Research and Application of Electromagnetic Compatibility Technology

Hong Zhao
School of Electrical Engineering, Dalian University of Technology, Dalian, Liaoning, China
Dalian Institute of Product Quality Supervision & Inspection, Dalian, Liaoning, China
Email: zhaohong@dlzjs.org

Guofeng Li and Ninghui Wang
School of Electrical Engineering, Dalian University of Technology, Dalian, Liaoning, China

Shunli Zheng and Lijun Yu
Dalian Institute of Product Quality Supervision & Inspection, Dalian, Liaoning, China

***Abstract*—Although still in its primary phase up to now, the research about EMC science and its technological application in modern industries has become more and more noticeable. In this paper the main subjects for EMC research are introduced, then discussed briefly are some hot research topics concerning the application of EMC technology, as in such areas as military field, industrial electronics or microelectronics, power industry, onboard or airborne electronics, communications, home appliances and lighting equipments. Then the topic of complex electromagnetic environment concerning modern informationalized battlefield is emphatically addressed. At last several outstanding problems in the development of electromagnetic compatibility technology are introduced concisely.**

***Index Terms*—EMC research, EMC technology application, Complex electromagnetic environment, Electromagnetic environment effect**

I. Introduction

The study of Eletromagnetic Compatibility (EMC) has close correlation with the life and work of the people, and the content of EMC study is much comprehensive. In this paper the main research subjects of EMC science are first introduced, then hot research topics within some areas of EMC research and technology are described, involving the war field electromagnetic environment effects, EMC control and management for industrial electronics or microelectronics, electromagnetic susceptibility (EMS) performance for electrical or electronic equipments in power systems, EMC performance for automobile electronics and EMI suppression for household appliances, etc. Then emphatically addressed is the complex eletromagnetic environment of modern informationalized battlefield under high-tech conditions. Then following the discussion about the development trends of EMC technology for military equipments in the informational age, several noticeable problems in the future development of EMC technology will be briefly described at last.

II. An Overview On The Emc Technology

Zhang Linchang has defined EMC as this: EMC is a science that studies a variety of electrical or electronic equipments (and living things, in a broad sense), which aim to operate smoothly and coexist with limited resources of space, time and spectrum, and not to degrade under such a condition [1]. EMC is a highly comprehensive boundary science and also an applied science of high practicality, based on the fundamental theories and technologies of electrical and electronic sciences, concerning the solution of each theoretical or technical problem arising from natural or man-made electromagnetic interference (EMI). The final purpose of EMC research is to ensure the EMC performance of each system or subsystem [2].

Within most of the modern industries there are EMC problems to be solved, as in the industries of power, telecommunication, transportation, spaceflight, computer, military and medical equipments, etc.

III. Research subjects for EMC Science and Technology

A. Sources of Electromagnetic Disturbances

Only if $\mathrm{d}i/\mathrm{d}t \neq 0$ or $\mathrm{d}v/\mathrm{d}t \neq 0$ under whatever circumstances, electromagnetic noises will be generated, and these noises make up the major part of electromagnetic disturbance. Sources of electromagnetic disturbances can be of two kinds: natural or man-made. The former includes the electromagnetic noises from outer space and the aerosphere(such as thunderbolt, ionosphere changes), and electrostatic discharge, thermal noise, etc; the latter includes those from radio frequency devices for industrial, scientific or medical use, and transmitters for communication, navigation, remote control or radio business, etc. The difficulties in the research about electromagnetic noise sources include the following.

doi:10.4304/jcp.7.9.2240-2247

The first is about the generating mechanisms of electromagnetic noise, which are too many and varied. For example, only for household appliances, there are at least four kinds of noise generating mechanism.

The second is the inherent conflict between EMC control and the development trends of some technical areas. For example, one trend in computer industry is that the CPU clock frequency goes higher and higher, but the higher the noise frequency goes, the more difficult the noise control gets.

The third difficult problem up to now is the digital modeling for the physical phenomenon of the generation of electromagnetic noise.

B. Propagation Characteristics of Electromagnetic Noises

Generally speaking, the transmission modes of eletromagnetic noise can be divided into two categories: conducted emission and radiation emission. The former means transmission of eletromagnetic noise energy through one or several conductors (such as power lines, signal lines, control lines etc). The latter means space transmission of noise energy in the form of electromagnetic wave, sometimes induction phenomenon also included.

The research method for the propagation characteristics is to build mathematical models according to electromagnetic field theory. The difficulties in this research are as follows.

The first is that in most of the mathematical models, both near field effects and far field effects of electromagnetic waves have to be considered at the same time, because the frequency bands of electromagnetic noises can be very wide.

The second, both the source and the channel of a noise have to be modeled in the same one.

The third is that the boundary conditions of the models are usually complicated because of the need for the models to be practical, and the idealization of the boundary conditions can be difficult in some degree.

C. Immunity Characteristics of Electronic Devices and Systems

The main concerns are about the responses of receivers for electromagnetic noises, and about how to improve the electromagnetic immunity. This kind of research has involved many technical areas such as telecommunication, navigation, radar, broadcasting, television, information technology, remote control and remote sensing. The excessive dependence on human experiences is the difficult point to overcome in this research.

D. Test Equipments, Test Methods and Statistical Methods

Electromagnetic noises are not normal sinusoidal voltages, but voltages taking on various shapes and different frequency spectrums, including pulse voltages. Therefore there are strict requirements about the test equipments, test sites and test methods. In the tests people always pay attention to instrument parameters, measurement fields, measurement methods, and such matters as the statistics, the evaluation, etc.

Since the coefficients or performance parameters of test equipments or test sites may drift from initial values with the lapse of time, it is recommended to perform routine checks (also called “spot checks”) of the test equipments and test sites in daily operation of EMC laboratory, say, once per week or twice per month. Timely corrective measures should be taken when deviations occur, to ensure that uncertainties in the own performance of test equipments or test sites can not lead to test data distortion. TABLE Ⅰ is part of a check list on the performance of some anechoic chamber; the judgement standard in this check list is that the difference between spot check value and corresponding original value should be within ± 3 dB. Here the unit of dB is an EMC unit that is frequently-used, for example, the ratio between two variable values can be stated as follows, with dB as the unit [3].

$$\text{dB} \equiv 10 \log_{10}\left(\frac{P_2}{P_1}\right) \quad \text{(ratio of power values)} \qquad (1)$$

TABLE I.
CHECK LIST ON THE PERFORMANCE OF SOME ANECHOIC CHAMBER

	NO	Date \ Frequency [MHz]	30	dev.	100	dev.	200	dev.	300	dev.	400	dev.	500	dev.	600	dev.	700	dev.	800	dev.	900	dev.	1000	dev.	Judge
Original		2007-5-1	63.9	0	97.7	0	90.2	0	84.7	0	92.5	0	91.7	0	90.2	0	89.9	0	89.3	0	85.1	0	82.7	0	
data	1	2009-1-4	64	0.1	98.2	0.5	90.2	0.05	84.3	-0.5	92.1	-0.4	91.9	0.19	90.6	0.32	90.3	0.45	89.9	0.58	85.3	0.14	82.6	-0.1	OK
	2	2009-1-14	64	0.09	98.2	0.47	90	-0.2	84.4	-0.3	91.9	-0.6	91.7	-0	90.4	0.16	90.2	0.31	89.7	0.41	85.3	0.17	82.6	-0.1	OK
	3	2009-2-7	63.5	-0.4	97.7	-0	89.6	-0.6	83.6	-1.1	91.9	-0.6	91.8	0.07	90.5	0.26	90	0.11	89.5	0.21	85	-0.1	82.3	-0.4	OK
	4	2009-2-24	63.6	-0.3	97.8	0.07	89.8	-0.4	83.8	-0.9	91.6	-0.9	91.6	-0.1	90.2	-0	89.9	0.01	89.2	-0.1	84.2	-0.9	82	-0.7	OK
	5	2009-3-2	63	-1	97.3	-0.4	90	-0.2	84.8	0.11	91.6	-0.9	91.4	-0.3	89.8	-0.4	89.5	-0.4	89	-0.3	84.3	-0.8	82.1	-0.6	OK
	6	2010-3-6	62.4	-1.5	96	-1.8	88.6	-1.5	85.2	0.5	90.8	-1.8	90.2	-1.5	88.7	-1.5	88.1	-1.8	87.7	-1.6	83.5	-1.6	81	-1.6	OK
	7	2010-3-26	62.4	-1.5	96.4	-1.3	89.3	-0.9	85.6	0.89	91.3	-1.2	90.6	-1.1	89.4	-0.8	88.3	-1.6	87.6	-1.7	85.2	0.08	81.7	-1	OK
	8	2010-4-8	62.3	-1.6	96.8	-0.9	89.5	-0.7	85.4	0.67	91.4	-1.1	90.8	-0.9	89.1	-1.1	88.6	-1.3	88	-1.3	84.6	-0.5	81.8	-0.9	OK
	9	2010-4-15	63.7	-0.2	97.6	-0.1	89.9	-0.3	84.7	-0	92.3	-0.2	91.3	-0.4	89.9	-0.3	89.5	-0.4	88.7	-0.6	84.3	-0.9	82.1	-0.6	OK
	10																								

$$\text{dB} \equiv 20 \log_{10}\left(\frac{v_2}{v_1}\right) \text{ (ratio of voltage values)} \quad (2)$$

$$\text{dB} \equiv 20 \log_{10}\left(\frac{i_2}{i_1}\right) \text{ (ratio of current values)} \quad (3)$$

E. EMC Analysis, Prediction and EMC Design

EMC design must rely on EMC analysis and prediction. Key points in EMC analysis and prediction are the building of mathematical models and programming for the computation and analysis of EMI that is within a system or between systems.

Nowadays, though the accuracies of EMC analysis and prediction are not likely to be very high, they should reach the level of being serviceable in practice. For example, basic mathematical model has been set up for the quantitative discussion of shielding effectiveness of metal shielding shells, which points out the relationship between the shielding effectiveness SE_{dB} and the reflection loss R_{dB}, absorption loss A_{dB} and multiple-reflection factor M_{dB}, as (4).

$$\text{SE}_{\text{dB}} = R_{\text{dB}} + A_{\text{dB}} + M_{\text{dB}} \quad (4)$$

Furthermore, practical mathematical models have been built for the determination of exact values of shielding effectiveness under the condition of far field source [3], as well as the approximate values of R_{dB} and A_{dB}, as (5), (6) and (7), with η_0 being the inherent impedance of free space, $\hat{\eta}$ being the inherent impedance of shielding layer, t being the thickness of shielding layer (in meters), δ being the skin depth of shielding material (in meters), σ_{r} being the relative conductivity, μ_{r} being the relative magnetic permeability and f being the frequency (in Hz).

$$\text{SE}_{\text{dB}} \cong 20\log_{10}\left|\frac{\eta_0}{4\hat{\eta}}\right| + 20\log_{10} e^{t/\delta} + M_{\text{dB}} \quad (5)$$

$$R_{\text{dB}} = 168 + 10\log_{10}\left(\frac{\sigma_{\text{r}}}{\mu_{\text{r}} f}\right) \quad (6)$$

$$A_{\text{dB}} = 131.4t\sqrt{f\mu_{\text{r}}\sigma_{\text{r}}} \quad (7)$$

IV. SOME HOT TOPICS IN EMC TECHNOLOGY APPLICATION RESEARCH

For the EMC technology there are many research and application areas such as weapon systems [4~7], industrial electronics or microelectronics [8~15], power systems [16, 17], onboard or airborne electronics [18~28], communications [29], home appliances [30], lighting equipments [31], see Fig. 1. In each area, there can be several levels of concrete applications, as levels of system, subsystem, interconnect and component, etc. The challenging EMC technology areas for all these applications can be restricted to three main themes: EMC Design, EMC Standardization and EM (electromagnetic) Safety [32]. Hot research topics in some of the EMC technology application areas are presented as the following.

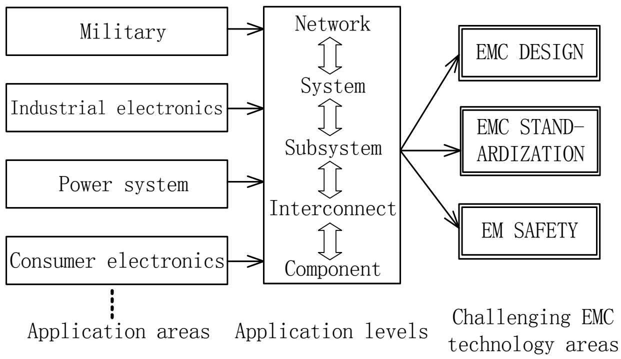

Figure 1. EMC view on electronic systems.

A. Electromagnetic Compatibility for Weapon Systems

With the technology development for military equipments, signal spectrum may be composed of by signals from various kinds of electrical equipments, and with the use schemes for electrical equipments changing at times, the characteristics of electromagnetic environment have become more and more complicated. Take a warship for instance, which can be considered as a platform holding lots of electronic weapons and electrical equipments, the embodiment of electromagnetic environment effects may have various forms. For example, the radio-frequency interferences may take on the characteristics of high amplitude and big density, the radiation from each electronic warfare system may have wide frequency spectrum, and the low-frequency communication equipments may be harmed by strong magnetic field environments or low-frequency heavy currents.

In a future war, effective management, control and flexible using of electromagnetic environment will become key factors in winning the initiative of the war. Therefore, listed below may be key points of the research with respect to war field electromagnetic environment effects [4].

1. Analysis techniques for electromagnetic environment.
2. Design techniques for electromagnetic safety of weapon system.
3. Simulation techniques for electromagnetic environment and strong electromagnetic environment.
4. Experimentation, test and evaluation of electromagnetic environment effects.
5. Techniques of control and management.

In the next section, complex eletromagnetic environment of modern informationalized battlefield under high-tech conditions will be emphatically addressed.

B. EMC Control and Management for Industrial Electronics or Microelectronics

The EMC research for electrical or electronic devices is still in its primary phase up to now. The research in the last years has been focused on such issues as techniques for modeling and suppression of EMI from power converter and motor transmission, parasitic effects of EMI filters, layout optimization for PCBs and numerical analysis techniques for EMI [8].

C. EMS Performance of the Equipments in Power Systems

Nowadays the application of digital instrument control system has been a hot topic for the research and development in nuclear power industry, and EMI immunity test of such system has become a focus of attention of the engineers. To improve EMC performance of the entire system, it is necessary to strengthen the design against EMI for such components as power supply, communication network, input/output module and CPU module, and reasonable design or corrective measures for electromagnetic environment of the system may also be necessary. Such measures may be proper grounding, standard wiring or dust prevention, etc [16].

Full-scale micro-computerization of the protection devices in power systems has become an irreversible trend. How to improve the anti-EMI ability of these devices to ensure the stable operation of power system has always been a hot topic for the research of microprocessor-based protection technology. To this problem, the anti-interference ability for the hardware as well as the software of such a device can be respectively taken into consideration [17].

D. EMC Performance for Onboard or Airborne Electronics

Take electric vehicles for example. For various kinds of electric vehicles such as fuel cell vehicles and HEVs, electromagnetic compatibility problems have been paid much attention, including the problems with car parts, control & management systems and entire vehicles. EMC research about electric vehicles aims at ensuring that the onboard electrical and electronic equipments can work compatibly together in the running state, each equipment being immune against interference from outside, meanwhile causing no interference beyond allowed range to other onboard or outside equipments.

E. EMI Suppression for Home Appliances

According to different kinds of operation principles and configurations, household electromotors can be sorted into two categories, i.e. commutator type and induction type. Electromagnetic disturbance from home appliances of the former type can be particularly serious, accordingly the anti-disturbance measures such as proper filtering, shielding and grounding should be considered in the early design phase [30].

V. ABOUT COMPLEX ELECTROMAGNETIC ENVIRONMENT OF BATTLEFIELD IN THE FUTURE

Electromagnetic environment of informationalized battlefield under high-tech conditions should be recognized as a composite environment, characterized by the joint action of various electromagnetic energy. In this composite environment, coexist both the sources of electromagnetic disturbances of natural origin, such as thunderbolts, electrostatic, etc., and those of serious man-made disturbances such as radars of various powers, radio communication, navigation and the antagonistic EW(electronic-warfare) equipments, new concept electromagnetic weapons, etc., see Fig. 2. The electromagnetic environment of any modern battlefield is mainly composed of various electromagnetic pulse fields [5].

For the research of complex electromagnetic environment, one should first get to know about some basic concepts and the relationships between each other, such as the concepts of electromagnetic environment, complex electromagnetic environment, electromagnetic disturbance, EMI, EMC, electromagnetic shielding, spectrum management and electronic warfare, etc. [6].

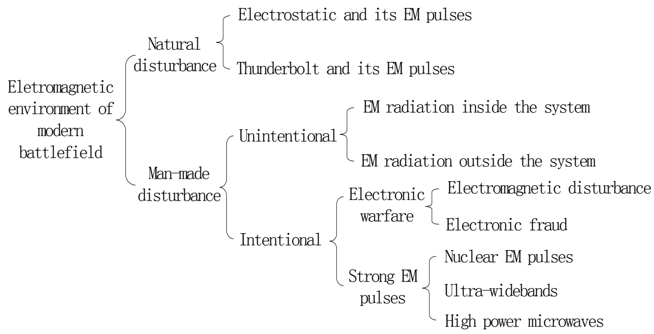

Figure 2. Formations of electromagnetic environment of modern battlefield.

A. Electromagnetic Environment and Complex Electromagnetic Environment

Electromagnetic environment commonly means the grand sum of all the electromagnetic phenomena consisting in some place.

On analyzing the formation and characteristics of electromagnetic environment of a future battlefield, electromagnetic environment under a battlefield condition can be defined as this: In a specific battlefield space, the grand sum of natural electromagnetic phenomena and man-made electromagnetic phenomena that may have influences on the warfare operations.

Complex electromagnetic environment may be defined as this: In a specific battlefield space, a battlefield electromagnetic environment having certain influences on the equipments, fuels and persernnel, environment being the superposition of different electromagnetic signals that may be densely distributed in complex modes, numerous in quantity, dynamic and stochastic in time domain, frequency domain, energy domain and space domain.

B. Electromagnetic Environment Effects

Electromagnetic environment effects refer to the effects of some factors or the collectivity of electromagnetic environment acting on the equipments, volatile materials and the organisms, etc. In Electronic

War published by the U.S. army in 2007, the concept of electromagnetic environment effects has been defined as the influences of electromagnetic environment on the operational capabilities of the armed forces, equipments, systems and platforms.

C. Electromagnetic Disturbance and Electromagnetic Interference

In GJB72A-2002, the concept of electromagnetic interference has been described as any conducted or radiated electromagnetic energy that can interrupt or hamper, even degrade or restrain the performance of radio communication or some other electrical or electronic equipment. The U.S. army defines electromagnetic interference as: any electromagnetic disturbance that can interrupt or hamper, degrade or restrain the working efficiency of electrical or electronic equipment.

The concept of electromagnetic disturbance contains the two meanings of natural and man-made disturbances, and it is a neutral concept without particular attributes, commonly signifying the electromagnetic disturbance phenomena in the combat systems of own side or the ally side. However, electromagnetic interference usually means a kind of man-made purposeful electromagnetic behaviors, generally the behaviors between the two warring sides.

D. Electromagnetic Compatibility, Electromagnetic Shielding and Spectrum Management

Electromagnetic compatibility refers to a coexistence state that in a common electromagnetic environment, the respective functions of equipments, subsystems or systems can be exercised all together. There are two aspects of this concept.

(1) When running in an expected electromagnetic environment, equipment, subsystem or system can fulfill its designed performance according to specified security margins, the performance not to be compromised or unacceptably degraded because of electromagnetic interference.

(2) When smoothly running in an expected electromagnetic environment, an equipment, subsystem or system is not likely to bring about unacceptable electromagnetic interference to the environment (or some other equipment).

Electromagnetic shielding refers to the measures taken for avoiding the influences or even damages that may be suffered by the electro-explosive devices, fuels and personnel from electromagnetic environment effects(or electromagnetic hazard sources), as well as the technical measures for electronic equipments and subsystems to lower their electromagnetic sensitivity and get the ability of anti-electromagnetic interference or anti-electromagnetic damaging, especially the countermeasures against enemy electromagnetic attacks.

The two research subjects of electromagnetic compatibility and electromagnetic shielding have coherence in their intensions and extensions, and both of the research purposes are to improve the viability and serviceability of any system in an expected electromagnetic environment.

Military electromagnetic spectrum management is a collective term for a set of activities of military leading bodies and electromagnetic spectrum management organizations, including the establishment of policies and systems for electromagnetic spectrum management; the division, planning, distribution and allocation of frequencies and spacecraft orbit resources; and the supervision, inspection and coordinating management for the usage of frequencies and spacecraft orbit resources, etc. In fact, spectrum management is also a sort of management and control measures for ensuring the electromagnetic compatibility of systems or equipments.

VI. Development trends of EMC technology application

In industrial production and human life, the harm of EMI has been recognized more and more widely. For example, for fear of security threat to a flying civil aircraft, it is forbidden to use mobile phones in the capsule cabin, because electromagnetic disturbance from a mobile phone may be coupled in the cables then to the sensitive equipments in the aircraft, and the disturbance may also radiate outward through the cabin windows and then be directly received by the antennas and sensors, which are numerous on the fuselage. As another example, electromagnetic radiation may interfere with electro-explosive devices, making them mistakenly detonated. The American Ellen Sugarman depicted in his *Warning-the Electricity Around you May be Hazardous to your Health: How to Protect Yourself From Electromagnetic Fields* that many epidemiology researches have revealed that being exposed to a magnetic field of over 2 milligausses may add to the risk of contracting cancer. And if a residence is within 100 meters far away from high-tension cables, the risk for children to contract leukaemia or brain cancer will increase.

With the fast increase of clock frequencies of integrated circuits in electronic systems (already up to 15 GHz in the year 2010), the number and variety of potential EMI sources and victims around us are going to increase exponentially in the near future. The question of how to control EMI is becoming a key issue in system design [32]. To meet the market needs for products that are safe to use, highly reliable and perfect in EMC performance, new methods and new means should be adopted to lower EMI from electrical components, interconnects and (sub)systems, meanwhile improve their immunity for EMI. Future electromagnetic environment needs to be controlled through the establishment of legislation and standardization, with new test methods, frequency bands and EMI limits.

Zhao Gang has made the discussion for the development trends of EMC technology in the information age for military equipments [7], which is also useful for reference by other EMC technology application areas and generalized as below.

1. Improvement of the viability and serviceability of C^4ISR system is a focus in EMC research in this century.

C^{4}ISR is a man-machine system that integrates the subsystems of command, control, communication, computer, intelligence, surveillance and reconnaissance. By the comprehensive use of modern electronic and information technologies and military science theories in a battle command system, C^{4}ISR can achieve the scientization of decision-making methods and the automation of operational information collection, transfer and processing, thus ensuring the operational command to be efficient.

2. Application of predictive analysis method will feature in EMC design and EMC control for electronic equipments in this century.

So called “predictive analysis method” means in the beginning as well as the whole course of weapon equipment development and design, with numerical calculation methods complemented with appropriate tests and according to the equipment characteristics, antenna layouts, armament layouts or the component characteristics and circuit layouts, making predictive analyses for electromagnetic characteristics of the systems, subsystems, equipments, parts, components and then among them making reasonable distribution of EMC targets; making requests and targets for the control devices, circuits, elements and continually making corrections and supplements for these requests and targets, and making solutions for EMC problems along with the development process.

3. Verification, evaluation and shielding of electromagnetic environment effects are hot problems to be solved in current days.

Electromagnetic environment effect refers to the influence from electromagnetic environment to the service ability of electrical or electronic system, equipment or device. It covers all of the electromagnetic disciplines including EMC, electromagnetic interference, electromagnetic vulnerability, electromagnetic pulses, electronic countermeasures, harms of electromagnetic radiation to armament and volatile substance, and natural effects such as thunderbolt or sedimentary electrostatic.

4. Proper management and utilization of radio frequency spectrum resources are becoming much important for EMC technology application in the information age.

Radio spectrum is a kind of natural resource that is important, limited and non-consumable. With the rapid development of information technology, spectrum resources are being made full use of (see Fig. 3), meanwhile the increasingly overcrowded spectrum occupancy plus serious electromagnetic pollution is making the available spectrum resources increasingly poor. As a result, how to meet the demands of information society for spectrum resources and how to make the best of and effectively manage the limited spectrum resources, have become critical problems to be solved in this information age.

5. Exploration and application of new techniques, new materials and new devices are the trends for EMC technology development.

The technologies for EMI suppression and anti-interference reinforcement are backbone technologies for EMC control. The bases of technologies for achieving good electromagnetic compatibility of circuit components, equipments, systems or armament platforms, are the carrying out of interdisciplinary and multidisciplinary joint researches, persistent development and application of new EMC technologies, new materials and new devices, and meanwhile the full using of classic techniques of shielding, filtering, decoupling, isolating and grounding, etc.

Gao Yougang has enumerated several outstanding problems in the current development of environment electromagnetism and EMC technology, briefly introduced as follows [33].

1. Electromagnetic compatibility prediction

EMC prediction is necessary in the development of a complicated equipment or system. At present time, EMC predictions are carried out at three levels.

1) EMC predictions at chip level

2) EMC predictions at component level

3) EMC predictions at system level

Unfortunately, it is hard to make perfect EMC prediction at whichever level by now. There has not been any serviceable prediction software. As extremely complex electromagnetic boundary-value problems, EMC problems are hard to solve using conventional methods.

2. Development of shielded-measurement technologies

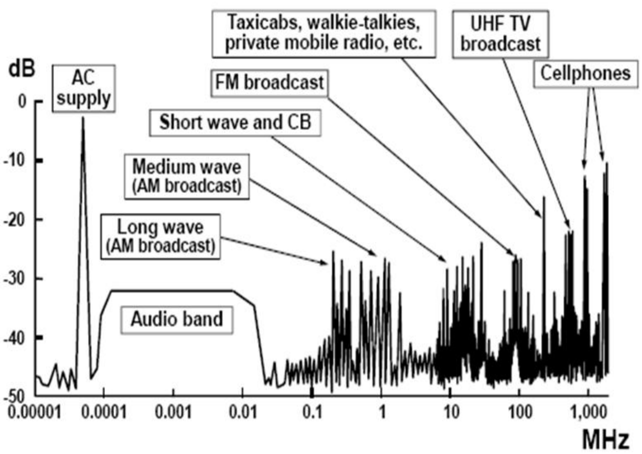

Figure 3. The frequencies we use.

Figure 4. A stirred-mode chamber.

Recently the development of stirred-mode reverberation chambers (see Fig. 4) has gained much attention. The need of reverberation chambers comes from the requirement for high EMI field intensity from the test standards like aerospace standards, military standards and motor vehicle standards.

3. Frequency spectrum allocation and management

From the mid-twentieth century people have come to realize that, the radio spectrum composed of the three factors of space, time and radio frequency is a unique kind of natural resources. It is a resource being limited but not consumable, being important but not visible or touchable. For this precious and special resource, scientific management is necessary, meanwhile the application of this resource needs to be most effective and strictly restricted, thus ensuring a desirable radio environment.

4. EMC problems of space vehicles

A space vehicle is a mixed system, combined with complex mechanical structures and complex electrical and electronic structures. EMC analysis and prediction for this system can be divided into two aspects.

1) For the basic component units in the system that can be effectively analyzed, corresponding analysis software packages should be worked out and mathematical models are made as perfectly as possible, by means of various electromagnetic numerical analysis methods that may be relatively complex and relatively accurate.

2) The inside of a space vehicle can be divided into several relatively independent subsystems, and each subsystem may be equivalent to an EMI source or an EMI victim. Following EMC analysis and prediction for each subsystem, corresponding mathematical models can be worked out.

5. EMC problems in radio communication technology

Some critical EMC problems need to be solved for mobile communication technologies in this century, so that the development of such technology can be based upon a reasonable foundation. The research work should include two aspects, namely in-system problems and those between systems.

1) EMC problems are very complicated inside a system, especially in a radio system equipped with high frequency components and circuits. Special attention should be paid to the systems for high-speed information transmission, and this will be an important research direction for EMC problems in this century.

2) Some critical EMC problems between systems should also get enough attention.

6. EMC problems in the computers

A computer is a low-level electronic system, commonly working in a complex electromagnetic environment, meanwhile radiating outward and leaking electromagnetic interferences in a wide frequency band. And yet from the angle of electromagnetic compatibility, the computer is mainly sensitive equipment. Generally speaking, the main measures for improving the anti-interference ability of computer systems can be outlined as follows.

1) The improvement of anti-interference ability of a system itself can be set about from the design of hardware and software.

2) Shield earthling is an effective measure for the improvement of anti-interference ability of a computer.

3) Filtering is an important method to suppress the transmission coupling interference.

4) High-density information can be transmitted using light technology, which is not easily affected by electromagnetic induction noises.

7. Ecological effects of electromagnetic fields

The influences of electromagnetic waves on biological tissues have strong frequency dependence. Currently there are two frequency bands being intensively studied, one is the electric power frequency (50Hz~60Hz), the other is the radio wave band(radio frequency).

1) Ecological effects of low-frequency fields

Foreign medical research results have shown that electromagnetic fields of high-tension cables can produce harmful effects on human tissues. The factors causing such electromagnetic environment problems include the noise waves from corona discharges, ozone and the magnetic fields and electric fields induced by the currents and voltages in the conductors.

2) Biological effects of radio frequency fields

Effects of electromagnetic waves on biological tissues can be divided into thermal effects and non-thermal effects. The mechanisms of thermal effects are relatively clear, while those of non-thermal effects are not exactly.

In conclusion, the effects of electromagnetic radiation on animals and human bodies are a kind of important research subjects, although there has been great progress in this research, many problems are still not clear and thus need further researches, especially those researches and tests being systematic, long-term and complying with scientific standards.

REFERENCES

[1] Zhang Linchang, "Developing electromagnetic compatibility undertaking in our country," *Transactions of China Electrotechnical Society*, vol. 20(2), pp. 23–28, 2005.

[2] Ma Weiming, "Several problems in the research for EMC prediction of independent system," *Electromagnetic Compatibility Technology*, vol. (2), pp. 1–4, 2005.

[3] Clayton R. Paul, *Introduction to Eletromagnetic Compatibility (Second Edition. Translated by Wen Yinghong etc.)* Beijing: Posts& Telecom Press, 2007.

[4] Hou dongyun, "Electromagnetic environment status and EME/EMC technology development," *Electromagnetic Compatibility Technology*, vol. (4), pp. 1–5, 2007.

[5] Liu Shanghe, "Weaponry furnishment and electromagnetic environment effects," *Electromagnetic Compatibility Technology*, vol. (3), pp. 1–7, 2006.

[6] Liu Shanghe, Sun Guozhi, "Analysis of the Concept and Effects of Complex Electromagnetic Environment," *Electromagnetic Compatibility Technology*, vol. (2), pp. 1–6, 2009.

[7] Zhao Gang, "Development trend of weaponry furnishment EMC technology in the informational age," *Ship Electronic Engineering*, vol. 27(1), pp. 20–22, 2007.

[8] Qian Zhaoming, Chen Henglin, "State of art of electromagnetic compatibility research on power electronic equipment," *Transactions of China Electrotechnical Society*, vol. 22(7), pp. 1–11, 2007.

[9] Ali Alaeldine, Nicolas Lacrampe, Alexandre Boyer, etc. "Comparison among emission and susceptibility reduction techniques for electromagnetic interference in digital integrated circuits," *Microelectronics Journal*, vol. 39(12), pp. 1728–1735, 2008.

[10] Zhou Changlin, Hu Mingxin, Lin Xin, etc. "Electromagnetic compatibility analysis and design for digital signal controllers," *Asia-Pacific International Symposium on Electromagnetic Compatibility*, pp. 668–671, 2010.

[11] Boyuan Zhu, Junwei Lu, Erping Li. "Electromagnetic compatibility benchmark-modeling approach for a dual-die CPU," *IEEE Transactions on Electromagnetic Compatibility*, vol. 53(1), pp. 91–98, 2011.

[12] Zhen Zhang, K. T. Chau, Zheng Wang, etc. "Improvement of electromagnetic compatibility of motor drives using hybrid chaotic pulse width modulation," *IEEE Transactions on Magnetics*, vol. 47(10), pp. 4018–4021, 2011.

[13] M. S. Sarto, A. Tamburrano. "Modelling approaches for nanotechnology applied to electromagnetic compatibility," *Asia-Pacific International Symposium on Electromagnetic Compatibility*, pp. 498–503, 2010.

[14] C. Fuentes, B. Allongue, G. Blanchot, etc. "Optimization of DC-DC Converters for improved electromagnetic compatibility with high energy physics front-end electronics," *IEEE Transactions on Nuclear Science*, vol. 58(4), pp. 2024–2031, 2011.

[15] Erping Li, Xingchang Wei, Andreas C. Cangellaris, etc. "Progress review of electromagnetic compatibility analysis technologies for packages, printed circuit boards, and novel interconnects," *IEEE Transactions on Electromagnetic Compatibility*, vol. 52(2), pp. 248–265, 2010.

[16] Huang Wenjun, Yu Haoyang, Ao Chunbo, "EMC test and design of I&C system in nuclear power plants," *Nuclear Power Engineering*, vol. 29(3), pp. 85–88, 2008.

[17] Peng Honghai, Zhou Youqing, Wang Hongtao, etc, "Anti-interference technology for microprocessor-based protection," *High Voltage Engineering*, vol. 33(10), pp. 49–53, 2007.

[18] Lucas E. A. Chamon, Claudio H. G. Santos, Kenedy M. dos Santos, etc. "Dielectric effects in electromagnetic compatibility experiments for automotive vehicles," *9th IEEE/IAS International Conference on Industry Applications*, pp. 1–6, 2010.

[19] Y. Li, F. P. Dawalibi, R. Raymond. "Electromagnetic compatibility analysis of power line and railway sharing the same right-of-way corridor: a practical case study," *International Conference on Future Power and Energy Engineering*, pp. 103–106, 2010.

[20] Wang Jian, Cai Bai-gen, Liu Jiang, etc. "Electromagnetic compatibility design of multi-sensor based train integrated positioning system," *International Conference on Electromagnetics in Advanced Applications*, pp. 753–756, 2010.

[21] Mohamed Youssef, Jaber A. Abu Qahouq, Mohamed Orabi. "Electromagnetic compatibility results for an LCC resonant inverter for the tranportation systems," *Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition*, pp. 1800–1803, 2010.

[22] Emmanuelle Garcia. "Electromagnetic compatibility uncertainty, risk, and margin management," *IEEE Transactions on Electromagnetic Compatibility*, vol. 52(1), pp. 3–10, 2010.

[23] R. De Maglie, A. Engler, "Radiation prediction of power electronics drive system for electromagnetic compatibility in aerospace applications," *Proceedings of the 14th European Conference on Power Electronics and Applications*, pp. 1–9, 2011.

[24] Guo Dandan, Su Donglin, Xie Yongjun, etc. "The complex network model of the airborne equipment electromagnetic compatibility," *9th International Symposium on Antennas Propagation and EM Theory*, pp. 1019–1022, 2010.

[25] Mohamed Youssef, Jaber Abu-Qahouq, Mohamed Orabi. "The electromagnetic compatibility design considerations of the input filter of a 3-phase inverter in a railway traction system," *IEEE Energy Conversion Congress and Exposition*, pp. 4210–4216, 2010.

[26] Liu Ying, Xie Yong-jun, Zhang Yong. "Top-down design flow and its applications in multi-vehicle communication system's EMC design," *Journal of University of Electronic Science and Technology of China*, vol. 39(5), pp. 720–724, 2010.

[27] Zheng Yali, Yu Jihui, Wang Quandi, etc. "Dynamic circuit model of the spark plug for EMC prediction of ignition system," *Transactions of China Electrotechnical Society*, vol. 26(2), pp. 8–13, 2011.

[28] An Jing, Wu Junfeng, Wu Yihui. "Electromagnetic compatibility design of electronic control system for attitude control flywheel," *Journal of Jilin University (Engineering and Technology Edition)*, vol. 41(4), pp. 998–1003, 2011.

[29] Nozad Karim, Jingkun Mao, Jun Fan. "Improving electromagnetic compatibility performance of packages and SiP modules using a conformal shielding solution," *Asia-Pacific International Symposium on Electromagnetic Compatibility*, pp. 56–59, 2010.

[30] Liu Ping, Sha Fei, "Improving the electromagnetic compatibility of home appliances with commutator electromotor," *Journal of Northern Jiaotong University*, vol. 26(6), pp. 64–68, 2002.

[31] Eugen COCA, Valentin POPA, Georgiana BUTA. "Compact fluorescent lamps electromagnetic compatibility measurements and performance evaluation," *IEEE International Conference on Computer as a Tool*, pp. 1–4, 2011.

[32] Van Doorn M, "EMC technology roadmapping: a long-term stragegy," *IEEE International Symposium on EMC*, pp. 156–159, 2006.

[33] Gao Yougang, etc, "Forecast of electromagnetic compatibility technology," *Electromagnetic Compatibility Technology*, vol. (1), pp. 1–5, 2006.