The Future of EMC and the EMC Society

Daniel D. Hoolihan, Associate Editor
Chairman, EMC Society 50th Anniversary Committee and the History Committee

When the EMC Society celebrated its 25-year anniversary in 1983, the EMC Society published a special issue of the IEEE Transactions on EMC devoted to the EMC Society's history. The issue was Volume EMC-25, No. 3 dated August 1983. As part of our 50-year anniversary in 2007, we published a special section in the *IEEE Transactions on EMC* honoring the 50th Anniversary of the EMC Society.

In the 1983 *IEEE Transactions on EMC*, there was an article by Andrew Farrar entitled "IEEE EMC Society – the Decades Ahead." This was an article that looked forward from the 25th Anniversary.

We have an article in this Newsletter that is also forward-looking from our 50th Anniversary; it is an article by Shuichi Nitta, a distinguished member of our Society from Japan who is also a past EMC Society Board of Directors member. He has written an article on The "Future of EMC Design" and it is an excellent "transition" article for our Society as we leave our 50th Anniversary Celebratory year and head into the next 25-year interval of our history. I think you will enjoy the article.

A Proposal on Future Research Subjects on EMC

From the Viewpoint of Systems Design

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Abstract—This paper reviews the present EMC technology level, introduces the problems to be investigated in the near future from the viewpoint of design technology, test and measurement and systems safety, and proposes what is a goal of technology level of EMC to be established for circuits, equipments and systems.

Keywords—EMC (electromagnetic compatibility); safety

I. Introduction

It is a risk that the author attempts to describe EMC technology in the future. However, we have many unsolved EMC problems even in the technologies widely used at present in order to realize the functions of electrical/electronics apparatus/systems from the viewpoint of design technology. Historically, an individual EMC problem such as the suppression of radiated emissions or the immunity enhancement of a product has been solved by trial and error for an individual apparatus/system to accomplish its stable operation and to satisfy the radiated-emission limits specified by regulations.

The design technology is not established in the EMC field as yet, according to the definition that "the design work is to confidently and quantitatively realize the specified function in the drawings or at the design stage." The following is an example showing the absence of design technology in the EMC field: Whether the radiated emissions from an equipment are less than the limit value specified in a regulation can't be predicted quantitatively on the schematic diagram or specification sheet at the design stage even if many noise suppression technologies were applied to circuits/apparatus at the design stage and the designer was full of confidence in the achievement of a solution to EMC problems. Although it was recently reported that the radiated emissions from large systems can be predicted based on the measurement of radiated emissions from large equipment such as Printed Circuit Boards (PCBs), power supplies and so on [1][2][3]; at present, the EMC specifications are quantitatively confirmed and decided by test and measurement. The above example is the difference between EMC technology and the technology applied to the realization of the specified function of circuits/apparatus/systems.

In short, a permanent and important subject in EMC is to establish the design technology by which quantitative EMC specifications on circuits/apparatus/systems can be predicted with confidence at the design stage. The words "EMC design" mean no more than the implementation of noise-reduction and noise-proof techniques at the design stage. Besides, new EMC problems are being born with the realization of the small-size, low-voltage, low-power consumption and high-speed parts due to the semiconductor technology development and the widespread use of digital apparatus in the home.

This paper reviews the present EMC-technology level and introduces the problems to be investigated in the near future and the author's general ideas about what is a goal of technology level of EMC to be established for circuits, equipments, systems, and the uncertainties in the measurement of radiated emission phenomena.

II. The Necessity of Progress to Systems EMC from Sub-circuit EMC

Many research results have been reported about the analytical approaches for sub-circuit EMC such as the following examples:

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- Radiated emissions from sub-circuits including one or two components (such as IC, LSI and so on) and the wiring
- Noise suppression effects of decoupling capacitors installed between Vcc (the power supply terminal) and the ground terminals of a single IC
- Crosstalk (coupling) between two wires and across three wires
- Absorption characteristics of single EM absorbing material
- Noise immunity of a single component

That is to say, the analytical methods and the design technologies on EMC are being established for a portion (sub-circuit or component) of the circuit with a specified function including noise suppression technique and it is expected that the piling or adding up of the sub-circuit/component EMC technologies will make it possible to predict the EMC of the printed circuit board/apparatus/system specifications at the design stage [2], [4].

However, the radiated/conducted emissions from the PCB and the apparatus consisting of the PCB, power supply, wiring and cabinet, and the immunity of them can't be predicted quantitatively at the design stage at present. A few approaches to solve the above problem are reported [5], [6]. It is reported in [5] that the superposition characteristics of plural radiated emission sources are approximated by a model substituting the plural radiated emission sources for a single radiated emission source with phases varying at random, and approximately have power summing characteristics. And, it is shown in [6] that the harmonic current from single equipment is less than that from two equipments connected together.

As PCB and apparatus have many current loops and parts, that is, many radiated emission sources, it is expected that progress of the above approaches will force the establishment of systems EMC, that is, design technology to quantitatively predict the EMC specifications at the design stage.

So far, parts such as IC and LSI included in sub-circuits have been dealt with as a black box or the passive circuit model [7] in the study on EMC. However, as the function of parts is becoming large and the Vcc plane and the ground plane and the vias are being included as parts, so a study on EMC of parts themselves is becoming important by going into the inside of parts, and the semiconductor engineers are starting a study on EMC [9], [10].

As described above, progress for both systems-EMC dealing with larger-scale objects and parts-EMC dealing with smaller-scale objects is demanded, although study on sub-circuit-EMC is becoming more important and still includes many problems to be solved.

It is expected that macro-models (that are not obtained by adding-up the component EMC) based on the new concept will be proposed to predict the systems-EMC, as found in the new research tendency shown in [8].

III. Poor Reproducibility (Uncertainties) in EMI Measurement

One of the problems in EMI (Electromagnetic Interference) is poor reproducibility in measurement, that is to say, uncertainty. Much discussion has been held about the cause and the magnitude of uncertainty in EMI measurement from the viewpoint of the accuracy and the dispersion of the measurement site, instrumentation including sensor, measurement systems and so on, as shown in the following examples [11]–[14].

Cause of Error	Magnitude of Dispersion
1. Site Attenuation	±3 dB
2. Antenna Factor	±5 dB
3. Cable Loss	±1 dB
4. Measurement Apparatus	±2 dB
5. EUT itself (software, hardware)	±10 dB ~ ±15 dB
6. EUT Layout (including the skill of test technician)	±10 dB

This section discusses the following examples of the essential and unsolved problems: the influence of AC-mains impedance on radiated emission measurement [15], [16], and the essential characteristics of poor reproducibility in the frequency-domain measurement which can be the cause changing the frequency-spectrum pattern in EMI measurement results [17], [18], and introduces the solution proposed by A. Maeda [19], the relationship between the operation commands in the μ-processor (μP) and the radiated magnetic field from the μP [20] and author's personal opinion of these problems.

A. The Influence of AC-Mains Impedance on Radiated Emission Measurements

Figure 1 shows the measurement results of radiated emissions from the same electronic apparatus at two different open area

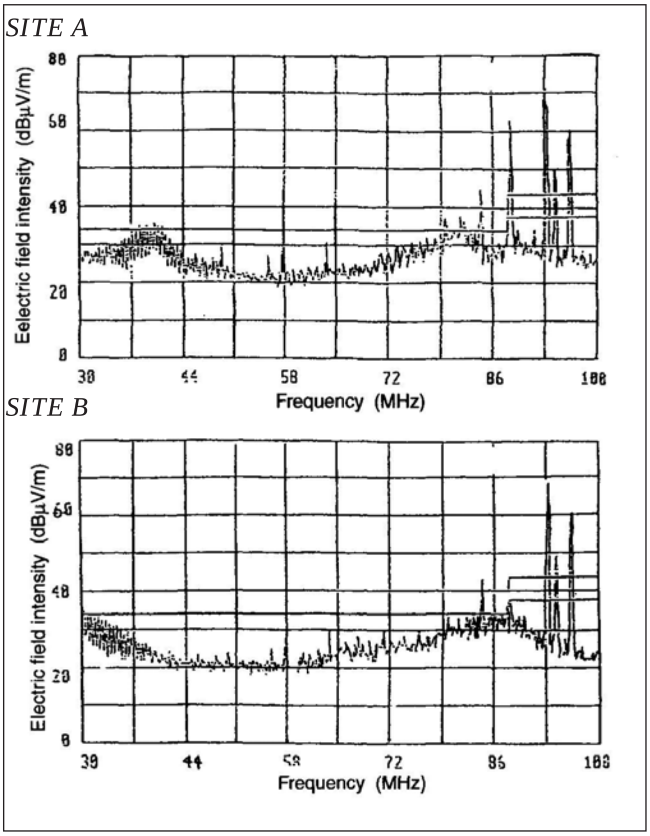

Figure 1. Radiated-emission test results at Site A and B for the same apparatus.

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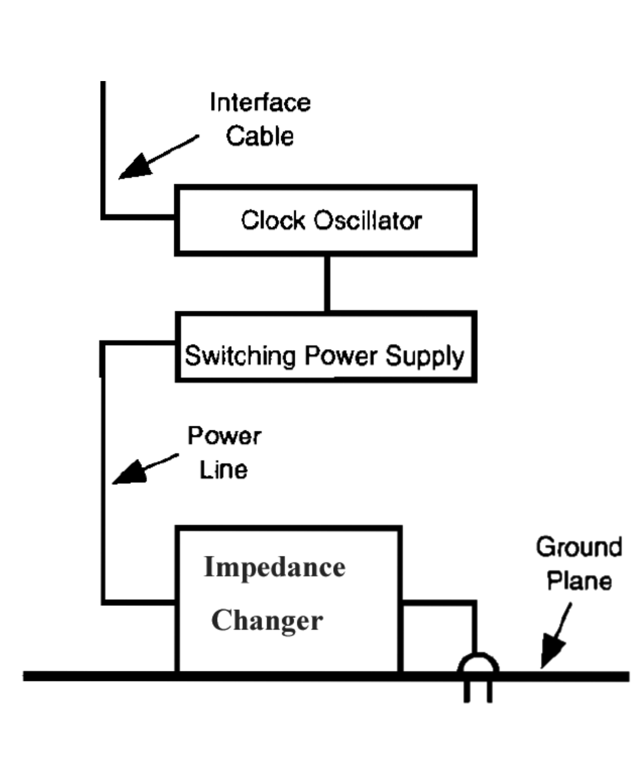
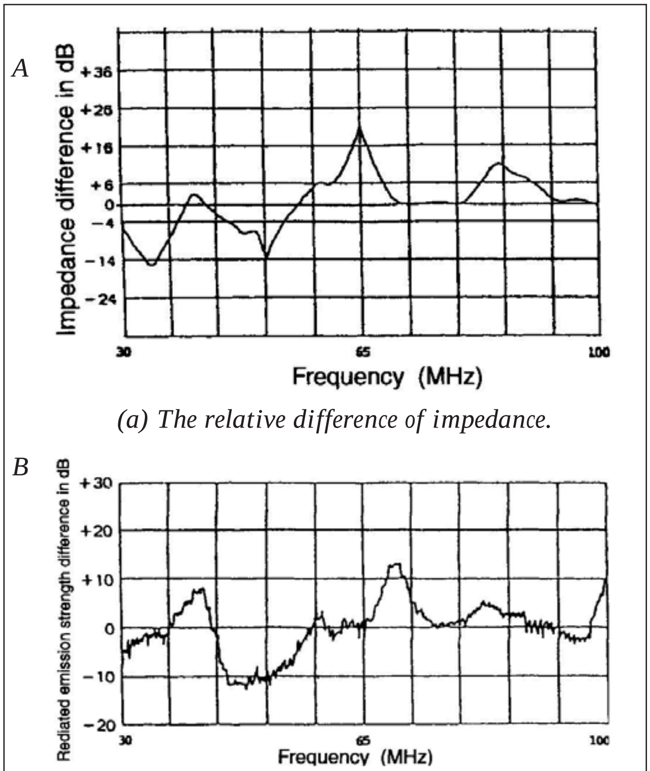


Figure 2. Block diagram of noise generator



(a) The relative difference of impedance.

(b) The relative difference of radiated emission strength due to the impedance difference.

Figure 3. The radiated emission strength difference corresponding to the impedance difference.

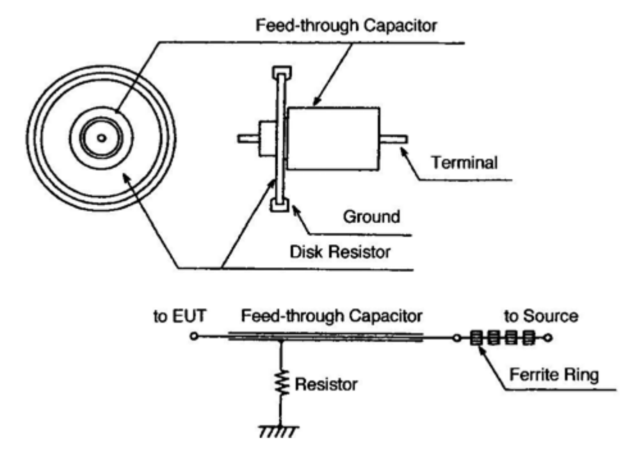


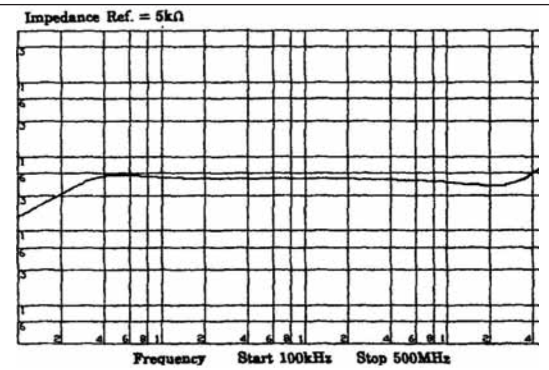
Figure 4. Configuration and circuit diagram of VHF/UHF LISN.

test sites, which satisfy ±2 dB site attenuation.

Different measurement results can be seen in the frequency range of 30 MHz–45 MHz. One of the causes of poor reproducibility in these examples is supposed to be due to the difference among AC-mains impedances. In order to confirm the influence of AC-mains impedance on radiated emission measurement, the following experiments are carried out. The circuit consisting of clock oscillator and switching regulator is used as EUT (equipment under test), and the radiated emission from EUT is measured by changing AC-mains impedance as shown in Figure 2. (Note: the peak values shown on the frequency regions over 74 MHz come from broadcasting stations.)

Figure 3(a) shows the relative difference of AC-mains impedance and Figure 3(b) shows the relative difference of radiated emissions resulting from the impedance difference shown in Figure 3(a). All of the above measurements are carried out using a 3-meter antenna-distance method in a semi-anechoic chamber. In order to improve the reproducibility of radiated-emission measurements, apparatus to stabilize the AC-mains impedance in the frequency range over 30 MHz is demanded.

In order to get rid of the influence of AC-mains impedance on radiated-emission measurement results, a VHF/UHF LISN shown in Figure 4 is proposed by A. Maeda [19]. Figure 5



AC outlet-to-ground impedance characteristics
(The case that VHF/UHF LISN is installed in AC outlet)

Figure 5. The impedance of VHF/UHF LISN seen from AC-mains terminal of EUT.

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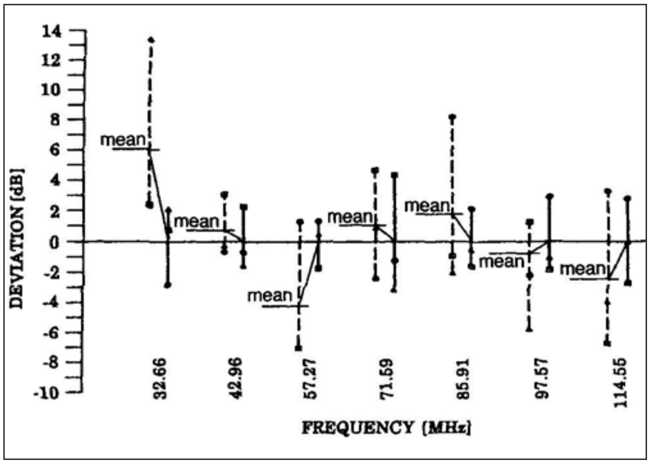

Figure 6. Difference in EMI level deviation before (Dashed line) and after (Solid line) installation of VHF/UHF LISN.

shows the impedance of the VHF/UHF LISN as seen from the AC-mains terminal of the EUT. The effectiveness of the VHF/UHF LISN on stabilizing the impedance over a wide frequency range can be observed up to 500 MHz.

Figure 6 shows a comparison of a measured EMI (radiated emission) level, from an EUT taken at three sites, before and after the installation of the VHF/UHF LISN, for seven frequency points.

For each frequency, the dispersion of measurement results made before the installation of the VHF/UHF LISN is on the left-hand side (the dashed lines), and the measurement made after installation is on the right-hand side (the solid lines). The average EMI level for the three sites with VHF/UHF LISN is plotted on the base line to represent a deviation of 0. The average EMI level before installation of the LISN is shown as a mean bar.

It can be seen that the variation among sites decreases when the VHF/UHF LISN is used. Before the installation of the VHF/UHF LISN, there were three frequencies at which the deviation of the measured EMI was more than ±5 dB. (The maximum difference is 11.1 dB.) After the installation of VHF/UHF LISN, the deviation was within ±3 dB except for one frequency, and the difference was less than 3.5 dB even at that frequency.

As a result, there were five frequencies at which the deviation decreased, two frequencies at which the deviation remained unchanged, and no frequencies at which the deviation increased.

It is concluded that stabilizing the AC-mains' impedance of the EUT and keeping it constant over a wide frequency range makes it possible for a reproducible/stable radiated-emission measurement. The VHF/UHF LISN developed by A. Maeda is effective for obtaining reproducible EMI measurements, however, a perfectly reproducible EMI measurement is not always achieved. Future issues are to develop a LISN having a constant impedance up to 1,000 MHz, and to investigate other factors influencing the poor reproducibility of radiated-emission measurements.

B. The Essential Characteristics of Poor Reproducibility in Frequency-Domain Measurement

The measurement results for radiated and conducted emissions are compared to a frequency-domain limit in the regulations. A Fourier transformation is applied to transform the noise measured in time-domain to the frequency-domain expression.

The definition of the Fourier transformation shows that it is necessary to perform Fourier transformation for non-periodical signals such as noises in the whole time-domain. That is, non-periodical signals should be integrated from $-\infty$ to $+\infty$. However, it is impossible to perform the numerical integration for time zone $(-\infty \sim +\infty)$. In order to solve such a problem, the window function w (t-b) shown in Eq. (1) is introduced in order to convert the infinite-time numerical integration into the finite-time numerical integration.

$$(W_b f)(\omega) = \int_{-\infty}^{+\infty} [e^{-j\omega t} f(t)]\, w(t-b)\, dt \qquad (1)$$

where, ω : angular frequency
$f(t)$: measured signals
t : time
b : sampling-window parameter.

By applying the window function to the numerical calculation of the Fourier transformation, it is possible to take out the local information of measured signal, and by moving the window function on the time base, the local information of frequency of measured signal can be obtained. The above is a concept of "short-time Fourier transformation (STFT)".

Generally speaking, the noises are poor in periodicity and appear at random, and their frequency components are unknown beforehand in many cases. In the case that the finite frequency components of $\eta_1, \eta_2, \ldots, \eta_n$ exist in measured noise and phase θ_i of η_i is taken into account, Eq. (1) is transformed to Eq. (2) [17].

$$\begin{aligned} P_{(\hat{w},\omega,\theta)}(b) &= \sum_{i=1}^{\infty} \left\{ \left| \hat{f}(\eta_i) \right| \overline{\hat{w}(\eta_i-\omega)} \right\}^2 \\ &\quad + 2 \sum_{i=1}^{\infty} \sum_{j=1}^{\infty} \left| \hat{f}(\eta_i) \right| \overline{\hat{w}(\eta_i-\omega)} \left| \hat{f}(\eta_j) \right| \overline{\hat{w}(\eta_j-\omega)} \\ &\quad \times \cos[(\eta_i-\eta_j)b + (\theta_i-\theta_j)] \\ &\qquad (i \neq j) \end{aligned} \qquad (2)$$

where, $P_{(\hat{w},\omega,\theta)}(b)$: power spectrum at the center frequency, ω
$\hat{f}$: Fourier transform of $f(t)$
$\hat{w}$: Fourier transform of $w(t)$ (window function).

It is clear from the above consideration that measured data of noise expressed in frequency-domain changes along with time. As one of the measured data changing along with time is expressed as frequency spectrum, the obtained measured result is different at different times. The above-mentioned leads to the poor reproducibility of measured noise in the frequency-domain. It is well known that the matter, which is usually called an "instrumentation error", is a phenomenon changing with time, depending on noise waveforms.

According to the above investigation, the simulation examples are shown in Figures. 7–10. Figure 7 shows the case that the great-

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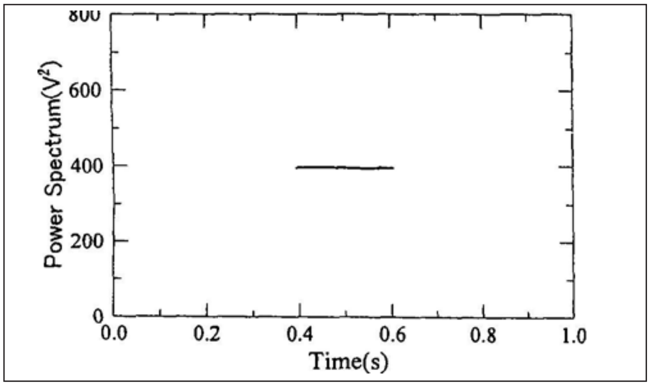

Figure 7. Time-power spectrum. (The case that only one frequency component is in the area of frequency window; center frequency: 10 Hz)

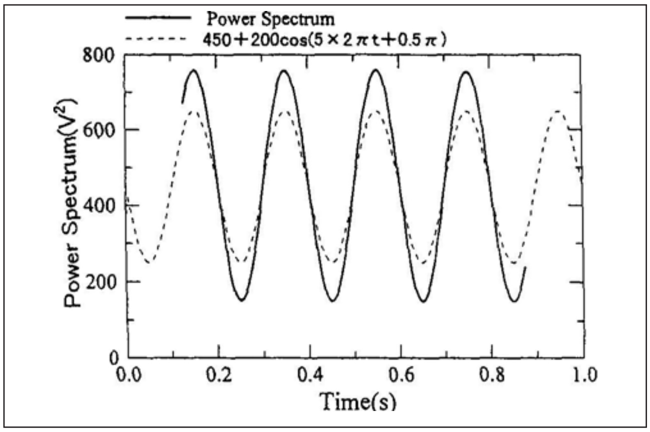

Figure 8. Time-power spectrum. (The case that two frequency components are in the area of frequency window; center frequency: 10 Hz)

$f_1 = 5\,\text{Hz}$ $\quad$ $f_2 = 10\,\text{Hz}$

$\theta_1 = 0$ $\quad$ $\theta_2 = 2\pi$

est common measure exists and the phase difference is zero across the frequency components included in noise. And, the measured power spectrum is constant. The fluctuation equivalent to cos $\{2\pi(f_2 - f_1) + (\theta_2 - \theta_1)\} = \cos(2\pi \times 5t + 0.5\pi)$ shown in Eq. (2) can be seen in Figure 8 which shows the case that the greatest common measure exists but the phase difference is not zero. Figures. 9 and 10 show the case that the greatest common measure doesn't exist across the frequency components included in noise, and the fluctuation similar to Figure 8 can be seen.

C. The Influence of the Program Running in the Digital Apparatus

As described in the beginning of this section, the uncertainty caused by EUT itself (software, hardware) is the largest ($\pm 10\,\text{dB} \sim \pm 15\,\text{dB}$). However, the relationship between the software running in the CPU and the radiated emissions from the CPU has not been analytically and experimentally discussed despite the fact that the influence of software on the uncertainties of radiated emission measurements is bigger than the other causes of uncertainties. As a simple case study, it is reported that the radiated near magnetic fields from the repeated execution of one machine language instruction ("Load" commend) in μP are

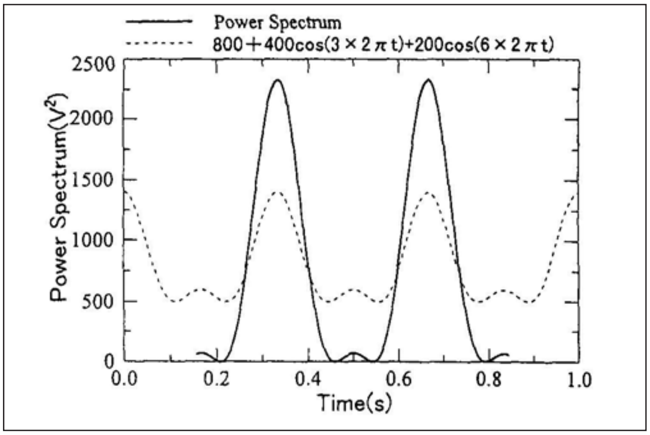

Figure 9. Time-power spectrum. (The case that three frequency components are in the area of frequency window; center frequency: 10 Hz)

$f_1 = 7\,\text{Hz}$ $\quad$ $f_2 = 10\,\text{Hz}$ $\quad$ $f_3 = 13\,\text{Hz}$

$\theta_1 = 0$ $\quad$ $\theta_2 = 0$ $\quad$ $\theta_3 = 0$

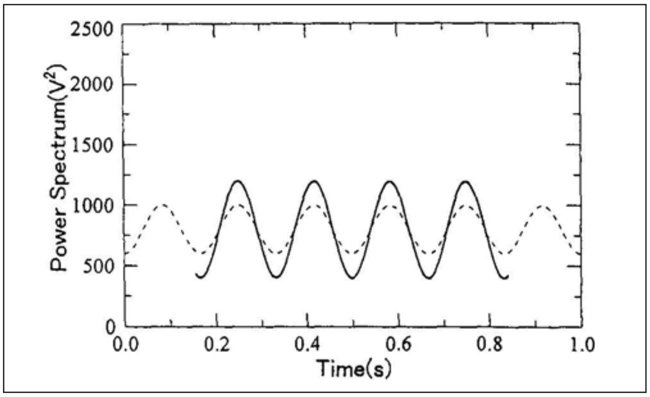

Figure 10. Time-power spectrum. (The case that two frequency components are in the area of frequency window; center frequency: 10 Hz)

$f_1 = 7\,\text{Hz}$ $\quad$ $f_2 = 10\,\text{Hz}$ $\quad$ $f_3 = 13\,\text{Hz}$

$\theta_1 = \pi$ $\quad$ $\theta_2 = \pi$ $\quad$ $\theta_3 = 2\pi$

different to one another corresponding to the operation mode such as "register to register" mode, "register to memory" mode and so on, and the frequency spectrum corresponding to each operation mode can be predicted by the timing chart of instruction [20]. However, as the practical running software has a very complex combination of instruction code and the software are made by the high class compiler, even the development of the macro-model to quantitatively predict radiated emission from simple digital apparatus may be very difficult or may be impossible. So, first of all, the development of the standard software for EMI measurement is demanded.

IV. A Guarantee of Safety for the Malfunction of Digital Equipment Due to Noise

An infinite noise immunity can't be realized in practice even if immunity-enhancement technology will make remarkable progress in the future. So, fail-safe technology is necessary in order to guarantee safety from the malfunctioning of digital equipment due to noise. Generally, the reliability enhancement techniques such as error-correction, duplex systems and so on

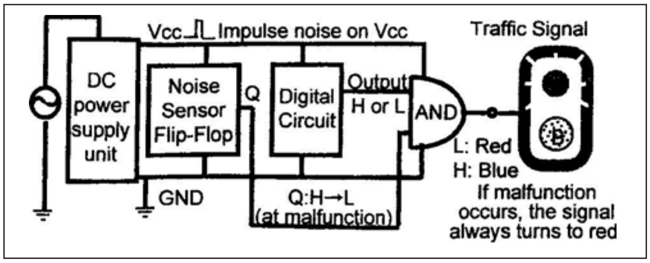

Figure 11. Application to fail-safe control of traffic signal.

are not a useful guarantee of safety from malfunctioning of digital equipment due to noise, since error-correction circuits and both duplex systems will upset due to noise. Many research results have been reported about the fail-safe function of digital equipment for system faults with parts failure [21], [22]. However, these can't guarantee the safety from the malfunctioning of digital circuits due to noise, since fail-safe circuits themselves will upset due to noise. Noise-sensor flip-flops to detect the malfunctioning of digital circuits due to noise are proposed and the fail-safe function utilizing these flip-flops is shown in Figure 11 [23].

The development of EMC technology taking account of systems safety is demanded to make social life stable.

V. EMC on Printed Circuit Boards (PCBs) in High Speed Digital Circuits

A great many research results have been reported about EMC on sub-circuit in PCB [24], as described in 1 and 2. Microprocessors with the clock frequency greater than 3 GHz are already realized. A technical break-through will arise when the clock frequency is over 3 GHz; the structure of the PCB will go to a three-dimensional form from a two-dimensional shape and come near to a sphere-like shape.

VI. Other Considerations

A. Review of Fundamental Noise Suppression Techniques

The principles of typical noise suppression techniques such as shielding, filtering and grounding are already well explained. However, for example, a new approach may be demanded for application of shielding to very small size parts such as LSI, which can be noise sources. Traditional noise filters consisting of inductance and capacitance have the characteristics that magnify a noise with the frequency corresponding to the case that an input reactance of the filter is equal to the negative (reactance of the noise source) or an output reactance that is equal to the negative (load reactance). Economical new types of filters such as a distributed-constant filter and an active filter are proposed [26]. And, new ideas may be demanded to cope with the tendency of small-size parts/apparatus/systems.

Much current flows through the earth these days in comparison with currents flowing through the earth in ancient times, and the effect of grounding for noise suppression is doubted. So, "what is grounding" shall be reconsidered.

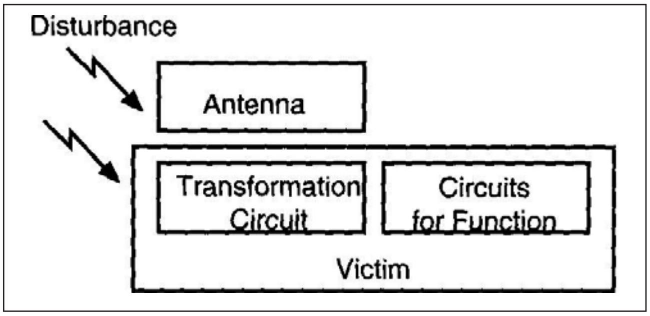

Figure 12. Noise reception of victim.

As described above, even in the traditional noise—suppression techniques, many problems to be investigated are still left. It may be necessary to review these techniques and make a list of subjects to be investigated.

B. The Relationship between the Noise Reception Characteristics of Victim and the Results of Radiated Emission Measured by Antenna Specified in Regulations

Generally, radiated emissions are measured by the antenna specified in the regulations and expressed in the frequency spectrum. While it is frequent in practice that the frequency spectrum of noise, which a victim receives, is quite different from that which an antenna receives, for the same radiated emission source. It is thought that these phenomena may be due to the existence of a "transformation circuit for receiving disturbance" in the victim; that is, each part of the apparatus has a different resonant-frequency, as shown in Figure 12. A study on "transformation circuits" shall be necessary in order to solve practical EMC problems.

C. The Relationship between Antenna Theory and EMC

Antenna theory is the study of how to efficiently transmit and receive electromagnetic waves, while EMC is the study of how not to transmit electromagnetic waves to the outside from the circuit/apparatus/systems and how not to be influenced by electromagnetic waves coming in to the circuit/apparatus/systems. That is to say, EMC technology development is to establish a technology to realize the very inefficient antenna from both points of transmitting and receiving. If the author dares to express "EMC technology" in short, it may be expressed as "Anti-Antenna Theory."

VII. Conclusions

In this paper, the author describes his personal opinion of EMC technologies to be investigated in the future as shown in the following [27]:

- The necessity to develop the macro-model based on the new concept to quantitatively predict the radiated emission and the immunity of systems/apparatus.
- The research subjects to improve the uncertainty of emission and immunity measurement:
  - o The development of LISN to stabilize AC-mains impedance up to higher frequency than GHz.

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- o To solve the uncertainties for the transformation to frequency domain expression from the noise waveforms.
- o To fix the software used in the measurement of radiated emission.

However, the author didn't describe the bioeffects of electromagnetic waves, as the author is not familiar with this area. The author is looking forward to waiting for comments and discussion from readers.

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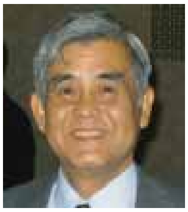

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