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Configuration and Radiation Characteristics of Polyhedral Array Antennas

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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]. However, many elements are required to realize both performance of high gain and wide beam steering [3]. In such case, the configuration of a spherical array antenna tends to be complicated because each element is individually fed by feeding network. Therefore, a polyhedral array antenna arranged on a polyhedron can be suited because of production costs. The polyhedral array antenna is composed of sub-arrays, and the sub-array is composed of several antenna elements arranged on the co-plane.

This paper describes the configuration of a polyhedral array antenna arranged on a polyhedron so as to steer a beam in the hemisphere. A regular dodecahedron, a regular icosahedron and a cut-vertex icosahedron (soccer ball type) are considered as the polyhedron [4]. Here, the relation between the size of an array antenna and the minimum directive gain of the proposed array antenna is discussed. Moreover, in order to extend the steering angle of a sub array, the phase control for each sub array is introduced.

2. Analysis Model for Polyhedral Array Antennas

Figure 1 shows the three types of polyhedral array antennas. The polyhedral array antenna is composed of regular polygons for polyhedron. The regular polygons are a regular dodecahedron shown in Fig.1 (a), a regular icosahedron shown in Fig.1 (b) and a cut-vertex icosahedron (soccer ball type) shown in Fig.1 (c) are considered. Here, the polyhedral array is composed of sub arrays, and each sub-array is arranged on a regular polygon.

In case of using a regular dodecahedron, the shape of the sub-array is pentagon. Five elements are arranged around the center of the sub array at the element spacing *d*. Similarly, in the case of a regular icosahedron, three elements are arranged inside of equilateral triangle without the central element. The cut-vertex icosahedron of soccer ball type has two kinds of polygons. One is pentagon and the other is hexagon as shown in Fig.1(c). The side length of a polygon is *d*.

In the calculation of the directive gain, it is assumed that the element pattern is expressed as $\cos^2\theta$. Here, θ is the angle from the zenith. The maximum directive gain and the minimum directive gain in the all direction are decided by only the element spacing *d*. The element spacing *d* is set 0.5λ to 0.8λ. Here, the maximum directive gain corresponds to the maximum directive gain of the sub-array, the minimum directive gain is determined the crossover level between radiation patterns of neighboring sub-arrays. And, it means the level ensured by the polyhedral array antenna. Table 1 shows the number of planes and the number of sides in polygon for the respective polyhedron.

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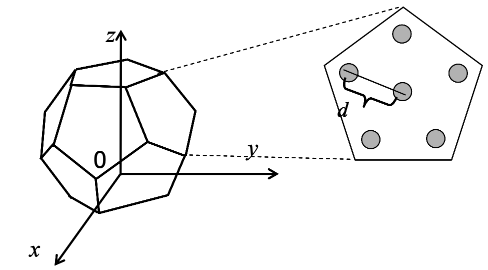
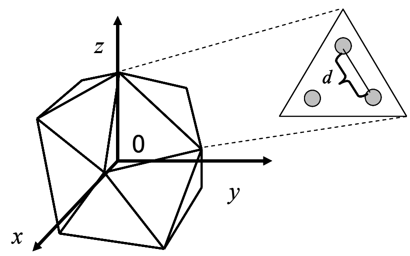


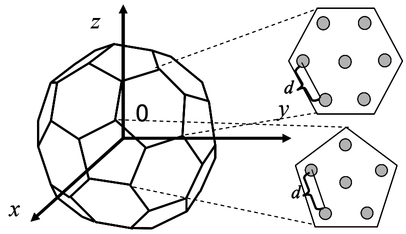
(a) Regular Dodecahedral Array



(b) Regular Icosahedral Array

Table 1: Number of Respects and Polygon of Polyhedron

Polyhedron	Number of planes	Polygon	
Regular dodecahedron	12	5	
Regular icosahedron	20	3	
Soccer ball type	32	5	6



(c) Cut-vertex Icosahedral Array (Soccer Ball Type)

Figure 1: Configuration of Polyhedral Array Antennas

3. Antenna Gain and Size of Regular Dodecahedral Array

Figure 2 shows the directive gain of switching array with d=0.5λ using a regular dodecahedron. Contours in Fig. 2 show the antenna directive gain of the pentagon sub-array. The horizontal axis and the vertical axis in Fig. 2 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 antenna gain becomes large as the radius becomes small. There are several points with the minimum antenna gain, but the levels of the points are the same each other, because the sub-arrays are uniformly arranged in the hemisphere. It is found from Fig. 2 that the maximum gain is more than 14dBi and the minimum gain is approximately 5.5dBi. Similarly, contours in case of d=0.6, 0.7 and 0.8 has been drawn, and the maximum gain and the minimum gain are evaluated for each cases.

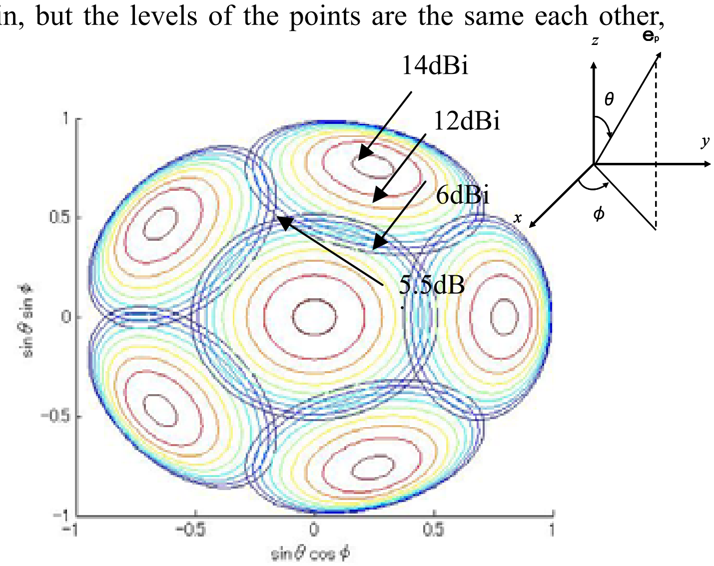


Figure 2: Antenna Gain Using Regular Dodecahedron Array (d=0.5λ).

Figure 3 shows the relationship between the element spacing and the directive gain in case of dodecahedral array antenna. And, the relationship between the element spacing and the antenna size is also shown in Fig. 3. The solid line, the broken line and the solid thin line in Fig. 3 indicate the maximum gain, the minimum gain and antenna size, respectively. Here, the size of polyhedron means the distance between the core and the surface of the polyhedron. The maximum gain is increased as the element spacing is extended. Conversely, the minimum gain is reduced when the element spacing is extended. This is because that the beam becomes sharp when element spacing is extended. The antenna size becomes large as the element spacing is increased.

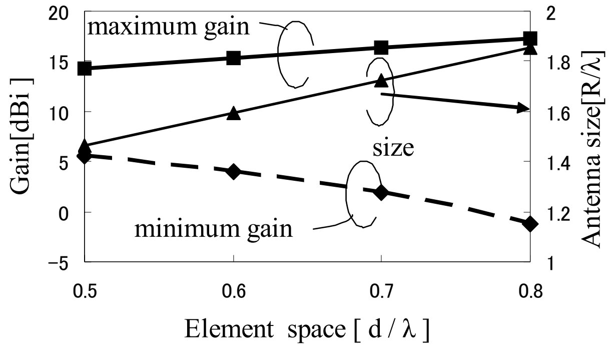


Figure 3: Polyhedron Size and Antenna Gain

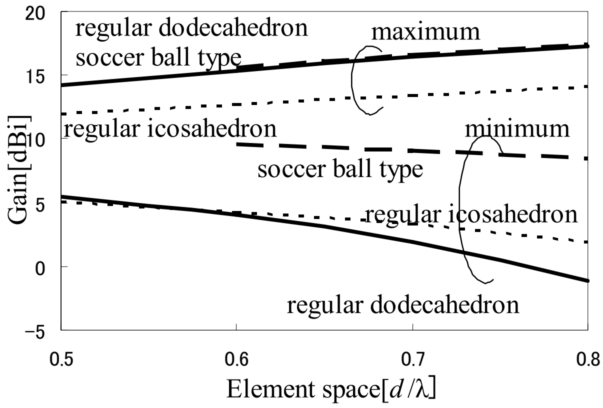


Figure 4: Influence of Element Spacing for Antenna Gain

4. Influence of Element Spacing on Antenna Gain and Size

Figure 4 shows the relationship between the element spacing and the antenna directive gain for three kinds of polyhedron. The solid line, the dotted line and the broken line show the directive gain of regular dodecahedron array, that of icosahedrons array, and that of the soccer ball type array, respectively. Since the directive gain of an array antenna is the same as the gain of sub-array, the maximum directive gain of polyhedrons is increased as the element spacing is extended. And, the minimum directive gain is reduced when the element spacing is extended for each polyhedron. As shown in Table 1, the number of the surface depends on the type of polyhedron. It is found from Fig.4 that the difference between the maximum directive gain and the minimum directive gain are reduced as the number of the surface of the polyhedron is increased. The minimum directive gain of dodecahedron is the smallest among all type of polyhedrons. The value of the minimum directive gain is -2dBi when element spacing is 0.8 λ. The number of antenna elements of the dodecahedron is 72, and the number of antenna elements of the icosahedron is 60. However, the minimum directive gain of the dodecahedron is smaller than that of icosahedron. The minimum directive gain of the soccer ball type array is the largest among the examined polyhedron, the 9dBi is obtained as minimum directive gain when d=0.7λ.

Figure 5 shows the relationship between the element spacing and the antenna size. The solid line, the dotted line and the broken line show the antenna size of the regular icosahedron, that of the dodecahedron and that of the soccer ball type array, respectively. The antenna size is increased according to the element spacing of each polyhedron. It is found from Fig.6 that the antenna size of icosahedral array is the largest among examined polyhedrons.

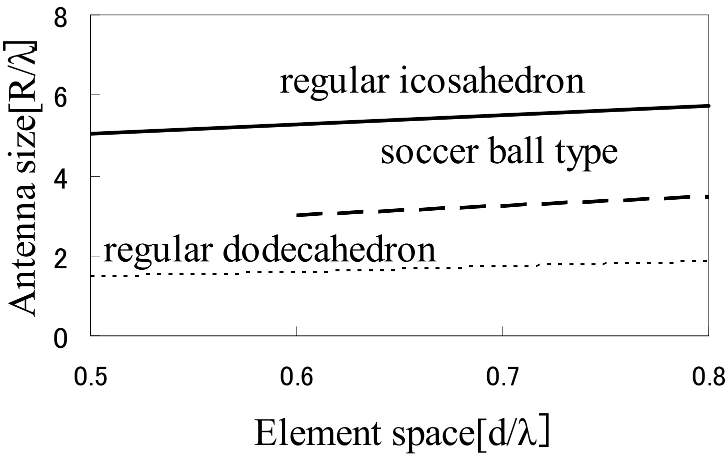


Figure 5: Relation between Element Spacing and Antenna Size

5. Improvement of Minimum Directive Gain by Phase Control

In order to extend the steering angle of a sub array, the phase control for each sub array can be introduced. Then, the minimum directive gain may be higher than the above-mentioned gain. Figure 6 shows the minimum directive gain of polyhedral arrays shown in Fig.1 when the phase control for each sub array is introduced. The phases of each element of sub-array are controlled so that the arrival signals from certain directions are combined with in-phase. The solid line and the broken line show the minimum directive gain with and without the phase control, respectively. The minimum directive gain is reduced as the element spacing is increased because beam width becomes sharp as element spacing is extended. However, the degradation of the antenna directive gain is mitigated when the phase control is adopted. The tendency is the same in any case of polyhedral antennas. In addition, it is found that the antenna gain in only the case of a soccer ball type array is increased as the element spacing is extended.

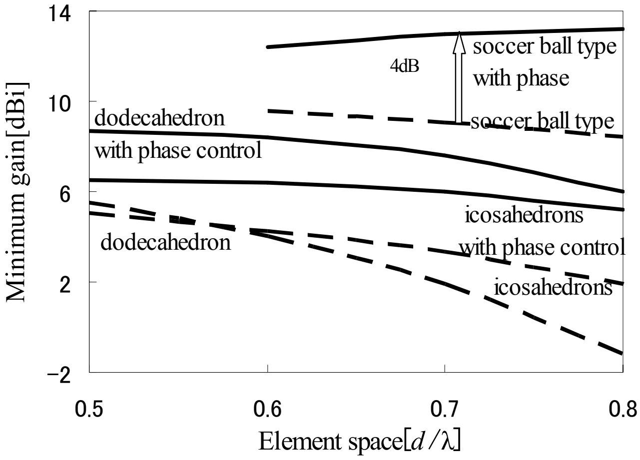


Figure 6: Improvement of Minimum Gain by Phase Control

Although the icosahedron is better than the dodecahedron concerned with the minimum directive gain without the phase control, the minimum directive gain using the regular dodecahedron is improved better than the regular icosahedron due to the phase control.

It is found that the minimum directive gain of a soccer ball type array is improved about 4dB when d=0.7λ. It is clarified that the minimum directive gain of the soccer ball type array without the phase control is better than the other polyhedrons with the phase control.

6. Conclusion

In order to cover the hemisphere, the conformal switching array antennas arranged on polyhedrons were proposed. Moreover, the relation between the array size and the minimum directive gain achieved by the proposed array antenna was discussed. The regular dodecahedron, the regular icosahedron, and the soccer ball type array were considered for the polyhedron. It was clarified that the size of the icosahedral array was the largest among examined polyhedrons. The minimum directive gain of the soccer ball type array was the largest among the examined polyhedrons, and the 9dBi gain was obtained as the minimum gain when *d*=0.7λ. And, it was found that the minimum directive gain of the soccer ball type array was improved about 4dB when d=0.7λ.

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