

Microwave Patch Antenna with Circular Polarization for Environmental Measurement

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, Tokyo, JAPAN
fukasawafuji@yahoo.co.jp

Abstract: - This paper proposes a novel microwave antenna for environmental measurement. This antenna is composed of three circular patches of feed and reactance patches on a ground plane.

The feed patch keeps long radius resonant to low frequency f_L along y axis. This patch is cut linearly at diagonal edges resonant to high frequency f_H along x -axis. The reactance patch is made of a smaller circular disk for resonant to the frequency f_M being set between f_L and f_H . By magnetic and electric coupling between the feed and the reactance patches, the phases of current i_L and i_H are delayed and proceeded. Circular polarization is brought by this process. 3dB axial ratio is obtained in wideband at 10GHz without higher mode between 5 ~ 15GHz.

Key-Words: - Circular polarization, Patch antenna, Axial ratio, X-band antenna, Environmental measurement

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

A wideband patch antenna were given by T. Noro and K. Ito, et al [2]. This patch antenna was composed with two square patches of central (with feed) and upper (without feed) patch on a bottom (ground) patch. Separation of degenerated modes was achieved by diagonal corner cutting of 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 higher modes, and feeding position was found so critical at the central patch.

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

This paper proposes a novel design of a patch antenna composed of circular patches with linear cutting of a feed patch. It proved wideband as 7% in 10 GHz without higher 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. 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.

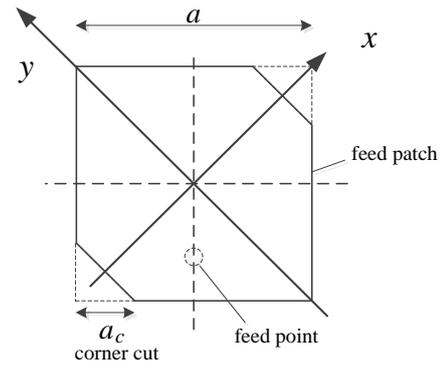
Circular polarization is obtained under the condition that orthogonal conditions are met for the cross-sectional plane ($x - y$) and the time axis (t). Between the lower and the higher resonant frequencies f_l and f_h , circular polarization is generated at the central frequency f_0 and the neighbor.

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

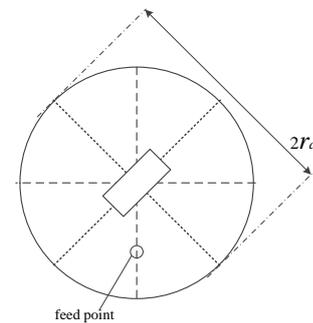
2.2 Enhancement of gain and bandwidth for circular polarization

Yagi-Uda antenna[4] is shown in Fig. 2. 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.

The proposed plane (patch) antenna is now given reflecting the specific configuration of antenna element.



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



(b) Circular patch antenna[2].
 Ground plane is abbreviated.

Fig. 1 Microwave plane antenna for circular polarization.

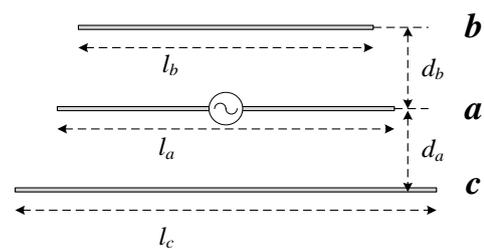


Fig. 2 Yagi-Uda antenna[3].
a : main element with feed
b : guide
c : reflector

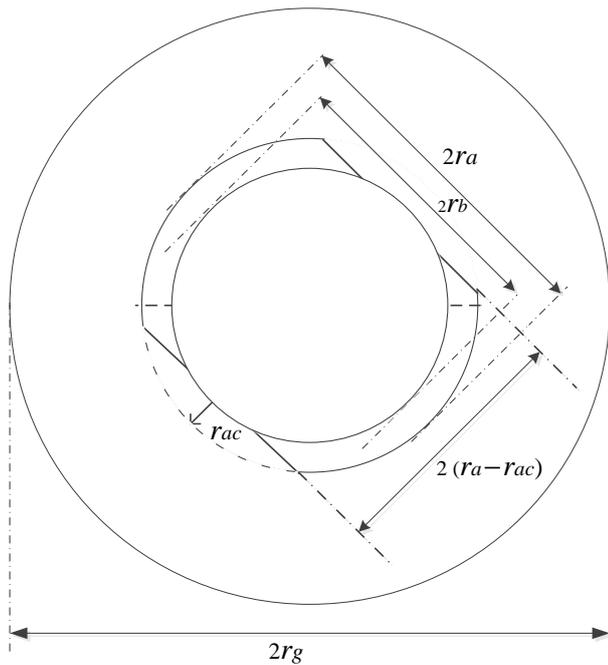


Fig. 3 Dimension of reactance patch.

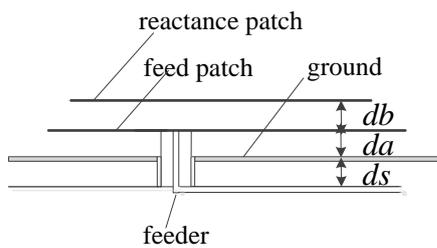


Fig. 4 Cross-sectional view of patches.

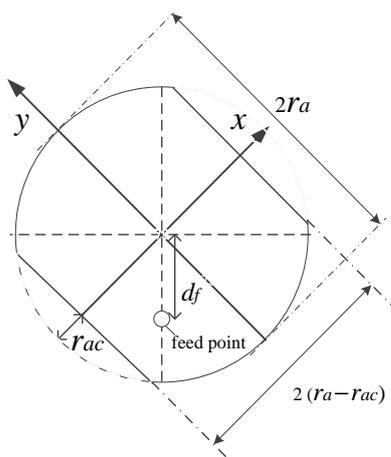


Fig. 5 Dimension of feeding patch.

3 Fundamental Design

3.1 Basis of the proposed patch antenna compared to Yagi-Uda antenna

Yagi-Uda antenna is shown in Fig. A-1 in Appendix. It is composed of the main (central), the guide (above), and the reflector (below) [3]. 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 .

3.2 Configuration of the proposed patch antenna

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

The configuration of the proposed patch 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 (b), and ground (g) patches are $2r_a$, $2r_b$, and $2r_g$ respectively. In Fig. 4, the distances between patches 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.

Metal patterns of patches, ground, and routing wires are formed by photolithography on the Teflon glass substrates.

Feed patch a:

In Fig. 5, the feed patch 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 patch a and the ground g form a microstripline resonator. The ground g provides the path for return current of the resonator a.

Reactance patch b

The patch b is made of a circular disc shown in Fig. 4. The patch b 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 patch *a* is fed by a short wire connected to the central conductor of 50Ω coaxial cable. This patch is made on the dielectric substrate under the ground patch *g*. By this configuration, microwave radiation 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 patch *a*, and f_M by the patch *b*, where the relation is kept as ;

$$f_L < f_M < f_H \tag{1}$$

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 patch *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 patch.

4 Characteristics of the Proposed Patch Antenna

4.1 Design parameters

Frequency band;

central frequency $f_0 = 10$ GHz

Dimension of the patch *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 patch *b*;

diameter $2r_a = 8.0$ (mm)

Dimension of the ground patch *g* :

diameter $2r_g = 31.0$ (mm)

Relative permittivity $\epsilon_r = 2.16$

Thickness of metal $d_M = 0.035$ (mm)

Distance between *a* and *b* patches

$d_b = 1.60$ (mm)

Distance between *g* and *a* patches

$d_b = 1.28$ (mm)

Distance between *s* and *g*

$ds = 1.28$ (mm)

4.2 Characteristics of the proposed patch antenna

Return loss, axial ratio, input impedance, and gain are shown in Fig. 6, 7, 8, and 9 respectively.

Radiation patterns are shown in Fig. 10 and 11.

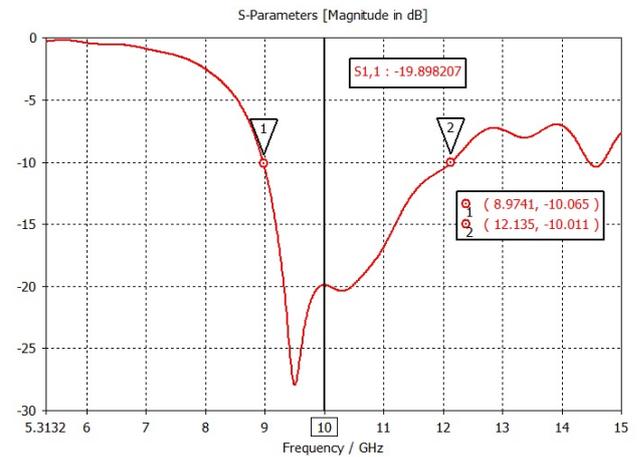


Fig. 6 Return loss

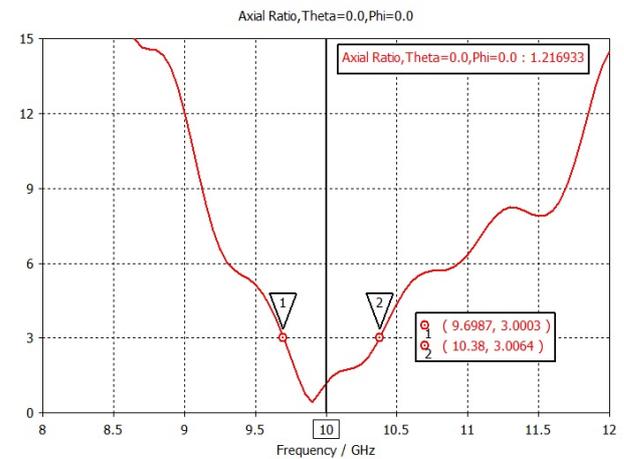


Fig. 7 Axial ratio

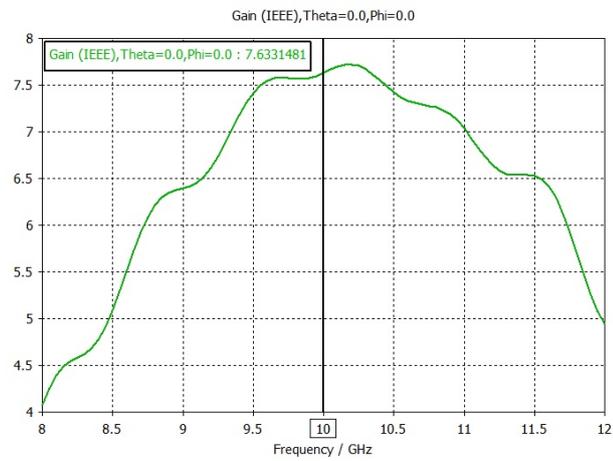


Fig. 8 Power gain.

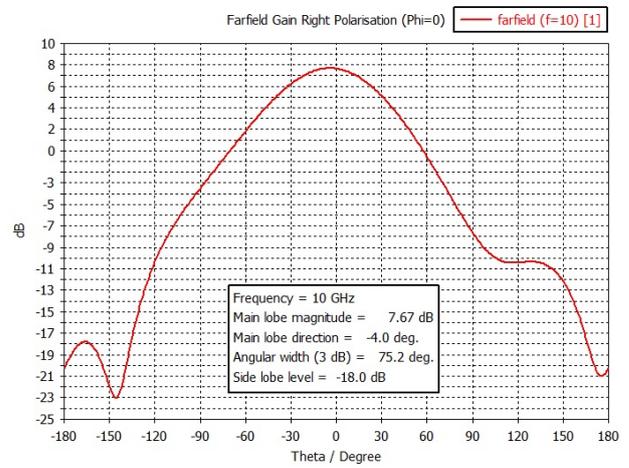


Fig. 10 Radiation pattern (linear).

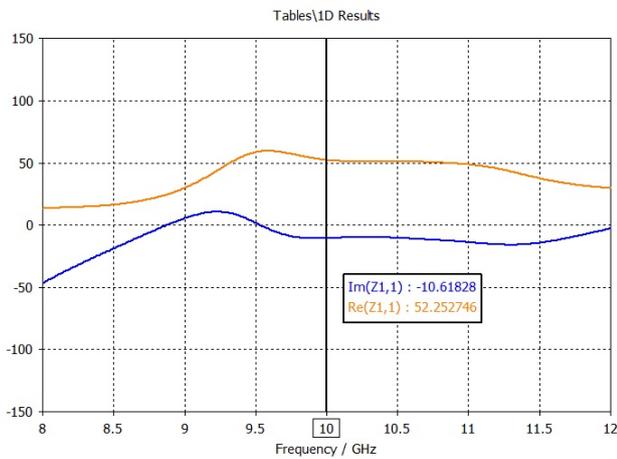


Fig. 9 Input impedance.

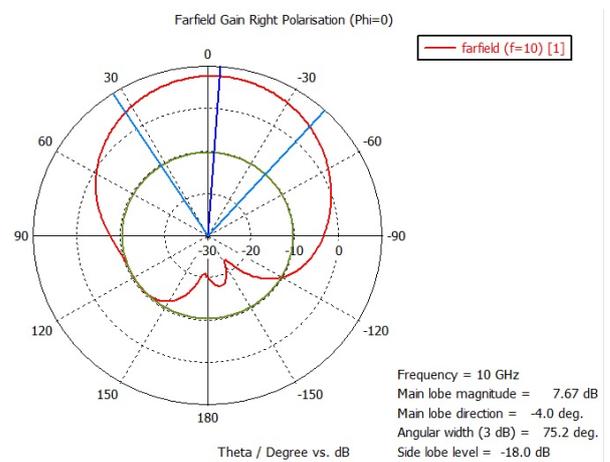


Fig. 11 Radiation pattern (polar).

5 Conclusion

A design of a wideband patch antenna has been proposed based on the knowledge of 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 utilized to compose patch array antenna and used for positioning and other wide area of environmental measurement.

Acknowledgement

The proposed antenna system was evaluated by computer simulations achieved in the Center for Environmental Remote Sensing, Chiba University.

The authors express their sincere gratitude for kind cooperation and supports by Prof K. Ito, and Prof. J. Tetuko Sumantyo, Chiba University.

We also express their sincere gratitude for simulation supports by Mr. C. E. Santosa, Graduate Student, Graduate School, Chiba University.

This study and technical development were supported by Mr. M. Abe, CEO, Musasino Co.Ltd and the scholarship donations given by Musashino.

And this research is supported by Prof. T. Higuchi, Director General, ISM and Prof. N. Kashiwagi, ISM, and financial support by MEXT/JSPS KAKENHI Grant Number 17K00067.

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.