Optimization Design Method of Arbitrarily Shaped Elements for Wideband Reflectarrays

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Abstract:
In this paper, the authors have proposed an optimization design method for arbitrarily shaped resonant elements with wideband property and have constructed an offset-feed reflectarray by the optimized elements in the X band. Its radiation pattern has been also investigated numerically and experimentally. Usefulness of the proposed method has been proved from comparison between the measured radiation pattern and the calculated ones.

Keywords: wideband reflectarray, genetic algorithm, antenna, method of moments

Classification: Antennas and propagation

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1 Introduction

Recently, many studies of reflectarrays have been carried out for various applications such as millimeter imaging systems, and deployable antennas for satellite systems [1, 2]. The GA (genetic algorithm) optimization for reflectarrays is one of useful design methods [3]. However, the conventional GA-optimized reflectarray with dual-polarization or low cross-polarization properties was limited in the narrow frequency band because of adopting experiential phase functions. In this paper, we propose a new GA procedure to expand the frequency bandwidth. Its usefulness is confirmed by evaluating radiation properties of the designed reflectarray in the X band numerically and experimentally. Our design method proposed here to get a broadband property could be useful for various reflectarrays, for example, the circular polarization conversion reflectarray [4], the multiband reflectarray, the reflectarray with resonant elements having four axial symmetry [5] and so on.

2 Optimization design method

In the conventional GA-optimized method [3], we determine the element geometry by fitting the frequency property of its reflection phase into a straight line with some slope over the specified frequency range. This procedure is repeated for the parallel straight lines with the same slope in the range of 360 degrees at the center frequency. Whereas, in the proposed optimization, we adopt two-step optimization and also search the element geometry by fitting its reflection-phase property into a curved line corresponding to the resonant characteristic of an element. Furthermore, optimization is not performed under the fitting line one by one, but done under all the fitting lines at a time. In the first step, we sort the GA-generated reflection-phase curves into the group of the N units at intervals of 360/N degrees, based on the phase value at the center frequency, continue this sort until the given number M of reflection-phase curves gathers every unit, and select the N initial geometries giving the suitable phase curve in each unit. Next, one of their phase curves is chosen as the basic fitting curved line and the N parallel fitting phase curves based on it are set. In the second step, the initial geometries are modified slightly to be matched with the fitting curves, and this procedure is repeated until fitness of the error function is satisfied. It should be noted here that the phase curve of the modified geometry is compared with all the

![Fig. 1. Algorithm of the proposed optimization design method.](image)
$N$ fitting curves, so that this process makes it possible to obtain the optimized geometry from the initial geometry of the different unit. Thus, this proposed optimization can shorten computation time and extend the specified frequency range. Figure 1 illustrates an algorithm of the proposed design procedure.

3 Reflection properties of designed elements

The reflection properties are analyzed as infinite array by the method of moments in spectral domain imposing the periodic boundary condition. The dimension of the unit cell is 12.0mm, and the thickness of the substrate with relative permittivity $\varepsilon_r=1.67$ is 3.0mm. The strip width of the element is 0.3mm. We design resonant elements as $M=20$ and $N=12$ in the frequency range from 6.5GHz to 13.5GHz. Figure 2(a) shows each geometries obtained by the optimization. Figure 2(b) and (c) shows the calculated reflection phases and amplitude properties of the cross polarization for the TE incidence, and also the properties for the TM incidence is very similar to them for the TE one. The phases vary almost in the range of 360 degrees over the specified frequency. The cross polarization level is less than about -30 dB except a few elements in the specified range. To evaluate degree of parallel between the reflection-phase curves of the optimized elements, Figure 2(d) shows their deviations by normalizing the phase value of each element to 0 degree at the center frequency 10 GHz. You can see from this figure that the deviations is suppressed within 45 degrees in the higher frequency region and 90 degrees in the lower one. Figure 2(e) shows the calculated reflection phases of "Initial Geometries” obtained in the first step for the TE incidence. Although their curves is similar to those in Fig. 2(a), they are not parallel comparing with Figure 2(a) and does not give the phase difference more than 360° in the lower frequency region. So it is expected that the designed elements are useful for constructing a reflectarray by their appropriate arrangement.

Fig. 2. Properties of the designed elements.
To confirm usefulness of the proposed elements, we designed an offset feed reflectarray antenna with a dimension 180mm × 180mm (15 × 15 cells). Figure 3(a) shows the fabricated reflectarray. The offset angle of the primary radiator is 30 degrees and the main beam is radiated in the specular direction. The distance from its phase center to the center of the reflectarray antenna was chosen to be 290mm. Figure 3(b) shows comparison of the radiation patterns between the calculated results and the experimental ones at the center frequency 10 GHz. The radiation pattern is calculated by AFIM (aperture field integration method) and HFSS (Ansys). You can see from this figure that main-beam pattern agrees well with the calculated ones. The cross polarization level using AFIM is not shown there, because it is suppressed less than -50dB. The measured level is suppressed less than -45dB except the specular direction. Figure 3(c) shows the aperture efficiency from 6 GHz to 16 GHz, although the experimental results are given only within the specified frequency range. The aperture efficiency is kept to the level of more than 50% over a wide range from 7.5 GHz to 15.0 GHz. It is clear from this experimental verification that the proposed optimization design method is useful.

5 Conclusion

We have proposed the GA-optimization method for designing resonant elements of a broadband reflectarray. By adopting two-step optimization, the desirable resonant elements with broadband property are obtained efficiently. Then the reflectarray constructed by using them has been evaluated from radiation property for the dual polarized wave, numerically and experimentally. As a result, the measured main-beam pattern agrees well with the calculated one and the cross-polarization is suppressed in the sufficiently low level. The broadband property of the proposed reflectarray has been confirmed from the aperture efficiency more than 50% over a wide range from 7.5 GHz to 15.0 GHz.

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