Progress In Electromagnetics Research, PIER 38, 269–281, 2002

APPLICABILITY OF TWO STOCHASTIC EVALUATION METHODS TO ELECTROMAGNETIC WAVE IN NEAR FIELD LEAKED FROM ITE GROUP UNDER PARALLEL WORKING SITUATION — INTRODUCTION OF SOME COMPOSITION PRINCIPLE IN SPACE AND TIME DOMAIN

M. Ohta

Hiroshima University
1106, Matoba 1-7-10, Minami-ku
Hiroshima, 732-0824 Japan

A. Ikuta

Faculty of Human Life & Environmental Science
Hiroshima Prefectural Women's University
Hiroshima, 734-8558 Japan

Abstract—In this study, by introducing fundamental composition principle in space and time domain, a trial of applying two stochastic evaluation methods to compound electromagnetic wave leaked from ITE group under parallel working situation are proposed. More specifically, a combined theory for the probability distribution based on the extended additive law on the cumulant statistics including an additive property for energy state quantity is proposed. Next, as a fundamental process in a time domain, an evaluation method for a compound of time ratio presenting in each state based on a stochastic exclusive property is proposed. The effectiveness of the proposed theory is experimentally confirmed by applying it to the observation data leaked from VDT group in the actual office environment.

1. INTRODUCTION

In the actual EM environmental systems, it seems essentially difficult to exactly evaluate a whole probability distribution form of stochastic fluctuation phenomena, owing to various types of natural, social and human factors. It is well-known that most observed data show variously complicated fluctuation patterns of non-Gaussian type on an instantaneous intensity scale (e.g., [1, 2]). Recently, the information technology equipment (abbr. ITE) and communication systems using many kinds of electronic devices tend to display their high-powered and high-performed ability, according to the development and digitization of the devices. Especially, the complex mutual relationships among ITE systems raise up seriously the complicated EMC problems inside and outside the systems. In order to evaluate as quantitatively as possible the electromagnetic environment in the actual working situation, it is important to grasp the fundamental principle on the mutual relation and/or compound whole phenomena, and find as systematically and hierarchically as possible the mutual correlation and/or composition laws existing latently in the phenomena. Its research motivation and mutual correlation analysis on EM environment in a VDT periphery are discussed in a fairly detail in references [3–10].

In this study, for the compound electromagnetic wave in near field leaked from ITE group under actual parallel working situation, a trial of applying two stochastic evaluation methods are proposed especially from some bottom-up way viewpoint by finding as structurally as possible the unified fundamental processes and their composition principle existing latently and objectively in the actual phenomena (even if it is mathematically simple and rough, in the context of the practical research situation today especially on the composition problem of many EM waves leaked from ITE group). More specifically, as a fundamental additive process for the mechanism on spatial distribution of electromagnetic waves generated in near field, a stochastic evaluation method based on an additive rule of cumulants among independent individual fluctuations is proposed on trial in the form of including a well-known additive property of energy (see Appendix). Next, as a fundamental process in a time domain, an evaluation method for a compound of time ratios presenting in each successive state based on a stochastic exclusive property is proposed by paying our attention to the specific fluctuation form in near electromagnetic field. The effectiveness of the proposed theory is experimentally confirmed too by applying it to the observation data leaked from VDT group in the actual work environment.

2. STOCHASTIC EVALUATION METHOD BASED ON THE COMPOSITION PRINCIPLE IN SPACE DOMAIN

2.1. General Expression of Probability Distribution Based on Additive Rule of Cumulants

Consider a random variable fluctuating within a range $[a, b]$, and express the cumulant vector of x as $\vec{\kappa} = [\kappa_1, \kappa_2, \ldots]$, where κ_n $(n = 1, 2, \ldots)$ are nth order cumulants. As well-known, the moment generating function $M_x(\theta, \vec{\kappa})$ of x can be expressed as:

$$M_x(\theta, \vec{\kappa}) \left(\equiv \int_a^b \exp(\theta x) P_x(x; \vec{\kappa}) dx \right) = \exp\left\{ \sum_{n=1}^{\infty} \frac{\kappa_n}{n!} \theta^n \right\}, \quad (1)$$

where $P_x(x; \vec{\kappa})$ denotes the pdf (abbr. probability density function) of x. By introducing a cumulant vector $\vec{\kappa}_0 = [\kappa_{10}, \kappa_{20}, \ldots]$ as some standard, which can be appropriately selected according to the objective of statistical analysis, and applying Taylor series expansion, Eq. (1) can be rewritten as follows:

$$M_x(\theta, \vec{\kappa}) = M_x(\theta, \vec{\kappa}_0) \cdot \sum_{r=0}^{\infty} \frac{C_r}{r!} \theta^r \quad (2)$$

with

$$C_r \equiv \left(\frac{\partial}{\partial \theta} \right)^r \left\{ \exp\left(\sum_{n=1}^{\infty} \frac{\kappa_n - \kappa_{n0}}{n!} \theta^n \right) \right\} \Bigg|_{\theta=0}, \quad (3)$$

$$M_x(\theta, \vec{\kappa}_0) = \int_a^b e^{\theta x} P_0(x; \vec{\kappa}_0) dx. \tag{4}$$

By integrating Eq. (2) r times by parts, under a fairly natural conditions on both ends of pdf form (especially for the case with a and $b \to \infty$), namely

$$(\partial/\partial x)^r P_0(x; \vec{\kappa}_0)|_{x=a \text{ or } b} = 0, \ (r = 0, 1, 2, \ldots), \tag{5}$$

the following relation can be obtained:

$$M_x(\theta, \kappa) = \int_a^b e^{\theta x} \left\{ \sum_{r=0}^{\infty} (-1)^r \frac{C_r}{r!} \left(\frac{\partial}{\partial x} \right)^r P_0(x; \vec{\kappa}_0) \right\} dx. \tag{6}$$

Substituting Eq. (6) into Eq. (1) then gives the following relation:

$$\int_a^b e^{\theta x} \left\{ P_x(x; \vec{\kappa}) - \sum_{r=0}^{\infty} (-1)^r \frac{C_r}{r!} \left(\frac{\partial}{\partial x} \right)^r P_0(x; \vec{\kappa}_0) \right\} dx = 0. \tag{7}$$

Eq. (7) must be always satisfied for any arbitrary real number θ, so that the following relationship must hold:

$$P_x(x; \vec{\kappa}) = \sum_{r=0}^{\infty} (-1)^r \frac{C_r}{r!} \left(\frac{\partial}{\partial x} \right)^r P_0(x; \vec{\kappa}_0),$$

$$C_r = \left(\frac{\partial}{\partial \theta} \right)^r \left\{ \exp \left(\sum_{n=1}^{\infty} \frac{\kappa_n - \kappa_{n0}}{n!} \theta^n \right) \right\} \Bigg|_{\theta=0}. \tag{8}$$

As the fundamental pdf $P_0(x; \vec{\kappa}_0)$, when the well-known Gaussian distribution is adopted:

$$P_0(x; \vec{\kappa}_0) = \frac{1}{\sqrt{2\pi\kappa_{20}}} \exp \left\{ -\frac{(x - \kappa_{10})^2}{2\kappa_{20}} \right\}, \tag{9}$$

the nth order cumulant can be as well-known expressed as:

$$\kappa_{n0} = \begin{cases} 0 \ (n \geq 3) \\ \kappa_n \ (n = 1, 2). \end{cases} \tag{10}$$

2.2. Generalization of Additive Property for Energy State Variable

As well-known, only a principle on an additive property for energy state variables can be widely applied to the compound phenomena still when the electromagnetic waves leaked from N total numbers of computers originate independently each other from two groups of N_1 and N_2 numbers ($N_1 + N_2 = N$) of computers. Though it is already-known only in the probability theory, this principle seems to be reasonably generalized especially in the physical meaning (see Appendix) to some extended type of additive rule applicable not only to the first order statistics (i.e., mean value of energy fluctuation) but also to the higher order statistical information of the stochastic fluctuation, in the context of the practical research situation today on the composition problem of many EM waves leaked from ITE group. More specifically, for the combined energy fluctuation x emitted independently from two different sources, an additive property of arbitrary order cumulant statistics is proposed:

$$ {}_3\kappa_n = {}_1\kappa_n + {}_2\kappa_n, \tag{11} $$

where ${}_i\kappa_n$ ($i = 1, 2$) are nth order cumulants for the mutually independent energy x_i ($i = 1, 2$), and ${}_3\kappa_n$ denotes the cumulant κ_n for the combined electromagnetic wave energy x_3 ($= x_1 + x_2$).

3. STOCHASTIC EVALUATION BASED ON THE COMPOUND LOW IN TIME DOMAIN

For example, the electric and magnetic waves leaked from computers in a near field under the situation of playing a computer game fluctuate in a periodic form of nearly rectangular pulse type with two typical amplitude fluctuation as shown in Figure 1 (Actually observed wave form).

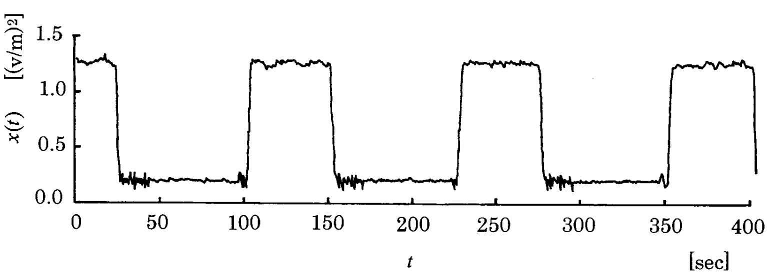

Figure 1. Fluctuation wave form of electric field.

Two types of fluctuation at both upper and lower levels (though a distinction between both levels is not sharp and accordingly an introduction of fuzzy theory is now in progress) show mutually probabilistic exclusive relationship in time domain, and each of them exhibits statistically local stationary property with statistics $\vec{a}_i = [\mu_i,\ \sigma_i,\ A_3^i,\ A_4^i,\ \cdots]$ $(i = 1, 2)$. Here μ, σ, A_n $(n \geq 3)$ denote the mean, variance and higher order statistics respectively. By assuming the probabilities staying at two state levels as P_1 and P_2 respectively, the pdf of amplitude fluctuation for the total time range can be constructed as:

$$P(x) = \int P(x|\vec{a})P(\vec{a})d\vec{a}, \tag{12}$$

$$P(\vec{a}) = P_1 \cdot \delta(\vec{a} - \vec{a}_1) + P_2 \cdot \delta(\vec{a} - \vec{a}_2). \tag{13}$$

Substituting Eq. (13) into Eq. (12), the nth order moment $\langle x^n \rangle$ and pdf $P(x)$ of the amplitude level x over a total time range can be given by

$$\langle x^n \rangle = P_1 \cdot \langle x^n|\vec{a}_1 \rangle + P_2 \cdot \langle x^n|\vec{a}_2 \rangle, \tag{14}$$

$$P(x) = P_1 \cdot P(x|\vec{a}_1) + P_2 \cdot P(x|\vec{a}_2). \tag{15}$$

As the respective pdf $P(x|\vec{a}_i)$, the statistical Hermite expansion series [11] applicable to arbitrary fluctuation of non-Gaussian type can be adopted.

$$P(x|\vec{a}_i) = N\left(x; \mu_i, \sigma_i^2\right)\left\{1 + \sum_{n=3}^{\infty} A_n^i H_n\left(\frac{x-\mu_i}{\sigma_i}\right)\right\},$$

$$N\left(x; \mu_i, \sigma_i^2\right) = \frac{1}{\sqrt{2\pi\sigma_i^2}} \exp\left\{-\frac{(x-\mu_i)^2}{2\sigma_i^2}\right\},$$

$$\mu_i = \langle x|\vec{a}_i \rangle, \qquad \sigma_i^2 = \left\langle (x-\mu_i)^2|\vec{a}_i \right\rangle,$$

$$A_n^i = \frac{1}{n!\sigma_i^n}\left\langle H_n\left(\frac{x-\mu_i}{\sigma_i}\right)|\vec{a}_i\right\rangle. \tag{16}$$

4. APPLICATION TO ELECTROMAGNETIC WAVES LEAKED FROM A VDT

By adopting a personal computer in the actual working environment as specific ITE, the proposed method is applied to evaluate the electromagnetic wave leaked from a VDT under the situation of playing a computer game.

In order to evaluate the electromagnetic environment in near field, the data of electric and magnetic field strengths are measured by use of a HI-3603 type electromagnetic field survey meter from Holaday

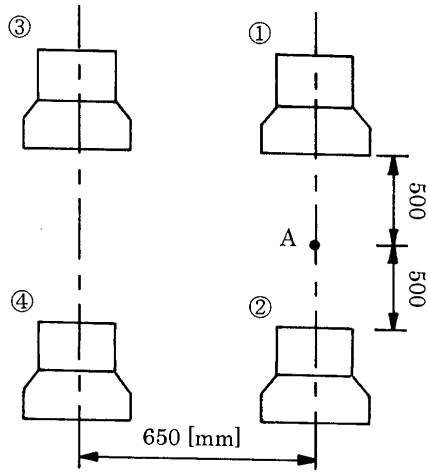

Figure 2. Arrangement of personal computers.

Table 1. A comparison between theoretical values based on the additive property and experimental values based on the measurement of cumulant statistics for the electric field.

Order	Cumulant statistics based on the additive property	Cumulant statistics based on the measurement
1	0.652	0.681
2	0.106	0.118
3	0.0140	0.0160
4	−0.160	−0.0200
5	−0.0100	−0.0130
6	0.00920	0.0136
7	0.0147	0.0222
8	−0.00910	−0.0157
9	−0.0364	−0.0626
10	0.00660	0.0160

Industries Inc., at the position A (cf., Figure 2) of an operator for the computer ①. The 3600 data points for each state variable are sampled with a sampling interval of 1s in three cases when i) only one computer (①) is working, ii) only three computers (② ③ ④) are working, and iii) all four computers (①–④) are working.

First, by using the actually measured data for electric field in the above three cases, the validity of the additive property for

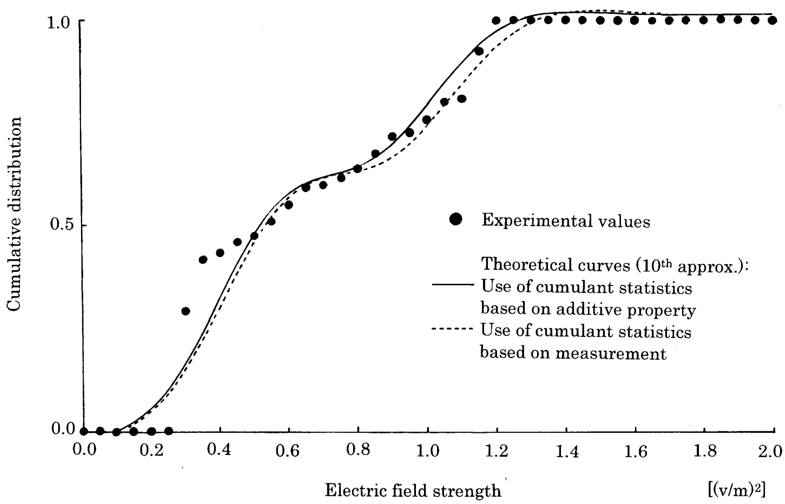

Figure 3. Evaluation of the cumulative distribution for the electric field based on cumulant statistics.

cumulant statistics expressing in Eq. (11) is experimentally confirmed roughly. The calculated results are shown in Table 1. It can be found numerically that the theoretical values calculated from Eq. (11) by using cumulants in two cases of i) and ii) show a fairly good agreement with the experimental values based on the measurement data in the case iii). Furthermore, by using Eq. (8) based on the theoretically calculated cumulant statistics in Table 1, the cumulative probability distribution is estimated as shown in Figure 3. The theoretically estimated curve shows a fairly good agreement with the experimentally sampled points.

Next, by applying Eq. (14) to the measured data of magnetic field in the case iii), the moment statistics in a total time range is estimated. Table 2 shows a comparison between the theoretically estimated values and the experimental values based on the measured data in a total time range. Furthermore, the cumulative probability distribution in a total time range estimated by using Eq. (15) is shown in Figure 4. It is obvious from these experimental values that the theoretically estimated values coincide a fairly precisely with the experimental values.

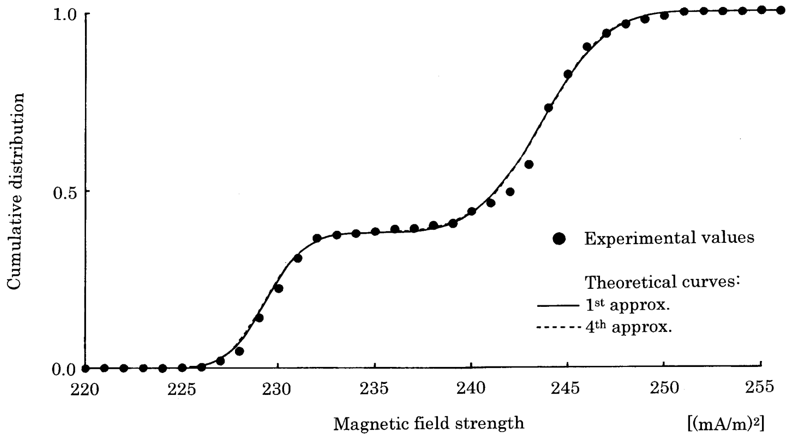

Figure 4. Estimation of the cumulative distribution for the magnetic field based on a stochastic exclusive property.

Table 2. A comparison between theoretically estimated values and experimentally observed values of moment statistics for the magnetic field.

Order	Theoretically estimated moment statistics	Experimentally observed moment statistics
1	2.38×10^2	2.38×10^2
2	5.69×10^4	5.69×10^4
3	1.36×10^7	1.36×10^7
4	3.25×10^9	3.25×10^9
5	7.78×10^{11}	7.77×10^{11}
6	1.86×10^{14}	1.86×10^{14}
7	4.47×10^{16}	4.46×10^{16}
8	1.07×10^{19}	1.07×10^{19}
9	2.58×10^{21}	2.57×10^{21}
10	6.19×10^{23}	6.18×10^{23}

5. CONCLUSION

In this paper, especially by focussing the applicability and physical meaning of study, a trial of practically applying two stochastic evaluation methods to compound electromagnetic waves leaked from ITE group under parallel working environment has been proposed by introducing two types of fundamental compound law in space and time domains (though it is formally well-known only in its mathematical side).

More specifically, a combined theory for the probability distribution based on the extended additive law on the cumulant statistics has been first proposed on trial in the form of including an additive property for energy state quantity. Next, the fluctuation of electromagnetic wave leaked from VDT in near field has been considered. After paying our attention to the probabilistic exclusive relationship as a fundamental principle in time domain, a stochastic compound evaluation method has been proposed by adopting the time ratio in two different states as stable information based on the internal mechanism.

In this study, it seems to be necessary to pay our special attention to the context of practical EM research state that only a principle on an additive property for energy state variable is widely applied to the compound EM phenomena. Finally, the validity and the effectiveness of theory have been experimentally confirmed too especially by applying it to the actually observed data in working situation at office environment.

ACKNOWLEDGMENT

The authors thank Messrs H. Ogawa, H. Motizuki and N. Yokobayashi for their helpful assistance.

APPENDIX A. PHYSICAL MEANING: INEVITABILITY OF INTRODUCING HIGHER ORDER STOCHASTIC QUANTITIES TO COMPOUND EM ENVIRONMENT

The necessity of inevitably introducing several of mutual stochastic quantities of higher order seems to be itemized as follows:

1. As seen in Figs. 3 and 4, and Tables 1 and 2, it is obvious that our experimental results can be theoretically understood by taking some higher order moment (or cumulant) statistics into consideration in order.

2. For example, as in the well-known study on a distorted periodical wave (deviated from a pure sinusoidal wave), the degree of distortion is hierarchically reflected in many higher harmonics and is measured sometimes in a scale of distortion factor as an existence style (the upper: behavior or pattern) of physical quantity differing from the direct connection to physical existence itself on an energy or amplitude scale (the lower: like an effective value). In the similar way, in the study on one stochastic variate of non Gaussian fluctuating wave too, many higher order statistics like skewness, kurtosis and so on seem to correspond to the scale on an existence style (behavior or probability distribution form) of physical quantity, differing from the lower order statistics like mean and variance directly connected to the scale of physical existence itself. However, it is noteworthy that the upper side behavior (like A_n^i with $n \geq 3$) is reasonably scaled based on a dynamic AC unit (fundamentally like σ_i) of energy fluctuation once after taking away a static DC unit (like μ_i) of energy fluctuation measured by the standardized instrument (e.g., as seen in

Eq. (16)). Accordingly, in our practical study, it is inevitable to introduce step by step the idea of higher order moment (or cumulant) statistics, especially among remote levels apart from mean values, in addition to the well-known idea of the 1st order statistics, especially in close connection with real physical mean energy.

3. In the extremum statistics of EM phenomenon, if we want to study hierarchically step by step based on the bottom-up way viewpoint (from the lower order to the higher order statistics) beyond only an apparently descriptive style study, it seems inevitable to introduce structurally such an idea of higher order moment (or cumulant, especially) in close relation to real physical state.

4. Only from an operational viewpoint as seen in the well-known signal processing techniques like AR, MA, ARMA and ARIMA models, the above higher order statistics is usually latently and artificially reflected only in the error style. But, in the real EM environment surrounding our human, since the human being is not only a biological but also high-ranking valuable existence (connected with truth, good and beauty) beyond only a physical existence, in our living nature and human, it is sure that many of the meaningful error, accident, exception, great genius, secret essence etc. certainly exit (sometimes partly related to the above higher order quantities?) and (in principle) should not be excluded artificially in our eagerness to hurry up our artificial realization (only from an operational standpoint forgetting our original quality of humanity), even if it might be a very important future study.

5. Since this paper remains at an early stage of study, it is very

difficult to give explicitly some physical and/or biological implications quantities. It is well-known that the electromagnetic waves are usually measured in a frequency domain under the standardized measuring situation in a radiofrequency anechoic chamber. Surely, these standard methods in a frequency domain are useful especially for the purpose of analyzing the mechanism of individual phenomena (from the bottom-up way viewpoint), but they seem to be insufficient for evaluating (from the top-down way viewpoint) total images on the compound (or mutual relationship) among electromagnetic waves in the actual complicated living circumstances (e.g., thunder, electrostatic discharge, earthquakes, some kind of energy in the eastern mind-body theory, microwave hearing, magnetophoshene and so on). Not to say, such studies on (mutual relationship among) electromagnetic waves leaked from ITE group in the actual working environment become more important year by year, according to the increase of various type of information and communication systems such as personal computers and portable radio transmitters.

REFERENCES

1. Middleton, D., "Statistical-physical models of electromagnetic interference," *IEEE Trans. Electromagnetic Compatibility,* Vol. EMC-19, No. 3, 106–127, 1977.
2. Middleton, D., "Canonical non-Gaussian noise models: Their implications for measurement and for prediction of receiver performance," *IEEE Trans. Electromagnetic Compatibility,* Vol. EMC-21, No. 3, 209–220, 1979.
3. Ohta, M. and A. Ikuta, "A stochastic analysis for EM interference noise in Shannon's multi-dimensional signal space and its relation to acoustic environment," *Institute of Statistical Mathematics Cooperative Research Report,* Vol. 80, 57–64, 1995.
4. Ohta, M. and Y. Mitani, "A basic theory from Shannon's multi-dimensional signal space for effective value measurement in the wave motion type environment and its experiment on electromagnetic or acoustic wave environment," Keynote paper in the *3rd Asian/Pacific International Symposium on Instrumentation, Measurement and Automatic Control,* 7–16, Beijing, 1996.
5. Ohta, M., A. Ikuta, and H. Ogawa, "Mutual relation characteristics among light, sound and electromagnetic waves leaked from the actual working VDT—Introduction of a system

model with nonlinear discrete regression type," *J. Acoust. Soc. Jpn.,* Vol. 53, No. 10, 807–810, 1997 (in Japanese).

6. Ikuta, A., M. Ohta, and H. Ogawa, "Various regression characteristics with higher order among light, sound and electromagnetic waves leaked from a VDT—measurement and signal processing in the actual working environment," *J. International Measurement Confederation IMEKO,* Vol. 21, No. 1–2, 25–33, 1997.
7. Ohta, M., Y. Mitani, and N. Nakasako, "A fundamental study on statistical evaluation of receiver response for electromagnetic wave environment," *J. EM Waves and Appl.,* Vol. 12, No. 5, 677–699, 1998.
8. Ohta, M. and H. Ogawa, "A methodological trial of regression analysis with higher order correlation between electromagnetic and sound waves leaked by a VDT in an actual working environment," *J. EM Waves and Appl.,* Vol. 12, No. 10, 1357–1367, 1998.
9. Ohta, M., A. Ikuta, and H. Ogawa, "A stochastic evaluation theory in multi-dimensional signal space for EM interference noise and its experimental relationship to acoustic environment," *Trans. IEE of Japan,* Vol. 118, No. 4, 465–475, 1998.
10. Ohta, M., Y. Mitani, and H. Ogawa, "Multi-dimensional generalization in space and time domains for Middleton's study in stochastic evaluation of correlative many EM noise processes," *Electromagnetic Waves PIER 24,* J. A. Kong (Ed.), Chap. 5, 97–118, EMW Publishing, Massachusetts, 1999.
11. Ohta, M. and T. Koizumi, "General treatment of the response of a non-linear rectifying device to a stationary random input," *IEEE Trans. Inf. Theory,* Vol. IT-14, No. 4, 595–598, 1968.