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RELIABILITY ANALYSIS AND EVALUATION OF ALL-ELECTRONIC EXECUTION UNIT BASED ON ELECTROMAGNETIC PERFORMANCE PARAMETERS

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Abstract. *The all-electronic execution unit has important functions and a wide range of applications. It is placed in a complex electromagnetic environment and is susceptible to various forms of electromagnetic interference sources. Under electromagnetic interference, the reliability of the all-electronic execution unit decreases, resulting in its shorter service life. The current product reliability analysis methods usually only consider product failure from the perspective of service life, neglecting the impact of product failure on performance parameters. In this paper, a reliability analysis and evaluation method for the all-electronic execution unit is proposed on the basis of the electromagnetic performance parameters. Taking the perspective of product electromagnetic performance, this method provides a basis for improving the product function design. By locating the product vulnerable parts, determining the key performance parameters, and establishing the electromagnetic performance margin model, this method also can evaluate the product performance reliability under electromagnetic interference.*

Keywords: Electromagnetic performance, Key performance parameters, Reliability evaluation, Internal and external cause parameters

1. **Introduction.** Under the backdrop of the widespread application of electronic technology in the present era, the electromagnetic environment (abbreviated as EME) within which all-electronic execution units carry out assigned tasks has become increasingly complex and diverse. EME encompasses all types of conductive and radiative electromagnetic emissions that all-electronic execution units might encounter in a given working environment [1]. This complex electromagnetic environment frequently affects the normal operation of all-electronic execution units. In severe cases, it can even lead to a permanent decline or even failure in working performance, thereby reducing product reliability and shortening the product's service life [2, 3]. Previous studies on the reliability of all-electronic execution units have mostly concentrated on the response simulation of products in the electromagnetic environment, with the expectation of enhancing the anti-electromagnetic interference capability of products by adjusting design parameters [3, 4, 5, 6, 8]. However, there exists an obvious deficiency in this process, namely the impact of the electromagnetic environment on the reliability of product performance is not merely reflected in the superficial aspect of normal operation. More profoundly, it causes issues such as the deviation of electrical performance parameters of electronic equipment from the working range by altering electromagnetic performance parameters, thereby influencing the reliability of the entire product. Therefore, for the all-electronic execution

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unit system, it is necessary to analyze the influence of variations in electromagnetic performance parameters on its reliability.

As far as the existing reliability analysis methods are concerned, the methods that can be applied to all electronic execution units mainly include statistical methods based on fault data and life prediction methods based on fault physical model. Traditional methods mainly rely on reliability block diagrams [10] and reliability evaluation models [11, 12], etc. to calculate product-related reliability indicators. When dealing with structured fault relationships such as reticular [13] and dendritic [14, 15], calculating with historical fault data is a common means of quantitatively inferring the probability of fault occurrence. With the continuous development of new technologies, numerous cutting-edge studies are dedicated to exploring the potential value of data to enhance the accuracy and effectiveness of reliability analysis. For example, [16, 17] delved deeply into how to extract key information from real-time large-scale fault data, thus achieving precise analysis of product reliability and maintainability. However, in practical engineering applications, with the increasing reliability of products, the failure of products in the use process is becoming increasingly rare, and the corresponding test data is becoming less and less. The scarcity of data has brought new challenges to reliability assessment. Therefore, data driven research has gradually turned to the application of small samples, fuzzy theory [18, 19, 20] and other perspectives. However, it will also lead to the problem of estimation accuracy due to the lack of data.

The life prediction method based on fault physical model is a deterministic model, which is more suitable for accurately describing the changes of all electronic execution units in the process of use. This method focuses on describing the quantitative relationship between the failure time or performance parameters and the factors causing the failure [21, 22]. The research based on fault Physics (POF) opens up a new direction for reliability assessment. [23] considered the interaction of various failure mechanisms and the influence of stress conditions on failure, and built IC reliability prediction model. Similarly, from the perspective of POF, [24] and [25] respectively carried out reliability analysis considering the development stage and cumulative effect of failure mechanism for cold standby system and K-N system. However, the life prediction method based on the physical model of failure mainly considers the product reliability from the perspective of availability [26], but ignores the impact of product failure on performance parameters. Although the failure mechanism analysis can identify local failures, the analysis results are difficult to effectively combine with the functional design of electronic systems. Electromagnetic performance parameters under EME will inevitably produce inherent uncertainty. At present, the research on how to carry out the related methods of electronic system reliability evaluation around the changes of electromagnetic performance parameters is still in a relatively scarce state.

In light of the limitations inherent in the extant methods as delineated above, this study puts forward a reliability analysis and evaluation approach for all-electronic execution units predicated on electromagnetic performance parameters. The core objective is to dissect the influence of electromagnetic environmental effects on the reliability of all-electronic execution units from the crucial vantage point of electromagnetic performance parameters. By doing so, it endeavors to redress the lacunae in existing research within this domain and furnish robust support for the precise appraisal of the reliability of all-electronic execution units in complex electromagnetic environments. In this paper, the system analysis methodology is harnessed to methodically elucidate the functional architecture of the all-electronic execution unit and the electromagnetic environmental stress endured by the product. In accordance with the shielding efficiency requisites of cabinets at diverse levels and the simulation outcomes, the pivotal performance parameters and their corresponding thresholds of the product are ascertained. Through quantifying the impact of internal and external factors on the key performance parameters, a performance margin model that takes account of the uncertainty of internal and external parameters is formulated. Based on the acquired distribution of internal and external parameters, disparate values of uncertain parameters are generated via Monte Carlo simulation, and the electromagnetic performance margin under varying values is computed using the electromagnetic performance margin equation. Thereby, the product reliability, factoring in parameter uncertainty, is attained. This methodology effectively compensates for the inadequacy of prior reliability evaluation endeavors, which preponderantly fixated on product failures and solely relied on product failure data or physical models to assess and prognosticate product lifespan, reliability, and other aspects. It zeroes in on the influence of the failure process on electromagnetic performance parameters and actualizes the reliability evaluation of the system from the perspective of uncertainty by constructing the margin equation. This renders it more congruent with practical engineering application scenarios and accentuates the rationality and scientific rigor of this research in resolving the issue of reliability evaluation of all-electronic execution units.

The specific arrangement of the article sections is as follows. Section 1 mainly introduces the existing reliability analysis work of all electronic execution units. In Section 2, the reliability analysis and evaluation method process of all electronic execution unit based on electromagnetic performance parameters is described in detail. In Section 3, the analysis and evaluation of railway control cabinets are carried out, and the proposed method is verified. Section 4 summarizes the content of the full text and provides the conclusion.

2. Reliability Analysis and Evaluation Based on Electromagnetic Performance.

The process of reliability analysis and evaluation based on electromagnetic performance is shown in Figure 1. The main steps include system analysis, performance margin analysis, electromagnetic simulation analysis, the establishment of a performance margin model and reliability evaluation. The key steps are introduced below.

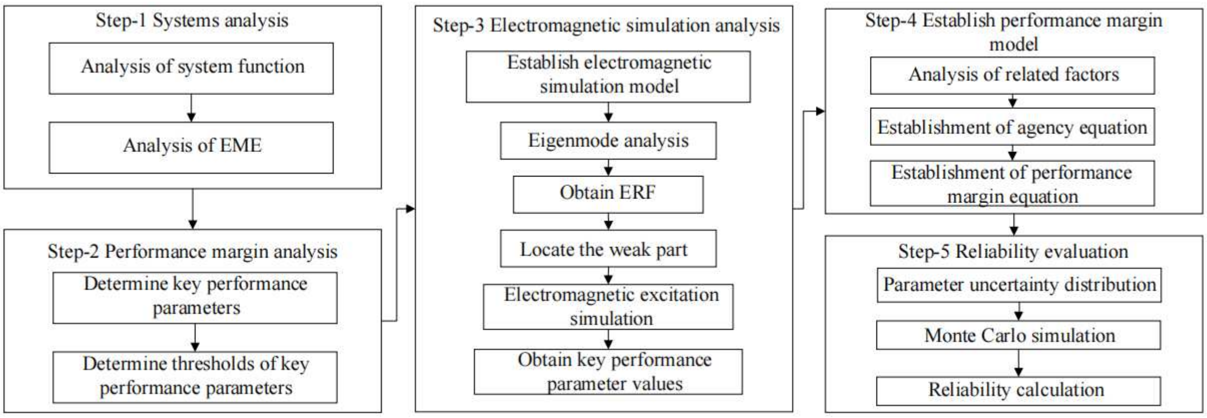

FIGURE 1. Flow chart of electromagnetic simulation

2.1. System analysis.

The purpose of system analysis is to clarify the functional structure of the product, the logical relationship of the system, and the surrounding electromagnetic environment, in order to obtain the electromagnetic environmental stress that the product is subjected to.

a) Analyze the product's functional structure, and clarify the product's structure and implemented functions.

b) Analyze the surrounding environment of the product, including its working and storage environment, as well as whether there are electromagnetic interference sources and the environmental stress effects on the product.

2.2. **Performance margin analysis.** The performance margin represents the distance between the performance parameter and the parameter failure threshold. The definition is that p is the performance parameter of the system and p_{th} is the parameter threshold leading to system failure, parameters can be divided into smaller-the-better (STB), bigger-the-better (BTB), and nearer-the-better (NTB).

Then the performance margin is expressed as

$$m = \begin{cases} p_{th} - p, & \text{if } p \in STB \\ p - p_{th}, & \text{if } p \in BTB \\ |p - p_{th}|, & \text{if } p \in NTB \end{cases} \tag{1}$$

The premise of product performance margin analysis is to determine the key performance parameters. The key electromagnetic performance parameters of the product can be determined as those directly related to the key functions of the system, such as the electromagnetic field distribution in the system. It can also be determined as the electromagnetic parameters related to the key components in the system, such as the electric field intensity and magnetic field intensity at the positions of key components. For products with a shield, the key electromagnetic performance parameter can be determined as the shielding effectiveness at the critical location, which is the measurement of the effectiveness of electromagnetic shielding of the chassis and cabinet.

After determining the types of key performance parameters are STB, BTB, or NTB, the relevant national standards or product technical requirements documents, standards and specifications should be consulted to determine the threshold of key performance parameters. If there are no relevant reference documents, determine it through simulation method.

2.3. **Electromagnetic simulation analysis.** The main process of simulation is shown in Figure 2.

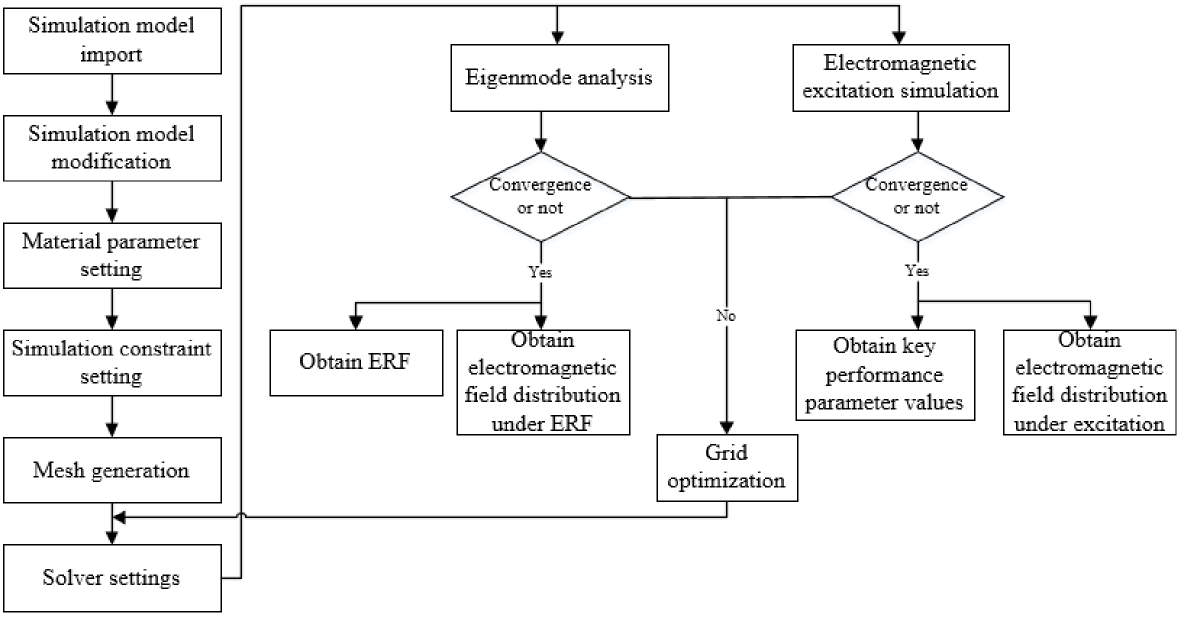

FIGURE 2. Flow chart of electromagnetic simulation

Firstly, establish an electromagnetic simulation digital prototype: import the geometric model of the product digital prototype into the electromagnetic simulation software, simplify and modify it appropriately, and use the modeling function of the electromagnetic simulation software to directly create the geometric model of the electromagnetic simulation digital prototype. Then set boundary conditions, including setting material electromagnetic properties, setting simulation constraints, and meshing. And then perform eigenmode simulation and electromagnetic excitation simulation on the product in electromagnetic simulation, obtain its first-order electromagnetic resonance frequency, the electric field strength at various positions of the product at the electromagnetic resonance frequency, and the response in the electromagnetic environment. The main purposes of simulation are as follows.

a) Eigenmode analysis: The electromagnetic resonance frequency (ERF) of the product is obtained by eigenmode analysis, and the weak parts in the product are located according to the distribution of the electromagnetic field of the product under the ERF. The devices with high functional importance and relatively weak are determined as the key components.

b) Electromagnetic excitation simulation: the electromagnetic excitation simulation is carried out to obtain the response of the product in the EME. The value of the key performance parameters at the position of the key components of the product under ERF is selected as the basis for the subsequent reliability analysis.

The shielding performance of the shielding body is measured by shielding effectiveness. When the electromagnetic field is isolated by metal materials, the strength of the electromagnetic field will significantly decrease, which is the shielding effect of metal materials. In electromagnetics, the electromagnetic shielding effectiveness (SE) at the critical position of a product is typically associated with the parameters [27] of the excitation source (SOM), the conductivity (SEC), the permeability (SMP), and the electric field strength (EF) of the shell material. The excitation source (SOM) serves as the origin of the external electromagnetic field. Its intensity, frequency, and other characteristics define the initial electromagnetic interference to which the product is subjected. The conductivity (SEC) and permeability (SMP) of the shell material pertain to the specific shielding implementation mechanism. SEC operates on the principle of electromagnetic induction. Materials with high conductivity can generate reverse electromagnetic fields under the influence of external electromagnetic fields, thereby counteracting the incident electromagnetic fields. Its efficacy is correlated with the intensity of the external excitation source (SOM) [28]. Both parameters have an impact on the shielding degree. SMP, relying on the distribution characteristics of the magnetic field within the medium, modifies the magnetic field path to diminish the amount of magnetic field penetrating the product when countering the interference of low-frequency magnetic fields (which is also contingent upon the frequency information encompassed by SOM). This also exerts an influence on the shielding effect [29] and collaborates with SEC to guarantee the shielding effect against diverse electromagnetic characteristics. We can characterize the shielding effect of metal materials by the ratio of the strength of the electromagnetic field without a shield at the same position to the strength of the electromagnetic field after adding a shield.

When the frequency is high, the calculation formula for electromagnetic shielding effectiveness is

$$SE = 20\lg(E1/E2) \tag{2}$$

When the frequency is low, the calculation formula for electromagnetic shielding effectiveness is

$$SE = 20\lg(H1/H2) \tag{3}$$

where SE is the electromagnetic shielding effectiveness at the critical position of the product, $E1$ and $H1$ are the electric field strength and magnetic field strength without shielding body, $E2$ and $H2$ are the electric field strength and magnetic field strength when there is a shielding body.

The simulation results can help locate the weak part of the PCB board in the chassis, determine the components that are susceptible to electromagnetic influence, and provide a basis for the reasonable allocation of component working frequency on the board and device design, selection, and layout in the future. In addition, based on the electromagnetic performance simulation response output results, it provides input for subsequent product performance margin modeling. Subsequently, based on a performance margin model considering the uncertainty of internal and external parameters, a reliability assessment is conducted to calculate the confidence level.

2.4. **Reliability analysis and evaluation based on electromagnetic performance.**

2.4.1. *Analysis of influencing factors of key performance parameters.* The purpose of correlation analysis of key performance parameters and influencing factors is to determine the factors that have a greater influence on the value of performance parameters. The influencing factors of key electromagnetic performance parameters can be measured from two aspects: internal and external parameters.

External parameters generally refer to the electric field intensity (EF) and frequency (f) of the external environment. Internal parameters include relative dielectric constant (RDC), relative magnetic permeability (RP), and electrical conductivity (EC) of the material. The value of electromagnetic key performance parameter (P_X) is determined by the internal factors P_i and external factors P_e that affect it.

$$P_X = f(P_i, P_e) \tag{4}$$

2.4.2. *Establishment of the electromagnetic performance margin equation.* The establishment of the electromagnetic performance margin equation is the basis of reliability assessment. To establish the electromagnetic performance margin equation, it is necessary to first determine the electromagnetic performance parameter equation considering the influence of internal and external factors. The steps include generating the m levels n factors simulation test scheme by using taguchi design of experiment (DOE), extracting the key performance parameters of each simulation sample, and recording them. The coefficient relationship of the agent equation between the key performance parameters and the uncertain factors is specified by using linear regression, logistic regression, or multivariate function regression methods, and the agent equation of the electromagnetic performance parameters is established. We validate the regression statistics R^2 of the coefficients of the proxy equation, and correct the form of the surrogate equation based on the fitting value, and retest until the fitting effect is excellent.

According to the type of key performance parameters, the electromagnetic performance margin equation can be established. The state feasible regions of the electromagnetic performance indexes are as follows:

$$\Xi_{EM} \in \begin{cases} \left(-\infty, \overline{P_X}\right), & \text{if } P_X \text{ is } STB \\ \left(\underline{P_X}, \overline{P_X}\right), & \text{if } P_X \text{ is } NTB \\ \left(\underline{P_X}, +\infty\right), & \text{if } P_X \text{ is } BTB \end{cases} \tag{5}$$

where P_X represents key performance parameters, $\overline{P_X}$ represents the upper limit threshold of key performance parameters, and $\underline{P_X}$ represents the lower limit threshold of key performance parameters.

The electromagnetic performance equation considering the influence of internal and external factors parameters is denoted as $P_X(P_i, P_e)$; then the general formula of the electromagnetic performance margin equation can be expressed as

$$M = \begin{cases} \overline{P_X}(P_i, P_e) - P_X(P_i, P_e), & \text{if } P_X \text{ is } STB \\ \min \begin{cases} \overline{P_X}(P_i, P_e) - P_X(P_i, P_e) \\ P_X(P_i, P_e) - \underline{P_X}(P_i, P_e) \end{cases}, & \text{if } P_X \text{ is } NTB \\ P_X(P_i, P_e) - \underline{P_X}(P_i, P_e), & \text{if } P_X \text{ is } BTB \end{cases} \tag{6}$$

where P_i represents the internal factors that have an impact on key performance parameters, P_e represents external factors that have an impact on key performance parameters.

2.4.3. *Reliability evaluation.* According to the product design manual and related design requirements, the distribution forms and distribution parameters of internal and external factors with uncertainty in the performance margin function are obtained, which can be used in Monte Carlo simulation to calculate the electromagnetic performance margin under different circumstances.

The reliability is calculated by the formula below

$$R = \frac{NUM_{M>0}}{NUM} \tag{7}$$

where R is the reliability of products, NUM is the total number of simulations, and $NUM_{M>0}$ is the number of simulations with $M > 0$.

3. **Case Study.**

This section takes railway control cabinet as an example to introduce the reliability analysis and evaluation process of all-electronic execution unit based on electromagnetic performance parameters.

The system analysis is the premise of reliability analysis and evaluation. The main function of railway control cabinet is to complete the motor drive control, status acquisition, and signal monitoring through the APU circuit board placed in the cage. The EME around the product can be carried out according to the test standard of the product, which is simulated as the EME with 80-1000MHz field strength of 10V/m and 800-2000MHz field strength of 20V/m.

The cabinet body of a railway control cabinet is typically constructed from a variety of conductive and magnetic materials. The parameter of electromagnetic shielding effectiveness comprehensively reflects the shielding capacity of the cabinet materials against electromagnetic radiation across different frequency bands. Materials with high conductivity are more favorable for conducting the current induced by electromagnetic induction, thereby diminishing the amount of electromagnetic energy that penetrates the cabinet to disrupt electronic components. Materials with high permeability can more effectively modify the magnetic field distribution when confronting low-frequency magnetic field interference, fulfilling the function of blocking and attenuating the magnetic field. The electromagnetic shielding effectiveness of diverse materials and their combinations varies, which is directly associated with the cabinet's ability to effectively impede external electromagnetic radiation and safeguard the normal operation of internal electronic components. Consequently, electromagnetic shielding effectiveness is a comprehensive and representative key performance parameter, holding significant importance in assessing the reliability of railway control cabinets within complex electromagnetic environments.

According to the shielding efficiency requirements of all levels of cabinets in GJB 5240-2004, the threshold value of the electromagnetic performance parameters of the product is determined according to the frequency: 10kHz-30MHz: 10dB, 30MHz-230MHz: 40dB, and 230MHz-1000MHz: 30dB.

The electromagnetic simulation model of railway control cabinet established by ANSYS Workbench is shown in Figure 3 and Figure 4. First-order resonant frequency of the product obtained by the eigenmode analysis is 376MHz. After analysis, it can be concluded that the intrinsic mode resonance frequency may have an impact on several high-speed operating components, including FPGA, NAND memory, SDRAM memory, processor, and small signal MOSFET devices. These devices cover the intrinsic mode frequency values of the cage within the operating frequency range, so there is a possibility of resonance. In actual circuit and functional design, it is important to avoid placing the operating frequency of components near the intrinsic mode resonance frequency of the cage, in order to avoid interference with the normal operating clock of the device.

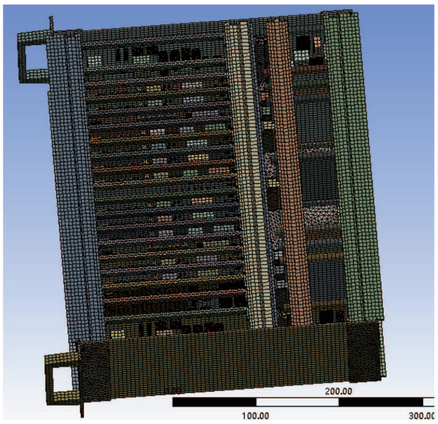

Figure 3. (color online) Electromagnetic simulation model

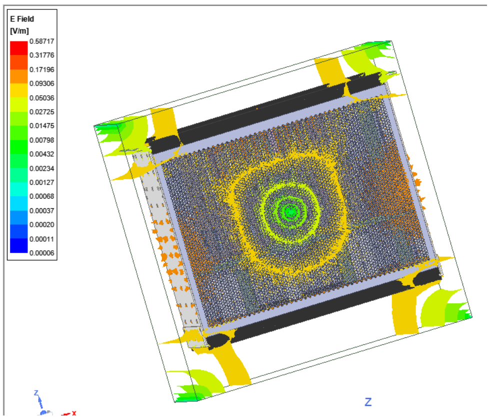

Figure 4. (color online) Grid division

By observing the overall electric field distributions of the 80-1000MHz chassis and the 800-2000MHz chassis (as depicted in Figure 5 and Figure 6, respectively), it becomes evident that the electromagnetic response is particularly prominent at the positions of the slot and the radiator. This phenomenon can be attributed to the structural features of the slot and the electromagnetic coupling effect that arises from the material properties of the radiator itself as well as its interaction with the surrounding environment. For designers, it is of utmost significance to give due attention to the electromagnetic response at these specific positions. Based on the simulation results, they should conduct optimization and improvement measures on these structures. For example, they can adjust the width and depth of the slot or optimize the material selection and structural design of the radiator. Such endeavors will contribute to a further enhancement of the overall electromagnetic compatibility of the railway control cabinet, thereby strengthening its reliability within the complex electromagnetic environment.

According to the electric field distribution of the railway control cabinet within the frequency range of 80-1000MHz and 800-2000MHz, the higher the frequency, the stronger the electric field in the railway control cabinet.

From the overall electric field distribution of the railway control cabinet, it can be seen that there is severe electromagnetic leakage at the connection gap of the chassis, and the left and right heat dissipation holes of the chassis have a significant impact on the electromagnetic shielding effectiveness of the chassis.

According to the simulation results, it can be determined whether the electric field shielding effectiveness at various positions in the computer box meets the requirements.

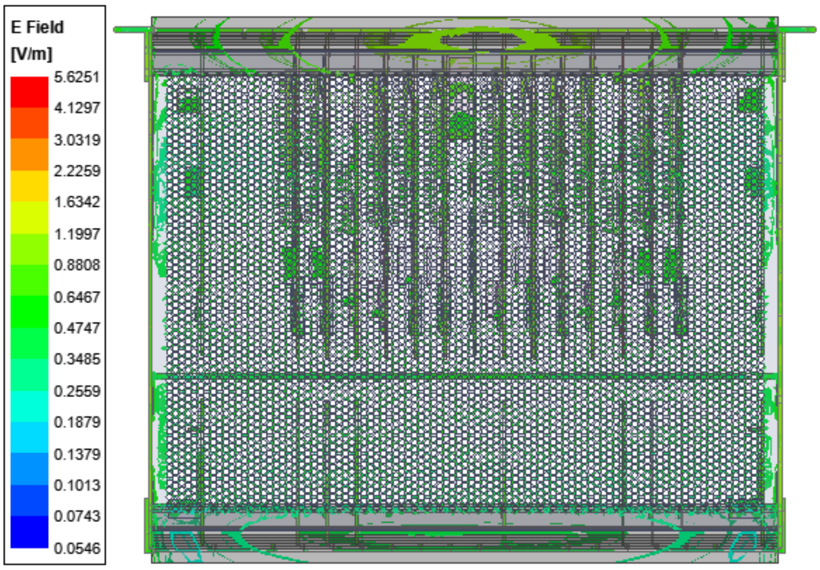

FIGURE 5. (color online) Overall electric field distribution of the cabinet at 80-1000MHz

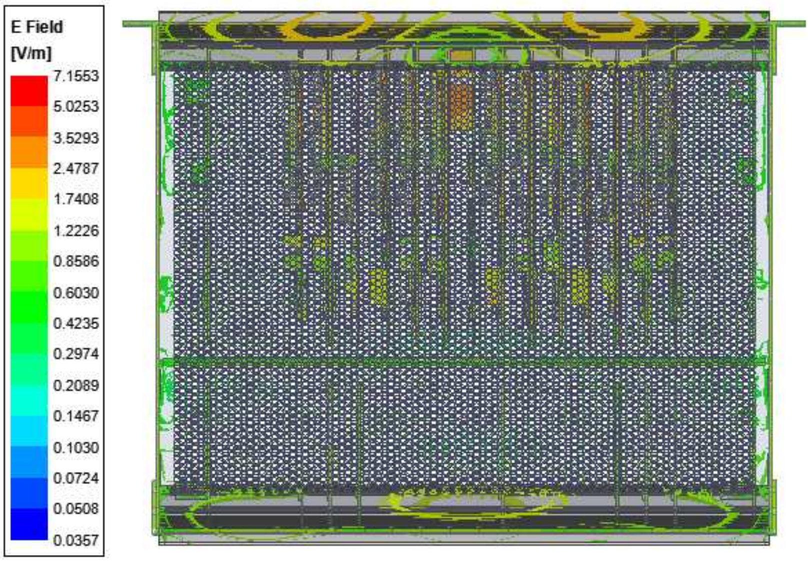

FIGURE 6. (color online) Overall electric field distribution of the cabinet at 800-2000MHz

According to the result in Figure 7, it can be concluded that the component with a high electric field strength between 80-1000MHz is PL0707 located on the NET board, with a field strength of 1.5206 and a shielding strength of approximately 12.36dB. The component with a high electric field strength of 800-2000MHz in the railway control cabinet is the SDRAM located on the NET board. In Figure 8, the field strength is 4.5496 and the shielding strength is approximately 12.86dB. The electromagnetic shielding effectiveness at this location only meets the requirements of the first level chassis and cannot meet the requirements of the second level chassis.

Figure 9 and Figure 10 show the electric field distribution of APU circuit board when electromagnetic resonance occurs. It can be seen from the figure that some components seriously affected by resonance may lead to controller function damage and failure, which

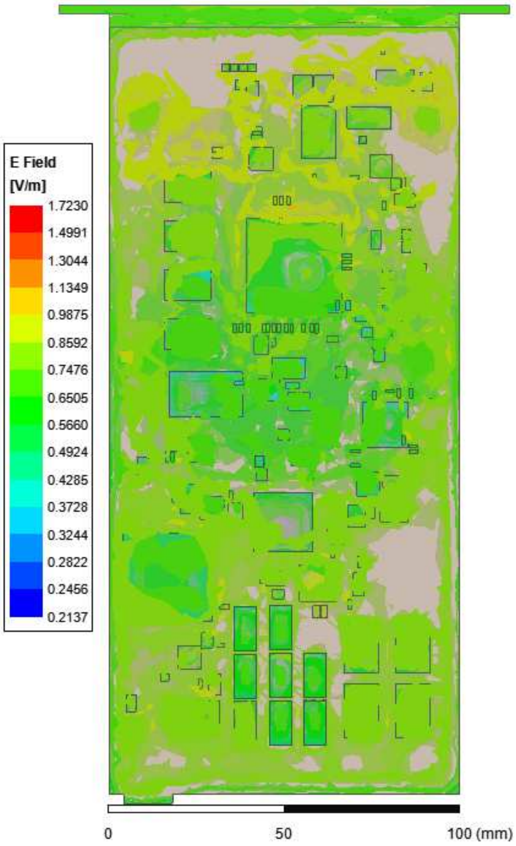

FIGURE 7. (color online) Electric field distribution of NET+AB board (80-1000 MHz)

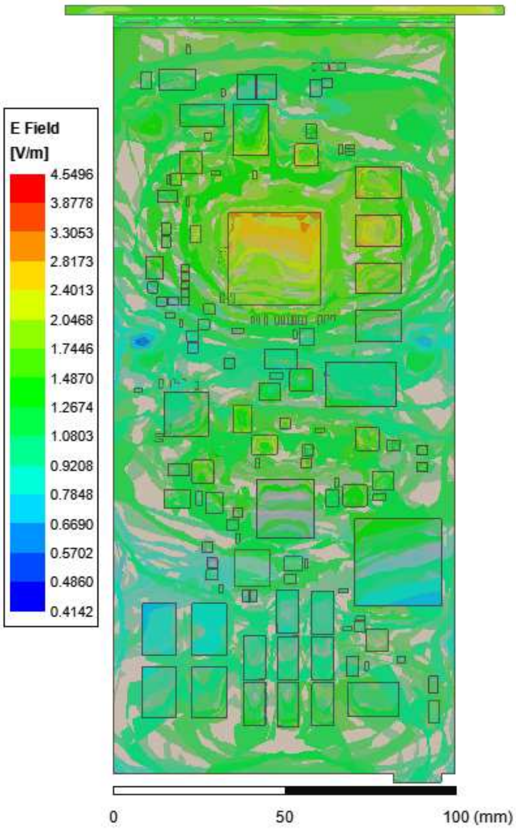

FIGURE 8. (color online) Electric field distribution of NET+AB board (800-2000 MHz)

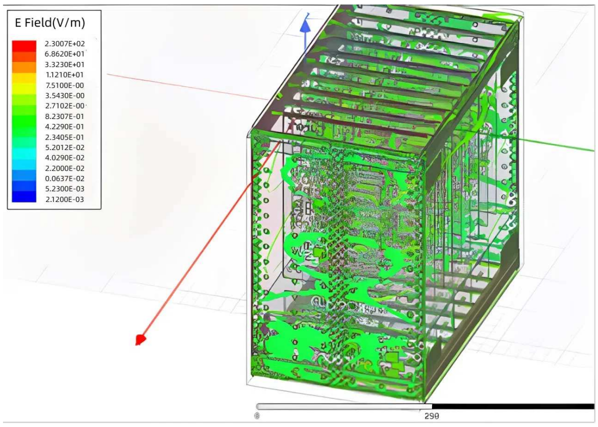

FIGURE 9. (color online) Electric field distribution of the railway control cabinet (electromagnetic resonance)

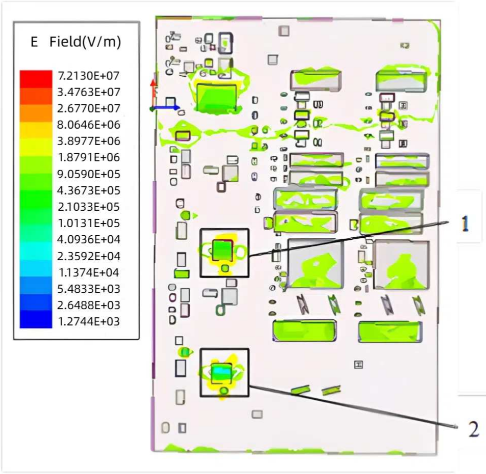

FIGURE 10. (color online) Electric field distribution of APU (electromagnetic resonance)

is the weak part of APU circuit board in the electromagnetic environment. These components shall be analyzed in the design phase and inspected in the evaluation phase. In combination with the electromagnetic response of the devices on the APU board and the analysis of the functional importance of the devices, CPU is determined as the key component. The Nos. 1 and 2 in Figure 10 indicate the position of CPU in the APU board.

The results of electromagnetic excitation simulation of cabinet and APU are shown in Figure 11 and Figure 12. The key performance parameters of the CPU in the electromagnetic environment: the response of the electromagnetic shielding effectiveness are shown in Figure 13.

For the key performance parameters of electromagnetic: shielding effectiveness, the internal factors that may affect the shielding effectiveness include the conductivity and relative permeability of the cabinet material, and the conductivity of the filling material

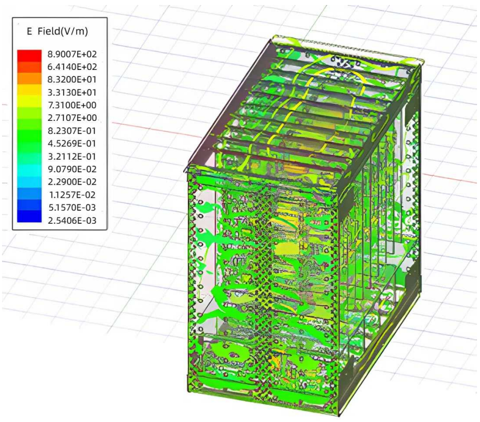

Figure 11. (color online) Electric field distribution of the railway control cabinet (electromagnetic excitation)

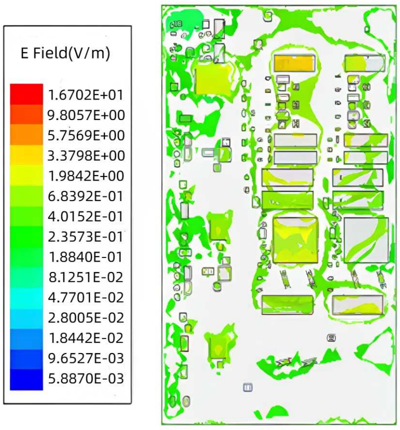

Figure 12. (color online) Electric field distribution of APU (electromagnetic excitation)

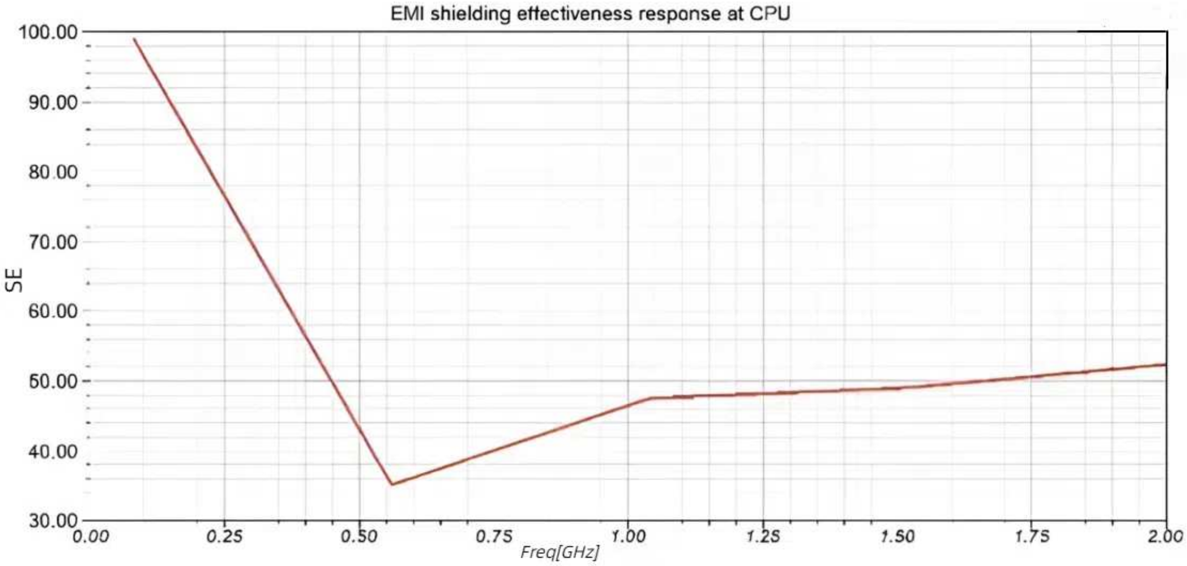

Figure 13. *EMI* shielding effectiveness response at CPU

at the gap of the chassis; the external factors include the electric field strength of the excitation source, etc. The Taguchi design method is employed to formulate a simulation test scheme involving four factors, each with three levels. Subsequently, the surrogate equation is subjected to testing. When the predicted variables are the size of the excitation source, the conductivity of shell material, the magnetic permeability of shell material, and the interaction term between the size of the excitation source and the shell material, the model has a good fitting effect. The summary parameters of the model are shown in Table 1.

Table 1. The summary parameters of the model

Parameter	S	R^2	$R^2(Adjust)$
Value	0.02281	84.44%	68.87%

S in Table 1 means the regression standard error. The statistical analysis R^2 of the regression model indicates that this regression model has good goodness of fit. $R^2(Adjust)$ indicates that this model performs well in regression with different numbers of predictive variables.

The final formula of the agent equation is as follows:

$$EF = 3.91 - 0.2093SoM + 0.03005SEC - 3.5SMP + 0.1995SoM * SMP \tag{8}$$

where SoM is the excitation source, SEC is the conductivity of shell material, SMP is the permeability of shell material, and EF is the electric field strength.

The simulation results show that the minimum shielding effectiveness appearing near the resonant frequency of the cabinet is 315MHz, which determines the threshold of electromagnetic performance parameters as 30dB. According to the calculation formula of electromagnetic shielding effectiveness, the electromagnetic performance margin equation is constructed as follows:

$$M = SE - SE_{th} = -20\lg\frac{EF}{SoM} - 30 \tag{9}$$

The main sources of uncertainty in the product are the fluctuation of the excitation source of electromagnetic interference and the batch dispersion caused by the process difference.

Therefore, the size of the EMI excitation source and the properties of the cabinet material, that is, the conductivity and relative permeability are uncertain, which can be described by the normal probability distribution, and the distribution parameters are as follows:

$$\begin{aligned} &SoM \sim N(15, 0.8333) \\ &SEC \sim N(3.225, 1.29583) \\ &SMP \sim N(1.031484, 0.005276) \end{aligned}$$

Monte Carlo simulation was used to obtain the number of groups $NUM_{M>0}$ of key performance parameter $M > 0$, and the calculation results of reliability considering internal and external parameter uncertainties are as follows:

$$R = \frac{NUM_{M>0}}{10000} = \frac{9984}{10000} = 0.9984 \tag{10}$$

Although the reliability analysis and evaluation process of the all-electronic execution unit predicated on electromagnetic performance parameters is expounded upon in meticulous detail with the railway control cabinet serving as a specific exemplar, this methodological approach exhibits extensive applicability and is not circumscribed by specific equipment typologies. The crux of the reliability analysis and evaluation method founded on electromagnetic performance parameters, as postulated in this research endeavor, lies in dissecting the impact of EME on the reliability of all-electronic execution units from the pivotal vantage point of electromagnetic performance parameters. This analytical paradigm based on electromagnetic performance parameters harbors the inherent rationality of universality. Across diverse varieties of all-electronic execution units, electromagnetic performance parameters constitute the essential constituents for mirroring their comportment within the electromagnetic milieu. Irrespective of the domain or particular functionality of the equipment, the trajectory of the influence of electromagnetic interference on its reliability can be trailed and quantified via these parameters.

For instance, within the aerospace domain, electronic apparatuses such as the flight control computer of an aircraft are situated in an exceedingly intricate and exacting electromagnetic environment. Numerous internal electronic systems interfere with each other electromagnetically. Meanwhile, they are confronted with external interference such as space radiation and flight electromagnetic pulses. This methodological framework undertakes a systematic analysis of the functional architecture and electromagnetic stress, ascertains the thresholds of crucial performance parameters, quantifies the impacts of internal and external factors, and formulates the performance margin model. Subsequently, it computes the reliability with the assistance of Monte Carlo simulation and the electromagnetic performance margin equation. This procedural sequence does not hinge upon the idiosyncratic structure or function of specific equipment but is founded on the generic correlation between electromagnetic phenomena and performance parameters. Irrespective of the specific nature of the all-electronic execution unit, it is capable of determining the shielding requisites, diagnosing resonance and electromagnetic response issues, and subsequently effectuating material selection and structural optimization in accordance with its own electromagnetic environmental characteristics and the sensitivity of internal components. This amply demonstrates that this research methodology has surmounted the constraints of equipment specificity and can assume a pivotal role in ensuring the reliability of all-electronic execution units across multiple fields and diverse types, thereby furnishing robust technical underpinning for the dependable operation of assorted electronic equipment within a complex electromagnetic milieu.

4. **Conclusions.**

In this paper, a reliability analysis and evaluation method of all-electronic execution unit based on electromagnetic performance parameters is proposed. The eigenmode analysis is used to determine ERF of all-electronic execution unit and locate the weak parts of products in the EME. The electromagnetic excitation simulation can determine the value of the key performance parameters of products in the EME, which provides guidance for the design improvement and lays a foundation for the subsequent reliability evaluation. The method proposed in this paper takes account of the influence of failure process on the electromagnetic performance parameters and evaluates the reliability of the system from the perspective of electromagnetic performance parameters by constructing a margin equation.

There are also methodological limitations in this study, so a simple critical discussion is made here. Firstly, this thesis lacks sufficient consideration of complex electromagnetic coupling effects. Within complex electronic equipment, particularly when multiple electronic components are closely arranged and their working frequencies interact with one another, the electromagnetic coupling effect becomes highly intricate. Although the current method accounts for the electromagnetic coupling between certain components and between components and the cabinet structure (such as through the analysis of resonant frequencies and electromagnetic responses at specific locations), it is arduous to conduct a comprehensive and precisely quantitative analysis of some profound and multi-dimensional electromagnetic coupling phenomena. For instance, in some highly integrated electronic systems, electromagnetic coupling might trigger certain unpredictable chain reactions that impact the electromagnetic performance parameters of the equipment. However, existing methods may not be capable of fully capturing these complex alterations, thereby imposing limitations in the identification of potential risks during the reliability assessment process. Regarding this issue, future research can draw on the experimental strategies in [30], use experimental data to verify the simulation results, and then accurately modify the simulation parameters accordingly, thus effectively enhancing the accuracy and reliability of the research on electromagnetic coupling effects.

Secondly, the current method adopted in this paper lacks the ability of dynamic real-time assessment. Currently, the proposed method primarily centers on the static reliability analysis and evaluation of all electronic execution units within a specific state or a relatively stable electromagnetic environment. Nevertheless, during the actual operation of electronic equipment, both the electromagnetic environment and the equipment's own working state are dynamic in nature. For example, the equipment may frequently switch its working modes in accordance with diverse task requirements. When confronted with such dynamic variations, this method lacks the capacity for real-time tracking and dynamic evaluation. To a certain extent, this restricts the effectiveness of ensuring equipment reliability under the actual complex working conditions.

In conclusion, although the reliability analysis and evaluation method of all electronic actuator units based on electromagnetic performance parameters offers an effective concept and approach for resolving related reliability issues, its limitations must be fully acknowledged. This recognition will facilitate further exploration of the improvement directions in future research and practical applications, help address the uncertainty problems encountered by this method, enable it to better adapt to various complex actual situations, and provide more precise and comprehensive support for the reliability guarantee of electronic equipment.

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