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Development of Japanese EMC Engineering in 1996–2009 and Prospects

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SUMMARY Subjects in Electromagnetic Compatibility (EMC) research that have been presented at meetings of the IEICE Technical Committee on Electromagnetic Compatibility (EMCJ) are overviewed and categorized. The temporal changes in the proportions of the categorized subjects among the total number of presentations each year is also shown. Finally, speculative opinions are presented on what EMC subjects will be studied in the near future.

key words: *IEICE, EMCJ, subjects, review, prospects*

1. Introduction

In Japan, subjects related to electromagnetic compatibility (EMC) have been covered at technical meetings of the Technical Committee on Electromagnetic Compatibility (EMCJ). The EMCJ was founded in 1977 as a part of the Institute of Electronics, Information and Communication Engineers (IEICE). Meetings have been held almost monthly, along with a few special events such as a tutorial workshop and another meeting, called the "Yuzawa Workshop," that deals with the hottest current subjects at that time of the year.

EMC research subjects arose immediately after the start of electric communication. Over the next century, bandwidth expanded beyond 100 GHz, while the range of communication extended to a few million kilometers, reaching Mars. The amount of information exchanged over the globe is seemingly limitless, and the speed of personal communication often exceeds 100 Mbits/s. Under these circumstances, EMC subjects has expanded their coverage from radio communication to electrostatic discharge (ESD), electromagnetic interference (EMI) from digital devices, the biological effects of radio waves, and even to electromagnetic (EM) theory itself, which has been modified to a form more suitable for the wider range of engineers working in electrical industries. Deeper understanding of EM theory is still being cultivated as new EMC subjects arise during technological development.

This report was first written for the annual report of the Kansai Electronic Industry Development Center [1]. It was then revised and submitted to the IEICE transactions of communications (Japanese Edition) [2]. The contents were revised to include newer materials and are presented here in English in order to introduce EMC research activities in Japan over the period of 1996–2009. Proceedings of EMCJ meetings are published as "Techinical Report of EMCJ" [3].

2. Research Subjects in the Last 14 Years

2.1 Technical Committees on EMC

Technical information about EMC is exchanged via the EMCJ, as mentioned in the previous section, as well as in the Technical Committee on Electromagnetic Compatibility under the Institute of Electrical Engineers of Japan, the Technical Committee on Electromagnetic Characteristics under the Japan Institute of Electronics Packaging, and various commercial seminars. The EMCJ is the central technical meeting among these. Table 1 classifies the subjects reported there from 1996 to 2009, which were thoroughly extracted, excluding invited lectures and subjects given by other technical committees cosponsored with the EMCJ. Figure 1 shows the temporal changes in the proportions of reports on each of the subjects to the total number in a year.

The figure shows that measurement technologies, EMI control, new materials, and the biological effects of EM radiation have been the dominant subjects. Most of the reported materials have been absorbers. Studies of biological effects were launched through governmental funds about 10 years ago, and the results are now being collected. EMI from power electronics is a serious problem, especially in developing hybrid and electric automotive technologies. A current controversy over EMI from power line communication (PLC) systems relates to how ham radio operators and radio astronomers who are still opposite to admit PLC from the standpoint of EM environment. The details of each subject are explained below.

2.2 PCBs, Devices, and Cable

The ultimate objective is to eliminate the common-mode current along the cable connected to a device under consideration [4]. This problem cannot be resolved for a design based only on Kirchhoff's laws; instead, the design process should recognize that the device is a distributed parameter system, or a microwave circuit. Precise numerical solvers like FDTD or MoM are often too heavy to obtain the ultimate solution, while lighter models, instead of a real model, have been proposed to give enough accuracy within a limited time to allow designers to improve their products' EMI performance. This approach is the mainstream effort in EMI

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Table 1 Categorized subjects for EMC presentations.

PCB	Power · GND System	
	Transmission Line	Signal Integrity
		Common Mode
		CrossTalk
		Radiation
	Radiation	NearField
		FarField
	Immunity	
Cable	Common/Radiation	
	Immunity	
	Balance-Unbalance Transformation	
Devices	Radiation	
	Immunity	
LSI	DriverModel	
	Immunity	
Bio-medical	SAR	
	Non-thermal Effect	
	medical Application	
Counter-measure	EMC Cases	
	Noise Suppression Parts	
	Grounding	
	Automobile	
	Airplane,Railway,Ship	
Material	Measurement of $\epsilon\mu$	
	meta-material	
	Absorber	
	Shield	
Discharge	ESD	
	Lightning	
	Contacts	
EM Analysis	Analysis	
	Radiation	
EM Environment	noise Source Model	
	Terrestrial EM ambiance	
	Space and Ionosphere	
Measurement Technology	Site	
	Antenna	
	Probe	
	Source Estimation Immunity	
Specific Devices	Power Line Communication	
	ITS/ETC	
	WirelessLAN BlueTooth	
	Power Elictronics	
Standards and Regulations		

control so far. A model to predict the resonance between the power and ground planes of a PCB has been developed. Excitation of common-mode current on transmission lines is also within the scope of this work [5], [6]. Research to accelerate the numerical computation of EM fields also continues, in order to reduce computational cost [7].

Waveform distortion in a micro-strip line only 10 mm long becomes unavoidable as the clock frequency reaches the gigahertz range, and similar problems occur even inside LSIs. The traditional guiding principle has been that "an electric signal runs inside a conductor," and Kirchhoff's laws have been the fundamental design basis. This framework should be changed to the principle that "electric power is guided by a pair of conductors and transmitted through the space around it." Engineers should embrace this refined approach.

Microstrip lines (MSLs) on printed circuit boards (PCBs) are suitable for mass production, but the problems of crosstalk between adjacent lines, distortion of signal profiles, and propagation delays require examination. Currently, the vias connecting different layers of a PCB inject EM energy into the cavity comprising the GND and Vcc layers. The EM energy is radiated from the edge of the PCB, supplying common-mode current to the cables connected to the PCB. The potentials of the GND and Vcc layers are modified by the EM energy, which changes the digital system's threshold for increasing the bit error rate. Three-dimensional design is necessary to cope with these problems: designing a device with either a two-dimensional PCB layout or a circuit diagram is insufficient. Many research activities are involved in this subject, but more research is necessary. Similar problems occur in LSIs as the frequency range increases, and enormous effort is being devoted to this issue, because the design stage is the only opportunity to resolve EMC problems in LSIs. Without further innovation in EM design for LSI interconnection technologies, neither further scaling nor increased speed will be achieved.

Very precise, detailed numerical EM solvers can show how an EMC problem occurs, but device designers require PCB and LSI models that make it quick and easy for engineers to obtain results in time to deliver their products to the market. A simple equivalent circuit model for an LSI driving the power distribution system of a PCB with level of effluent noise has been proposed [8]. This model should be accepted internationally, and negotiation is currently underway within the International Electrotechnical Commission (IEC).

2.3 Materials

Absorbers are used to reduce unnecessary EM radiation inside a closed or limited space. Electronic toll collection (ETC) systems installed at highway tollgates suffer serious interference between automobiles and reflections from the road surface and roofs. Unless these systems are covered by EM absorbers, they cannot distinguish one car from the next [9]. For local area networks (LANs), excellent absorbers will be required both to enhance security and to exploit a limited number of channels. Absorbers' performance as building materials should also be considered, in addition to their EM performance.

Meta-materials could overcome the limits of natural materials in terms of EM characteristics, including anisotropy, negative dispersion, and controllability of frequency dependence. Artificial structures, with active elements in some cases, have been examined [10]. These could provide solutions when extreme performance is required.

2.4 ESD and Lightning

Lightning has been described since the beginning of

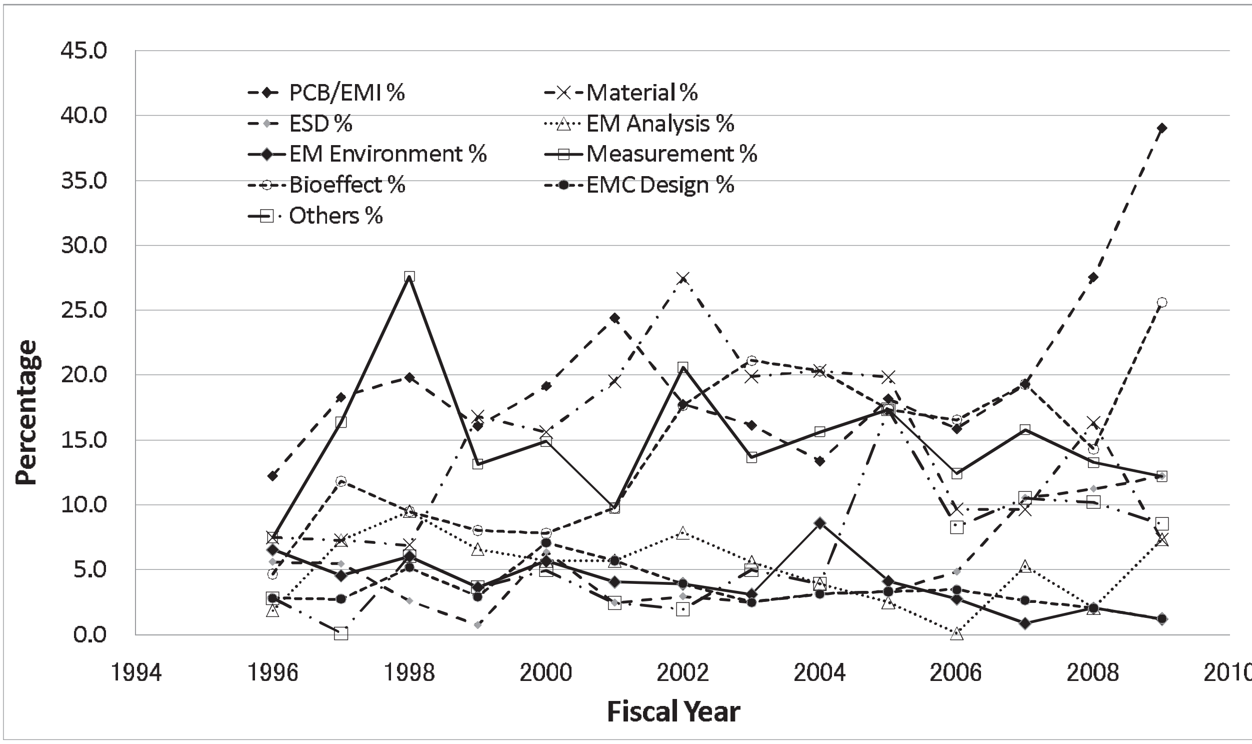

Fig. 1 Temporal changes of number of subjects in proportions of total subjects in a year.

Japanese history as one of four terrible things†. The generation mechanisms and properties of lightning still attract many researchers. Protection from lightning strikes is one of the most important immunity subjects, along with high-power EM pulse (HEMPs) and nuclear EM pulses (NEMPs). HEMP and NEMP subjects have rarely been mentioned in the EMCJ, because military subjects are confined to *ad hoc* consideration as a result of Japan's political situation since 1945. Lightning-related research is presented more commonly in meetings other than those of the EMCJ. ESD, however, is frequently reported in the EMCJ. A tiny amount of ESD originating from a human body can crash a large computer system protected strictly with multiple layers. Researchers are struggling to study the generation and propagation of sub-nanosecond impulses, and their results are often reported in the EMCJ [11]. Impulses from electrical contacts are also similar to ESD, and many phenomena remain unaccounted for, even though contacts are essential elements of electronic devices [12].

2.5 EM Environments

Atmospheric conditions and corona discharges as sources of noise have been considered in the area of radio communication, and seismic EM noise accompanying earthquakes is another active subject [13]. Environmental EM noise has been increasing as electrical and electronic devices become more common in both residential/commercial and industrial areas. Wireless LANs are being widely utilized with increasing area coverage. The noise levels in rural and suburban areas differ more than ever. These factors require revising models of environmental EM noise levels, and the notion of amplitude probability distribution (APD) could provide a new scheme for such evaluation [14].

2.6 Measurement Technologies

New technologies require new methods of measurement, pushing development of measurement technologies to the frontier of engineering. New problems have arisen as clock and carrier frequencies increase. Both emission from LSIs and driving currents are now also of concern, in contrast to the former situation in which only PCBs were ever examined to control EM noise. The currents in LSI pins should be directly measured, which requires new probe techniques not [15].

EMC subjects relate closely to regulations, and compliance with those regulations does not necessarily rest on a logical or scientific basis. Both regulations and solutions have been *ad hoc* and temporary. Invention of new measurement technologies as well as advanced EM models for devices will resolve this problem by helping make regulations as scientific and logical as possible.

2.7 Biological Effects

The question of whether radio waves from mobile phones

†Earthquakes, lightning, house fires are terrible as well as a stern father according to a Japanese proverb.

affect human health has been posed since the beginning of these devices' popularization. It has been very difficult for specialists to find a rigorous answer to this problem, which is still of interest to the public. Thermal effects are dominant over the frequency range of the HF band, and the specific absorption rate (SAR) is used to evaluate these effects. Prediction of SAR and measurement for a handy phone under examination are necessary for commercial items to comply with regulations. For SAR prediction, a precise human body model of typical Japanese people for numerical calculation was developed at the expense of enormous time and labor [16]. The model is used for various examinations of SARs under different situations. Non-thermal effects in the low-frequency region, as in areas adjacent to power transmission lines, is still under study [17] but could require more time before any conclusion is reached. A conclusion that is sufficiently persuasive for both the public and specialists could be intrinsically impossible.

In contrast to the above subjects, research on heating by electromagnetic induction is expected to lead to cancer treatments [18]. The technologies developed in this research could also be useful for EM field control of PCBs.

2.8 Facts of EMI/EMS and EMC Design

The facts of "EM interference: EMI" and "EM susceptibility: EMS" are ubiquitous throughout the industrial world, but they are not reported to the public because they are a "dirty secret" for engineers and organizations, which prefer not to mention these facts in public. Only suppliers of EMC components proudly report the performance of their products.

The hottest current subject requiring EMC design is electric and hybrid car development. These cars are expected to effectively reduce both fuel consumption and the air pollution contributing to the global temperature rise. Although there are currently too many technical problems to develop a pure electric car driven only by electric motors, i.e., an electric vehicle (EV), automobile manufacturers cannot continue to exist without marketing electric and hybrid vehicles. The space inside a car is closed, and achieving compatibility between radio communication systems, such as AM/FM radio receivers, and high-power inverter/converter systems to drive electric motors is a very difficult engineering task [19]. From another viewpoint, however, this difficult situation will push EMC technologies to a more innovative stage, in which new devices and technologies that were previously uneconomic become affordable because of the gravity of the problem.

Aircraft development has been managed by mechanical engineers, rather than electrical engineers, since its inception. Airplane electrical systems have been designed and operated in a manner that is not amenable to the concept of EMC. In that field, electricity is still considered to propagate "in conductors," ignoring the idea that an electric signal propagates in the neighborhood of the guiding conductors. Only DC signals are within the range of the aircraft industry's consideration. Demands for the capability to use mobile phones and personal computers, not to mention wireless LANs, are becoming stronger over time, and airline companies have begun pushing aircraft manufacturers to resolve the undergoing problems for passengers [20]. ESD is also a serious problem in airplane cabins, where humidity is extremely low.

In railways, compatibility between power and signals has been important [21], and public emission and the immunity of signaling systems to environmental EMI has become more serious issues than ever before. A very large amount of experience and data should have been accumulated, but only limited reports have been made public, perhaps because of fears of intentional or unintentional misunderstandings that could disturb ongoing operation and development.

As for ships, EMC subjects likely come up only accidentally in the development and construction of ships. Ship engineers are still not aware of EMC design for their system, except for avoiding fatal outages in high-power transmitters for radio telecommunication.

2.9 PLC

The development of consumer electronics has been invigorated by the spread of TCP/IP and LAN technologies. The goal is to share information-processing functions among different devices in a house over a LAN. In addition to this, PLC systems are expected to operate within LANs. These systems should not only connect ordinary devices like refrigerators and washing machines, but also carry video signals to and from high-definition televisions (HDTVs) as well as computer systems. Radiation of EM noise in the HF range, which leaks from these systems, has been well anticipated, and considerable controversy has ensued over the last few years. Ham radio operators and radio astronomers have claimed to suffer from such leakage [22]. After elaborate examination and discussion involving the Japanese government, academics, industrial experts, ham operators, and astronomers, a formal regulation was issued in 2008 [23]. Commercial products meeting this regulation are now being supplied to the market. This regulation is sufficiently strict to encourage suppliers to achieve further innovation.

3. Forecast of Future EMC Technologies

The increase in frequencies is the largest issue making EMC problems more difficult. Higher frequencies, with shorter corresponding wavelengths, require the use of distributed parameter models for devices instead of lumped models.

The use of direct numerical methods, such as FDTD or MoM, though necessary in certain cases, requires too many computational resources and cannot be applied by a designer who prefers to use only a personal computer on a daily basis. Therefore, a simulator that can more quickly evaluate the level of EMI of designed products is required. The key strategy is to replace fundamental calculations from Maxwell's equations with secondary numerical models based on the practical conditions under which a device is used.

Research in this area has been ongoing for about 10 years by a few institutions and is expected to provide sufficiently practical tools in the near future. Planar PCBs are already within the scope of this research, and models of the LSIs that drive PCBs are also under consideration. Equivalent circuit models for specific LSIs are necessary and should be distributed by vendors; otherwise, device designers cannot utilize such models. Linear equivalent circuit and current source (LECCS) models have been proposed in Japan, and a similar model has also been proposed in Europe. These models are to be unified, and negotiation is underway within the IEC. This will combine the advantages of the SPICE and IBIS models that are now in practical use.

On the other hand, designers of highly integrated systems that simultaneously incorporate digital and analog systems within a small casing, such as mobile phones, must rely on direct numerical tools to analyze these systems' intense transmission signals, or their combination of high clock frequency and high receiving sensitivity.

3.1 Materials

Ferrite is used in the high-frequency region because of its high permeability, μ, and low loss, $\tan\delta$. The permeability decreases, however, beyond a frequency of 1 GHz, and designers long for innovation to overcome this problem. A new material could resolve the problem but has not been achieved. A compromise is possible with "meta-materials," as mentioned in Sect. 2.3. Controlling the nano-scale structure of such materials might lead to solutions. An absorbing material with the characteristic impedance equivalent to that of free space also has not been obtained, but it would facilitate shielding for EM invisibility or other innovative purposes.

3.2 Electromagnetic Analysis

It is unknown whether the performance of personal computers will continue to increase, and whether a drastic decrease in electric power consumption is possible. If these goals are achieved, integrated systems of multiple computers will provide numerical power to designers, enabling them to confirm that designs based on the "modeling" approach work well. This indicates the possibility, though it may be rare, of anticipation error in the "model-based" approach. Antenna designs will be seriously expedited.

3.3 Electromagnetic Environments

The EM environment is, in almost all cases, told, based on a sinusoidal function of time as well as in the frequency domain. Theoretically, all EM subjects could be considered in this manner. The upper limit of the frequency region under consideration and application of non-sinusoidal waveforms, however, arise in ultra-wideband (UWB) systems and spread-spectrum systems (SSSs) and could arise in future communication systems utilizing non-sinusoidal carriers that are not amenable to the traditional Fourier transform. A new self- or bi-orthogonal system of base waveforms will contribute to the development of future communication systems.

3.4 Biological Effects of EM Waves

It is difficult to describe the effects of EM waves on the human body quantitatively and reliably, but such examination will continue. This problem has a facet of social recognition. I previously coined the term, "Margaret syndrome," for the social phenomenon of people claiming harm from EM radiation. The origin of the term lies in a specific recent Japanese subculture and is omitted here for brevity.

Medical applications, however, will improve as EM technologies improve. It will be increasingly easier to control EM beams with further progress in computer technologies and materials. EM radiation over 100 GHz or 1 THz will open the door to a new field of EM applications

3.5 EMC Problems in Mobile Platforms

EMC problems in automobiles and airplanes require innovative technologies to cope with the greater integration of multiple EM functions and higher frequencies. The lack of "ground" is also a serious problem, and our traditional technologies fail to resolve compatibility problems between different devices installed in the same platform. Modeling of EM electronic devices in terms of their nearby EM fields should be pursued.

Epilogue and Acknowledgements

The author has benefited from this opportunity to overview the subjects presented in EMCJ meetings on behalf of the distinguished people engaged in EMC research in Japan. Here, I add my personal thoughts to the above analysis. During the 12 years covered in this report, a few people who have contributed to the progress of EMC subjects have passed away, but younger researchers have joined us. This report is dedicated to all who have contributed to our efforts to understand EMC. He extends his gratitude to the Special Section Editorial Committee, who afforded him the opportunity to prepare this contribution.

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