Theoretic Analysis & Study on Automobile EMC Based on the Synergetics Theory

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Abstract. Considering the microelectronic application in the automobile of equipment increases, and the electromagnetic environment of external world worsens day by day, it is important to study the problems of the auto EMC. The traditional researching approaches of EMC have already become riper, but because of the complicated characteristics of the automobile’s complex electronic system, there is no simple mathematical model to describe and analyze the auto EMC. The traditional methods mostly proceed with parameters of the circuits, and they have not risen to the system grade. They are based on the thought of reduction. As a kind of brand-new theory, synergetics pay more attention to the cooperation and competition between subsystems, and then it can reach harmonious stability from the whole. This paper investigates a new thought about applying the synergetics theory to the EMC’s analysis of the complex system like the Automobile’s, thus received corresponding theory support.

1. Introduction

Because the automobile moves and exposes in various electromagnetic radiation sources which are very different in intensity, the questions of EMC are increasing constantly. The steady of the auto EMC has been the important problem that the academia and industrial circle have paid close attention to together all the time, because it directly related to the safe operation of the automobile and the economic benefits of the manufacture department.

EMC technology has roughly gone through following three stages: (1) solving problems; (2) standardize criterions; (3) system engineering. Among them, the method of system engineering is managing in the course of designing entirely at the same time, so it improves the result and it is the most scientific method at present. But these traditional analytical methods always base on the circuit calculating and the analyzing of the launch-respond models, this need to know the detailed mathematics model of every component in the system precisely. These analytical methods are the thought of reduction; it is very difficult to show the electromagnetic dynamic characteristic of the electronic system of the automobile. These methods only considered the local change while studying the EMC problems of the automobile, and it lack theory and analysis of the whole, so the results of the designs are insignificant actually.

How to analyze and predict effectively to the automobile’s complex electronic system with theory is the key problem while analyzing the auto EMC.
In this passage we proceed with the Maxwell equations from the synergetics theory and its principle of approximate heat insulation to study relevant theoretical research.

2. Synergetics theory

Synergetics theory is a comprehensive interdisciplinary science which was found by German scholar H. Haken. It is about the conditions and regulations when the phenomenon of the self-organization appears. In the system that makes up of similar characteristic subsystems, the mutual efforts among the subsystems may lead to order and structure; hot sports will cause out of order and confusion. The system can reach the balance when two kinds of sports are evenly matched, or else it appears critical change. Synergetics is a study of regulation about non-linear dynamical system including random fluctuations. Haken has described the behavior near the critical point in the synergetics theory, he proposed the servo principle and order parameter principle.

2.1. Servo principle

To a huge system making up of a large number of subsystems, its number of variables included in the evolution equations is very great, it is impossible to deal with these equations. So, how to simplify these evolution equations and to describe the original system approximately by low dimension equations is an important research in synergetics. It developed a basic principle-Servo principle. Its core is principle of approximate heat insulation.

According to the thought of synergetics theory, there are two critical behaviors these token to the states of subsystems and the subsystems’ coupling: the rapid parameters that result highly damping on critical phase, and the slow parameters that result no damping when the system is on the critical phase. The number of slow parameters is few, but they are driving the sports of other rapid parameters. The final state of the system development is decided by them.

The principle of approximate heat insulation is that when the system is on critical phase, it is shaping fast in order; the external influence on the system can be ignored. But inside system, when neglecting the change of the rapid parameters that decays quickly, the equations can be simplified greatly. Then there are equations only including slow parameters-order parameter equations. This method makes the equation easily to be solved because it decreases the number of variables.

2.2. Order parameter principle

Among the synergetics theory, order parameters figure the character and degree of the ordered system. Under the old structure before becoming critical phase, the order parameter is 0, but it is not the null value when the critical phase happens. The order parameters in synergetics own 3 characteristics in common: (1) they are macroscopical to describe behaviors of system in the whole; (2) they are cooperative effect of collective movement of microcosmic subsystem; (3) they control the behaviors of the subsystem, and dominate the course of system evolution.

3. The universality and particularity of the automobile EMC

3.1. Three key elements of the EMC question

Any electromagnetic interference process needs three key elements: source of interference, the coupling way of the electromagnetic interference and target interfered. So to the automobile complex electronic system, if the three elements of the EMC are expressed in the function of \( S(t, f, r, \theta) \), \( C(t, f, r, \theta) \), \( R(t, f, r, \theta) \) which are figured by time variable \( t \), frequency variable \( f \), space variable \( r \) and orientation variable \( \theta \), then it must be satisfied with inequation (1) if electromagnetic interference happens:

\[
S(t, f, r, \theta) \cdot C(t, f, r, \theta) \geq R(t, f, r, \theta)
\]  

(1)

But to the automobile’s complex electronic system, every subsystem will become potential interference source for each other. So it is very complicated to simply explain the auto EMC question by three elements.
3.2. Complexity of automobile electronic system

The particularity of automobile electronic system just lies in its complexity. The electromagnetic environment of the automobile is very complicated, and with the development of technology of the semiconductor, more and more integrated chips are applied in them, so it will become more complicated. Its characteristics are: (1) The automobile is made up of a large number of different kinds of components, these components are distributed in each area of automobile body, link to each other closely through CAN network; (2) The automobile electronic system is always changing with space and time, as a dynamic system, it have characteristic of time harmonious; (3) Automobile electronic system often receives different disturbance, for example, interference of the climate of lightening storm, sudden load change, operation by mistake, all these may cause the incident instantly. (4) A large amount of high integrated chips of high frequency will appear in the automobile electronic system, it will become a complicated system mixed with digital and simulation devices.

Just because automobile electronic system has so complicated characteristics, it is unable to describe and analyze its EMC questions by simple mathematics model.

4. EMC order parameter equations based on synergetics of automobile electronic system

From the description above, it is obviously founded that the EMC question of the automobile electronic system is a consideration of the system behaviors when the critical change happens, so it can be thought of a kind of stabilization question while nearing critical phase macroscopically. According to the equations of Maxwell, in thought of synergetics, this following argumentation can be fetched in the use of the servo principle and order parameter principle.

In the equations of Maxwell, there are four physical variables E, D, H and B which describe the characters of the electromagnetic field. They respectively represent electric field intensity, electric flux density, magnetic intensity, magnetic flux density. Generally speaking, these physical variables are the continuous functions of the position vector r and time t. The current density J and charge density ρ of electromagnetic field source are the continuous functions of the position vector r and time t too. Under the circumstances that the above is described, the differential form of the equation group of Maxwell is as follows:

\[ \nabla \times E(r,t) = -\frac{\partial}{\partial t} B(r,t) \]  \hfill (2)

\[ \nabla \times H(r,t) = -\frac{\partial}{\partial t} D(r,t) + J(r,t) \]  \hfill (3)

\[ \nabla \cdot D(r,t) = \rho(r,t) \]  \hfill (4)

\[ \nabla \cdot B(r,t) = 0 \]  \hfill (5)

In addition, the continuity equation of signifying the law of conservation of electric charge in continuous medium is regarded as a basic equation too:

\[ \nabla \cdot J(r,t) + \frac{\partial}{\partial t} \rho(r,t) = 0 \]  \hfill (6)

Let S(r, t) =E(r, t)×H(r, t) is Poynting vector that stands for the power current intensity. According to the Poynting theorem, there is:

\[ -\oint_S \cdot dS = \frac{d}{dt} \iiint \left( \frac{1}{2} \mu H^2 + \frac{1}{2} \varepsilon E^2 \right) dV + \iiint \sigma E^2 dV \]  \hfill (7)

It is the energy principle of the electric magnetic field.

According to Fourier transformation, any electromagnetic field that change over time can be regarded to the summing up of the different time-harmonic electromagnetic fields generally, so the solving of any electromagnetic field can be reduced to solving of time-harmonic electromagnetic fields in actually. Let F(r, t) stands for a time-harmonic electromagnetic field whose angular frequency is \( \omega \), then F can be expressed by the form of complex form below:
\[ F(r, t) = \text{Re}[F(r)e^{i\omega t}] \]  
(8)

\[ \frac{\partial}{\partial t} F(r, t) = \text{Re}[i\omega F(r)e^{i\omega t}] \]  
(9)

In fact, the questions of the automobile EMC are the research about energy transform of the electromagnetic wave that transmits in automobile space. According the theory of synergetics, we choose Poynting vector as the main order parameter by three terms which are referred in order parameter principle. For simplicity, it is deemed to use only two kinds of variables \((S, u)\) to figure the EMC of automobile electronic system. \(S\) is slow parameter and \(u\) is rapid parameter. They are the functions of the position vector \(r\) and time \(t\) and frequency \(f\) and orientation \(\theta\), they are deformations of the three key elements in inequation (1). Draw lessons from document [3] thought, and utilize synergetics, the systematic evolution equation can be written for the form of Langevin equation:

\[ \dot{S} = K(S, u) + F(r, t) \]  
(10)

\(F(r, t)\) is the form of equation (8), it is deemed to express the force of random fluctuations here. \(K(S, u)\) is a nonlinear function that represents the internal cause of system; \(F(r, t)\) represents cause of external random influence. To simplify the model, ignore the cause of external random influence \(F(r, t)\), then equation (10) turns into:

\[ \dot{S} = K(S, u) \]  
(11)

To two dimension system, there is \(K(S, u) = \alpha S - \beta u\) in equation (11), so there is:

\[ \dot{S} = \alpha S - \beta u \]  
(12)

\(u\) can be showed below:

\[ \dot{u} = -\beta S + S^2 \]  
(13)

Then there is:

\[ u(t) = \int_{-\infty}^{\infty} e^{-\beta(t-\tau)} S^2(\tau) d\tau \]  
(14)

Use the law of integration by parts, there is:

\[ u(t) = \frac{1}{\beta} S^2(t) - \frac{1}{\beta} \int_{-\infty}^{t} e^{-\beta(t-\tau)} 2(S \cdot \dot{S}) d\tau \]  
(15)

\(S\) is small when \(S\) change slowly according to the principle of approximate heat insulation, ignore the integration in equation(15),there is:

\[ u(t) = \frac{1}{\beta} S^2(t) \]  
(16)

Take it back to (12), there is:

\[ \dot{S} = \alpha S - \frac{1}{\beta} S^3 \]  
(17)

Equation (17) is the order parameter evolving equation of automobile electronic system, \(S\) is Poynting vector, \(\alpha, \beta\) are the best parameters under the appointed algorithm.

Equation (17) shows that other behaviors of factors are served to Poynting vector in automobile. In fact, Poynting vector stands for the power current intensity of the energy of electromagnetic wave, so if \(S\) is steady, the EMC characteristic of this total mark area is compatible; on the contrary, if \(S\) changes, the EMC characteristic of this total mark area will change thereupon too. So if \(S\) has been known, we can get EMC quantitative analysis of the corresponding area and predict according to the equation (7) and (17) by the use of Computational Electromagnetics.
5. Conclusion
To the automobile’s complex electronic system which is include many subsystems, the variables’ number of its basic electromagnetic equations is large, and their dimensions are very high. It is impossible to solve the equations like that. So, According to synergetics and the characters of automobile electronic system, we proceed with the Maxwell equations to get the order parameter evolving equation of automobile electronic system, and advance a new thought of solving of auto EMC.

Compare to the law of system engineering, This method not only eliminates the number of mass variables so that the equations are solved easily, but also can profoundly reflect the EMC’s order parameters synergistically produced in the automobile’s complex electronic subsystems. The EMC’s order parameters dominate behaviors of subsystems. The behaviors impel the state of the whole automobile’s complex electronic system to an ordered one, so to achieve the goal of analyzing and designing of the auto EMC.

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