Configuration and Radiation Characteristics of Soccer Ball Type Array Antenna

Ayako TAKAHASHI [1], Toshikazu HORI [1], Mitoshi FUJIMOTO [1]
Kiyotake ANDO [2] and Yozo TAKEDA [2]
[1] Graduate School of Engineering, University of Fukui
3-9-1 Bunkyo, Fukui, 910-8507 Japan
E-mail: takahashi@wireless.fuis.fukui-u.ac.jp
[2] JSAT Corporation
1-14-14, Akasaka, Minato-ku, Tokyo, 107-0052 Japan

1. Introduction

A conformal array antenna arranged on the curved surface features to steer a beam in the hemisphere. As such a conformal array antenna, a spherical array arranged on a sphere has been studied, so as to apply to a mobile antenna for mobile satellite communications [1][2][3]. However, many elements are required to realize both performance of high gain and wide beam steering [4]. Therefore, it is necessary to arrange the antenna elements uniformly on a sphere in order to obtain a higher coverage gain. A polyhedron is suited for arranging the antenna element uniformly [5]. For that reason, we examined about a polyhedral array antenna arranged on the polyhedron. It is clarified that a soccer ball type antenna is suitable for the polyhedron to achieve the higher minimum coverage gain [6].

This paper describes the configuration of a soccer ball type array antenna arranged on a polyhedron so as to steer a beam. Here, the soccer ball type antenna is composed of sub-arrays, and the sub-array is composed of several antenna elements arranged on a co-plane. In order to extend the steering angle of the sub array, a phase control for each sub array is introduced. The purpose of the phase control is to achieve higher coverage gain than that of antenna when antenna elements switched one by one. The minimum coverage gain of proposed soccer ball type antenna with phase control is introduced. Furthermore, the performance of the proposed array antenna is verified by experiments.

2. Minimum Coverage Gain of Polyhedral Antenna and Feature of Soccer Ball Structure

The polyhedrons are suited for arranging antenna elements uniformly. For that reason, we examined about a polyhedral array antenna arranged on the polyhedron. It has been clarified that a soccer ball type antenna is suitable for polyhedron to achieve the higher minimum coverage gain [6]. Here, the minimum coverage gain means the level ensured by the polyhedral array antenna. The minimum coverage gain is the crossover level between radiation patterns of neighboring antenna elements. The maximum coverage gain corresponds to the directive gain of an element antenna.

Figure 1 shows a soccer ball type antenna. Figure 2 shows the coverage gain of polyhedral antennas when antenna elements switched one by one. In Fig.2, the horizontal axis shows the number of antenna elements. And, the left and the right vertical axes show the coverage gain and the radius of the polyhedral antenna, respectively. Here, the radius is calculated from the aperture area when aperture efficiency is 100%. The horizontal axis means the number of polygons on the polyhedron. For example, dodecahedron antenna has 12 polygons. In the case of dodecahedron, we can find from Fig.2 that maximum coverage gain is 10 dBi, limitation of minimum coverage gain is 6 dBi, and radius of dodecahedron is about 1λ.

As shown in Fig. 2, the maximum coverage gain and the minimum coverage gain increase by increasing of the number of the antenna elements. However, the radius of antenna is also increased.

It is clarified as shown in Fig.2 that a soccer ball type antenna is an efficient arrangement of antenna elements; because soccer ball type antenna can achieve the higher minimum coverage gain although antenna size is small. For example, minimum coverage gain of soccer ball type antenna is higher than that of Hexacontahedron. Hexacontahedron is composed 60 triangles. In short, soccer ball type antenna can achieve high gain though it needs few antenna elements. As shown in this figure, it was clarified that limitation of minimum coverage gain in case of soccer ball type antenna is 10 dBi when antenna elements switched one by one.

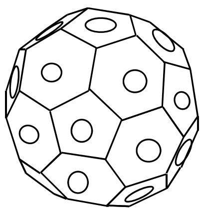


Figure 1: Soccer ball type antenna

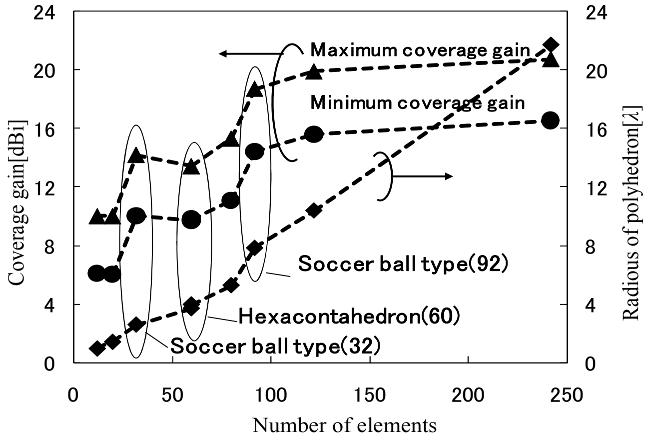


Figure 2: Relationships between number of elements and coverage gain

3. Coverage Gain of Soccer Ball Type Array with Phase Control

3.1 Antenna Model for Soccer Ball Type Array with Sub-Arrays

In order to achieve higher minimum coverage gain, we propose the soccer ball type antenna composed of sub-arrays. Figure 3 shows the model of soccer ball type array antenna. A soccer ball type array has two kinds of polygons. One is pentagon and the other is hexagon as shown in Fig.3. We use sub-arrays in order to achieve higher coverage gain by steering a beam. Each sub-array is arranged on a regular polygon. Therefore, the shapes of the sub-array are a pentagon and a hexagon. Here, we assume that six elements are arranged around a center element of the hexagon as sub-array with the element spacing *d*. Similarly, seven elements are arranged on the pentagon, for simplifying the model. In the calculation of the directive gain, it is assumed that the element pattern is expressed as $\cos^2\theta$ on the assumption that microstrip antennas. Here, θ is the angle from normal direction of sub-array.

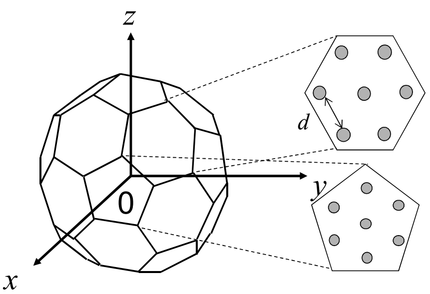


Figure 3: Configuration of soccer ball type antenna and sub-arrays

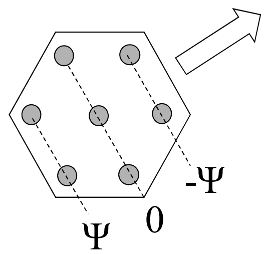


Figure 4: How to control the phase

Phased control is introduced for achieve higher minimum coverage gain than that of switching array as mentioned in Sec.2. Figure 4 shows a method of phased control. 7 elements are divided into 3 groups to simplify the phase control like Fig.4. The phase shifts of each antenna group are given as Ψ . Consequently, a beam is steered to the direction to the arrow indicated in Fig.4

3.2 Influence of Element Spacing on Minimum Coverage Gain

Figure 5 shows the relationship between the element spacing and the antenna directive gain. The horizontal axis shows phase shift, Ψ, and vertical axis shows minimum coverage gain. The parameter is element spacing in sub-arrays. Each minimum coverage gain for respective phase shift is shown by the solid line, the dotted line, the broken line and chain line, respectively.

As shown in Fig.5, minimum coverage gain is decreased as the element spacing is extended if phase control is not introduced (phase shift = 0 degree). Moreover, the optimum phase shift is different for element spacing. The optimum phase shift is about 65 degrees when element spacing is 0.5λ. It is found from Fig.5 that minimum coverage gain is largest when element spacing *d*=0.9λ and the optimum phase shift is 90 degrees. Then, the minimum coverage gain is about 15 dBi. As mentioned in Sec.2, limitation of minimum coverage gain of soccer ball type antenna is 10 dBi when antenna elements switched one by one. This limit is indicated by horizontal solid line in Fig.5. Accordingly, minimum coverage gain is improved about 5 dB by introducing phase control.

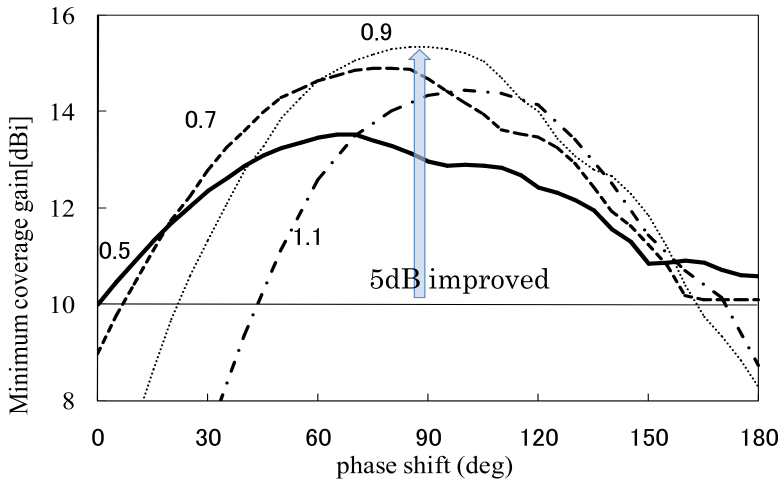
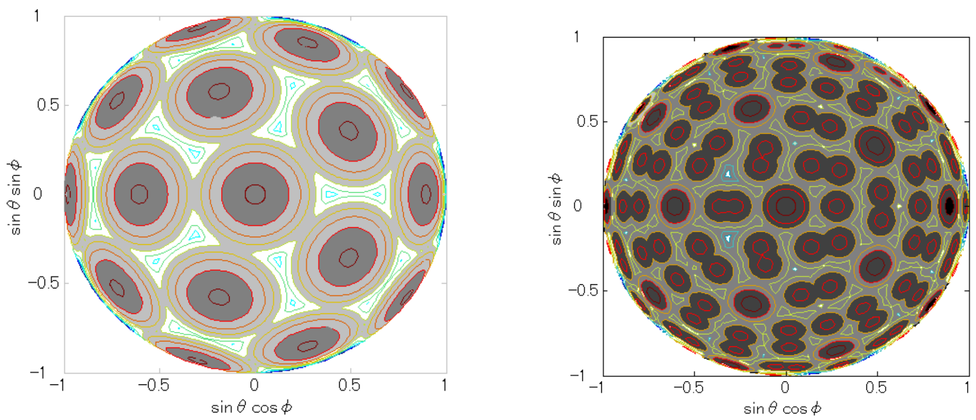


Figure 5: Relationships between phase shift and minimum coverage gain



(a) Without phase control (b) With phase control (Ψ = 90 degree)

Figure 6: Radiation characteristics of soccer ball type antenna

3.3 Radiation Characteristics

Figure 6 shows the radiation characteristics of switched-element soccer ball type antenna. Figures 6 (a) and 6(b) show the radiation pattern without phase control and with phase control when element spacing is 0.9λ, respectively. The horizontal axes and the vertical axes in Fig. 6 show the projection of gain to the x-y plane. For example, the value where the horizontal value is 1 and the vertical value is 0 indicates the directive gain at the direction of θ=90° and φ=0°. The dark part means high coverage gain.

As shown in Fig. 6 (a), the levels of several directions with the low minimum coverage gain are the same each other, because the antenna elements are uniformly arranged in the hemisphere. We can find from Fig.6 (b) that minimum coverage gain is improved by adopting the phase control. From these results, it can be said that antenna elements arranged on the polygons have an effect for increasing minimum coverage gain.

4. Fabricated Soccer Ball Type Array and Experimental Results

In order to verify the performance of proposed array antenna, the soccer ball type array antenna with 7 elements is fabricated. The element spacing of the sub-array is 0.9λ, and the phase shift is 90 degrees. Figures 7 and Fig.8 show the fabricated soccer ball type antenna and feeding circuit, respectively. Figure 7 shows the situation in several sub-arrays. These sub-arrays are set on soccer ball type frames. The radiation pattern of center array antenna of this figure is measured.

The radiation pattern without phase control in measurement is shown in Fig 9. The solid line and the broken line indicate the measured radiation pattern and the simulated ones, respectively. As shown in these figures, it is found that the radiation pattern in measurement is well agreed with in calculation. Moreover, radiation pattern with phase control was measured, too. Also, this radiation pattern in measurement is similar as well as in calculation.

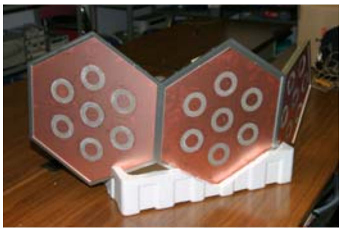


Figure 7: Array antenna on soccer ball type

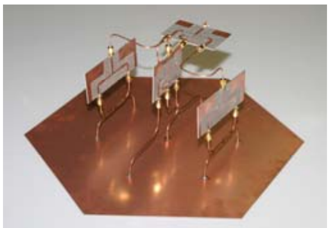
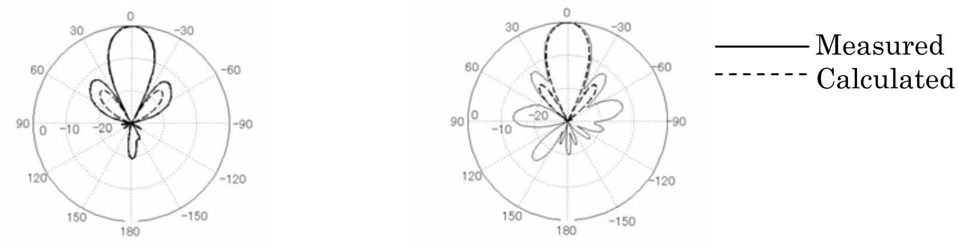


Figure 8: Feeding circuit



(a) Plane of arranging antenna elements (b) Plane of among arranging antenna elements

Figure 9: Radiation pattern of array antenna

6. Conclusion

In order to cover the hemisphere, the soccer ball type switching array antennas arranged on polyhedrons were proposed. Moreover, the relation between the element space and the minimum directive gain achieved by the proposed array antenna was discussed. The gain limitation of soccer ball type antenna was 10 dBi, and it was found that minimum coverage gain of soccer ball type antenna improved about 5 dB by introducing the phase control. Finally, in order to verify the calculated results, the sub-array of soccer ball type array antenna with 7 elements was fabricated. The experimental results coincided nearly with the calculated results.

References

[1] T. Shiokawa, F. Watanabe, S. Nomoto, “Spherical Array Antenna for General Mobile Satellite Communications,” IEICE Tech.Rep.AP84-30, 1984(in Japanese).

[2] Y. Konishi, “Phased Array Antennas,” IEICE Trans. Commun. vol.E86-B, no.3, pp.954-pp.967, Mar,2003.

[3] T. Hori, N. Terada and K. Kagoshima, “Design of switched-element spherical array antenna,” IEICE Tech. Report AP84-68, Nov.1984 (in Japanese).

[4] N. Terada, T. Hori and K. Kagoshima, “Radiation characteristics of switched-element spherical array antenna,” IEICE Tech. Rep. AP85-63, Oct.1985 (in Japanese).

[5] A. Takahashi, T. Hori, M. Fujimoto, K. Ando and Y. Takeda, “Configuration and Radiation Characteristics of Polyhedral Array,” Proc. ISAP2007, Niigata, Japan, 2B3-5, Aug. 2007.

[6] A. Takahashi, T. Hori, M. Fujimoto, K. Ando and Y. Takeda, “Coverage Gain Limitation of Polyhedral Array Antennas,” iWAT2008, Chiba, Japan, p339, Mar. 2008.