X-band circular polarization array antenna with parallel arrangement of three-element plane antennas

Atsushi Fukasawa and Yumi Takizawa

Abstract—This paper presents novel configuration of wideband microwave circular polarization antenna. This array antenna is composed of four units of three elements plane antennas. This unit antenna is composed of three circular elements of feed and reactance elements on a ground plane. The unit antenna is composed of a feed and a reactance elements on a ground element. The feed element is made of a disc truncated at both sides to separate generation of higher and lower frequencies (f_H and f_L), Four units of the above antenna are applied to the parallel array antennas. It was found that the axial ratio was about 3 dB or less at the frequencies 9.5, 10.0, and 10.5 GHz. But minimum axis ratio of around 0 dB was not achieved by parallel arrangement of four antennas.

Keywords— Separation of degeneration, Circular polarization, Axial ratio, Three-element-structure.

I. INTRODUCTION

WIDEBAND microwave antennas are studied for circularly polarized wave emission and reception. This antenna is applied as an element of array antenna system.

Circular polarization is utilized conventionally in satellite systems. It is effective to hold the polarization axis against the earth without control of the attitude of satellite. Circular polarization is also utilized to reduce interaction among different broadcasting systems.

This work is supported by MEXT/JSPS KAKENHI Grant Number 17K00067, and the technical development is supported by Mr. Masaji Abe, CEO, Musasino Co.Ltd and the scholarship donations given by Musasino Co.Ltd.

Atsushi Fukasawa was former professor, Chiba University, Chiba, Japan. (e-mail:fukasawafuji@yahoo.co.jp).

Yumi Takizawa is with the Institute of Statistical Mathematics, Tachikawa, Tokyo, 190-8562 Japan (phone: 81-50-5533-8539, fax: 81-42-526-4332; e-mail: takizawa@ism.ac.jp).

In the actual systems, circularly polarized microwave are effective to reduce interaction from mounts, seas, tall building and fog and rain in the air.

Nowadays C-, S-, and X-band compact microwave plane array antenna systems are studied in practice for navigation using circularly polarization [1].

A wideband plane antenna were given by T. Noro and K. Ito, et al [2]. This plane antenna was composed of two square elements (patches) of the central (with feed) and the upper (without feed) elements on a bottom (ground) plane. Separation of degenerated modes was achieved by diagonal corner cutting of feeding element. The circulation bandwidth of the unit antenna was 10 % for 3 dB axis-ratio at C-band. This structure is accompanied by multiple spurious resonances.

The authors found in computer simulation that the above antenna are suffered by generation of multiple higher modes, and feeding position was found so critical at the central element.

Another design of plane antenna was given by M. Haneishi, et al [3]. The feeding element was composed of circular plane with central or edge slots for degeneration of TM_{11} mode. But the effective bandwidth of a unit and an array antenna were limited to be 2.2 ~ 2.3%.

This paper proposes a novel design of polarization antenna composed of a circular disc with linear cutting of a feed element. It proved wideband as 7% in 10 GHz without higher modes, and easy decision of feeding position.

And four units of the above antenna are applied to an array antenna with parallel arrangement. A wider bandwidth array antenna was obtained better than conventional 2.2 ~ 3 % [3].

II. Fundamental Consideration

A. Yagi-Uda antenna for a novel antenna structure

Yagi-Uda antenna[4] is shown in Fig. 1. This system is composed of three elements of (a) main element with feed, (b) guide, and (c) reflector. The gain and bandwidth are effectively enhanced, when parameter values of lengths (a), (b), (c) and distance d_a, d_b are chosen adequately.

It is composed of the main (central), the guide (above), and the reflector (below).

The central element operates as the main element with feed. When mutual distances d_a and d_b are designed appropriately, they operate to the guide and the reflector. Actually the distances d_a and d_b are chosen longer comparable to the wave length λ.

B. Functional differences of Yagi-Uda and the novel antennas

The fundamental points of the difference of the novel antenna (section 3.) and the Yagi-Uda antenna are as follows;

(1) Spatial structure of antenna elements

The elements of the Yagi-Uda antenna are made of linear rods of metal. On the other hand, the elements of the target antenna must be formed as plane metals on multi-layered substrates.

(2) Functions of three elements

About the Yagi-Uda antenna, the difference of lengths of three antennas are not distinguish. And the distance between three antennas are sufficiently large corresponding to wave length.

About the proposed plane antenna, the dimension of ground element is larger enough than that of feed- and reactance elements. And the distance between two elements and ground are enough short referring the wave length.

Now in this paper, the ground plate of the proposed antenna does not operate as a reflector but as ground itself. And the reactance element does not operate as guide but as reactance component attached to resonant feed element.

The proposed wideband antenna was realized in this paper referred to the point of the configuration of the Yagi-Uda antenna, in spite of the difference of the functions of each element.

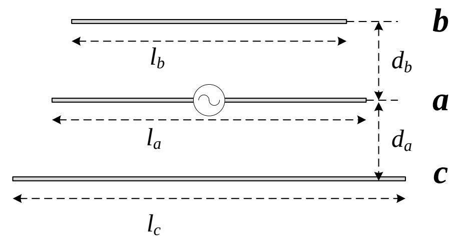

Fig. 1 Yagi-Uda antenna[4].
a : main element with feed
b : guide
c: reflector

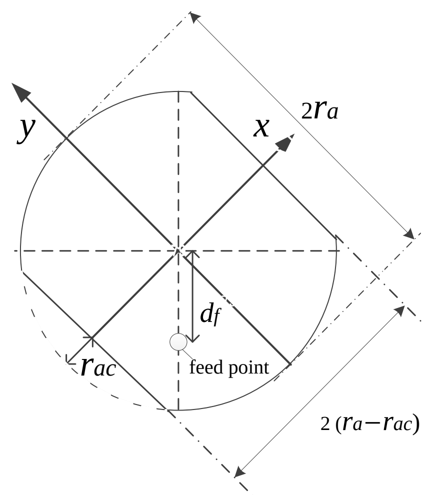

Fig. 2 Dimension of feeding element.

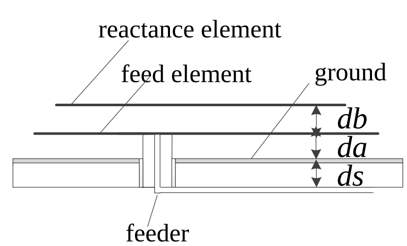

Fig. 3 Cross-sectional view of the unit circular polarization antenna with three elements and a feeding circuit.

III. Design of a Unit antenna

In this study, a planar antenna is considered for microwave circular polarization. Electromagnetic fields exist in *x* and *y* plane, and it is transmitted along *z* axis.

Potential *v* is the highest at the edge, and the lowest at the center point. The current *i* is minimum at the edge and maximum at the center. The length of plane is λ_g /2. But the resonance occurs at multiple frequency and modes.

A. Configuration of the proposed unit antenna

The proposed unit antenna is composed of the feed (*a*), the reactance (*b*), and the ground elements (*g*).

The configuration of the proposed antenna is shown in Fig. 2, 3, and 4. Figure 2 shows the feed element (a). Figures 3 and 4 shows the cross-sectional and the overhead views.

In Fig. 3, the diameters of feed (*a*), reactance (*b*), and ground elements (*g*) are $2r_a$, $2r_b$, and $2r_g$ respectively. In Fig. 4, the distances between elements *g*, *a*, and *b* are shown by d_a and d_b. The routing wires for feeding is formed on the surface of the substrate under the ground, which distance is d_s.

Metal patterns of three elements and routing-wire plane are formed by photolithography on the Teflon glass substrates.

Feed element *a* :

In Fig. 2, the feed element *a* is made of a circular disc $2r_a$ with linear cutting $2r_{ac}$. It provides a dual resonator along the axes *x* and *y*. A long and short resonant wavelength are composed by the distance $2r_a$ and $2(r_a - r_{ac})$. The former and the latter correspond to the lower and the higher resonant frequencies f_L and f_H .

In Fig. 3, the distance d_a is kept close to the ground. Now the element *a* and the ground *g* form a microstripline resonator. The ground *g* provides the path for return current of the resonator *a*.

Reactance element *b* :

The reactance element *b* is made of a circular disc shown in Fig. 4. It works as a reactive element providing inductive (delay in time) or capacitive (proceeding in time) effects to the resonator.

The distance d_b is also kept short, which works as an added reactance component.

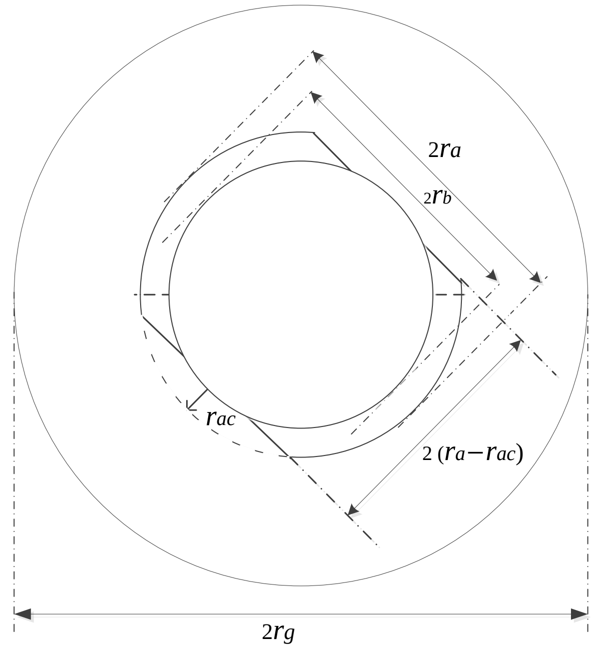

Fig. 4 Overhead view of a unit circular polarization antenna with three elements.

Routing-wire plane *s* :

The substrate *s* should be prepared under the ground *g* for routing wire connected to the feed element *a*. The impedance of feeding must be 50 Ω. By this configuration, microwave radiation is cut by the ground *g* for forward direction of the *z*-axis.

B. Degeneration of resonant frequencies to f_l and f_h

Circular polarization is obtained under the condition that orthogonal conditions are met for the cross-sectional plane (*x* –*y*) and the time axis (*t*).

Frequencies of resonance of a round disc are generally degenerated to have the same frequencies. Different resonant frequencies are provided by differentiation of wavelengths corresponding to differentiation of effective lengths along *x* and *y* axes of the resonant disc.

The degenerated frequencies could be separated to the lower and the higher frequencies f_L and f_H . Circular polarization of microwave is brought at the central frequency f_0 and its neighbor.

In this structure, three resonant frequencies appear at f_L and f_H by the element *a*, and f_M by the element *b*, where the relation is kept as ;

$$f_L < f_M < f_H \qquad (1).$$

In this structure, the current i_L (f_L) is delayed and i_H (f_H) is proceeded by magnetic and electric coupling between current i_M (f_M) on the element *b*.

Circular polarization is realized by the time-space vectors i_L and i_H being controlled by the vector i_M .

It is pointed that another scheme was given by M. Haneishi, et al [2]. Circular polarization was realized by a rectangle slot in the center of the circular feeding element.

C. Design parameters

Frequency band;
central frequency $f_0 = 10$ GHz

Dimension of the element *a*;
length along *y* axis $2r_a$ = 10.8 (mm)
cutting width $2r_{ac}$ = 3.00 (mm)
length along *x* axis $2(r_{a-} - r_{ac})$ = 7.8 (mm)
feeding position *df* = 4.5 (mm)

Dimension of the element *b*;
diameter $2r_a$ = 9.0 (mm)

Dimension of the ground *g* :
diameter $2r_g$ = 31.0 (mm)

Relative permittivity εr = 2.16
Thickness of metal d_M = 0.035 (mm)
Distance between *a* and *b* elements
d_b = 1.59 (mm)
Distance between *g* and *a* elements
d_b = 1.21 (mm)
Distance between *s* and *g*
ds = 0.56 (mm)

D. Characteristics of the proposed unit antenna

The proposed antenna was designed for the right-hand polarization. The following characteristics have been obtained by the simulation on CST STUDIO SUITE 2012ver. MICROSTRIPES.

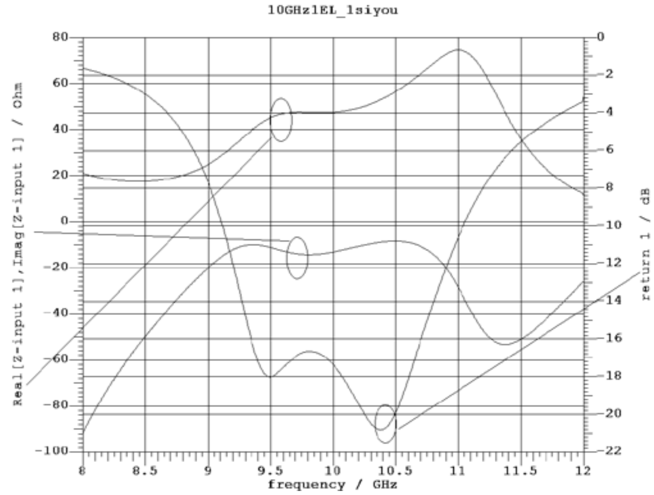

Fig. 5 Return loss and input impedance.

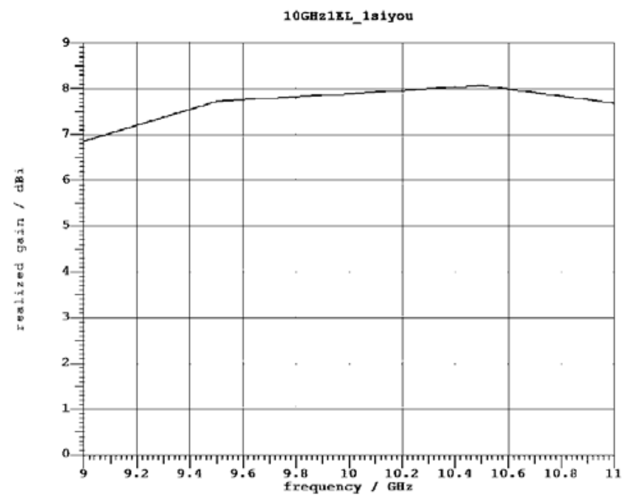

Fig. 6 Power gain.

(1) Return loss
The frequency characteristics of impedance matching by return loss is shown in Fig. 5. Matching bandwidth is 3 GHz for return loss 10 dB. The matching bandwidth of 30% is obtained at the central frequency.

(2) Axial ratio
The frequency characteristics of axial ratio is shown in Fig. 5. Where, axial ratio is defined by ratio in dB of electric field strength along *x* and *y* axes. For 3dB axial ratio, about 0.7 GHz is obtained.

(3) Power gain
The characteristics of power gain is shown in Fig. 6. It is found that any spurious radiation modes are not included between 8 to 12 GHz.

IV. Circular Polarization Array Antenna

A. *Configuration of array antenna*

Four units are allocated in parallel on a plane stripline substrates. The configuration is shown in Fig. 7. The *x* and *y* axes of each unit antenna are set to have the same direction.

Routing wires for the parallel array antenna are shown in Fig. 8. This pattern is given at the backward of routing wire substrate. Microwave radiation from routing wire is separated by the metal conductor of the ground.

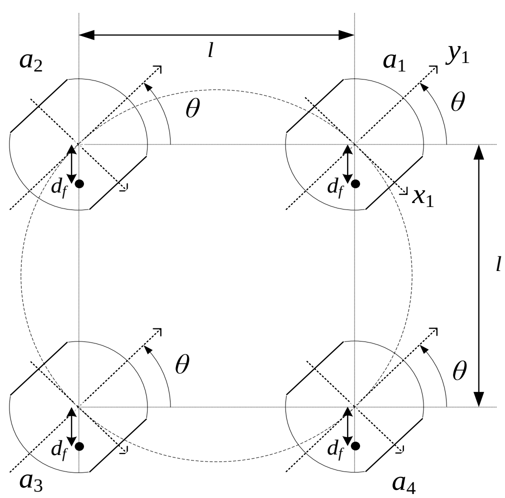

Fig. 7 An array antenna with parallel arrangement (the central elements).

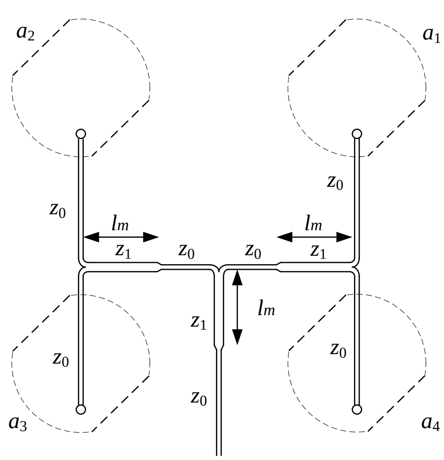

Fig. 8 Routing wires for the parallel array antenna (backward feeding).

B. *Characteristics of array antenna*

Return loss vs. frequency is shown in Fig 9. It is suggested that hump of mismatching are expected to be removed for better axis ratio.

Gain vs. frequency is shown in Fig. 10. High directional gain 12 dB is realized within the band 9.5 ~ 10.5 GHz.

Axis ratio vs direction in angle is shown in Fig. 11 by dotted line. It is supposed that axis ratio 3dB should be affected by impedance mismatching along x and y components.

Directive gain vs frequency is also given by solid line in Fig. 11. Unexpected spurious response is not found the bond.

V. Conclusion

A design of a wideband plane antenna has been proposed based on the knowledge of Yagi-Uda antenna. The effective bandwidth of 3dB axis ratio was 0.7GHz at frequency band 10GHz. Any multimode resonances were not found in 5 ~ 15 GHz band. The position of feed point was decided without critical adjustment. This antenna unit was utilized to compose an array antenna with parallel arrangement for positioning and other wide area of environmental measurement.

Four units of the proposed unit antenna are applied to an array antenna with parallel arrangement. A wider bandwidth array antenna was obtained as 7 % (0.7 GHz) in 10GHz.

Acknowledgment

The proposed antenna system was evaluated by computer simulations conducted by Musasino Co., Ltd.

The authors express their sincere gratitude for kind advices given by Prof Koichi Ito, and Prof. Josaphat Tetuko Sri Sumantyo, Chiba University.

This study was supported by Mr. Masaji Abe, CEO, Musasino Co. Ltd and the scholarship donations given by Musasino Co. Ltd. And this research is supported by Prof. Tomoyuki Higuchi, Director General, ISM, and Prof. Nobuhisa Kashiwagi, ISM.

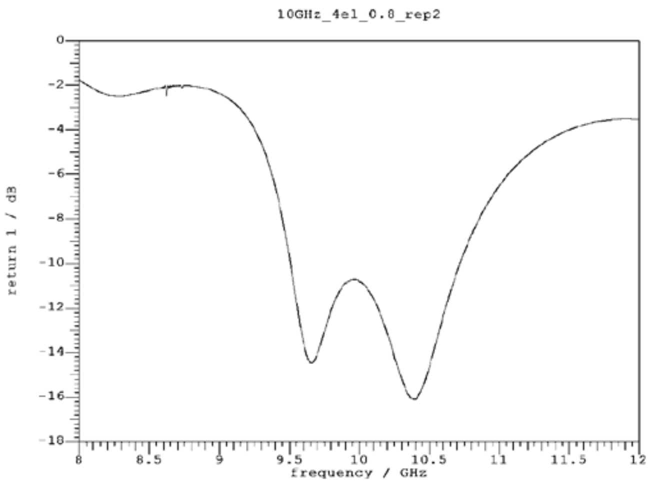

Fig. 9 Return loss vs. frequency.

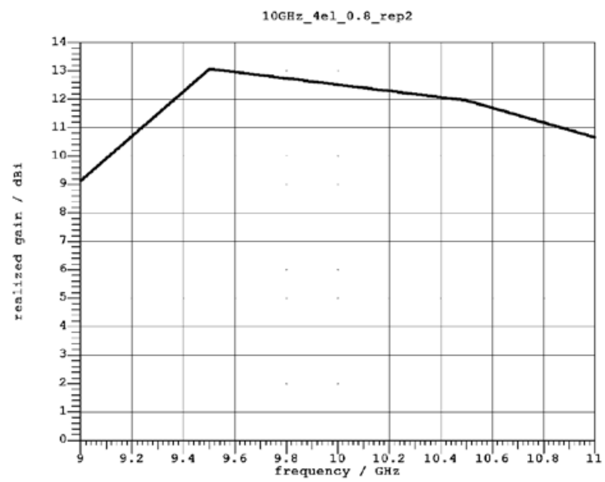

Fig. 10 Gain vs. frequency.

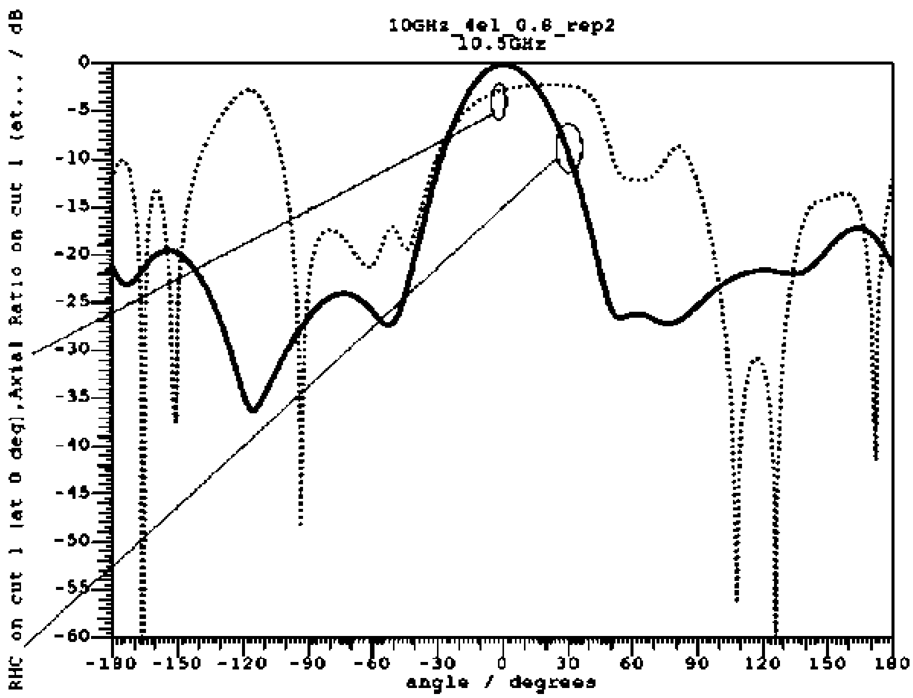

Fig. 11 Axis ratio (dotted, blue) and RHC (solid, red) vs. horizontal angular.

REFERENCES

[1] Sumantyo Josaphat T. S., "Dual-band Singly-Fed Proximity-Coupled Trip-Truncated Triangular Path Array for Land Vehicle Mobile System," Makara Journal of Technology, 19/3, pp.141-147, 2015.

[2] Noro T., Ito K., et al, "Circularly Polarized Patch Antennas Combining Different Shaped Linearly Polarized Elements," IEICE Trans., vol. J91-B, No.5, pp.595-604, 2008.

[3] Haneishi M., et al, "Radiation properties of ring-shaped microstrip antenna array," IEICE, Trans., E78-C, pp.995-1001, 1995.

[4] Yagi S., Mushiake Y., "Yagi-Uda Antenna," Sasaki Co., 1954.

[5] Takizawa Y., Fukasawa A., "Measurement of Boundary Position in Liquid Medium," Proc. of Int. Conf. on Mathematical Methods & Computational Techniques in Science & Engineering (MMCTSE'14), Nov., 2014.

[6] Haneishi M., et al,, "Analysis, design, and measurement of small and low-profile antenna," Artech House (U.S.A), pp.1-270, 1991.

[7] Takizawa Y., Fukasawa A., "Knowledge on Events in Time, Space, and Motion with a Synchronous Neural System," Proc. of Int. Conf. on NEUROLOGY (NEUR '13), Chania, Greece, pp. 104–109, August 27-29, 2013.

[8] Takizawa Y., Fukasawa A., "Wideband microwave circular polarization array antenna with orthogonal arrangement of three-element plane antennas," to be presented in NAUN International Journal of Systems Applications, Engineering & Development, vol.11, 2017.

Atsushi Fukasawa received the Master of Arts degree and the Ph.D. degree from Waseda University in 1967 and 1983. He joined Graduate School of Natural Science, Chiba University as a professor in 1997. He received the Award of the Agency of Science and Technology, Japan in 1982, and Ohm (publisher) Prize in 1994. He received Telecommunication System Technology Prize from the Foundation of Telecommunication Association, Japan in 2004. He has been awarded for the Best Paper on NEUROLOGY'12. He is a senior member of the IEEE.

Yumi Takizawa. Yumi Takizawa received the B.S. degree in Physics from Shinshu University in 1984, and the Ph.D. degree from the University of Tokyo in 1994. She joined the Institute of Statistical Mathematics (ISM) as an associate professor in 1995. She received the Prize on Telecommunication System Technology from the Foundation of Telecom Association, Japan in 2004. She has been engaged in neural systems in brain based on electro-physical and biological studies at the University of Virginia, USA, 1998-2000. She has been awarded for the Best Paper on NEUROLOGY'12.