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Broadband Design of Reflect-Array Antenna Using Genetic-Swarm-Optimization Method*

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1. Introduction

The printed reflect-array (RA) is widely used in satellite communication system as a good substitute for the parabolic reflector due to its low profile, easy fabrication, low cost and light weight, but its bandwidth and aperture efficiency are less than the latter. In order to keep high gain within a wide bandwidth, at first the broadband elements with multilayer structures are recommended, and also the phase compensation should be insensitive to frequency. Though the delay-lines can completely compensate the phase difference caused by different lengths of ray paths, they are inconvenient in structure. On the other side, the single-layer sized patches can flexibly control the phase of reflection coefficient; however, it becomes sensitive to the frequency. So a broadband reflect-array should be designed for multi-frequency optimization, rather than for single frequency only.

Various optimization methods had been developed for antenna design. One kind of those evolutionary methods outperforms others due to their simple implementation, and no constraints on solution domain. Among them, the Genetic Algorithm (GA) can find global solution with slow convergence speed, while the Particle Swarm Optimization (PSO) converges fast with being easily trapped in local maxima. Thus, the combination of GA and PSO can realize global optimization with fast convergence. As presented below, an optimization method called Genetic-Swarm-Optimization (GSO) [1] algorithm is employed to design the entire RA structure on a specified frequency range.

In this paper, firstly the reflection phase *vs*. element sizes is analyzed; and also the phase- and amplitude-distribution of illuminated field at each element depending on the feed pattern and ray-path difference are calculated. Then the GSO algorithm with fast convergence is programmed and then run for the target of maximized gain with wider bandwidth as possible (> 20 %), and restriction of side-lobe-level (SLL< –15 dB), by means of adjusting the parameters as sizes and position of each element. The simulated result for optimized structure indicates that the maximal gain approaches 18.7 dBi, which is 1 dB higher than that of principial design without optimization; about 32.3 % bandwidth (8.3~11.5 GHz) for –1.6 dB gain-drop; and –14.6dB SLL at 10 GHz are performed.

2. Element Design and Analysis

The typical stacked square patches [2] are adopted as the element of reflect-array as shown in Fig.1. The different sizes between upper- and lower-patches, and the air-gap from upper-layer to lower-layer also lower-layer to the ground plate, bring up the broadband phase property of the reflection coefficient from the element within a wider dynamic range as shown in Fig.2. The curves are simulated by using Ansoft HFSS Software with a normal incident plane wave of $\hat{y}$ -linear

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This work is supported by National Natural Science Foundation of China (No. 60371026 & No. 60671016)

ISBN: 978-4-88552-223-9 C3055©IEICE

polarization, and periodic boundary condition for analogy of the array environment involving the mutual coupling between the elements. However, the reflect-array is not a really periodic structure due to different element sizes for phase compensation. This is just a reason why an entirely optimized design becomes necessary.

A set of appropriate sizes of elements are designed for 4GHz bandwidth around frequency f_0=10 GHz, with unified substrates and air gaps. To avoid grating lobes, setting the period of array as A=18 mm ≈ 0.6 λ In Fig.2a, the size b of upper-patch is fixed, a set of curves as the phase of reflection coefficient *vs.* the size a of lower-patch are calculated for different frequencies. In Fig.2b, both of upper- and lower-sizes b and a are adjusted, a curved surface is drawn at the frequency of 10 GHz. It can be observed that with both a and b increasing, the value of phase decreases smoothly; and more than 500° dynamic range can be achieved. On the other side, the amplitude of the reflection coefficient is almost the same, since the patch array is backed a perfect-conducting ground plate. Besides, slightly adjusting the central position of the elements within the period lattice is helpful to reduce side lobe level of the reflect-array antenna.

3. Array Optimization and Simulation

A 37-element reflect-array shown in Fig.3 consists of a planar array of elements with broadband phase compensation and a broadband feed with type of tapered slot-line radiator. The latter is printed on a substrate with 0.5 mm thickness and permittivity of ε_r=2.2 as shown in Fig.4a. Its optimized design performs almost the same –10 dB beamwidth $2\theta_F$ in both E- and H-planes within the designed frequency band, and $\theta_F \approx 33.4^\circ$ at f_0 as shown in Fig.4b. According to the aperture size of the array D=126 mm, the focal length can be determined as F = 84 mm, based on the formula $D/2F = \tan\theta_F$. Hereby, the phase- and amplitude-distribution of illuminated field at each element depending on the feed pattern and ray-path difference can be calculated.

Because of the symmetry in the array architecture, only eight kinds of elements need to be optimized, their numbering is marked on Fig.3a. The initial sizes of each element are simply designed for phase compensation at the central frequency; then entirely optimized by a hybrid Genetic-Swarm-Optimization (GSO) method, which combines GA for global optimization and PSO with fast convergence. The target of optimization is maximized gain with wider bandwidth as possible (> 20 %), under the restriction of side-lobe-level (SLL< –15 dB), by means of adjusting the parameters as sizes and position of each element.

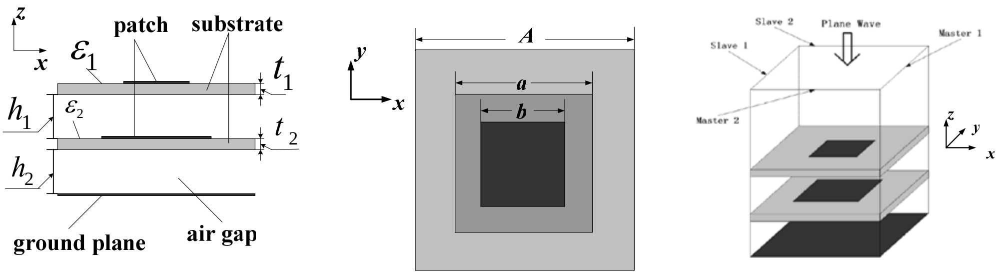
The optimized sizes and position of each element are listed in Table 1. Considering a ground plate with finite size in practical, a full-wave simulation for the entire reflect-array structure by using CST Microwave Studio is necessary. The simulated result indicates that the maximal gain approaches 18.7 dBi, which is 1 dB higher than that of principial design without optimization Fig.5; about 32.3 % bandwidth (8.3~11.5 GHz) for –1.6 dB gain-drop; and –14.6 dB SLL at 10GHz are performed.

Furthermore, another problem in reflect-array design is feed blockage, i.e. a part of reflected energy is absorbed by the feed located in front of the array, which results in the fall of antenna gain. In order to avoid this feed blockage, to adopt offset feed is a common scheme, but it brings other problems such as asymmetry in structure and then in pattern, difficulty in the design, and rising in side lobe level. An alternative scheme employs a piece of traveling-wave feed with twisted 45° polarization and replaces the square-patch of array elements as rectangular-patch to perform polarization transform in reflection[3], which can reduce the feed blockage and keep the symmetric pattern simultaneously.

The optimized design for a reflect-array antenna with polarization transform is continuing now, in which more parameters need to be optimized.

4. Conclusion

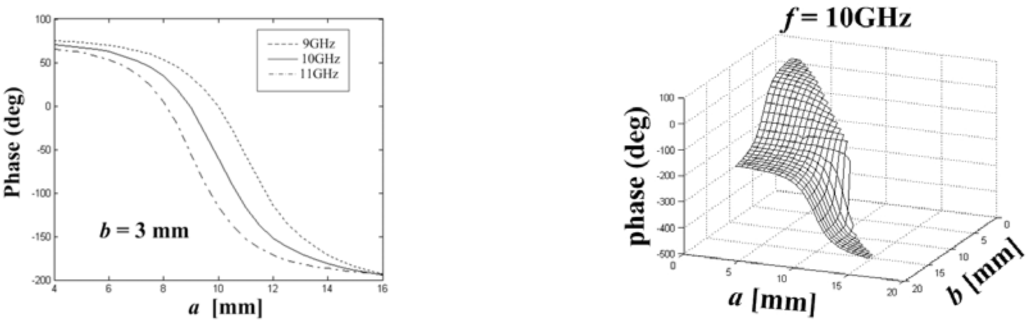
A hybrid Genetic-Swarm-Optimization method has been employed to optimize a two-layer 37-patch reflect-array, based on the analyzed phase- and amplitude-data at each element. The optimized parameters are the sizes and position of each element. The optimized result is validated by simulation and compared to that without optimization. Furthermore, an idea of polarized transform has been proposed, which is predicted to achieve more that 1dB gain enhancement.



(a) Side view (b) Top view (c) Model for simulation

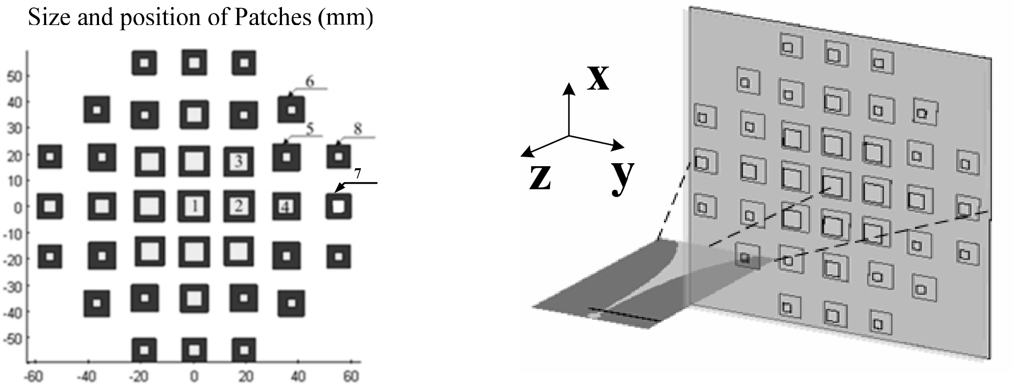
Fig.1 Geometry of the broadband element structure.

(thickness $t_1 = t_2 = 0.5$mm, dielectric constant $\varepsilon_1 = \varepsilon_2 = 2.2$, spacing of air gap $h_1 = h_2 = 2$mm.)



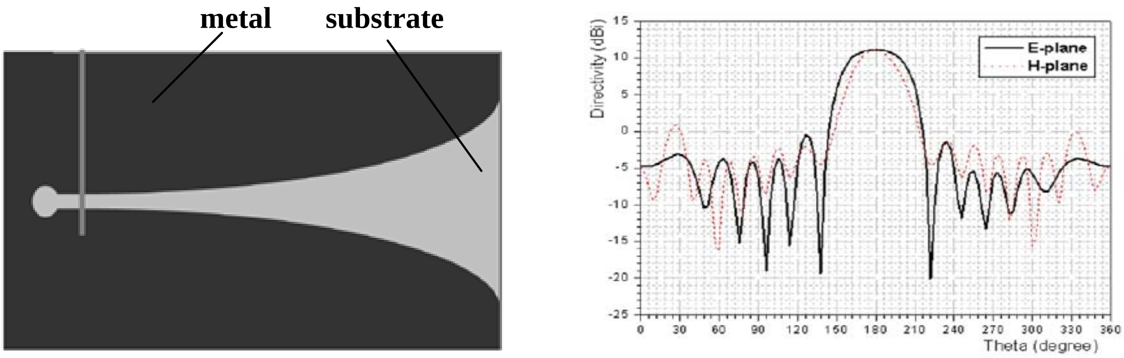
(a) With respect to lower-size *a* (b) With respect to both sizes of *b* and *a*

Fig. 2 Curves of reflection phase *vs.* patch sizes



(a) Planar array architecture (b) Entire structure in simulation

Fig.3 Structure of 37-element reflect-array



(a) Structure (b) Radiation pattern of E- and H-plane

Fig.4 Tapered slot-line radiator used as feed of reflect-array

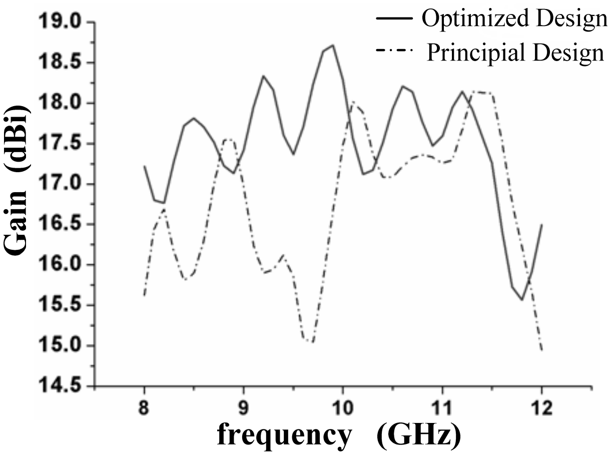


Fig.5 Gain of reflect-array

Table 1: Optimized result of sizes and position of the patches (mm)

ν-th Elements	1	2	3	4	5	6	7	8
b_ν of upper-patch	11.9	11.6	11.2	10.5	10.2	9.8	9.4	8.9
a_ν of lower-patch	7.8	7.5	7.1	5.8	3.3	3.3	4.7	3.4
x_ν of patch center	0	17.1	17.0	35.0	35.0	37.0	55.0	55.0
y_ν of patch center	0	0	17.0	0	18.8	37.0	0	19.0

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