rapid economic development since the opening of the first metro line in Beijing in 1956 [1]. It is the primary task to ensure that the rail train design meets the standards in the factory and is safe during its operation. There are two major factors affecting the safe operation of rail trains, namely the electromagnetic interference (EMI) from their own equipment and the electromagnetic radiation formed throughout the city. Most of electrical and electronic systems in rail trains, such as signal transmission systems (including track circuits and other train detection systems), train traffic control systems and railway side control systems, use high-power inverters, rectifiers and various advanced signal controller. This makes the rail trains become huge EMI sources in the city. Therefore, EMI occurs between the equipment inside the rail trains, between the rail trains and the railway infrastructure, and between the rail trains and their external environment [2].

Literature [3] presents a theoretical basis for the electromagnetic compatibility (EMC) design of high-speed multiple unit trains. Literature [4] adopts data mining (DM) technique to analyze the



electromagnetic emission measurement data of high-speed trains, and can predict the EMC data of the equipment, thus giving the key equipment for anti-EMI. In [5], a wiring scheme based on high frequency structure simulator (HFSS) is designed by SOLIDWORKS modeling and simulation. In [6], the EMC problem in the subway station is studied, and a method to determine the minimum space for the coexistence of the strong and weak electric systems is proposed. Based on this, the layout of the electromechanical equipment is reasonably planned.

The EMC problem of rail trains should be analyzed from three aspects, namely the interference source, EMI propagation path and sensitive equipment. The EMI sources of rail transit trains include train interference sources and trackside system interference sources. Firstly, the train interference sources include the traction motor, high speed circuit breaker, main switch box, variable voltage and variable frequency (VVVF) main inverters, filter reactor, auxiliary inverters, transformers, and bus bar breakers, etc. Secondly, the EMI sources of the track systems include the power supply equipment of overhead lines and the signal system equipment in the track. The sensitive equipment of rail trains includes lighting systems, air conditioning systems, communication systems, passenger information systems, train control systems, door operating systems, train signal systems and auxiliary systems.

Once the interior of the rail train is subject to EMI, the video in the rail train may appear to be jittered, or the communication quality of the passengers' mobile phone in the train is affected. More seriously, the command signals may be changed to give an error indication, thereby inducing a safety accident. Because the EMC problem seriously affect the safety and reliability of rail trains, a reliable and comprehensive EMC design scheme is particularly important.

For this reason, this paper proposes an EMC layout scheme for rail train systems from the general viewpoint. The different parts of train body, which are divided into three modules: the roof, the bottom and the inside of the train, are different in EMC design. Therefore, the detailed EMC partition layout scheme is then carried out for them. Finally, some test scenarios for testing the EMC performance of the rail train are set based on Shanghai Metro Line 6, and the test results are given.

## **2. EMC System Layout of Rail Trains**

The overall EMC layout scheme for the railway trains is determined by some factors, such as the overall train structure, train operating environment, performance requirements, and maintenance. This involves in the coordination and cooperation of various aspects of the systems. It is very necessary to make a certain electromagnetic evaluation before the EMC design scheme. Then, especially the layout of the electrical wiring and the design of the wiring harness should be considered, which is closely related to the train body, pipeline structure arrangement, internal structure, and interface design of the electrical equipment. Therefore, in the design process, it is also necessary to comprehensively consider from various aspects to ensure that the EMC system layout is optimal. From the viewpoint of the rail train structure, it mainly consists of two parts, namely, the equipment that plays various roles and the cables that connect the equipment. Therefore, the overall layout of the equipment inside the rail trains and the overall layout of the electrical wiring are the basis of the EMC system layout scheme, and also the principle of the EMC design scheme for each subsystem. This paper firstly designs the overall EMC system layout scheme for the rail trains, and then designs the EMC partition layout scheme based on their three parts, i.e. the roof, the bottom and the inside.

### *2.1. Overall Layout of Electrical Equipment*

The overall layout of the electrical equipment should make the entire system concentrated and compact. The specific layout scheme is listed as follows.

First, fully consider the train characteristics, modularize the roof, interior and bottom, and functionally combine similar equipment. For example, the main equipment of main circuit, large equipment, and electrical components with large noise and vibration are placed under the train as much as possible or isolated with other equipment or components. For functional or comfortable electrical equipment, such as switchboards, and water and sanitation systems, are placed at both ends of rail trains for easy access, maintenance and passenger use. Passenger information systems (PISs), such as broadcast and video systems, and commonly-used switch buttons, should be placed in convenient and obvious locations.

Second, focus on the design of wiring path. On the one hand, trunking, conduit and wire bracket should be set up. Except the special design structure requirements, weld slag, riveting and screws should be avoided in the cable passing area. Otherwise, there will be hidden dangers for breaking lines. On the other hand, according to the wiring and installation area, the protective area of the wiring in the structural drawing should be identified. Technical requirements are presented in the structural assembly or component drawings. That is to say, the structure with cable passing and the fitting surface need to be removed from the protrusions and corners. The wiring path is designed to avoid cluttering of cable connections between the devices, or the appearance of bare wires. These cases provide the conditions for unnecessary EMI. Therefore, the EMC design must be carried out in strict accordance with the proposed scheme.

Third, design the electrical wiring connection method. When planning and resolving the connections between electrical equipment, between electrical connection boxes, and between electrical connection boxes and controlled devices, three principles should also be fully considered:

- The connection terminals with standard specifications according to the current size and the number of input and output lines should be selected.
- A connection terminal or an industrial connector is used between the electrical cabinets or their controlled boxes, in order to facilitate the correction and withstand voltage test of the lines after the train assembly is completed.
- For the selection of connection terminals and connectors, the accessory interchangeability of different train types should be selected on the premise of achieving the technical performance.

## 2.2. Overall Layout of Electrical Wire

The electric field effect generated by cables of different voltage levels in rail trains will become the EMI interference source of the whole system. In order to suppress EMI and improve the stability of the overall wires, the electrical wiring design scheme should follow the principles of top-down and module design. The specific layout design principles are as follows:

- The driving safety equipment line, the control wire and the radio line are pre-wired, and after the pre-wiring under the rail train is completed, the rail train can be lifted and erected. The wires are located in the wiring grooves on both sides of the train body, and the wire grooves should be grounded nearby at multiple points.
- The EMC design of traction motor cable is very important [7]. The pre-wired method is adopted for the traction motor wires and auxiliary circuit wires. The auxiliary circuit wires should be as far as possible from the traction motor wires and protected by electromagnetic shielding with metal protection.
- The metal casing of equipment must be grounded nearby through a braided wire, and the grounding wires should be coated with electrical contact grease to ensure good grounding.
- Light wires are arranged separately from control wires and under the top cover.
- The control wires entering into the operator cab also adopt the form of pre-wiring, and enter into the operator cab from the top left side of the train body. The auxiliary wires enter into the operator cab from the bottom of the middle corridor floor.

The above scheme scientifically and rationally arranges the main cables of the rail trains. Meanwhile, the electromagnetic protection measures for the wires are indispensable. Next, this paper designs a scheme to suppress EMI between wires for rail trains from the viewpoint of electromagnetic coupling. The electromagnetic coupling ways in rail trains mainly belong to non-conducting coupling, i.e. electric field coupling, magnetic field coupling and hybrid coupling of electric field and magnetic field. According to their characteristics, the following EMI suppression methods are designed.

- Methods of suppressing electric field coupling: reduce the distributed capacitance between wires by increasing their distances, shortening the wire length or increasing the ground plane, and use a shielding layer on the wires.
- Methods of suppressing magnetic field coupling: reduce the mutual inductance between circuits by making the wires as close to the ground plane as possible and making the magnetic field directions perpendicular to each other, and use a shielding layer on the wires.

- Method suppression hybrid coupling: add shielding layer and ground.

### 3. EMC Partition Layout Scheme for Rail Trains

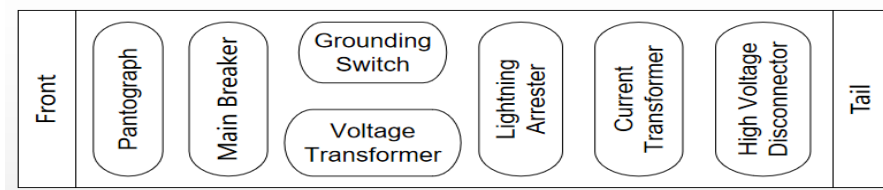
In order to meet the EMC requirements, the layout design of rail trains should consider its three elements. Firstly, it is necessary to control the emission of the interference sources. Secondly, from the perspective of EMI propagation, the coupling impedance should be increased in the electromagnetic coupling. Thirdly, measures are taken to improve the anti-jamming capability of sensitive equipment.

Completing any of these three links can interrupt the closed loop of “EMI source-coupling path-sensitive components” in the EMC problem. And in order to reduce a large part of EMI, it is important to partition the rail trains because not only high-voltage, high-frequency and high-power interference source equipment, but also a lot of sensitive equipment that is susceptible to interference concentrate within the limited space of rail trains, which cause severe mutual EMI interference.

Based on this, this paper divides the rail trains into three modules, i.e. the roof, the inside and the bottom. High-voltage power supply interference source of the pantograph mainly concentrates on the roof. The main communication system, PIS, train control system, door system, train signal system and sensitive equipment are distributed inside the rail trains. At the bottom of the rail train, system interference sources, such as traction motors, high-speed circuit breakers and main switch boxes mainly concentrates on. Next, this paper expands the design from the above three modules.

#### 3.1. Roof Layout of Rail Trains

The high-voltage equipment on the roof of the rail trains needs to have a certain margin in electromagnetic shielding and insulation performance on the basis of satisfying their electrical performance [8], in case it is eroded by harsh natural conditions, such as wind, sand, rain and snow. Figure 1 shows the equipment layout plan on the roof of rail trains.



**Figure 1.** Equipment layout on the roof of rail trains.

- Pantograph: It is a device that obtains electric energy from an overhead contact system by a rail train and is installed on its roof. When the pantograph is raised, the air will be compressed, and the pantograph slide will contact the overhead lines to introduce 25 kV single-phase AC into the rail train from the overhead lines. When the pantograph is fallen, the compressed air will be discharged [9]. Its EMC design mainly considers the overvoltage caused by the pantograph as the power input terminal. It is arranged close to the front of rail train.
- Main circuit breaker: As the main switch and total protection of the railway train power, when the rail train has a serious fault, its total power supply can be quickly cut off to protect it. The main circuit breaker consists of a combination of high-voltage and low-voltage parts, which requires appropriate electromagnetic shielding and is placed close to the pantograph.
- High-voltage voltage transformer: After detecting the voltage of the overhead contact system, the voltage signal is supplied to the network control system of the rail train to control and protect the corresponding system.
- Grounding switch: It is installed next to the main breaker and is used in conjunction with the main breaker to ensure the safety grounding of the rail train during maintenance and repairing.
- Lightning arrester: It used to protect the electrical system on the rail trains to prevent lightning overvoltage and overpressure.
- High-voltage current transformer: Similar to the function of high-voltage voltage transformer, the only difference is that its transmitted signal is the current signal.

- High-voltage isolating switch: It automatically connects the two carriage roofs when they are connected. It is generally installed at the rear of the rail train.

### 3.2. Bottom Layout of Rail Train

The EMC layout of the rail train bottom should follow the principle that the wiring and electrical equipment are closely combined, and their weight balance calculation is reasonably combined with the train boundary. Minimizing the electromagnetic radiation of equipment and cables within a controlled range is the goal of EMC design. In the specific design process, firstly, the wire trunking is used reasonably for wiring. In this way, not only the limited train space is saved, and the number of wires and tubes is reduced, but also the standardized design of EMC and electromagnetic radiation calculation can be facilitated. Meanwhile, from an overall perspective, the efficient combination of electrical equipment and cables can improve EMC performance. In addition, in order to ensure the safety and reliability of the rail trains, some factors, such as safety, fire prevention, overhaul, and cold resistance, should be fully considered when designing the bottom layout.

#### 3.2.1. Bottom equipment layout of rail trains.

Large-size equipment at the bottom of rail trains may become the interference source. Therefore, its proper configuration not only meets EMC requirements, but also makes the overall layout reasonable.

- The larger equipment must at first meet the weight balance requirements, and then is arranged in accordance with electrical principles, EMC standards and wiring sequences.
- For equipment requiring ventilation cooling, such as braking resistors and motors, sufficient space must be provided to prevent other equipment from blocking its ventilation passages while avoiding accidental EMI [10].
- In order to avoid EMI to other equipment, the arcing direction of the equipment with outward arcing function, such as busbar high-speed circuit breaker, should face the carriage outside.
- Heating equipment should follow the principle of staying away from heat sensitive equipment and near non-sensitive equipment. If necessary, heat insulation should be added to prevent heat from being transmitted to the passenger compartment, and accelerating the aging of the wires to cause unexpected EMI.

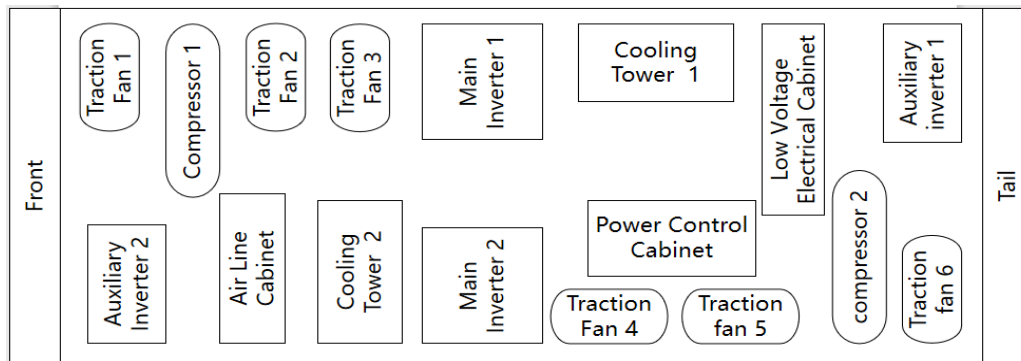
Based on these principles, figure 2 shows the layout of the main equipment for the rail trains. The specific design ideas are as follows. The main inverter is placed in the middle of the rail train bottom to provide high voltage for each tractor. The auxiliary inverter is arranged at the front and rear parts of the rail trains, and the auxiliary system is powered by the high-voltage isolating switch. Its position is mainly determined by the action and position of the high-voltage isolating switch. Both the traction fans and the compressors belong to the auxiliary motors on the rail train. The compressor provides the wind source for the locomotive. The traction fan forcibly cools the rectifiers, compressors and traction motors. It needs to be arranged in multiple places at the bottom of the rail train to reduce the temperature of the electronic equipment. As a cooling and exhausting device in an air conditioning system, the cooling tower needs to be avoided in a high temperature environment. Therefore, the cooling tower is arranged around the traction fans. These devices are distributed in different positions according to their functions and EMC features, and are supplemented with different electromagnetic shielding methods to improve the EMC performance.

#### 3.2.2. Bottom cable layout of rail trains

The wiring carrier of the undercarriage of the rail trains is mainly divided into three types: wire trough, electric conduit and coupling box. The layout design of the wire trough is as follows:

- The material of the current wire trough is divided into aluminum and steel. Both types of wire troughs have their own advantages and disadvantages. For aluminum wire troughs, their flatness is good, but it is not easy to be curved. It is generally used when there is a large space at the bottom of train. Steel wire troughs are easier to bend than aluminum, and are generally used when other electrical equipment needs to be properly avoided. In terms of EMC, the aluminum wire trough has better magnetic field shielding effect, and is usually selected.

- If the cable laid inside the wire trough has different voltage level inclusions and DC/AC inclusions, the internal division of the wire trough is inevitable. In order to ensure stable operation between the subsystems, the cables with different natures need to be isolated.
- In the special cases, such as the maintenance space of the reserved equipment, the cross section of the wire trough should be deformed on the basis of ensuring the basic cross section.



**Figure 2.** Equipment layout at the bottom of rail trains.

The layout design of the electric conduits is as follows:

- Similar to the current wire trough, the material of the wire conduit is generally divided into steel and aluminum. Most rail trains use internally coated aluminum tubes to reduce both body weight and tube deformation, and enhance shielding.
- The electric conduit must be close to its associated equipment, and its relative position should be selected according to the principle of connection between the various devices, so that the external interface can be better connected to avoid EMI generated by improper connection.
- Overall, electric conduits distribute in an obvious area division with the brake pipe to ensure the lowest degree of line coupling between them. In their shared area, it is strictly necessary to ensure that they do not interfere with each other.

The layout design of the coupling box is as follows:

- Similar to the electric conduit, the coupling box is also made of steel and aluminum. The aluminum is generally selected in the rail trains, because the aluminum coupling box can better weaken the EMI of the wires to the electrical system.
- The size of the coupling box is determined according to the actual situation. The following factors are mainly considered, i.e. the number of wires in the coupling box, the height difference between it and the external interface of other equipment, the space size at the coupling box, and whether it interferes with the surrounding electrical equipment.
- From the viewpoint of appearance, according to the actual situation, the coupling box can be locally widened and partially narrowed on the basis of the standard rectangular parallelepiped.

### 3.2.3. Bottom interface layout of rail train

The rail train system integrates a traction system, a braking system, and an auxiliary power supply system. These systems need to install equipment supporting their functions. There are mutual and complex EMI between these various systems. It is very important to clarify the layout design of the bottom interface of rail trains to improve the EMC performance. The interface layout scheme for the bottom of the rail trains is as follows:

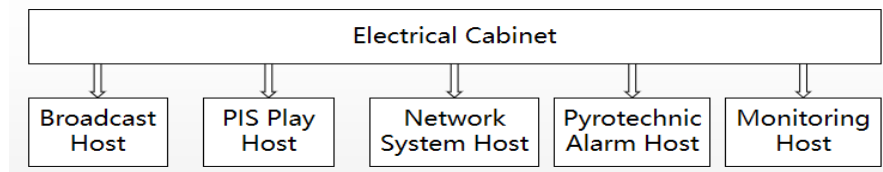
- Based on different actual conditions, the external interface of the electric equipment under the rail trains can be selected from bare wire type, joint type, splint type and connection type.
- The protection and grounding of equipment is the most important. When the electrical equipment, wire trough, electric wire conduit and coupling box are made of metal, they must be protected and grounded. Grounding protection should be considered for electrical equipment, such as combiner boxes, switchboards and low-voltage circuit coupling boxes.

- The isolation of equipment from lines can also reduce EMI. For the devices or lines that are close to each other, it is necessary to consider their signal coupling or signal interference, and if necessary, use an isolator. For the devices with high noise, use noise isolators to reduce noise interference. For high voltage circuits, ensure their insulation and safety distance.
- To avoid aging and damage of the interface under extreme weather or improper operation, its fire protection, and heat and cold resistance are considered for better EMC performance.

### 3.3. Interior Layout of Rail Trains

In rail train system, most of control components are centrally installed in the electrical cabinets, which have become the control hub of rail trains. Therefore, EMC system layout of the rail trains is mainly reflected in the electrical cabinet layout. It is of great significance to make reasonable EMC analysis and find practical and feasible EMC measures to ensure the safety and stability of each system.

Each system host and its control unit are installed in the electrical cabinet. As shown in figure 3, its main parts include broadcast host, PIS play host, network system host, pyrotechnic alarm host and monitoring host. Only by making reasonable shielding design and grounding treatment design according to the operation principle and work frequency of these devices can the EMC standard be met. Prior to this, cable shielding and grounding design are critical to the EMC design of rail trains.



**Figure 3.** Host equipment inside electrical cabinet.

The cable shielding is to wrap a shielding metal mesh around the cable. A small part of the electromagnetic energy is converted into thermal energy through the eddy current loss inside the metal shielding body, and most of the electromagnetic energy is introduced into the earth through the grounding point. Therefore, the cable shielding must be matched with the grounding. Depending on the signal frequency, the grounding of the shielding layer is also different. For high-frequency signals, double-ended grounding is required to shield the electric field, and for low-frequency signals, only single-ended grounding is needed to achieve the purpose. When the signal frequency is in the low frequency range ( $f < 1$  MHz), if both ends of the cable are grounded, a ground loop will be formed, and a magnetic field will be formed in the shield layer, and noise interference will occur between the cables. When the signal frequency is in the high frequency ( $f > 1$  MHz), the impedance of the shielded cable cannot be ignored. If there is only single-ended grounding, the noise current will easily cause a voltage drop on the shield layer to make the electric potential different and affect the shielding effect. The EMC design of each host is described below.

#### 3.3.1. Broadcast host

The broadcast host acts as an important device for transmitting voice signals inside the rail trains. It broadcasts the stations after reading the station information or the train running status information.

The broadcast host uses the data buses and audio buses of local operation network (LON) to connect with other main devices. It connects the internal auxiliary equipment through RS485 data buses and audio buses, and connects the external devices through the multifunctional vehicle bus (MVB), RS485, RS232 and standard audio buses. All its internal and external audio buses and data buses use shielded twisted lines to resist EMI. Its data bus transmissions adopt the form of differential signals. Therefore, they must be grounded at both ends. The audio bus transmissions adopt the form of analog level transmission, which can be single-ended grounding according to the equipment installation situation.

### 3.3.2. PIS play host

The PIS player host is mainly used to provide passengers with some riding information, train TV advertisements and emergency information. It is connected to external devices through VGA interface, RJ45 interface, RS232 interface, RS485 interface, standard audio interface, aviation plug and other interfaces to realize communication display function. Its inner and outer cables are shielded and twisted, and are single-strand multi-core cables. Its internal data use digital signal transmission. Therefore, each device is grounded at one end.

### 3.3.3. Network system host

The network system host includes four main modules: central control unit (CCU), remote input and output module (RIOM), RS485/MVB gateway, and data recorder. Their functions and their cable EMC design are listed as follows.

- CCU is the bus management host of the train network monitoring system, and its functions include bus management, process data transceiving, message transceiving and bus status monitoring. More importantly, CCU is responsible for the control, monitoring and protection of the entire rail trains, completing a series of control logic and fault diagnosis. Its external power cable uses a single-strand multi-core cable.
- RIOM collects the digital and analog signals in the rail trains, and then transmits the collected signals to the MVB network. Its external power cord uses a single-strand multi-core cable.
- RS485/MVB gateway connects MVB device and RS485 device, and processes the data from one to another. After such steps, the data interaction between the MVB device and RS485 device is completed. Its external RS485 bus cable uses a shielded three-core cable, and its external power cable uses a single-strand multi-core cable.
- The data recorder obtains status information of various devices on the rail train through the MVB bus and records information. Its power cable uses a single-strand multi-core one.

All MVB buses, RS485 buses and control local area network (CAN) buses transmit differential signals. Therefore, these three types of buses must be grounded at both ends.

### 3.3.4. Pyrotechnic alarm host

Pyrotechnic alarm host amplifies and filters the sensed smoke signals in the detector and suppresses their interference to perform a pyrotechnic alarm, and the alarm data is transmitted through a CAN bus or an RS485 bus. It uses low-pass filters, surge suppression devices, electrical transient suppression devices, radiated electromagnetic fields, and conducted disturbance suppression devices to suppress many outside interfering signals, while using filter capacitors and opto-isolation technology to reduce the internal interference.

### 3.3.5. Monitoring host

The monitoring host displays and stores the video data collected by the train driver's cab and the guest room camera, and simultaneously uploads the real-time monitoring video to the monitoring center in response to its instructions. Its inner and outer cables are shielded twisted wire and single-strand multi-core wire. Each device adopts single-ended grounding because of digital signal transmissions.

## 4. EMC Test Result

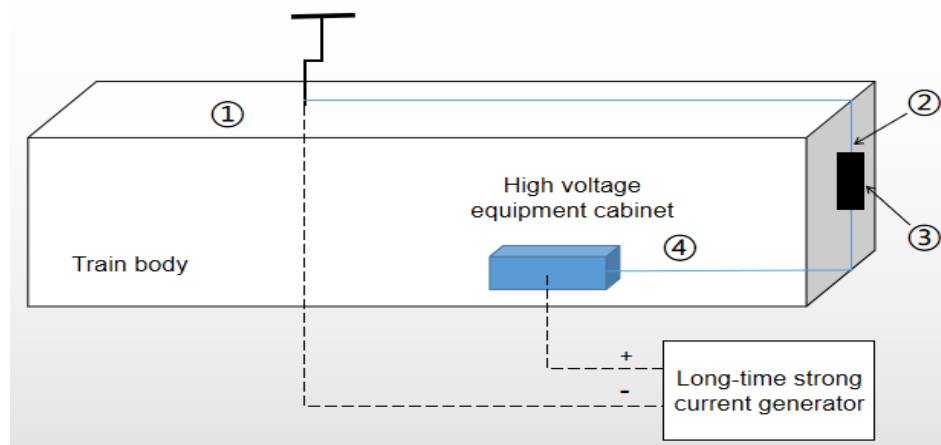
In order to evaluate the reliability of the EMC system layout scheme for rail trains, this paper selects the Shanghai Metro Line 6 for EMC testing.

### 4.1. Internal Anti-Interference Test

The internal anti-interference test is to verify the EMC performance between any electronic equipment, systems and subsystems inside the rail trains. Three items are set to test separately, as shown in table 1. According to the test results, the interference between the electronic devices inside the rail train is within the standard range, and does not cause EMI between the electronic devices, thus affecting the safe operation of the entire rail train.

#### 4.2. Magnetic Field Strength Test of Train Body

This experiment is mainly to test whether the distribution of the magnetic field strength of the train body and the magnetic field emission intensity meet the requirements of the relevant standards and the owner's contract. Figure 4 shows the test method. There is a high-voltage cable between the pantograph and the high-voltage equipment box under the rail train. The cable has a rated operating current of 200 A and a frequency of 50 Hz. Firstly, test the magnetic field strength generated at different positions of the high-voltage cable. The four measuring points are respectively located under the top plate of the ultra-high-voltage (UHV) cable, the top of the anti-magnetic plate of the side-wall special pressure cable, the center position of the anti-magnetic plate, and the UHV line under the rail train. Secondly, three test points are arranged in the lower compartment of the pantograph to test the maximum electromagnetic induction intensity at 30 cm, 90 cm and 150 cm from the measuring point.



**Figure 4.** Magnetic field strength test of train body.

**Table 1.** Internal anti-interference test of rail trains.

Project name	Test train status	Test procedure	Experimental results
Interference of main and auxiliary converters to control circuits	Static	1) Observe brake control unit (BCU) of electronic control circuits, traction/ auxiliary/ battery unit, door control unit (DCU), HVAC system, PIS, train CCU. 2) Read the information from the event recorder.	Each electronic control circuit operates in accordance with its respective specifications and there is no significant error in the event recorder of fault diagnostic circuit.
	Full acceleration		
	Maximum braking force deceleration		
Interference between main and auxiliary converters	Static	1) Observing the electronic control circuits of main inverters and auxiliary inverters. 2) Read the information from the event recorder.	The individual traction inverters and auxiliary inverters operate according to their respective specifications and there is no significant error in the event recorder.
	Full acceleration		
	Maximum braking force deceleration		
Transient impulse interference when opening and closing of switches, relays, and contactors	Static	1) Turn on and off the switches, relays and contactors in the main and auxiliary circuits. 2) Read data information from the event recorder.	There is no important error in the event recorder.
	Full acceleration		
	Maximum braking force deceleration		

Table 2 shows the test results. It can be seen from the table that according to the magnetic induction intensity at 30 cm of the measuring point, it exceeds 100  $\mu\text{T}$  (1 GS=100  $\mu\text{T}$ ), and the farther away from the interference source, the smaller the electromagnetic induction intensity. Therefore, if a passenger is exposed to a distance of 30 cm from the interference source for a long time, it may cause physical discomfort. At the same time, it will cause strong interference to the electronic equipment carried by passengers. In the position where the anti-magnetic plate is provided, the magnetic field strength is reduced by about 40% compared with the measuring point without the anti-magnetic plate, which indicates that the anti-magnetic plate has a certain magnetic separation effect. In summary, the stainless steel anti-magnetic plate with different thicknesses should be added to the roof panel directly under the pantograph, and no passenger seat should be provided directly under the pantograph. In addition, the magnetic induction at all other test points meets the magnetic field strength standard of the rail trains.

**Table 2.** Test results of magnetic field strength test of train body.

Distance (cm)	Current (A)	Measuring point 1 (GS)	Measuring point 2 (GS)	Measuring point 3 (GS)	Measuring point 4 (GS)
<b>30</b>	200	1.21	1.92	1.14	1.06
<b>90</b>	200	0.46	0.80	0.51	0.22
<b>150</b>	200	0.33	0.43	0.32	0.18

#### 4.3. Immunity Test

##### 4.3.1. Conducted Immunity Test

Test purpose: Test the EMC performance of the rail trains and the infrastructure next to the track. From a quantitative point of view, whether the harmonic current generated at a specific frequency point exceeds the required limit during train operation.

Test train status:

- Turn on all on-board equipment that may affect the interference current, including but not limited to auxiliary AC module (ACM), battery charger (BC), air conditioning unit (ACU), and lighting devices of rail train.

Train operating conditions:

- Continuous high speed, intermittent high speed, simulation operation.

Test equipment:

- Current probe, data acquisition card, acquisition signal computer.

##### 4.3.2. Radiation immunity test

Test purpose: Verify whether the train radiation emission meets the compatibility requirements by testing the electromagnetic radiation emission of the whole rail train.

Test train status:

- Static state: The traction circuit is powered on but does not work, the auxiliary converter remains in operation, and all electrical systems on the rail train capable of generating radiation emissions are turned on.
- Slow state: The working state of the train electrical system is exactly the same as the static state, and accelerates or decelerates by 1/3 of the maximum traction force when passing through the antenna.

Test environment:

- In order to minimize the influence of weather conditions on the measured values, the weather conditions during the test should be: the temperature is not lower than 5 °C, the wind speed is not more than 10 m/s, and the humidity is kept from being condensed on the power supply.
- Environmental noise: Trees, walls, bridges or tunnels should be avoided within 10 m of the test point. There should be no substations or transformers nearby. Other rail trains cannot be driven within 20 m of the same power supply section.

#### 4.3.3. Immunity test results

After testing according to the above test plan, the conducted immunity and radiated immunity of rail trains are within the reference range, as shown in table 3. In other words, the EMC layout scheme for the rail trains designed in this paper fully meets the requirements of EMC performance.

**Table 3.** Immunity test results.

Criterion	Project	Reference	Measurement	Qualified or not
IEC 61000-4-6	Conducted immunity	150 kHz-80 MHz	200 kHz	Qualified
IEC 61000-4-3	Radiation immunity	Peak is less than 20 V/m	18V/m	Qualified

## 5. Conclusion

In this paper, an EMC system layout scheme for the rail trains is proposed and then tested on Shanghai Metro Line 6. Firstly, this paper designs the equipment layout plan and the electric wiring layout for the rail trains from the whole. Secondly, according to the difference of equipment distribution, a rail train is divided into three parts, i.e. its roof, its interior and its bottom, and based on this partition, an EMC partition layout scheme is proposed. The test results show that the proposed EMC layout scheme fully meets the EMC requirements of rail trains, minimizes the risk of EMI before the operation of the rail trains, and provides a favorable guarantee for the safety and reliability of urban rail train operation.

## 6. Acknowledgments

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