Offset reflectarrays with dense microstrips for wideband use

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1 Introduction

Microstrip reflectarrays have been developed to realize an ordinal pencil beam [1, 2] or a shaped beam [3] and are very attractive aperture antennas because of their planar structure. Microstrip elements are tuned to obtain desired phase all over the reflecting surface. However, since the reflection phase of each element greatly depends on the frequency, conventional reflectarrays usually employ a multi-layer structure for wideband use [3, 4]. To realize wideband characteristics in a single-layer reflectarray, this paper proposes reflectarrays with microstrip elements that are arranged densely. Two reflectarrays with different radiation angles are designed by using the optimization technique based on the method of moments [5]. The effectiveness of the proposed reflectarrays is verified by comparing with previous one in X band.

2 Design principles

Figure 1 shows basic geometry of a microstrip reflectarray antenna that consists of a two-dimensional array of printed dipoles with variable length, a finite ground plane and an illuminating feed. To realize high gain in a specified direction Θ, the reflection phase on the reflecting surface is approximately chosen so that total phase delay from the phase center $\mathbf{R}_s$ to the aperture plane can be constant for all elements, where Θ is independent of the specular-reflection direction. Figure 2 shows two examples of the desired phase of elements along the x-axis at $y = 0$ (see Fig. 1) at frequencies $0.8f_0$, f_0, and $1.2f_0$, where $\theta_s = 30°$ and $|\mathbf{R}_s| = 15\lambda_0$. Case of $\Theta = 30°$ has a main beam in a direction reflected by the ground plane. On the other hand, case of $\Theta = 0°$ has a main beam in a direction perpendicular to the reflectarray plane to improve the effective aperture area [6]. Thus the realization of the specified beam direction is one of some advantages of the reflectarrays.

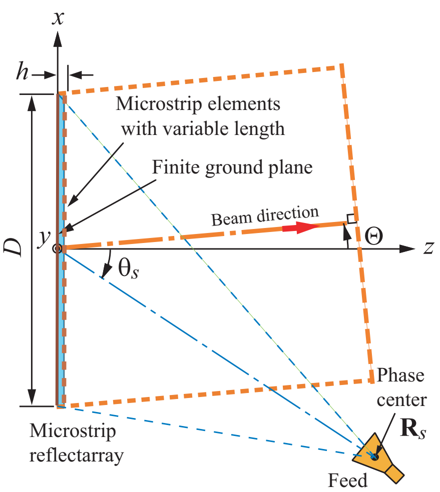

Fig. 1. Basic geometry of microstrip reflectarray with offset feed.

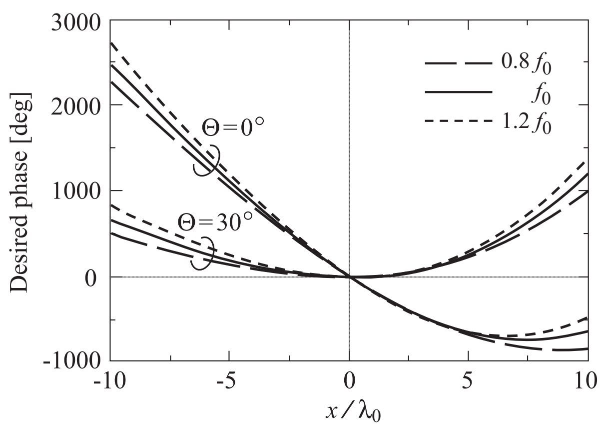

Fig. 2. Desired reflection phase for microstrip elements. Where f_0 and λ_0 denote the centre frequency and wavelength, respectively.

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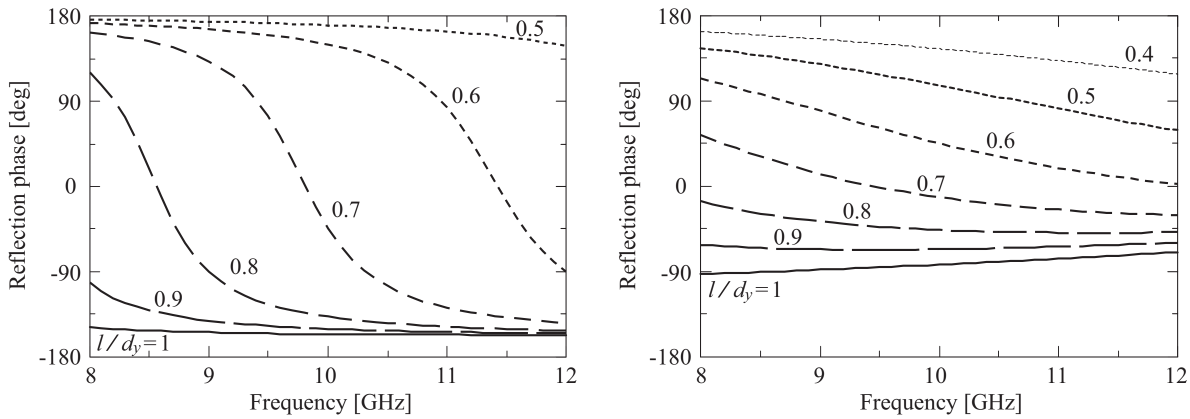
Also, it is found from Fig. 2 that it is more important to examine the microstrip elements with similar frequency characteristics in the reflection phase properties. Figure 3 shows frequency characteristics of reflection phase of infinite microstrip reflectarray with equal length l, where the incident plane wave is the TM wave with incident angles of $\theta_{in} = 30°$ and $\phi_{in} = 0°$. The reflection properties are analyzed by using the method of moments with periodical boundary condition [5]. Although sparsely arranged elements as shown in Fig. 3 (a) can realize phase range of nearly $0 - 2\pi$ [rad] in single-layer structure, each element has different properties. Therefore, the reflectarray with these sparse elements may work well at only centre frequency. Figure 3 (b) shows results of elements chosen by taking account of the deviation of the frequency characteristics, and also Fig. 4 shows them as a function of the length at 8–12 GHz, where the width $w = 0.4$ mm, the element spacings $d_x = 1$ mm, $d_y = 16$ mm and the thickness $h = 4$ mm. Although the phase range becomes narrower than that of the case in Fig. 3 (a), these dense elements provide phase properties with similar curves as shown in Fig. 4. Therefore, a set of the elements that are arranged densely can be used for designing the reflectarray for wideband use. Furthermore, to improve the aperture efficiency, the element lengths can be optimized over the specified frequency band.



(a) $d_x = 8$, $d_y = 20$ and $h = 2$ mm. (b) $d_x = 1$, $d_y = 16$ and $h = 4$ mm.

Fig. 3. Frequency characteristics of reflection phase of infinite microstrip reflectarray with equal length.

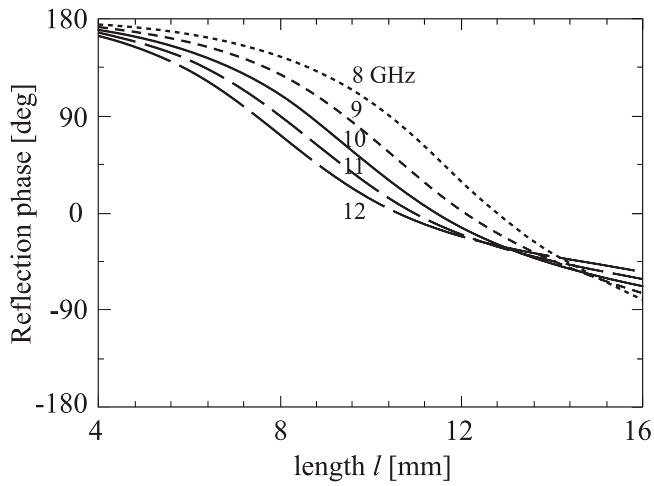
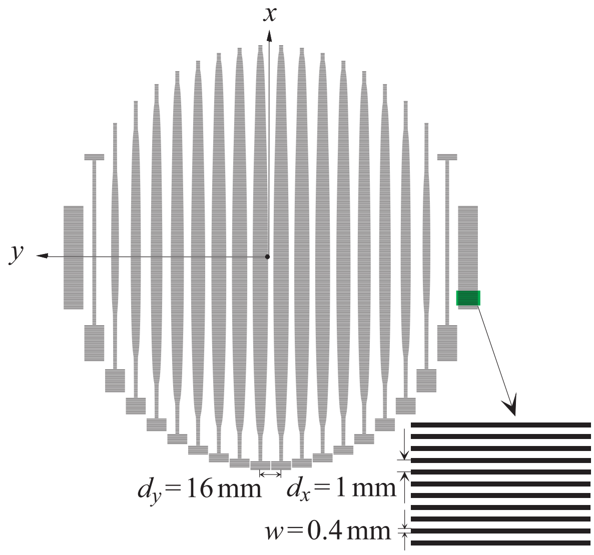


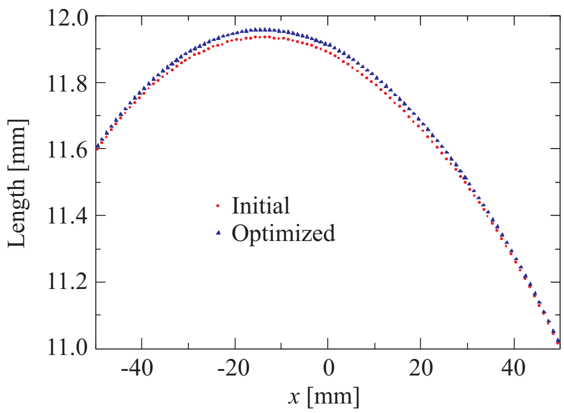
Fig. 4. Reflection phase property of infinite microstrip reflectarrays as a function of element length.

3 Design examples

We now design reflectarrays with a circular surface of diameter $D = 330$ mm with $\theta_s = 30°$ and $|\mathbf{R}_s| = 490$ mm. The primary pattern is approximated by $\cos^n \theta$, where $n = 30$ for -10 dB edge level. Figure 5 (a) shows a design example for the reflectarray with the beam direction $\Theta = 30°$. To improve the efficiency, we have optimized the lengths at 9 frequencies in 8–12 GHz. The initial lengths of all the elements can be designed by the previous method using the phase properties at the centre frequency as shown in Fig. 2 and Fig. 4. A part of element lengths along the x-axis at $y = \pm 8$ mm is plotted in Fig. 5 (b). The optimized results are compared with the initial lengths. Also, Figure 6 (a) and (b) shows a reflectarray which has the main beam in $\Theta = 0°$. In both cases, parameters w, d_x, d_y and h are same values as indicated in Fig. 3 (b). It is found from comparison between Fig. 5 (b) and Fig. 6 (b) that the optimization approach is useful for improving the aperture efficiency in the beam direction that is different from the specular-refection direction.

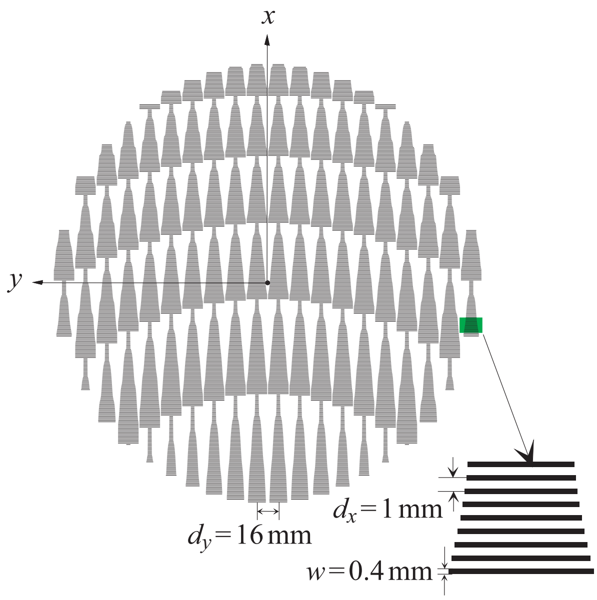


(a) Top view of reflectarray.

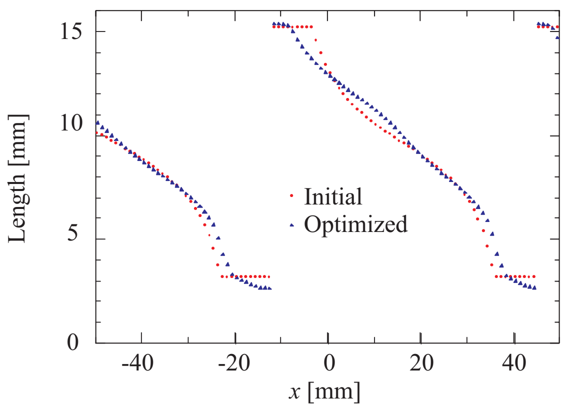


(b) Element lengths.

Fig. 5. Designed microstrip reflectarray with $\Theta = 30°$.



(a) Top view of reflectarray.



(b) Element lengths.

Fig. 6. Designed microstrip reflectarray with $\Theta = 0°$.

The predicted H-plane radiation patterns at the centre frequency are illustrated in Fig. 7. The radiation pattern can be expressed in terms of a superposition of the radiation field due to both array elements and their images and reflection field due to the finite ground plane, that are calculated from an infinite reflectarray analysis based on the method of moments. Also, Figure 8 shows frequency characteristics of the aperture efficiency. Where, the aperture dimensions on $x - z$ plane are D in $\Theta = 0°$ and $0.87D$ in $\Theta = 30°$, respectively. It is clear that both the designed reflectarrays have higher efficiency than the previous one over wide frequency band.

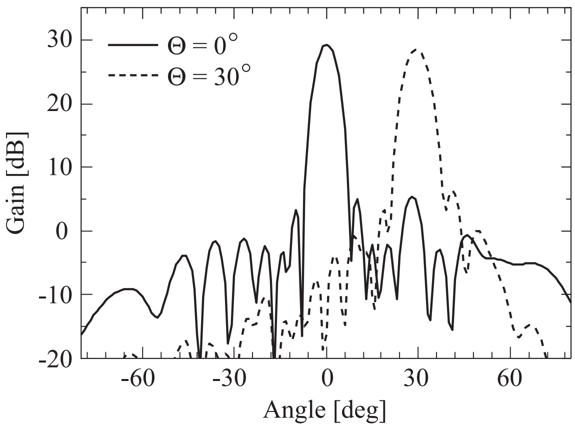


Fig. 7. H-plane radiation patterns at 10 GHz of designed two reflectarrays. Where Θ denotes main-beam direction.

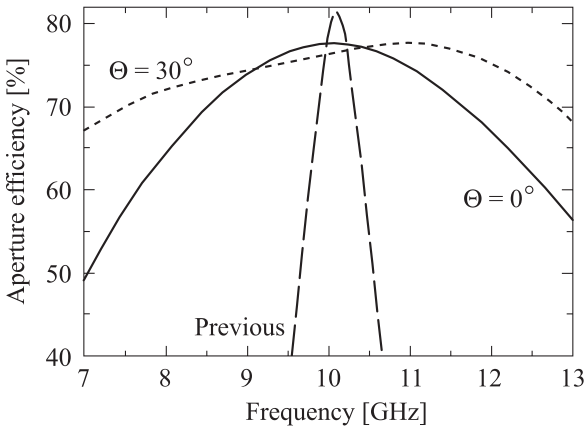


Fig. 8. Comparison of aperture efficiency between designed reflectarrays and previous one in [6].

4 Conclusions

We have presented the offset reflectarrays with dense microstrips for wideband use. The performance of the designed reflectarrays has been numerically verified by comparing with the previous one. The detail discussion for the reflectarray with a wideband primary horn will be presented at the talk.

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