Proceedings of ISAP2012, Nagoya, Japan

POS2-22

Reflectarray with Arbitrary Shape Elements Suppressing Their Mutual Coupling

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1. Introduction

This paper proposes a reflectarray antenna consisting of arbitrarily-shaped conductor elements on a flat surface. Reflectarray antennas with specified elements have been developed as a high-gain antenna and they can be applied to design for millimeter-wave antennas [1], deployable antennas [2] and millimeter wave imaging system [3]. Reflectarray antenna transforms an incident spherical wave into a planar one by adjusting the reflection-phase property on the aperture. The reflection phase of each element greatly depends on the frequency. Therefore, as long as the elements with similar phase characteristic are not used, a phase error due to difference between the frequency characteristics cause a gain loss and an increase of side-lobe level. So, it is firstly important that we find a group of resonance elements with similar frequency characteristics and arbitrary phase value in the range from 0 to 360 degrees. However, when the arbitrary shaped elements that we have developed [4] are used for antenna design, the mutual coupling between the adjacent elements often causes the unexpected phase properties, so that the antenna performance is deteriorated. So, in this paper, we propose arbitrarily-shaped elements suppressing such a mutual coupling. An example of a reflectarray antenna designed by using them is demonstrated, and the measurement of the fabricated reflectarray antenna verifies its usefulness.

2. Design Procedure

Reflectarray antenna is composed of resonant elements on the conductor-backed dielectric substrate as shown in Fig. 1. Arbitrarily-shaped conductive elements produced by the genetic algorithm (GA) optimization are used as a resonant element. Its optimization procedure is shown in Fig. 2. By using the axially symmetric unit cell, the number of the gene expressing an arbitrary shape can be reduced to 1/4. The elements without conductor are put at the outer fence part to make effect of the mutual coupling small, as shown in Fig. 2. The reflection phase characteristic of the unit cell is approximately obtained from the analysis for the infinite array by the method of moment [5]. However, to use such a phase characteristic of the unit cell for antenna design often causes deterioration of the antenna performance due to mutual coupling effect as described in the following section.

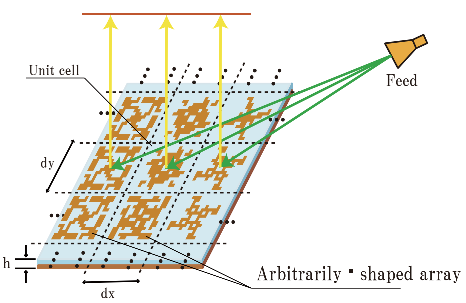


Fig. 1. Reflectarray consisting of arbitrary shape elements.

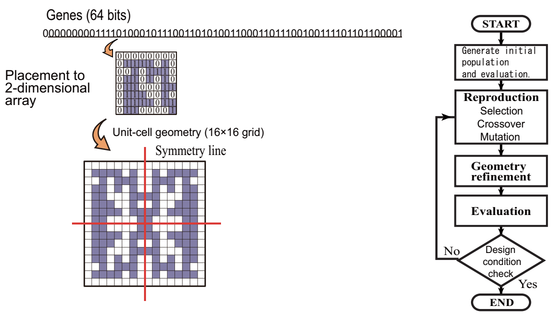
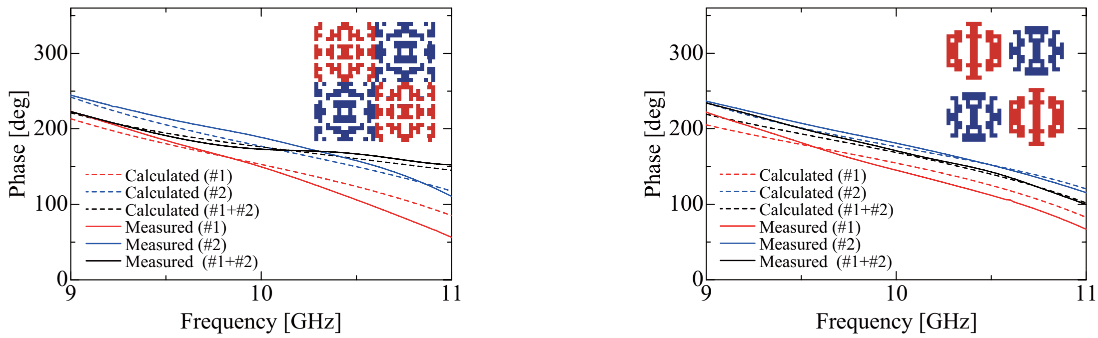


Fig. 2. Optimization-design method based on GA.

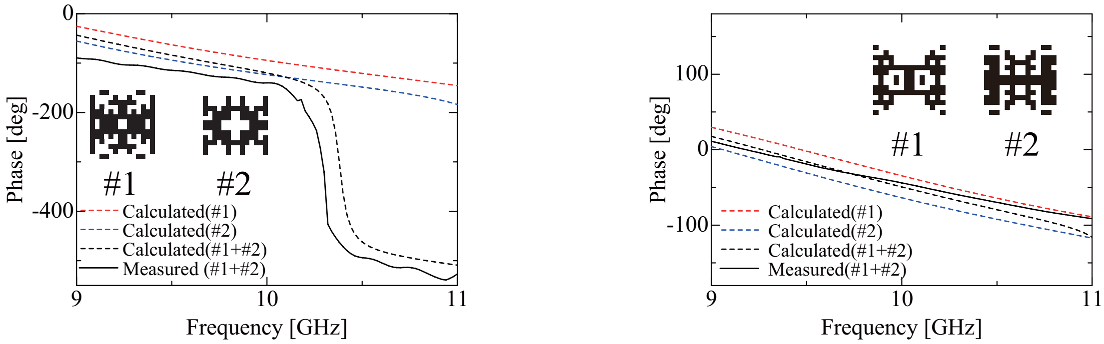
3. Phase characteristics of arbitrarily-shaped elements

It is necessary for antenna design to find a group of the elements which have arbitrary reflection phase value in the range of from 0 to 360 degrees, but have the similar frequency characteristic. In this paper, we prepared twelve kinds of elements by the GA optimization. Their elements have a reflection phase value in the range of 360 degrees at 30 degrees intervals at the center frequency $f_0 = 10.0$ GHz. To investigate the effect of the mutual coupling, we calculate frequency characteristics of the reflection phase for three kinds of infinite array. That is, two of them consist of the single unit case #1, and #2. The phase difference between #1 and #2 is 30 degrees at 10 GHz. The other is infinite array that #1 and #2 are arranged alternatively. Figure 3 (a) and (b) shows their calculated results in case of the elements with and without conductor at the outer fence part of the unit cell, respectively. It is obvious that the phase characteristic for the combined elements #1+#2 without conductor at the outer fence part is the average one of the elements #1 and #2 as expected, whereas the elements #1+#2 with conductor brings the unexpected phase characteristic as shown in Fig. 3 (a). Furthermore, even if the elements without conductor at outer fence part are used, some combined elements #1+#2 cause the unexpected resonance due to the mutual coupling depending on the element combination as shown in Fig. 4 (a). Figure 4 (b) shows the phase characteristic for the desirable element combination. Therefore we select twelve kinds of such element combinations for antenna design. As a result, the twelve elements shown in Fig. 5 are obtained, and their phase characteristics are given in Fig. 6, where the black lines depict the characteristics for the single unit cell, and the red curves are the characteristics for the combination of adjacent elements.



(a) With conductor. (b) Without conductor.

Fig. 3. Frequency characteristics of reflection phase for geometry (a) with and (b) without conductor at the outer fence part.



(a) Case A. (b) Case B.

Fig. 4. Examples of frequency characteristics of reflection phase.

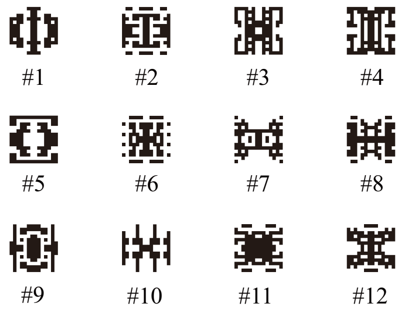


Fig. 5. Geometry of the elements.

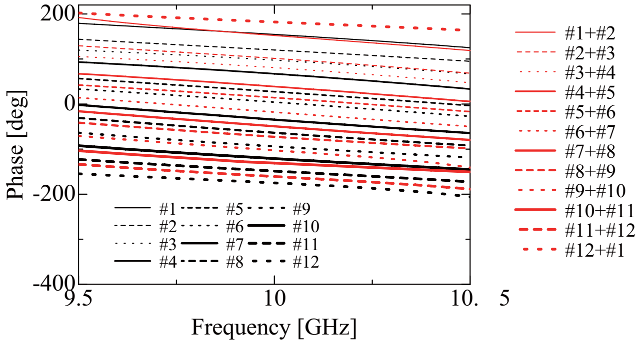


Fig. 6. Frequency characteristics of reflection phase.

4. Design and evaluation of reflectarray antenna

In this section, we design and evaluate an offset reflectarray antenna by using arbitrarily-shaped elements shown in Fig. 5. The antenna configuration is given in Fig. 7, where the aperture area is 180 × 180 mm^2, the thickness of dielectric substrate is 3 mm, the distance R_s from the reflectarray to the phase center of the primary radiator is 420 mm and the offset angle θ_s is 30°, and the main beam Θ is 0°. The aperture phase distribution for the incident angle 30° is shown in Fig. 8, and the designed reflectarray is shown in Fig. 9. Next, we fabricated reflectarray and measured characteristic to verify its performance. Figure 10 shows the photograph of the reflectarray fabricated by the photo-etching technique. The measured characteristics of radiation patterns at 9.5 GHz, 10.0 GHz and 10.5 GHz are shown in Fig.11, where the comparison between the measured radiation patterns and the calculated ones is shown in Fig. 11. It is clear that agreement between both results is very good. At center frequency $f_0 = 10.0$ GHz, the measured gain and the measured aperture efficiency are 22.6 dB and 40 %. Then the calculated gain and aperture efficiency are 24.0 dB and 55 % respectively. At 9.5 GHz and 10.5 GHz, we get a similar performance with the center frequency 10 GHz, so that it is confirmed numerically and experimentally that the elements proposed here are usefully applied to design reflectarray antennas.

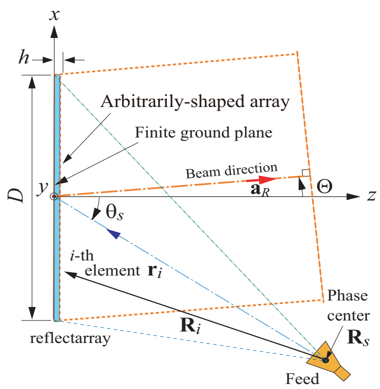


Fig. 7. Reflectarray with an offset feed.

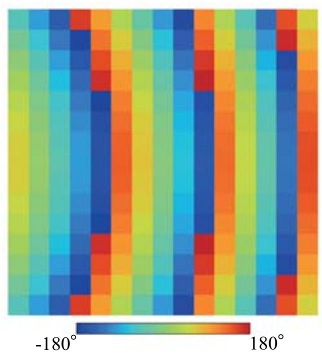


Fig. 8. Phase distribution on the aperture.

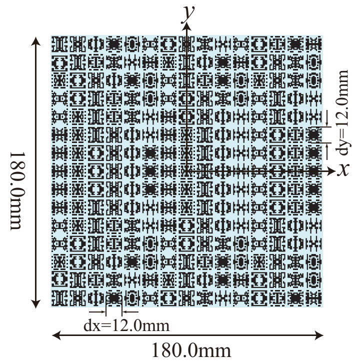


Fig. 9. Design pattern.

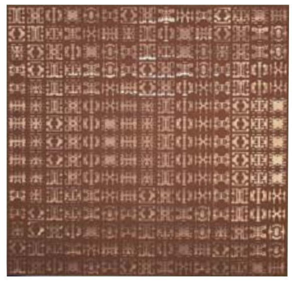
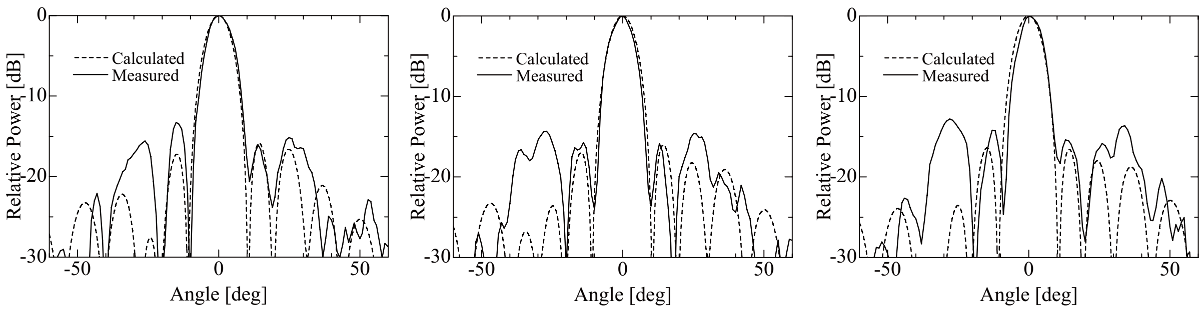


Fig. 10. Photograph of fabricated reflectarray.



(a) 9.5 GHz. (b) 10.0 GHz. (c) 10.5 GHz.

Fig. 11. Characteristics of radiation patterns.

5. Conclusion

We have presented a reflectarray with arbitrary shape elements suppressing the mutual coupling. The mutual coupling between the adjacent elements can be made small by introducing the element without conductor at the outer fence part of the unit cell and also investigating the phase characteristics for infinite array which is alternatively arranged by adjacent elements. Finally, the usefulness of the designed reflectarray has been verified numerically and experimentally.

Acknowledgments

This work was supported by a Grant-in-Aid for Scientific Research on Innovative Areas "Electromagnetic Metamaterials" (No.22109004) of The Ministry of Education, Culture, Sports, Science, and Technology, Japan.

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