A Simulation-Based Method for EMR Assessment of Aviation Electronic Products

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Abstract - **With the application and development of electronic devices, the electromagnetic energy in our surrounding space is gaining rapidly. Especially for those aviation electronic products in the limited space, their characters, such as variety, high density, sensitivity and power, make them susceptible to electromagnetic interference. Traditional electromagnetic compliance (EMC) analysis focuses on EMC design, targeting passing the EMC tests. However, there are few researches on EMC reliability or even the reliability index. Concerning this issue, this paper puts forward to a complete theory to assess the electromagnetic reliability (EMR) of the aviation electronic product. It combines stress-strength interference (SSI) model, probabilistic physics of failure (PPoF) method and simulation analysis, which provides theory support to solve the EMC problems and improve its reliability.**

Keywords - **EMC, simulation, EMR, PPoF, SSI**

I. INTRODUCTION

With the advent of the information age, the level of electrification and automation has improved and electronic products are turning to be more miniature, integrated, high-power, high-frequency, high-speed and high-sensitivity, which make electromagnetic environment around us more and more complex. These electronic devices are diffusing a variety of useful or useless electromagnetic waves to outside, interfering the normal operation of other electronic devices. Such as military, electric power, transportation, communications, almost all the modern industry are faced with the problem of electromagnetic compatibility.

Aviation electronic products have been the most important and flexible electronic countermeasures platforms. The electromagnetic spectrum they occupied is getting wider and wider, and their transmitting power is becoming higher with a rising sensitivity requirement. In addition, airborne platform space is limited. All of these lead to the formation of a complex and harsh external electromagnetic environment. On the other hand, the function of aviation electronic products is growing abundant, the internal microelectronic components and circuits are increasing , the width of the line is getting narrower and narrower, the signal frequency increases suddenly while the edge is also getting steeper and steeper, all of which constitute a harsh internal electromagnetic environment. The worrying internal and external electromagnetic environments make the electromagnetic compatibility of aviation electronic products more and more prominent. Therefore, the study for compatibility is particularly urgent and important with an important significance in engineering technology, economic trade as well as military field[1] - [4].

Currently, EMC problems have received great attention around the world. The United States, Germany, Japan and other countries have developed technologies in EMC research and application areas. In theory area, they put forward various exact and approximate algorithms, which are embedded in commercial software with the use of computer simulation; In the project, they not only proposed measures to eliminate and weaken electromagnetic interference, but also formulated the relevant standards, such as MIL-STD-461E and VCCI [5] [6].

Huang Jin[7] researched the establishment of system-level electromagnetic compatibility index and prediction formula. Many studies[8]-[15] focused on the design of electromagnetic compatibility, however, they didn't propose explicit electromagnetic reliability index which can provide a very important reference for the EMC design and optimization of products.

This paper conducts research in allusion to the above issues with the purpose to analyze the reliability of aviation electronic products in electromagnetic environment. During the research process, it blends in computer simulation technology and the thought of failure physics. Finally, it adopts stress-intensity intervene theory and PPoF method to quantize relevant reliability indexes of products, obtaining more intuitive understanding and cognition on product quality. At last, it takes high frequency switching power supply for an example, to validate and testify the feasibility of the whole theory.

II. A METHOD FOR EMR ASSESSMENT OF AVATION ELECTRONIC PRODUCT

The implementation process of the simulation-based method for EMR assessment is shown in Fig.1.

Seen from the Fig.1, the EMR assessment method is made of four parts, namely data collection, EMC simulation, EMR assessment of hard fault and EMR assessment of the cumulative damage fault.

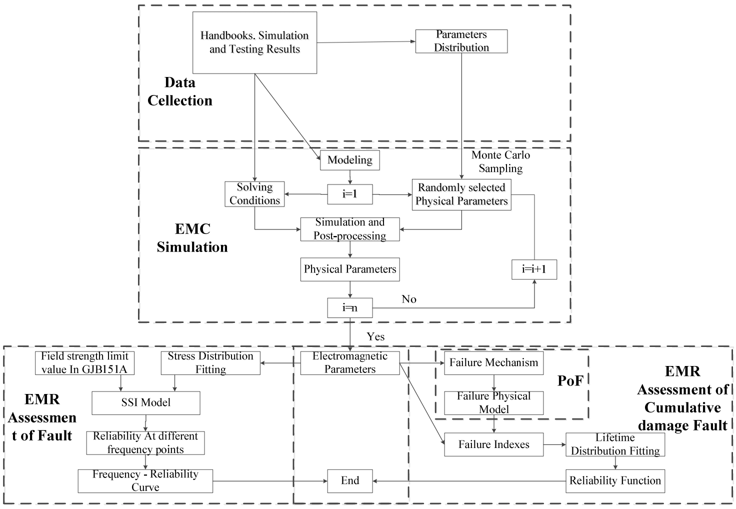

Fig.1. Implementation process of EMR assessment method.

A. Data Collection

Data collection can be conducted through historical data collection , simulation and physical testing and other means, which are used to add or revise the parameters of the material, size, process, simulation conditions for the models establishment.

B. EMC Simulation

In EMC simulation, the Monte Carlo method is used for random sampling of physical parameters, the professional electromagnetic analysis software used for electromagnetic compatibility calculations to obtain an electromagnetic physical parameters for EMR evaluation.

1) *Information Collection*: Information collection is the first step in the EMC simulation. Information is gathered mainly by referring to the relevant handbook, physical test and virtual simulation results. Including the function of the board, work stress conditions, the composition of the list of components, structural panels and components, materials, process parameters, solder joints and through-hole information are needed to collect.

According to gathered information, a simulation model of the circuit board model can be created in the EDA software.

2) *Simulation Conditions Setting*: Select the target traces and then add its excitation source port; After that set background material, boundary conditions, the grid parameters, work frequency response of the models.

3) *Solving and Post-processing*: Upon completing of the above step, the software begins to solve the circuit board's signal integrity, power integrity, electromagnetic field distribution and the far-field radiation to obtain scattering parameter (S parameters) processing of the circuit board, signal eye diagram, the electric field distribution, magnetic field distribution , surface current, far-field radiation situation and other related information.

The circuit board's signal integrity, power integrity and field radiation are closely related to its electromagnetic compatibility. Tests show that the system which has good signal integrity and power integrity not only has low intensity electromagnetic radiation, but also has good anti-jamming capability. Therefore, the simulation can help designers identify problems and improve electromagnetic compatibility.

C. EMR Assessment

The faults caused by electromagnetic interference can be divided into three categories: soft fault which can achieve self-repair after the temporary failure; hard fault, such as burning, over-voltage breakdown, silicon melting and other permanent failure; cumulative damage fault, such as electrical parameters deterioration and damage threshold decrease which lead a functional demotion. According to GJB72A-2002, electromagnetic compatibility failures refer to the failures occur in the relevant system or subsystem, reducing performance permanently due to the electromagnetic interference or susceptibility. Therefore, this paper only takes hard fault and cumulative damage into consideration.

1) *EMR assessment of Hard Fault*: In practical engineering, stress and strength will be affected by external factors, in which the structural geometry, size and environment are main factors affecting the stress and physical properties of the materials, processing methods are the main factors affecting the strength. Affected by these random factors, stress and strength have a certain dispersion characteristics, therefore, all the stress and strength are showed as distribution of random variables. The distribution of stress and strength represented in the same coordinate system, as shown in Fig.2.

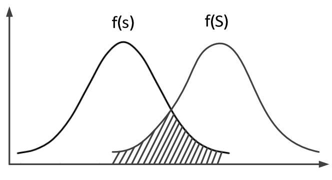

Fig.2. Stress - strength interference model.

Reliability can be obtained by the following formula:

$$R = \Phi(\beta) \qquad (1)$$

where： $\beta = -z_0$ (2)

$$z_0 = -\frac{\mu_z}{\sigma_z} = -\frac{\mu_S - \mu_s}{\left(\sigma_S{}^2 + \sigma_s{}^2\right)^{\frac{1}{2}}} \quad (3)$$

Where μ_S is the mean of strength, μ_S is the mean of stress, σ_S is standard deviation the of strength, σ_s is the standard deviation of stress.

In EMR assessment of hard fault, the stress distribution in the SSI model is field intensity distribution which is affected by the size, materials, process and other factors; The limiting value of electromagnetic field intensity is prescribed in the GJB151A.

According to the distribution of parameters obtained by data collection in the first step, make the Monte Carlo sampling of the physical parameters. Conducting the above EMC simulation method, n maximum field intensity values can be obtained at each frequency point with repeated calculation. Its distribution is fitted as stress distribution in SSI model. The limiting value of electromagnetic field intensity prescribed in GJB151A is considered as the strength in SSI model. Then the reliability R_h at each frequency point can be calculated and the frequency - reliability curve can be drawn.

2) *EMR Assessment of Cumulative Damage Fault*: In the probabilistic physical of failure (PPoF) method, with the identification of the failure mechanism and the failure physical model, the dispersion of material, structure, process defects, stress and other parameters are incorporated into the a failure physical model and the prior distribution which life obeys is given by the Monte Carlo method. And then utilize Bayesian theory to update model parameters distribution, forming probability description of life. Finally use Monte Carlo method to obtain single point of failure probability density and related reliability index.

For cumulative damage fault, it will take some time to fail and the strength of circuit board will gradually decrease, thus reliability is no longer a constant value. Therefore, the PPoF method is conducted to carry out the EMR assessment of the circuit board.

Similarly, referring to the distribution of parameters obtained by data collection, conduct the Monte Carlo sampling of the physical parameters. After n times solving by EMC simulation method, the electromagnetic physical parameters of the target traces can be obtained. The physical parameters considered electromagnetic the parasitics of the circuit board. Then take electromagnetic physical parameters into the corresponding physical model to get the failure time of the circuit board at this electrical stress condition and conduct its distribution fitting in which the failure distribution function and reliability function R_d can be obtained.

3) *Integrated EMR Assessment*: Assume that the process of hard fault and cumulative damage fault are independent, the integrated EMC reliability R_s of system can be expressed as the product of hard fault EMC reliability R_h and cumulative-damage EMC reliability R_d, namely:

$$R_s = R_h \cdot R_d \quad (4)$$

III. CASE STUDY

A high frequency switching power supply of aviation electronic device is taken for an example to validate and testify the feasibility of the whole theory. Its implementation process is as follows.

A. EMC Simulation

The circuit board in the power has a 152mm length, 102mm width, 18.2mil thickness. There are two metal layers, two solder resist layers and one dielectric layer in this board. Then the switching power supply model is established by Altium Designer, as shown in Fig.3. In CST software, open board map file generated by Altium Designer.

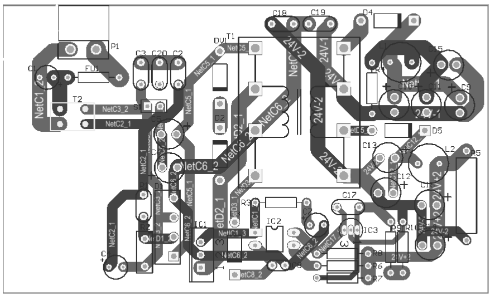

Fig.3. The circuit board diagram of power module.

Set the frequency range with 0 ~ 4GHz, set NETC5_1 and NETC3_2 as the analyzed traces and put two excitation ports on each trace: port1, port2 and port3 , port4.

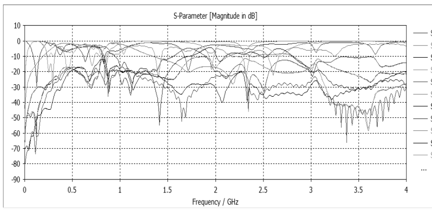

Fig.4 Scattering parameters.

Take NETC5_1 for an example, its scattering parameters is shown in Fig.4. From the figure, the return loss S11 reflected back by the excitation signal of port 1 has a fluctuations around -30dB; the return loss S21 reflected back by the excitation signal of port 2 is approaching 0dB. Therefore, the signal transmission of this trace is efficient.

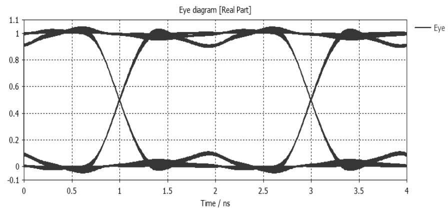

Fig.5. Eye diagram.

The size of the "eyes" reflects the strength of crosstalk and inter-symbol interference and interference noise in eye pattern. The eye pattern of NETC5_1 trace is shown in Fig.5 where the "eyes" open wide. Therefore, NETC5_1 trace is subjected to slight crosstalk and interference.

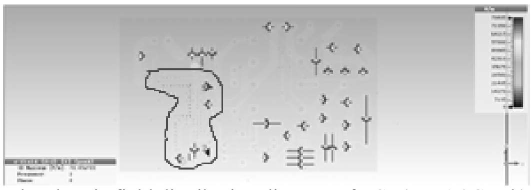

Fig. 6. The electric field distribution diagram of PCB(Port1 2GHzb).

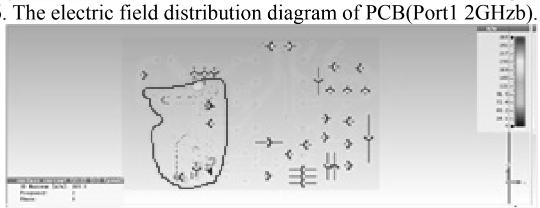

Fig.7. The surface current distribution diagram of PCB(Port1 2GHzb).

The electric field distributions as well as surface current distribution diagrams of PCB board, shown in Fig.6 and Fig.7 ,will contribute to observing the impact of signal routing addition on other routing signals and help to guide the layout design of PCB board. The red arrowheads on the above diagram are excitation ports, the blue ones are component on PCB board, and other arrowheads are field distribution. It is thus clear that the routing around the excitation routing is easily but slightly affected.

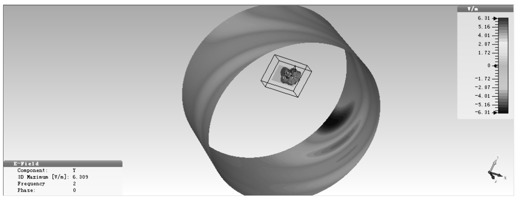

Fig.8 Far-field radiation pattern(Port1 2GHzb).

The radiation situation of signal routing to the space around will be figured out through far-field radiation pattern. And then we can tell the direction to which the radiation is strongest and the gain margin. The better the directionality of aerial radiation is, the further the radiation will be transferred.

B. EMR Assessment

1) *EMR assessment of hard fault* :Conduct the hard fault EMR assessment of switch power supply modules. Based on the analysis of radiated interference theory, it can be realized that electric field radiation is related to relative dielectric constant of material, and the parameters can be chosen as electric field distribution source. The material of PCB board medium is FR4, and its dielectric constant is 4.3. As most material parameters submit to normal distribution, relative dielectric constant of FR4 material submit to normal distribution N（4.3,0.5）. A group of random data submitting to normal distribution N（4.3,0.5）through normmd function in Matlab, two digits were reserved after the decimal point of the data as simulation input value and rank them from lowest to highest as 4.16、4.27、4.29、4.30、4.33、4.36、4.41、4.44、4.53、4.63.

Conduct an EMC simulation of PCB board and obtain electric field values at 2GHz frequency as 64.28，62.87，60.95，58.18，55.81，52.36，50.90，49.83，47.57，44.91dBμV/m. Performing distribution fitting of above 10 values according to SPSS software, it submits to normal distribution, namely N(54.76，6.682). According to RE102 rules in GJB151A, the radiation limiting value under 2GHz is 60dBμV/m which will be as strength distribution in SSI model. And take the electric field distribution by simulation as stress distribution in SSI model, namely =60， s~N(54.76， 6.682) ,as shown in Fig.9.

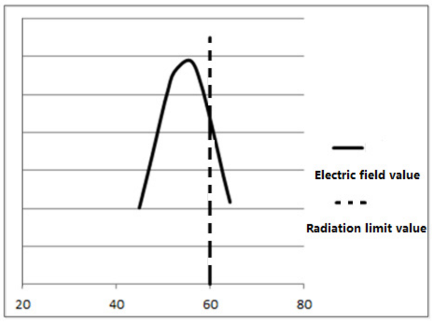

Fig.9. SSI model.

$$P(s \le S) = P\left(\frac{s-54.76}{6.68} - \frac{60-54.76}{6.68}\right) = \Phi(0.78) \quad (5)$$

Referring to the standard normal distribution table, we can know the reliability of PCB board under 2GHz frequency is:

$$R_h = 0.7823 \quad (6)$$

Using the same method, the reliability of the PCB were figured out as 0.8115, 0.8012, 0.7936, 0.7764, 0.7717, 0.7682 and 0.7629 at the frequency of 0.5GHz, 1GHz, 1.5GHz, 2.5GHz, 3GHz, 3.5GH and 4GHz. The fitting curve of frequency-reliability is shown in Fig.10.

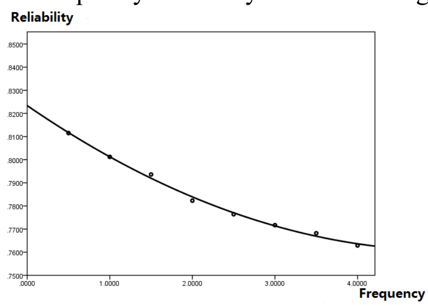

Fig.10. The fitting curve of frequency-reliability.

2) *EMR assessment of cumulative damage fault*: Conduct a cumulative-damage fault EMR evaluation of switch power supply modules. Still choose randomly sampled 10 FR4 relative dielectric constants, namely 4.16、4.27、4.29、4.30、4.33、4.36、4.41、4.44、4.53、4.63 to make a cumulative damage fault EMR evaluation combined with PPoF method. Conduct an EMC simulation of PCB board and the current values of NETC5_1 under 2GHz frequency are 3.73、3.69、3.63、3.60、3.56、3.52、3.50、3.48、3.46、3.44A.

Conduct a curve fitting of electric current values and their corresponding FR4 relative dielectric constants.

Calculate failure time of power supply module with Cacle PWA under the failure mechanisms , respectively electromigration, secondary breakdown, hot carrier injection, TDDB and overheat damage. By comparisons, the failure time of electromigration is the shortest, hence we can know that the major failure mechanism of power supply module is electromigration. Analyze the cumulative-damage fault caused by electromigration. Exert Cacle PWA to obtain the failure time under electromigration, namely 4222、14548、15033、15284、15647、15969、16189、16357、16527、16759h. In the life distribution fitting, the above 10 failure time were tested by Weibull distribution in Matlab. As in Fig.11, we can see it is in a nearly straight line. And then it is convinced that the lifetime submits to Weibull distribution.

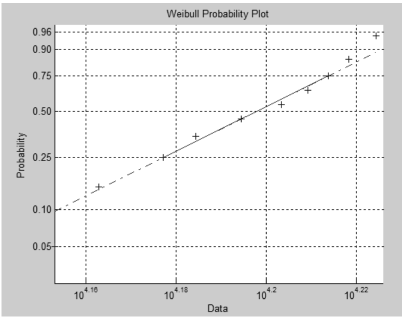

Fig.11. Weibull probability plot.

After a further solution, we can obtain the shape parameter of Weibull distribution is 0.01, the dimension parameter is 22.1267, namely W（0.01, 22）, its distribution function is as following:

$$F(t)=1-e^{-t^{0.01}/22} \quad (7)$$

Reliability function is: $R(t_0)=e^{-t_0^{0.01}/22}$ (8)

It's assumed that the process of hard fault and cumulative damage fault are independent when conducting integrated EMR assessment of this switching power supply module. The integrated EMC reliability of the circuit board traces in the power supply module can be expressed as:

$$R_S = R_h \cdot R_d = 0.7823e^{-t_0^{0.01}/22} \quad (9)$$

If the life index of this switching power supply is15 years, it is assumed to work eight hours per day and 200 days per year, that is, t_0=24000*h*, then:

$$R_s = 0.74$$

IV. CONCLUSION

This paper proposed to a complete theory to assess the electromagnetic reliability (EMR) of the aviation electronic product. It combined EMC simulation analysis, stress-strength interference (SSI) model, method of probabilistic physics of failure (PPoF). Signal integrity simulation, power integrity simulation and electromagnetic field simulation were conducted in the EMC simulation to evaluate the electromagnetic compatibility. SSI model and PPoF method were introduced to calculate the EMR index of hard fault and cumulative damage fault. At last, it took high frequency switching power supply for an example, to validate and testify the feasibility of the method. The results show that the EMR assessment method proposed in this paper is a feasible scheme to assess the reliability of the aviation electronic product under electromagnetic environment and this method can be used to guide designers to make assessment on electromagnetic compatibility reliability of products at product design phase.

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