Novel Structure and the Characteristics of A Microwave Circular Polarization Antenna

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Abstract: - This paper gives a novel structure of circular polarization antenna at the X-band. This antenna is made as plane antenna composed of a feed- and a reactance-elements on a wide ground plate. The feed element is made by a circular disc cut linearly at the both sides along x-axis. The resonant frequencies are f_H and f_L along x- and y- axes respectively. Degeneration is achieved by shifting the resonant frequencies to be $f_H > f_L$ which correspond to resonant lengths along x- and y- axes. By defining the position of the feeding point, $\pi/2$ phase difference is provided for circular polarization with the current i_L and i_H. The reactance element is made of a circular disk smaller than the feed element. This element expands the bandwidth f_H - f_L of resonances, which brings expansion of effective band width of circular polarization. A circular polarization plane antenna with 0.7 GHz bandwidth was realized at 10GHz without spurious radiation between 5 ~ 15GHz.

Key-Words: - Circular polarization, Plane antenna, Degeneration of resonances, spurious frequencies, Axial ratio, X-band antenna.

1 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.

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 array antenna systems are studied in practice for navigation using circularly polarization [1].

A wideband patch antenna at 1.6 GHz were given by T. Noro and K. Ito, et al [2]. This antenna was composed with square feed- and parasitic patches on a ground plane. Separation of degenerated modes was achieved by diagonal corner cutting of the feeding patch. The bandwidth was 10 % for 3 dB axis-ratio at C-band.

The authors found in computer simulation that the above antenna are suffered by generation of multiple spurious radiation modes. And the feeding position was found critical at the feed element.

Another point of practical problem is as follows; that all antenna elements are made of metal plates. Any dielectric substrates are not used for fabrication, so characteristics of array antenna are not estimated easily by an elementally antenna of this structure.

Another design of antenna was given by M. Haneishi, et al [3]. The feeding element was composed of circular disc with central slot for degeneration of TM_{11} mode. But the effective bandwidth was limited to 2% or less.

This paper proposes a novel design of plane antenna composed of feed- and reactance-elements. These elements are produced with multi-layered substrates. The feed element is made by circular disc being cut linearly. A ground plate and feeding circuit layer are also produced with multi-layered substrates.

It proved wideband as 7% in 10 GHz without spurious modes, and easy decision of feeding position.

2 Generation of Microwave Circular Polarization

2.1 Generation of circular polarization

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. To degenerate multiple resonances, special scheme is needed for design of resonant plane. Square or circular planes have been utilized for degeneration of multiple resonances.

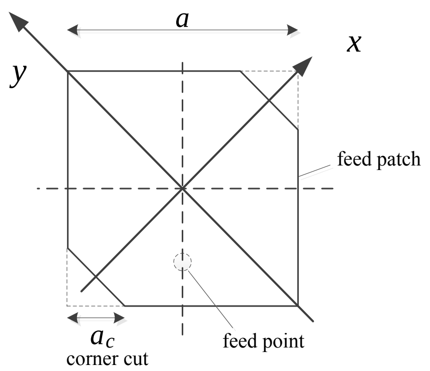
Square or circular plane antennas are shown in Fig.1 (a) and (b). 3 ~ 5 % of lengths of a side or a radius are truncated. Resonance frequencies are separated (degenerated) by this truncation. A single feeding is used with phase difference of $\pi/2$ (rad) for both axes to meet this condition.

Circular polarization is obtained under the condition that orthogonal conditions are met for the cross-sectional plane (x –y) and the time axis (t). Between the lower and the higher resonant frequencies f_l and f_h , circular polarization is generated at the central frequency f_0 and the neighbor.

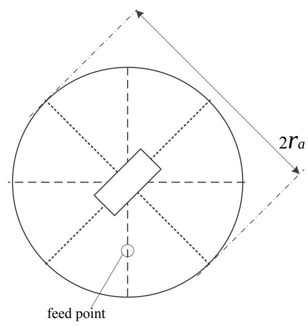
But the effective bandwidth of circular polarization is as narrow as 2 ~ 3 %. Furthermore number of resonant frequencies (modes) appear.

2.2 Enhancement of gain and bandwidth for circular polarization

The configuration of the Yagi-Uda antenna[4] is shown in Fig. 2. This antenna is composed of three antenna elements, which are (a) main element with feed, (b) guide, and (c) reflector. The antenna gain and the bandwidth are effectively enhanced, when parameter values of lengths l_a, l_b, and l_c of the elements (a), (b), (c) and the distances d_a, d_b between ***a*** – ***b*** and ***a*** – ***c*** are chosen adequately.



(a) Square patch antenna.
Ground plane is abbreviated.



(b) Circular patch antenna[3].
Ground plane is abbreviated.

Fig. 1 Microwave plane antenna for circular polarization.

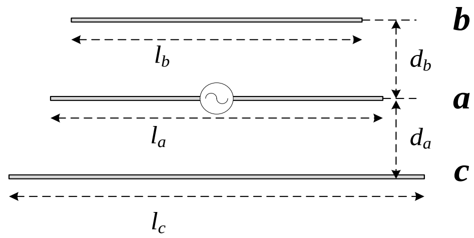


Fig. 2 Yagi-Uda antenna[4].
a : main element with feed
b : guide
c: reflector

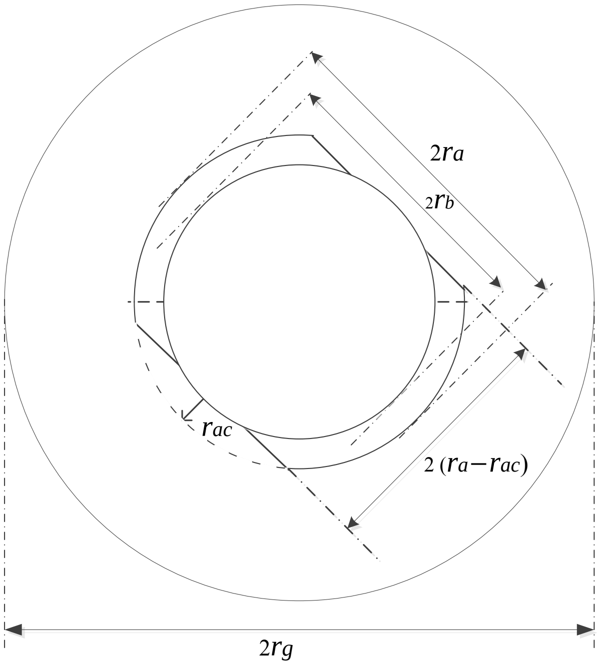


Fig. 3 Overhead view of the proposed antenna. The dimension of reactance element is included.

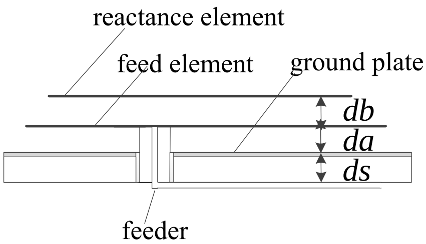


Fig. 4 Cross-sectional view of the proposed antenna.

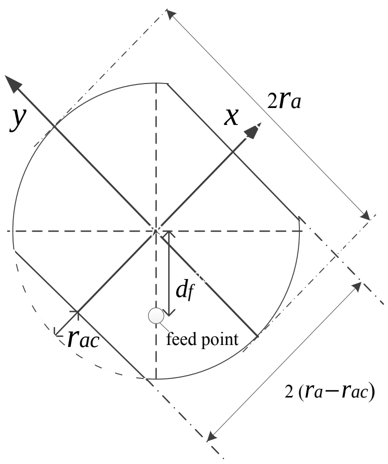


Fig. 5 Dimension of feeding element.

3 Theoretical Study of Wideband Microwave Antenna

3.1 Fundamental consideration

The fundamental points of the difference of the proposed antenna and the Yagi-Uda antenna are as follows;

(1) Space 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) Function of the 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 an 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.

3.2 Configuration of the proposed antenna

The proposed antenna is composed of the feed element (a), the reactance element (b), and the ground plate (g).

The configuration of the proposed antenna is shown in the overhead and the cross-sectional views of Fig. 3 and 4.

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

Feed element *a*:

In Fig. 5, 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, t he distance d_a is kept close to the ground. Now the feed 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.

Routing-wire substrate *s*

The substrate *s* should be prepared for routing-wire connected to the feed element *a*.

The impedance of feeding must be 50Ω coaxial cable. This is made by thin dielectric substrate under the ground plate *g*. By this configuration, microwave interference is cut by the ground *g* for forward direction of the *z*-axis.

3.3 Generation of circular polarization

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 [3]. Circular polarization was realized by a rectangle slot in the center of the circular feeding element.

4 Characteristics of the Proposed Antenna

4.1 Design parameters

Frequency band;
central frequency f_0 = 10 GHz

Dimension of the feed element *a*;
length along *y* axis $2r_a$ = 10 (mm)
cutting width $2r_{ac}$ = 3.00 (mm)
length along *x* axis $2(r_{a-} - r_{ac})$ = 7 (mm)
feeding position df = 2.60 (mm)

Dimension of the reactance element *b*;
diameter $2r_a$ = 8.0 (mm)

Dimension of the ground plate *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*
d_b = 1.60 (mm)
Distance between *g* and *a*
d_b = 1.28 (mm)
Distance between *s* and *g*
ds = 1.28 (mm)

4.2 Characteristics of the proposed plane antenna

The proposed antenna was designed for the right-hand polarization. The following characteristics have been obtained.

(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) Axial ratio

The frequency characteristics of axial ratio is shown in Fig. 7. W here, 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. 8. It is found that any spurious radiation modes are not included between 8 to 12 GHz.

(4) Input impedance

The frequency characteristics of input impedance is shown in Fig. 9. The thin (red) and the thick (blue) lines show the real and imaginary parts of impedance. The real part is 50 Ω, and the imaginary part is enough small in wideband.

(5) Radiation pattern at $\Psi = 0$ (rad) by linear scale

The gain of directional radiation pattern at $\Psi = 0$ (rad) is shown by linear scale in Fig. 10. The side robes are low enough.

(6) Radiation pattern at $\Psi = 0$ (rad) by directional angle

The gain of directional radiation pattern at $\Psi = 0$ (rad) angle is shown by directional in Fig. 11. The 3dB radiation angle is ±30 degree.

(7) Radiation pattern at $\Psi = \pi/2$ by linear scale

The gain of directional radiation pattern at $\Psi = \pi/2$ is shown by linear scale in Fig. 12. T he side robes are low enough.

(8) Radiation pattern at $\Psi = \pi/2$ by directional angle

The gain of directional radiation pattern at $\Psi = \pi/2$ is shown by directional angle in Fig. 13. The 3dB radiation angle is ±30 degree.

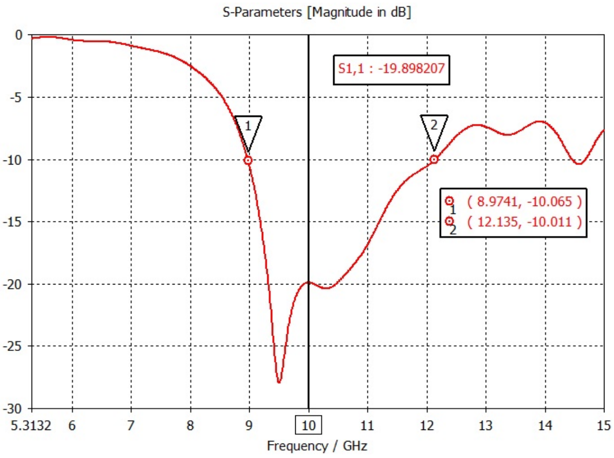


Fig. 6 Return loss

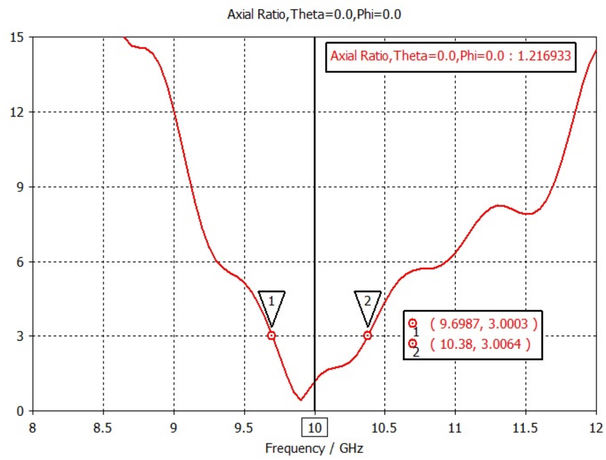


Fig. 7 Axial ratio

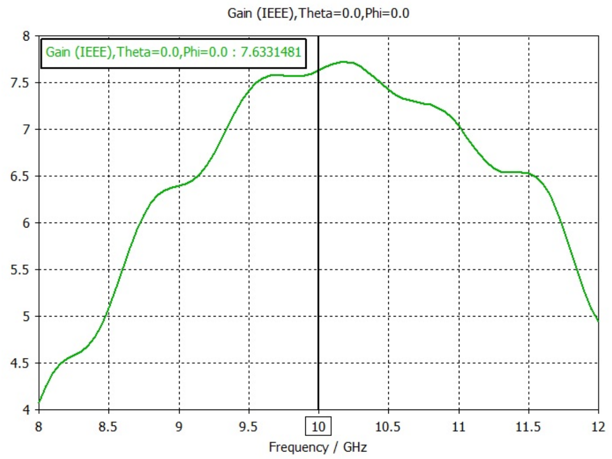


Fig. 8 Power gain.

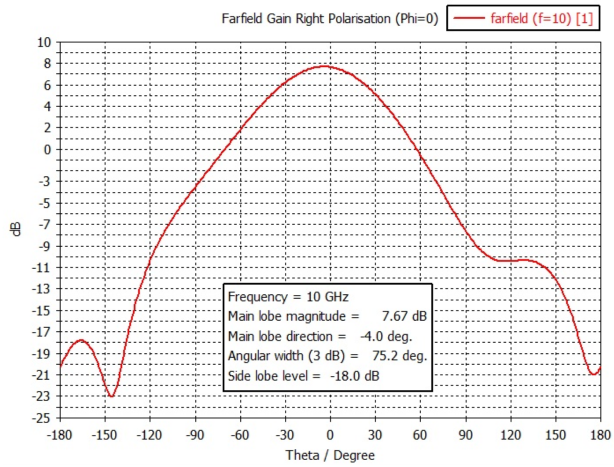


Fig. 10 Radiation pattern (linear).
$\Psi = 0$ (rad).

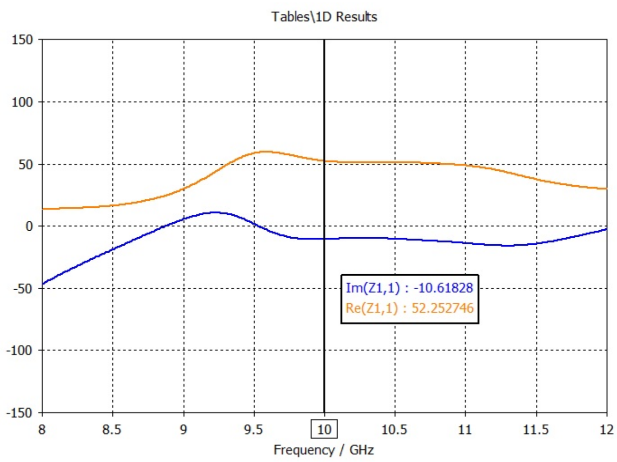


Fig. 9 Input impedance.

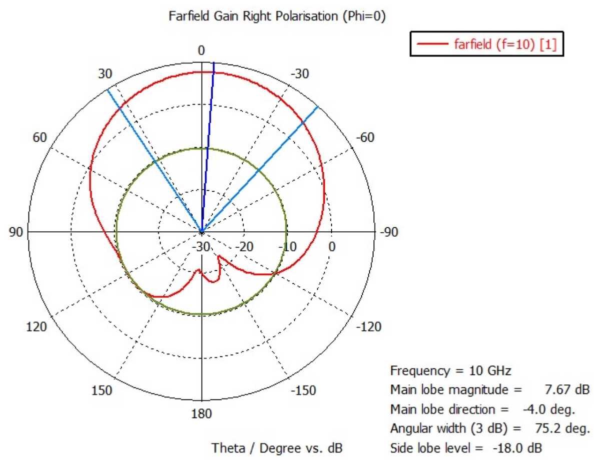


Fig. 11 Radiation pattern (polar).
$\Psi = 0$ (rad).

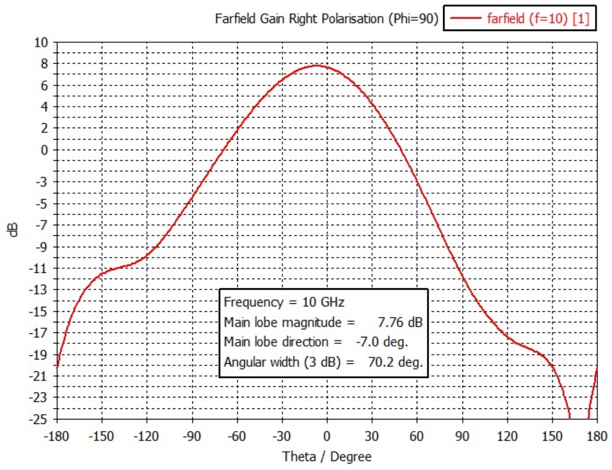


Fig. 12 Radiation pattern (linear). $\Psi = \pi/2$ (rad).

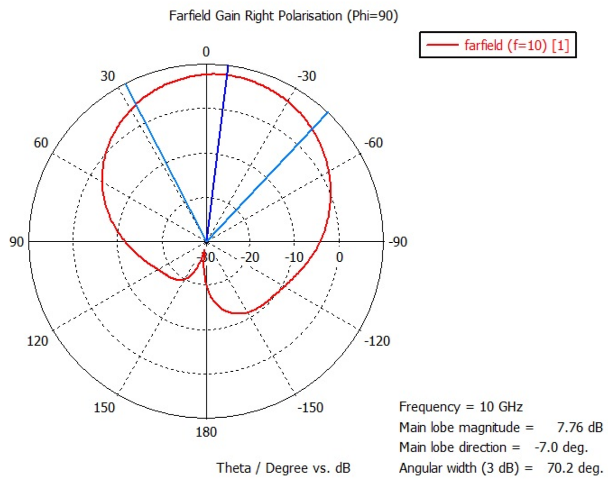


Fig. 13 Radiation pattern (polar). $\Psi = \pi/2$ (rad).

5 Conclusion

A design of a wideband plane antenna has been proposed based on the knowledge of the Yagi-Uda antenna and the conventional patch antenna. The effective bandwidth of 3dB axis ratio was 0.7GHz at frequency band 10GHz. any multimode was not found between 5 ~ 15 GHz. The position of feed point was decided without critical adjustment. This antenna will be applied for antenna array system for wideband use including microwave measurement of environmental conditions.

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References:

[1] B. Sumantyo, J.S. Sumantyo, 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.