A Circular Aperture Array Configuration with a Small Antenna Radius

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Abstract

In this paper, small sized array configurations with small number of element are investigated. As the antenna size, the diameter less than 3λo is assumed. The investigated configurations are a non-uniform arrangement, Triangular arrangement and uniform arrangement. The gain characteristics of these configurations is calculated using the method of moment and compared them. As a result, it is found that optimum number of elements and arrangement to realize the maximum gain is changed by the element and that the triangular arrangement is not necessarily adequate to obtain maximum gain for small sized array antenna with small number of element.

1. INTRODUCTION

Recently, a demand for small-sized array antennas is increasing[1][2]. For example, the satellite for Inmarsat system employs high gain spot beam antenna to reduce the size of the antenna for a ship earth station.

Usually, for a large array antenna, it is said that a regular triangle arrangement is almost a best way to obtain a maximum gain with a minimum number of elements.

There can be found a few papers on a planar array configuration with a large number of element [3], [4]. In reference [3], it is apparent there are some situations that the triangular arrangement is not necessarily suitable, because a distance between elements is so small that the elements can't work effectively as an array antenna.

Authors have previously investigated array antenna with the diameter of almost 3λo using helical antennas as an array element [5]. In that study, we have examined the performance of 14-element non-uniform arrangement array antenna. As a result, we have shown that non-uniform arrangement is better than triangular arrangement to obtain a maximum gain with a minimum number of elements.

In this paper, instead of helical array antenna, isotropic element array and circularly polarized patch [6] array are investigated focusing on array arrangement with antenna diameter of almost 3λo.

2. A NON-UNIFORM ARRANGEMENT ARRAY ANTENNA

Figure 1 shows each element antenna position of 14-element non-uniform arrangement array which is studied in reference [5]. On the other hand, figure 2 shows each element position of 19-element triangular array. Both antennas are on a same-sized ground plane, so antenna size is the same. The diameter of the ground plane is 3.0 λo.

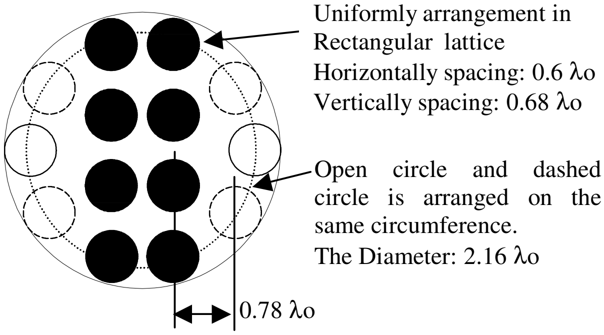


Fig. 1 14-element non-uniformly arranged array antenna.

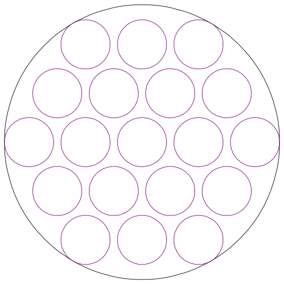


Fig.2 19-element regular triangle array antenna.

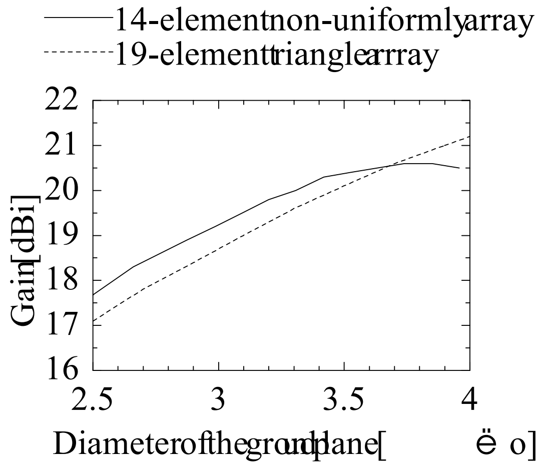


Fig.3 Antenna gain versus ground plane size for a patch antenna case.

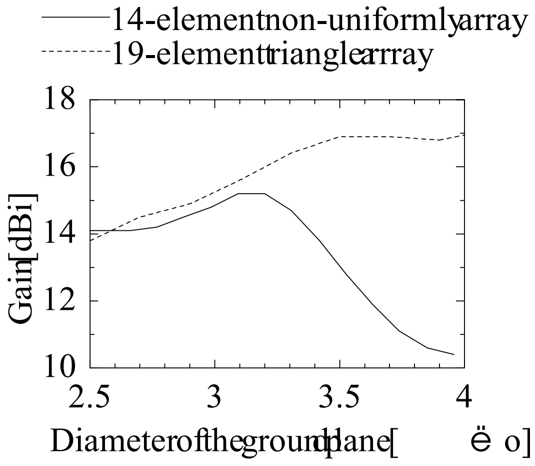


Fig.4 Antenna gain versus ground plane size for an isotropic case.

Figure 3 shows the gain characteristics of the non-uniform and triangle arrangement of patch array antenna. In this figure, antenna gain is plotted as a function of an antenna diameter, that is an diameter of the ground. As the antenna diameter becomes large, only the spacing between each element is extended. From this figure, it is found that the gain of the non-uniform arrangement array is superior to that of the triangular array within the range of the diameter between 2.5 λo and 3.7 λo, while the triangular array is superior to the non-uniform array when the diameter is greater than 3.7 λo.

For example, diameter in case of the diameter of the ground plane, 3 λo, the gain of the non-uniform array is 19.17dBi, while that of the triangular array is 18.2dBi.

From the above mentioned result, the triangular arrangement is not necessarily adequate arrangement to obtain a maximum gain for small sized array antenna.

To confirm the above result, isotropic element array is investigated. Figure 4 shows the gain characteristics of the array antennas. The arrangement of the arrays is the same as that of patch antennas. The antenna gain is calculated by using array factor instead of moment method which is used in patch array. From this figure, it is apparent that triangle arrangement is superior to non-uniform arrangement.

As a result, it is recognized that element antenna and antenna diameter strongly affect antenna gain for small sized array antenna with small number of element.

3. AN UNIFORM ARRANGEMENT ARRAY ANTENNA

A. A determination of an Array configuration

In an array antenna, it is well known that the antenna gain increases in proportion to the inter-element distances, which are less than one lambda. From the mass-production point of view, it is important to reduce the number of elements in order to obtain the required gain. In this section, we consider the uniformly arranged array antenna. The elements of the array are arranged in concentric circles. The distances between elements on the same circle are identical. In this arrangement, there are two parameters to determine: the number of elements in each circle and the diameter of each circle. Our final purpose is to consider an array configuration that is arranged on a ground plane with a diameter Dg = 3.0 λo. Usually, the size of the antenna can not be derived from only the arrangement of elements in the array because the size of the ground plane may change even though the array arrangement is fixed. To estimate the size of ground plane in relation to the array arrangement, an effective antenna area is introduced. We assume the shape of the effective area is a circle. The center of the circle corresponds to the center of the antenna element. The diameter of the virtual circle Dv is 0.7 λo. The edge of the circular ground plane contacts with the edge of the virtual circle of the element which is arranged on the outer most concentric circle.

The procedure is the following.

1) The diameter Dg of an imaginary ground plane is defined. In our case, Dg is 3.0 λo. Then the diameter of outer most circle Do is determined from the equation

$$Dg = Do + Dv \qquad (1)$$

, where Do is a diameter of the circumference on which the outer most elements are placed.

2) In the next step, the diameter Di of the inner circle is determined to enlarge the distance between the outer elements and the inner elements, $(Do\text{-}Di)/2$. Moreover, the diameter Di is as large as possible. The following relationships are derived from these two restrictions.

$$Di = 0.5\,Do \qquad (2)$$

3) The last step is to determine the number of elements n on each circle. The distance L between the elements on the same

circle is given by the following equation which is divided by *n*, so we call a polygonal.

$$L = 0.5 \times Dx\sqrt{2\{1-\cos(2\pi / n)\}} \qquad (3)$$

, where *Dx* is *Do* or *Di* .
Usually the spacing of the elements is selected to be less than 1λ so as to avoid the reduction of the antenna gain due to grating lobes. Then equation (3) is restricted by equation (4).

$$Dx < \frac{2\lambda}{\sqrt{2\{1-\cos(2\pi / n)\}}} \qquad (4)$$

B. The calculation of the Array parameters

From the equation (1) through (4), the array parameters can be determined. The parameters are summarized in table 1.

TABLE 1: ARRAY PARAMETERS

The radius of ground plane Rgnd	3.0 λ
The radius of virtual effective antenna area Rv	0.7λ
The radius of inner circumference Ri	1.15λ
The radius of outer circumference Ro	2.3λ
Number of element for inner circumference	4
Number of element for outer circumference	7

C. Gain characteristics

Based on the above mentioned results, the number of elements is determined for the antenna of size of 3.0 λo. Then the optimum number of elements is determined by using the method of moments. The method includes the effects the mutual coupling between elements, but the effect is not considered in the previous section.

At first, only the elements on the inner circle are investigated. The elements arranged on the outer circle are nonexistent in this stage. After the number of elements for the inner circle are determined, the number of elements for the outer circle are investigated.

Three types of configurations as shown in fig. 5 are considered: a 4-element array with a square lattice, a 5-element array with a pentagonal lattice, and a 7-element array with regular triangle lattices. The elements of the array are circularly polarized microstrip antennas. The configurations of the microstrip antenna are shown in Fig.6. The detailed parameters are referred to in [6].

Figure 7 shows the calculated result of the antenna gain for the various configurations as shown in Fig. 5 when the antenna parameters are varied according to equations (1), (2) and (4). In this case, the number of elements and the diameter of the inner circle are variable parameters. When the diameter of inner circle is less than 1.18 λo, the 4-element array has a higher gain than that of the other arrangements. On the other hand, when the diameter of the circle is between 1.18λo and 1.4 λo, the 5-element array has a higher gain than that of the others. From Table 1, the diameter of the inner circle is 1.15λo for a ground plane diameter of 3.0λo. Hence the 4-element array is suitable in this case.

For comparison with the microstrip array, the same arrangement is also investigated for an isotropic element. The gain characteristics are shown in Fig. 8. In this case, it is found that the triangular array is the best configuration.

Finally, the array configurations shown in Fig. 9 are investigated. From the previous result, the number of elements on the inner circle is fixed at four elements, and the elements on the inner circle are arranged on the square lattice from the previous investigation. Table 3 shows the gain characteristics when the number of elements on the outer circle is increased from 7 elements to 10 elements. The gain does not increase when the number of elements is increased greater than 8 elements. It is found that the most suitable array configuration for an antenna diameter of 3 λo is Fig. 9 (c) to obtain a maximum gain with a minimum number of elements.

TABLE 2: ARRAY PARAMETERS AND SIMULATION RESULTS

Number of element	Spaces between elements [λ]	Gain [dBi]
7	1.0	18.9
8	0.9	19.18
9	0.8	19.16
10	0.72	19.17

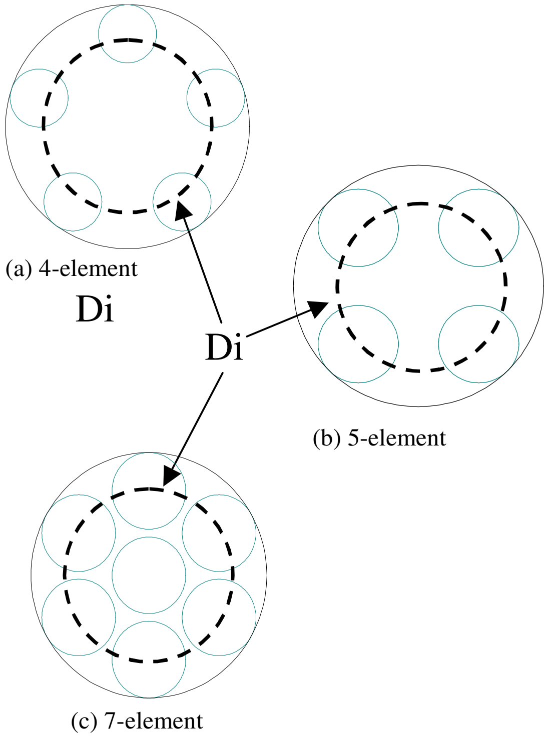
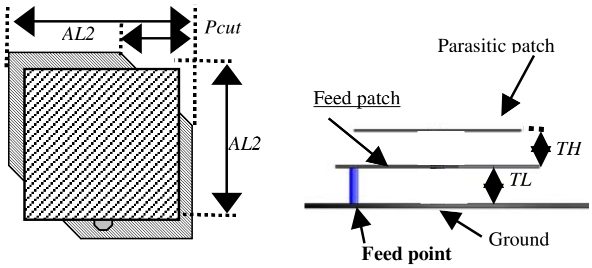


Fig. 5: The array configuration for the inner circumference.



(a) Top view (b) Side view

Fig. 6: Configurations of patch antenna.

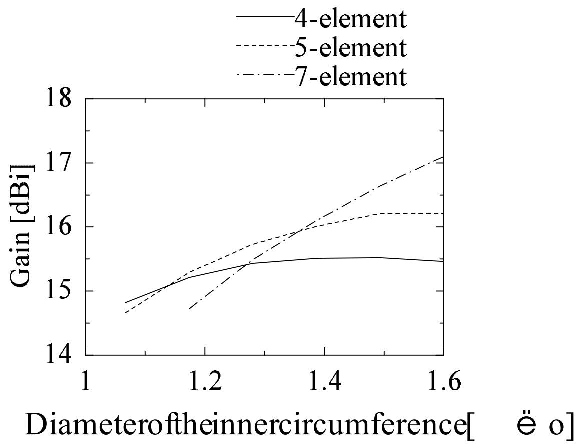


Fig. 7: Calculated antenna gain for the case of microstrip antenna as a antenna element.

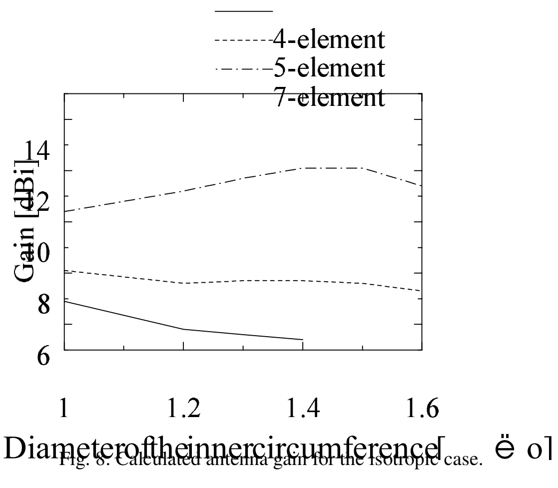
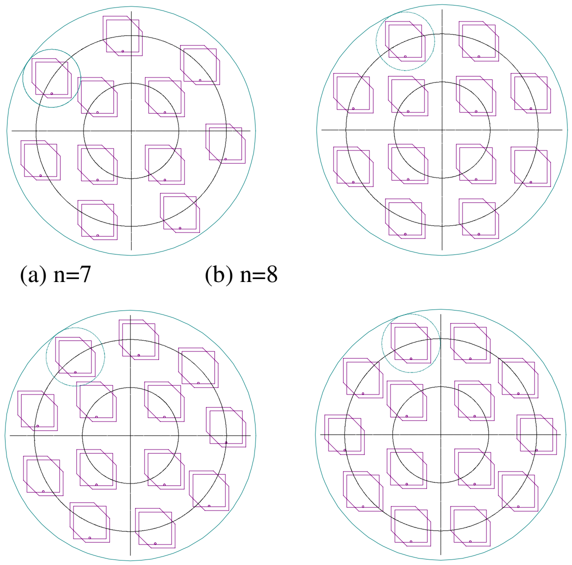


Fig. 8: Calculated antenna gain for the isotropic case.



(a) n=7 (b) n=8

(c) n=9 (d) n=10

Fig. 9: Array configuration with 3.0 ramda of antenna diameter.

4. Conclusion

In this paper, small sized array configurations with a circular aperture are investigated. We pointed out that optimum number of element and arrangement to realize the maximum gain is changed by the element for array antennas. Next, design procedure is presented for small sized array antenna with a circular aperture. And then using this procedure, uniformly arranged circular aperture array antenna is designed for an antenna diameter of 3.0 λo. The antenna gain of 19.18dBi is obtained. As the result, we found that the triangular arrangement is not necessarily adequate to obtain maximum gain for small sized array antenna with small number of element.

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