Wideband microwave circular polarization array antenna with orthogonal arrangement of three-element plane antennas

Yumi Takizawa and Atsushi Fukasawa

***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 orthogonal array antennas. Two types of spatial arrangements with four unit antennas are given with individual routing wire circuits. Wideband characteristics of circular polarization are achieved extremely wide bandwidth 10% compared to 2.2 ~ 2.4 % bandwidth by conventional parallel arrangements. This result was brought by the original configuration of the unit antenna with three elements.

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

I. INTRODUCTION

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. 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].

Design of circular polarization array antenna was given by M. Haneishi, et al [2]. The unit antenna was composed of round disc resonator truncated at both sides of edges by squares shown in Fig. 1. Separation of degenerated resonances is done by these truncations. However, the effective bandwidth of a unit and an array antenna were less than 2%.

The array antenna was composed by parallel arrangement of the above unit antenna with routing wires shown in Fig. 2.

This paper proposes a novel design of unit antenna composed of three elements of feed, reactance, and ground. The feed element is linearly truncated circular disc.

And four units of the novel antenna units are applied to an array antenna with orthogonal arrangement. Two types of spatial arrangements are given for orthogonal configurations.

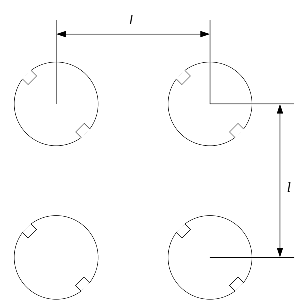

Fig. 1 An example of circular polarized plane antenna array by Haneishi, et al [2].

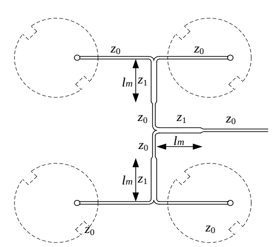

Fig. 2 Routing wire pattern for parallel array arrangement of the array antenna in Fig. 1.

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II. 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 $\lambda_g/2$. 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. 3, 4, and 5. Figure 4 shows the feed element (a). Figures 3 and 5 shows the overhead and the cross-sectional 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. 5, 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. 4, 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. 5, 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. 3. 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.

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.

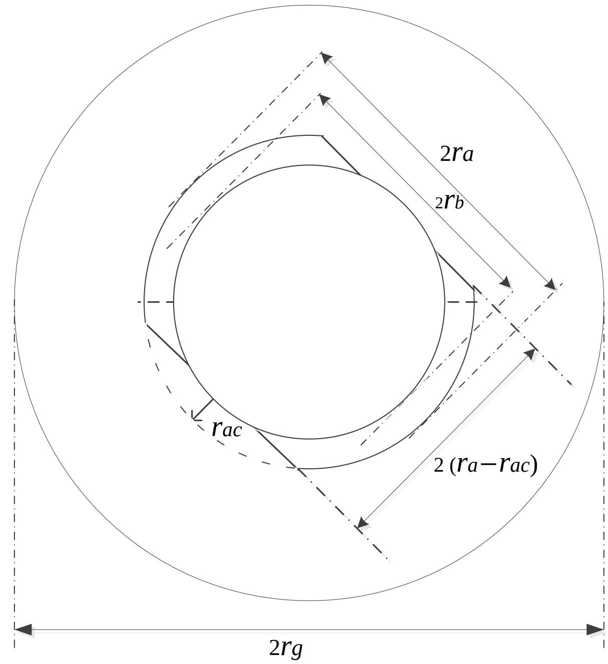


Fig. 3 Overhead view of a unit circular polarization antenna with three elements.

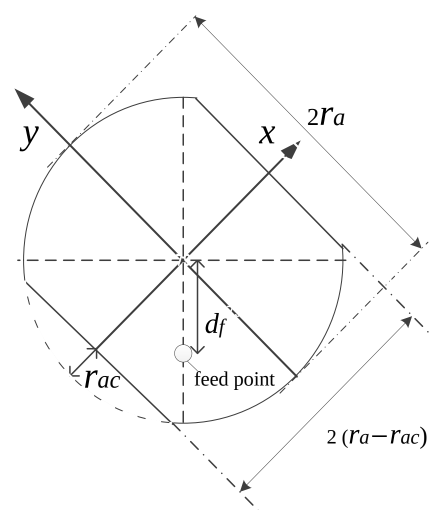


Fig. 4 Dimension of feeding element.

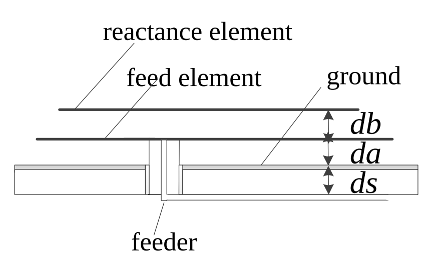


Fig. 5 Cross-sectional view of the unit circular polarization antenna with three elements and a feeding circuit.

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 ϕ)
  length along x axis $2(r_{a-} - r_{ac}) = 7.8$ (mm ϕ)

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

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

Substrates for three elements and routing wires:
  Relative permittivity $\varepsilon r = 2.17$
  Distance between a and b elements
    $d_b = 1.59$ (mm)
  Distance between g and a elements
    $d_a = 1.21$ (mm)
  Distance between s and g
    $ds = 0.56$ (mm)
  Relative permittivity $\varepsilon rs = 2.18$

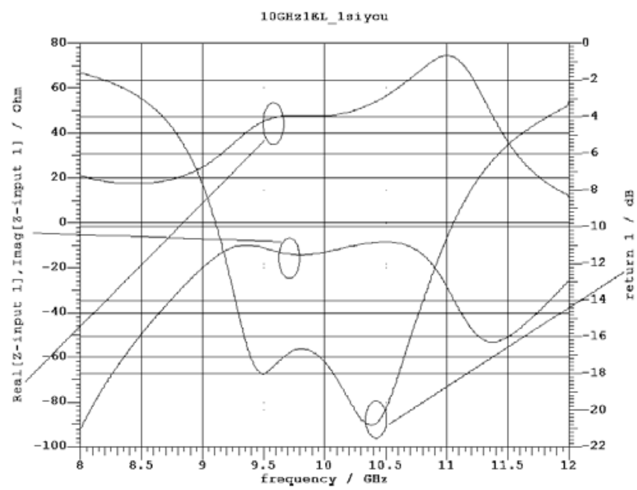


Fig. 6 Return loss and input impedance.

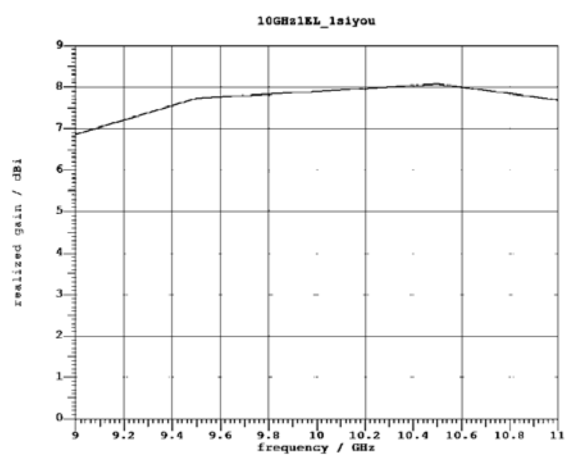


Fig. 7 Power Gain.

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. The coordinate system for radiation patterns are defined by φ (rad) for horizontal (*x*, *y*) plane, and by ψ (rad) for vertical (z axis) plane.

(1) Return loss

The frequency characteristics of impedance matching by return loss is shown in Fig. 6. Matching bandwidth is 3 GHz for return loss 10 dB. The matching bandwidth of 30% is obtained at the central frequency.

(2) Input impedance

The frequency characteristics of input impedance is shown in Fig. 6. The thin and the thick lines show the real and imaginary parts of impedance. The real part is 50 Ω, and the imaginary part is enough small in wideband.

(3) Power gain

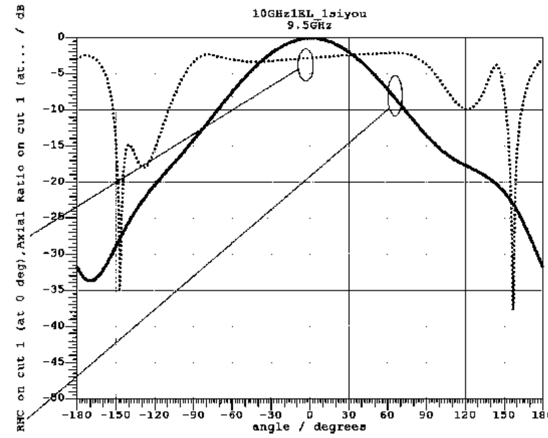
The characteristics of power gain is shown in Fig. 7. It is found that any spurious radiation modes are not included between 9 to 11 GHz.

(4) Axial ratio

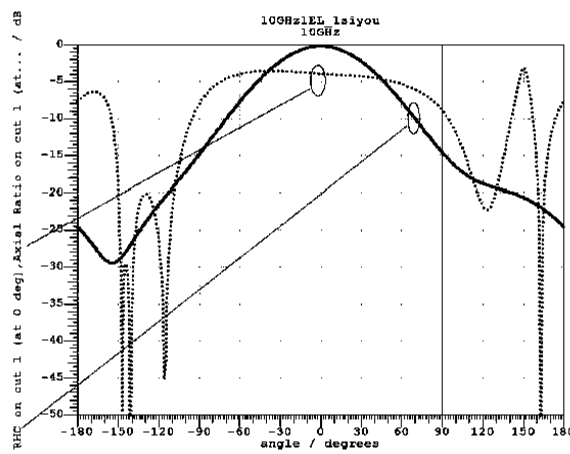
The axial ratio is shown in Fig. 8. Where, axial ratio is defined by ratio in dB of electric field strength along *x* and *y* axes. The axial ratio is obtained as about 3dB from 9.5 GHz to 10.5GHz.

(5) Directivity of right-hand circulation

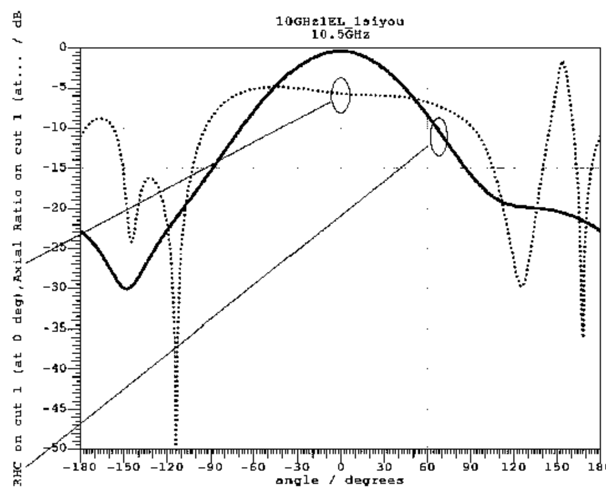
The directional radiation of right-hand circulation is shown by linear scale in Fig. 8. The 3dB radiation angle is ±30 degree. The side robes are less than 20dB at the range in ± 180 degrees.



(a) 9.5 GHz



(b) 10.0 GHz



(b) 10.5 GHz

Fig. 8 Frequency characteristics of axial ratio and directivity of right-hand circulation.

III. CIRCULAR POLARIZATION ARRAY ANTENNA WITH ORTHOGONAL ARRANGEMENT

A. *Configuration of array antenna*

Four units are allocated in orthogonal on a plane in Fig 9. The *xi* and *yi* (i = 1,.. ,4)axes of each unit antenna are set to have orthogonal directions each other.

Routing wires for the orthogonal array antenna of arrangement 1 are shown in Fig. 10. 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.

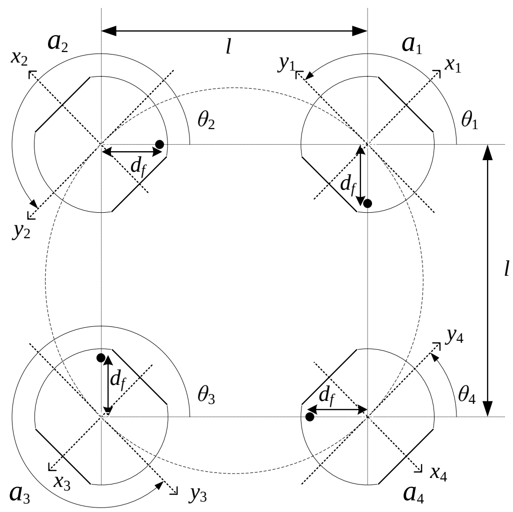


Fig. 9 An array antenna with orthogonal arrangement (arrangement 1).

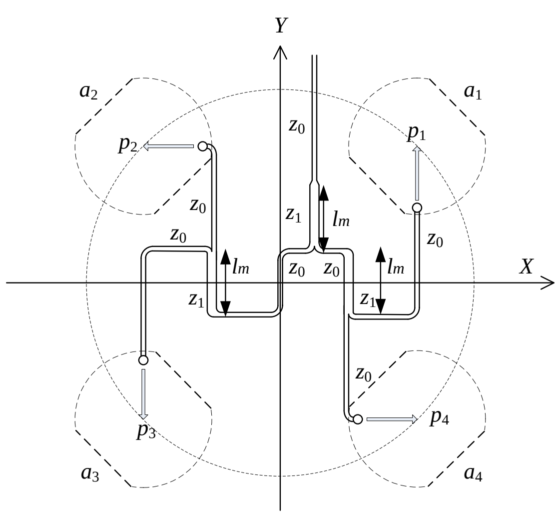


Fig. 10 Routing wires for the orthogonal array antenna (arrangement 1).

z_0 = 50 (Ω), z_1 = 35.4 (Ω) , l_m = 5.0 (mm)

Four units are allocated in orthogonal on a plane of arrangement 2 in Fig 11. The *xi* and *yi* (i = 1,.. ,4) axes of each unit antenna are set to have orthogonal directions each other.

Routing wires for the orthogonal array antenna of arrangement 2 are shown in Fig. 12. This pattern is given at the backward of routing wire substrate.

The mutual relations of electromagnetic radiation field specified in Fig. 9 are different to the field specified in Fig. 11.

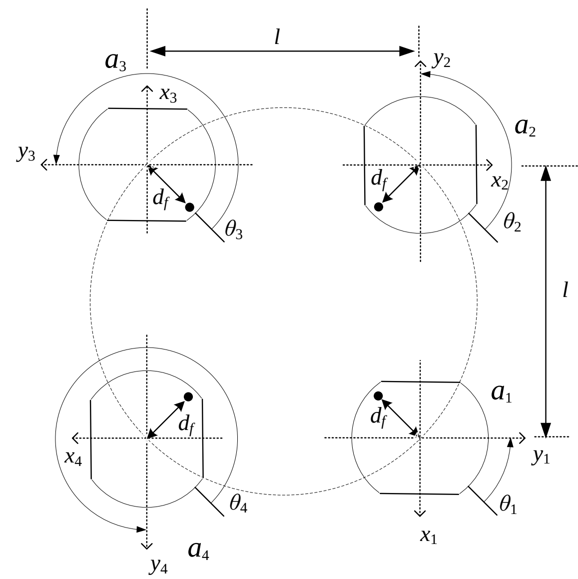


Fig. 11 An array antenna with orthogonal arrangement (arrangement 2).

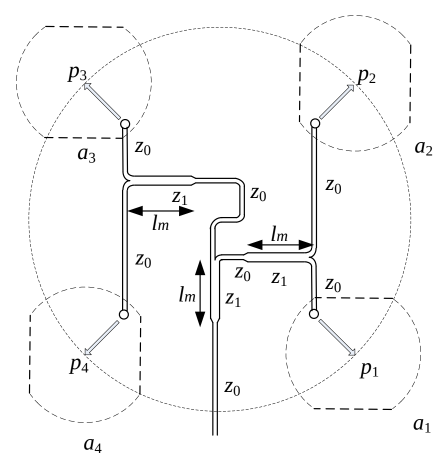


Fig. 12 Routing wires for the orthogonal array antenna (arrangement 2).

z_0 = 50 (Ω), z_1 = 35.4 (Ω) , l_m = 5.0 (mm)

IV. CHARACTERISTICS OF ARRAY ANTENNA

The characteristics of the proposed antenna was evaluated by three dimensional computer simulation. The orthogonal arrangement 2 was used for the simulation.

(1) Return loss

The frequency characteristics of impedance matching by return loss is shown in Fig. 13. The return loss was 14 dB at the bandwidth of 10% (1GHz).

(2) VSWR

The frequency characteristics of input VSWR is shown in Fig. 13.

(3) Power gain

The characteristics of power gain is shown in Fig. 14. It is found that the gain is flat, and any spurious radiation modes are not included between 9 to 11 GHz.

(4) Axial ratio

The frequency characteristics of axial ratio is shown in Fig. 15 (a), (b), and (c). The axial ratio is obtained as better than 3dB from 9.5 GHz to 10.5GHz.

(5) Directivity of right-hand circulation

The directional radiation of right-hand circulation is shown by linear scale in Fig. 15 (a), (b), and (c). The 3dB radiation angle is ±15 degree.

The side robes are less than 17 dB at the range in ± 180 degrees.

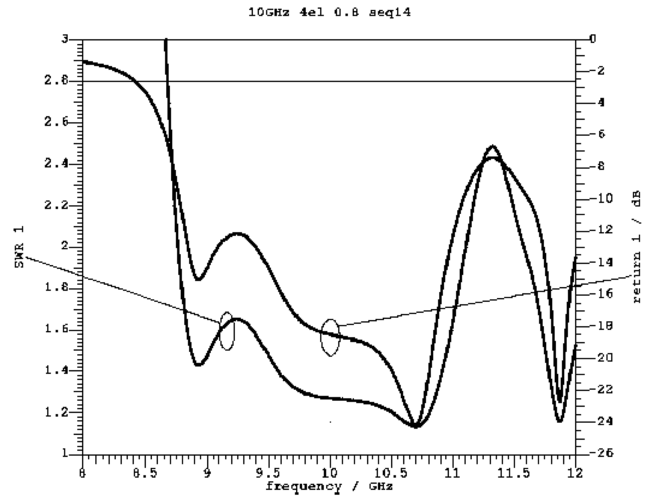


Fig. 13 Return loss vs. frequency.

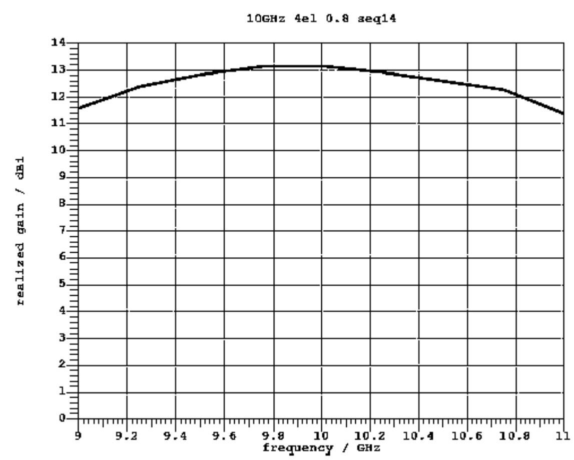
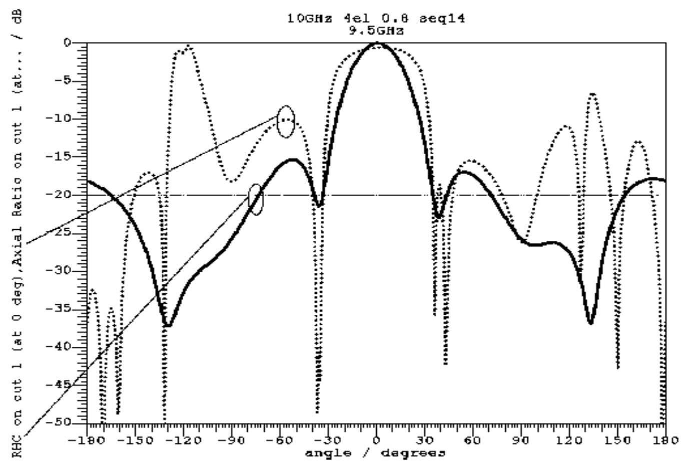
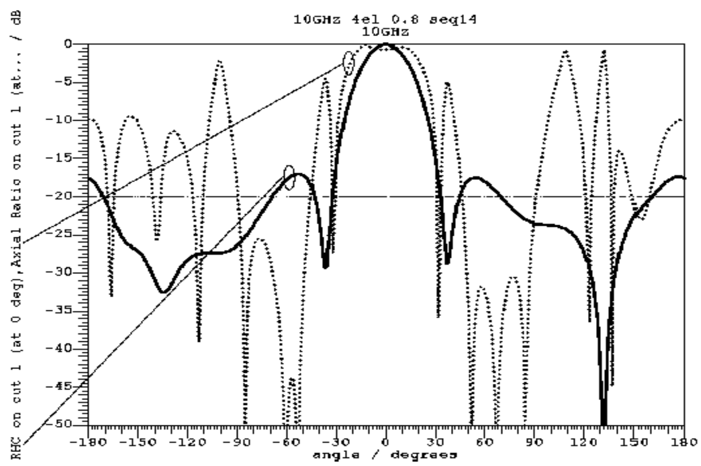


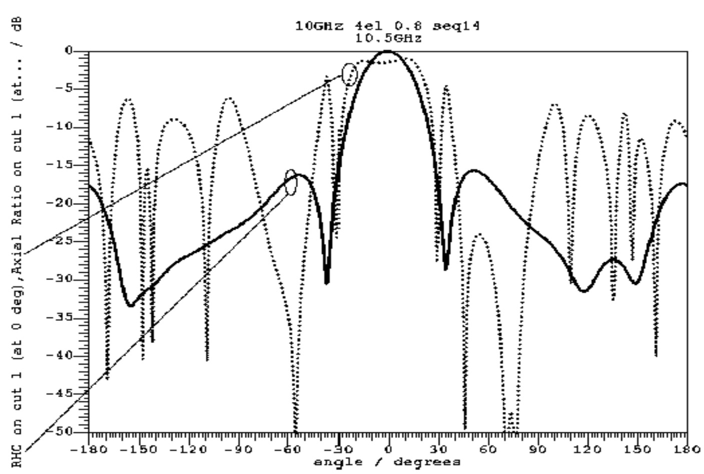
Fig. 14 Gain vs. frequency.



(a) 9.5 GHz



(b) 10 GHz



(c) 10.5 GHz

Fig. 15 Axis ratio (dotted) and RHC (solid) vs. horizontal angular.

V. Conclusion

A novel design was proposed for a circular polarization plane antenna at X- band. This unit antenna is composed of three elements of feed, reactance, and ground. Separation of degeneration is done by linearly truncated round disc. This structure provides smooth electromagnetic field in space, which contributes to give wideband response to prevent multiple spurious resonance at 5 – 15 GHz. The effective bandwidth of 3dB axis ratio was 0.7GHz at frequency band 10GHz.

This paper has given an orthogonal arrangement of array antenna. This array antenna is given by orthogonal arrangement of four antenna units said above.

Two types spatial arrangements of four antenna units are given with individual routing wires.

A wider bandwidth array antenna was obtained as 10 % (1 GHz) at 10GHz.

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