Circular Polarization Array Antenna with A Grounded Cylindrical Collar for Elimination of Cross-Sectional Radiation

YUMI TAKIZAWA† and ATSUSHI FUKASAWA††

†Institute of Statistical Mathematics
Research Organization of Information and Systems
10-3 Midori-cho, Tachikawa, Tokyo, JAPAN
takizawa@ism.ac.jp

†† Former Professor, Chiba University
Kamimeguro, Meguro-ku, Tokyo, JAPAN
fukasawafuji@yahoo.co.jp

Abstract: - This paper describes a novel structure of circular polarization plane antenna. Conventionally z-axis directivity was enhanced by increasing number of antennas. A novel plane array antenna is made by feed- and reactance-elements over a ground plate. A quarter-wavelength stripline with short circuit termination is made of a cylindrical collar connected to the ground plate. This element brings elimination of radiation along $x-y$ plane to enhance z axis directivity. The characteristics of the proposed antenna are shown by 3D computer simulation. 1/3 radiated power was effectively inverted from $x-y$ plane to z axis, and z axis directivity was found 1.2 dB higher than that of the original antenna. This effect contributes to minimize size of array and number of antennas into 2/3.

Key-Words: - Circular polarization, plane array antenna, orthogonal arrangement, smoothed routing wire, wideband characteristics.

1 Introduction

Recently microwave measurement system is concerned for remote sensing of landscape, weather observation, and broad casting receivers. For this system, linear polarization has been used for the purpose. This system causes unreliability in sensing effects because of nonstable reception of reflected signals from moving targets.

Circular polarization have been respected on the capability of robustness for interference among undesired multipath components. In place of conventional waveguide antenna system, plane antennas are respected for the small size and economic advantages.

Plane antenna is composed of the stripline microwave resonators. An array antenna is made of large number of unit plane antennas composed on a common plane. Directive gain and side lobe levels of circular polarization are not increased in spite of increased number of unit antennas.

This paper presents a circular polarization array antenna with improved response for directivity including gain and suppression of side lobe levels of the array antenna with limited number of antennas. For the purpose of the above, a wideband plane antenna was first composed of three elements; ground, inner conductor, and reactance element. A wideband plane antenna was secondly composed of orthogonally arranged four antennas on a common ground. A wide metal band was provided with extended ground around four antennas.

2 Wideband Array Antenna with a Folded Ground Plate

2.1 Configuration of the proposed array antenna

A proposed array antenna is shown in Fig. 1. Four unit antennas ai, (i = 1~4) are set at each quadrant around the center O in $X-Y$ plane. Z axis is perpendicular against X-Y plane.

Each unit antenna generates right-handed polarized wave. To get right-handed polarized wave totally, each antenna must be fed by the signal with 90 degree phase delay along the left-handed circulation. The directions of Poynting vectors pi are defined according to the orthogonal arrangement as shown in Fig. 1. d_f shows the position of feeding point at each unit antenna.

The diameter of the ground plate $2rg$ must be large enough compared to the size of total space of inner conductors.

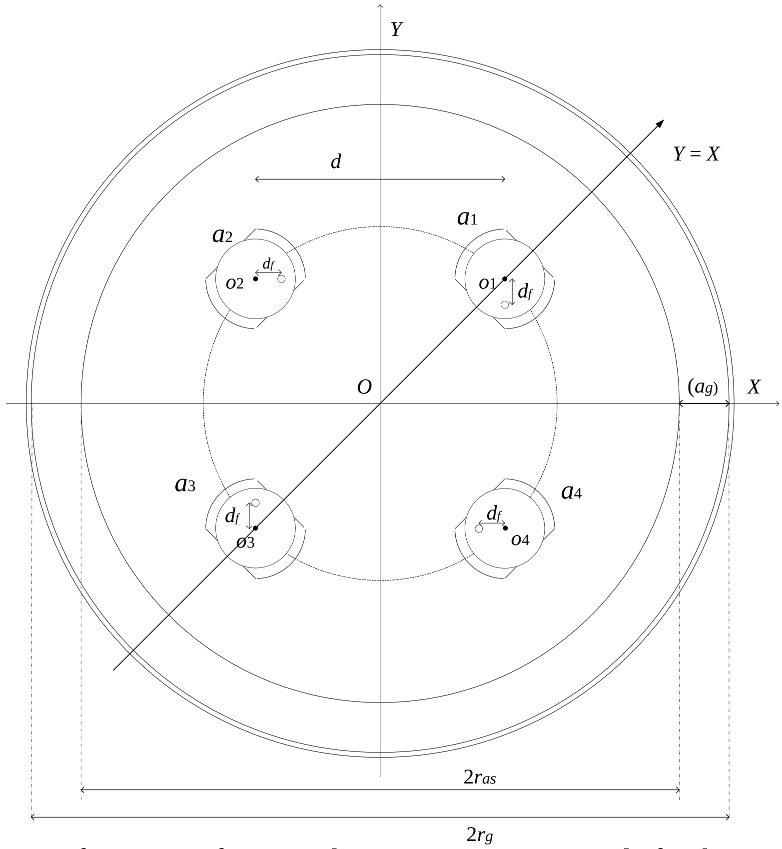

Fig.1 Configuration of proposed array antenna composed of orthogonally arranged four antennas with grounded cylindrical collar.

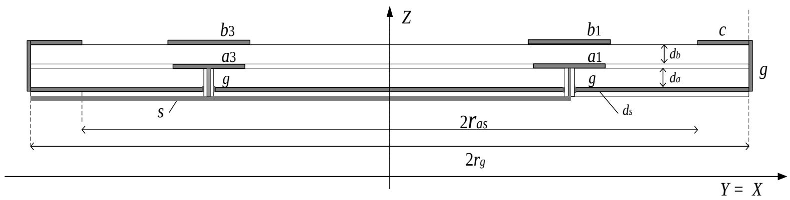

Fig.2 Cross setional view of the propose array antenna with ground cylindrical collar on the line $Y = X$.

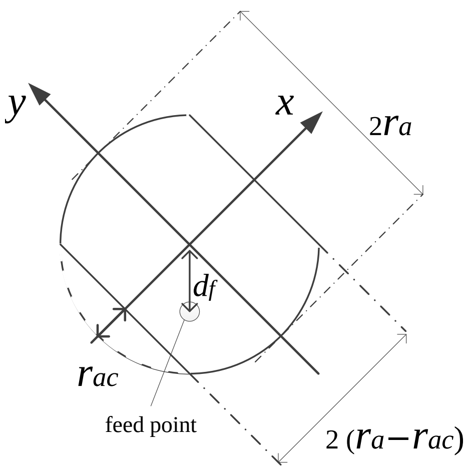

Fig. 3 Main element a with feeding.
df: Feeding point.

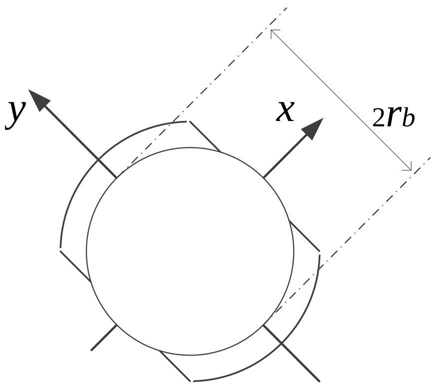

Fig. 4 Overview of a unit antenna of main and reactance elements (a and b) .

2.2 Improvement of directivity

The array antenna is covered by a cylindrical collar *c* connecting the ground metal plate in Fig.2. The array of four antennas play as a unified circular polarization antenna, and the above metal plate provide return current against the direction of current produced by unified circular polarization antenna. At the far field, the electromagnetic field is composed of the component caused by a unified array antenna and the other components caused by the current flow on the cylindrical collar. They are cancelled each other to give enhanced directive gain and reduced side lobe level.

2.3 Unit plane antenna

Each unit antenna composing the array is made of three elements; ground (***g***), feed element (***a***), and reactance element (***b***) among microwave dielectric substrates. The length of the feed element is a half wavelength. The reactance element provides capacitive or inductive components for microwave resonation.

Feed element *ai* (i = 1, 2, .., 4):

The feed element *a* is made of a circular disc $2r_a$ with linear cutting $2r_{ac}$ shown in Fig. 3. 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. 2, the distance d_a is kept close to the ground. Now the feed element *a* and the ground *g* form a stripline resonator. The ground *g* provides the path for return current of the resonator *a*.

Reactance element *bi* (i = 1, 2, .., 4):

The reactance element *bi* 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.

2.4 Routing wires for parallel feeding

The design of routing wires for feeding to four antennas is shown in Fig. 5. This scheme forms a parallel composition of routing wire.

The condition of 90 degree phase difference are given between right hand elements *a*1 vs *a*4, and the left hand elements *a*3 vs *a*2. At the connection of the right and the left elements, 180 degree and 90 degree phase delay are provided by corresponding line lengths.

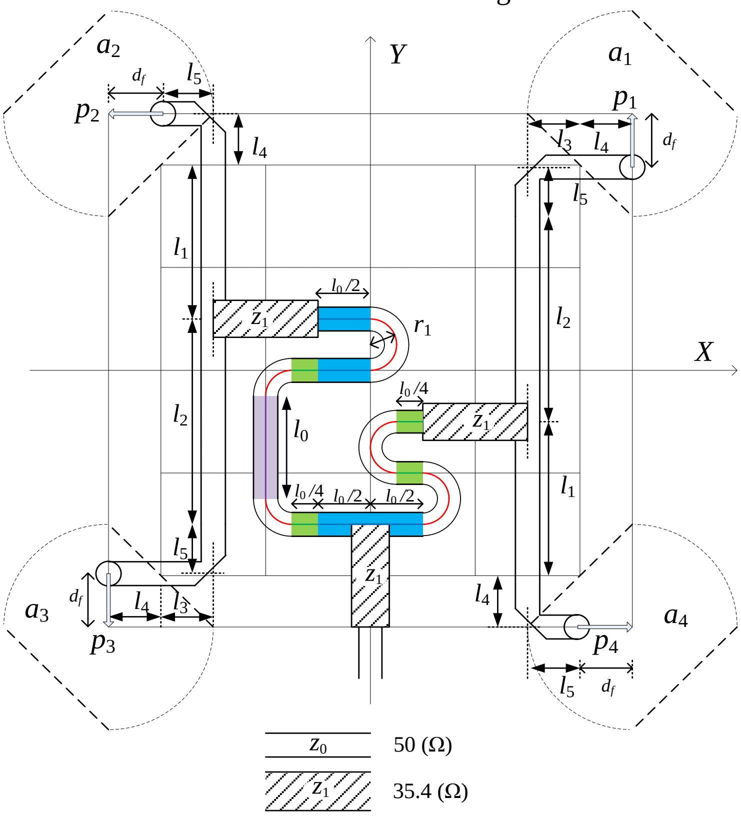

Fig. 5 Configuration of routing wire for feeding.

3 Characteristics of the Proposed Array Antenna

The central frequency and the bandwidth are designed for the X-band. The array antenna is composed of 4 unit antennas.

Thickness of the substrate; *da* = 1.6 (mm), *db* = 1.6 (mm), *ds* 0.38 (mm). Permittivity ε is 2.17.

The parameter values of the proposed antenna (unit) are;
The length of the resonator is 10.0 (mm) for lower frequency length, 7.0 (mm) for high frequency resonator. The diameter of reactance element is 8.0 (mm).
The array configuration of unit antennas are perpendicular with each other along *x* and *y* axes.
The spacing between unit antennas *d* = 25.0 (mm).
Frequency characteristics of the proposed array antenna are shown in Fig. 7~10 based on 3D computer simulation with CST Studio Suite.

(1) Return loss
The frequency characteristics of return loss is shown in Fig. 6. The return loss is better than 15 dB between 9.2~ 10.7 GHz.

(2) Directive gain
The frequency characteristics of directive gain is shown in Fig. 7. The proposed ground plate enhances maximum gain 1.4 dB up compared to the conventional configuration of ground plate. And the bandwidth is expanded about 15% at X-band.

(3) Input impedance
The frequency characteristics of input impedance is shown in Fig. 8. The source impedance is 50 Ω. The upper and the below curves are the real and the imaginary parts of complex impedance. Extremely wide and flat input impedance was obtained from 8.8 to 11.2 GHz. It proves that larger size array antenna becomes practical by this paper.

(4) Axis ratio
The frequency characteristics of axis ratio is shown in Fig. 9. The axis ratio of circular polarization is smaller than 3 dB between 9.1 ~ 11.3 GHz. The axis ratio shows flat and wideband characteristics of circular polarization at X band.

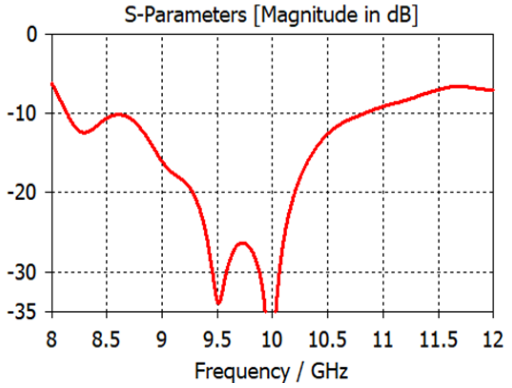

Fig.6 Return loss.

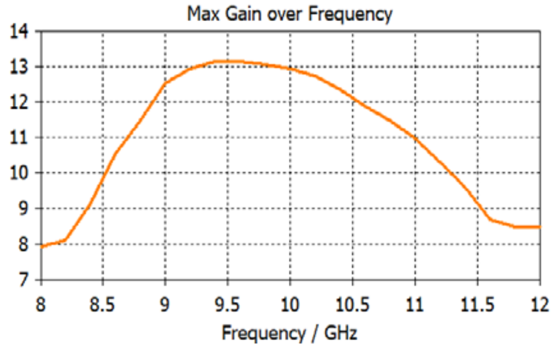

Fig. 7 Gain.

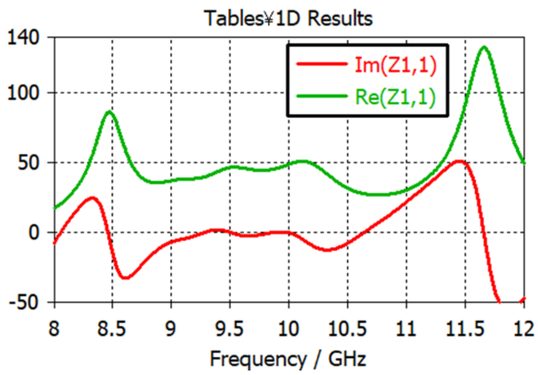

Fig. 8 Frequency characteristics of input impedance.
Upper line: the real part of impedance.
Below line: the real part of impedance.

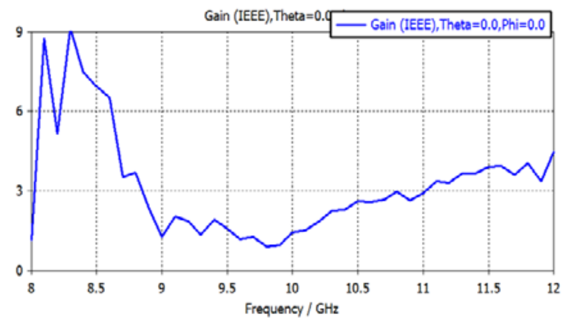

Fig. 9 Frequency characteristics of axis ratio of circular polarization.

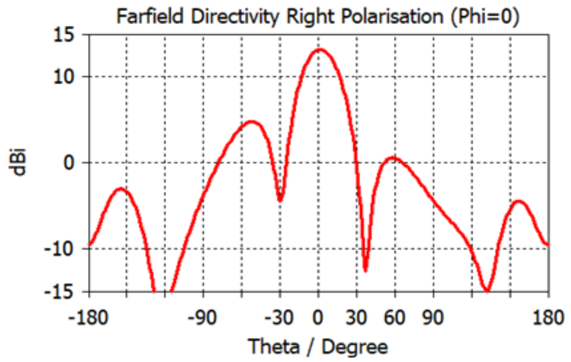

Fig. 10 Radiation pattern at Ψ = 0 (rad) by linear scale.

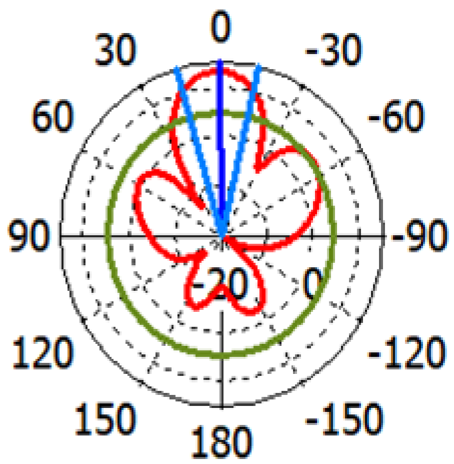

Fig. 11 Radiation pattern at Ψ = 0 (rad) by polar scale.

(5) Radiation pattern at $\Psi = 0$ by linear scale
The far field radiation patter at $\Psi = 0$ (rad) is given by linear scale in Fig. 10. The side lobe levels are reduced 3dB compared to the conventional configuration of ground plate.

(6) Radiation pattern at $\Psi = 0$ by directional angle
The far field radiation patter at $\Psi = 0$ (rad) is given by polar scale in Fig. 11. The side lobe levels are reduced inside green circle corresponding to the expected characteristics.

4 Conclusion

A novel method was given for eliminating cross-sectional radiation and to enhance *z* axis directivity in this paper.

A plane array antenna was made by feed and reactance elements over a ground plate.

A cylindrical metal collar was made outside the array and at the surface of substrates, which are connected to the ground plate.

This element works as a quarter wavelength stripline with short circuit termination.

By 3D computer simulation, it was found that an extremely wideband circular polarization array antenna was developed by this study. Extremely wideband input impedance and axis ratio were found with higher directive gain and lower side lobe level compared to conventional plane circular polarization antennas.

It was also found that by introducing grounded cylindrical collar, total number of antennas for an array was reduced 1/3 compared to conventional array antennas.

Acknowledgement

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

The authors express their sincere gratitude for kind support by Prof. Tomoyuki Higuchi, Director-General, the Institute of Statistical Mathematics.

References:

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

[2] 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.

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

[4] Fukasawa A., Takizawa Y., "Circular Polarization Array Antenna with Orthogonal Arrangement and Parallel Feeding by Simplified Routing Wires," to be presented in *WSEAS Conference in IMCAS'18*, Paris, France, Apr. 13th, 2018.

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

[6] Takizawa Y., Fukasawa A., "Novel Structure and the Characteristics of a Microwave Circular Polarization Antenna," WSEAS Transaction on Communications, vol. 16, pp. 184-191, 2017.

[7] Fukasawa A., Takizawa Y., "Circular Polarization Array Antenna with Orthogonal Arrangement and Parallel Feeding by Simplified Routing Wires," Journal of Electromagnetics, Vol. 3, pp. 3-8, Apr. 11, 2018.

[8] Takizawa Y., Fukasawa A., "Circular Polarization Array Antenna with Orthogonal Arrangement and Parallel Feeding by Smoothed Routing Wires," Journal of Electromagnetics, Vol. 3, pp. 14-19, Apr. 11, 2018.