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Single-Layer Microstrip Reflectarray based on Dual-Resonance Behavior

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1. Introduction

Microstrip reflectarrays are very attractive aperture antennas because of their planar structure and a simple feed system [1], [2]. Recently, most of reflectarrays employ multi-layer structure to achieve high performance [3]. To improve the radiation characteristics in single-layer ones [4], this paper proposes a novel reflectarray based on dual-resonance behavior unlike ordinary design for dual-band use [5]. The proposed reflectarray can shape main beam in direction that's independent of an offset angle of the primary feed while suppressing specular reflection due to the ground plane. The effectiveness is verified by comparing between calculated results by using the method of moments and measured results in Ku band.

2. Design principles

Figure 1 shows basic geometry of the microstrip reflectarray antenna with an offset feed. The reflectarray consists of a planar array of dipoles with variable length printed on grounded single-layer substrate. The feed illuminates it with offset angle θ_s. The dimensions of individual elements can be designed to control reflection phase according to specified main-beam direction Θ. Figure 2 shows an example of the desired phase of the elements along the x-axis at $y = 0$ (see Fig. 1) at several frequencies, where $\theta_s = 30°$ and $\Theta = 0°$. In this case, the main-beam direction is perpendicular to flat surface of the reflectarray. It is observed that the desired phase properties are similar around the centre frequency f_0. Thus it is more important to reduce difference between frequency characteristics of the reflection phase of all the elements in addition to obtaining phase value over 0-2π [rad] around the f_0.

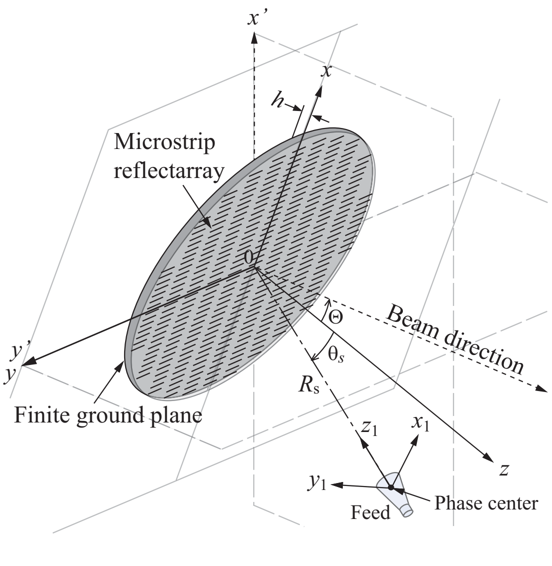

Fig. 1. Basic geometry of microstrip reflectarray.

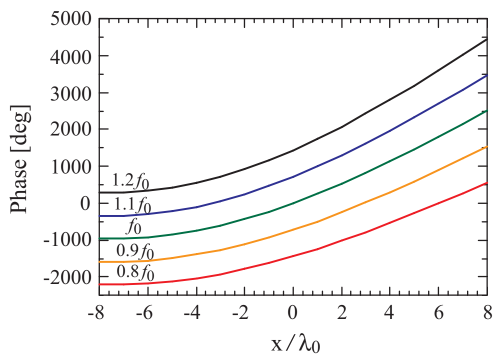

Fig. 2. Desired reflection phase properties to shape main beam in direction $\Theta = 0°$ with $\theta_s = 30°$ and $R_s = 15\lambda_0$.

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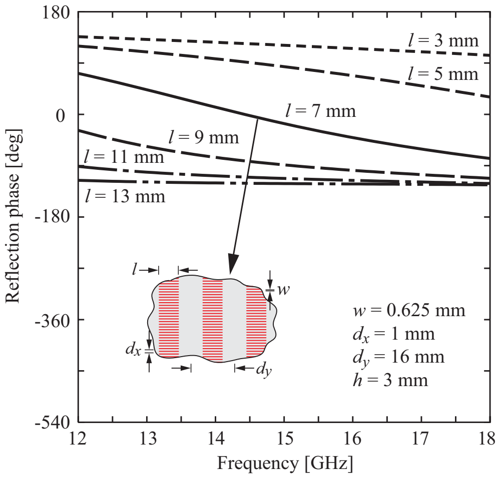

Fig. 3. Reflection phase of previous infinite reflectarray with equal length [4].

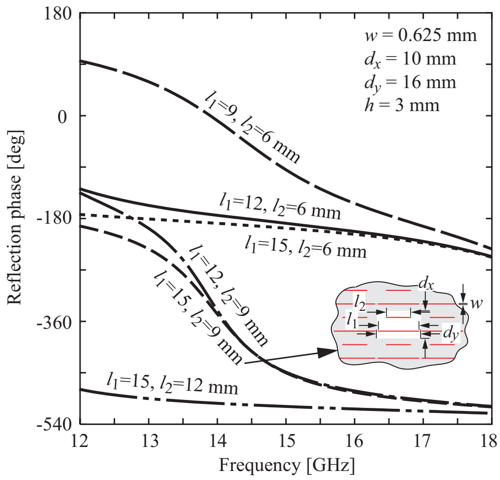

Fig. 4. Reflection phase of infinite reflectarray with dual-resonance elements.

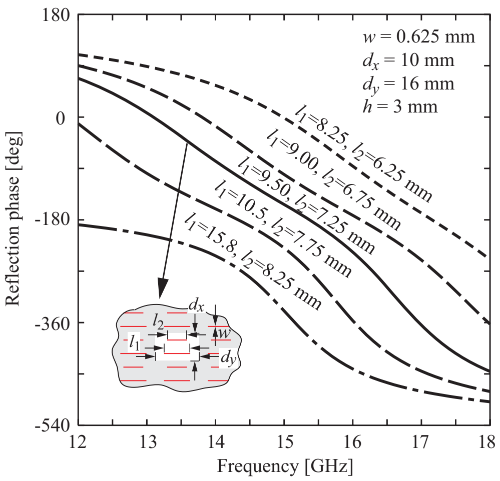

Fig. 5. Reflection phase of infinite reflectarray adjusting element lengths.

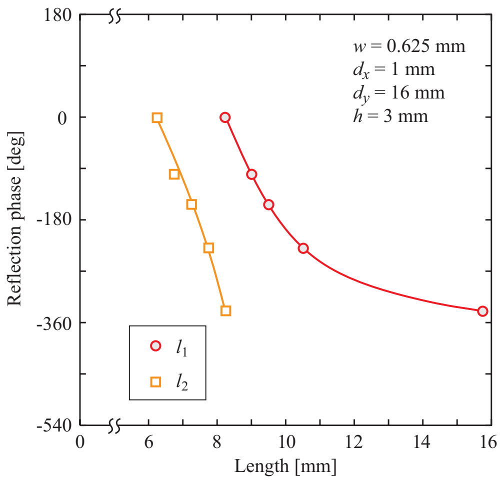

Fig. 6. Relationship between reflection phase and lengths of proposed dual-resonance elements.

Figure 3 shows frequency characteristics of the reflection phase of infinite reflectarrays with equal length l, where the incident plane wave is the TM wave with incident angles of 30°. All the parameters are indicated in this figure. The reflection properties are analyzed by using the method of moments based on the spetral domain Green function with periodical boundary condition [6]. Current distribution on the strips is expanded by roof-top sub-domain function which is defined in unit cell $d_x \times d_y$ divided into 64×64 meshes. The elements are densely arranged to reduce deviation of the frequency characteristics for wide band use [4]. However phase error on the aperture increases, as the range of the reflection phase due to one resonance becomes narrow. To improve the phase properties, we consider an infinite reflectarray consisting of a pair of elements with different lengths. Figure 4 shows some examples of reflection phase in such dual-resonance elements with 6, 9, 12, 15 mm as lengths l_1 and l_2. Furthermore, we determine appropriate set of elements from parametric study (see Fig. 5). It is clear that the proposed single-layer dual-resonance elements achieve good phase properties with similar curves required for wide band use while providing phase range enough to realize the desired phase over the aperture. Figure 6 shows the design chart, where the relationship between the phase at $f_0 = 15$ GHz and the lengths l_1 and l_2 are plotted and interpolated.

3. Design example and evaluation

We now design a reflectarray with a rectangular aperture of dimension 176 × 190 mm. The standard gain horn in the Ku band is used as a primary radiator, where the edge level is −10 dB and $R_s = 15\lambda_0$. The beam direction is $\Theta = 0°$ that's different from the offset angle $\theta_s = 30°$. Figure 7 shows contour map of the desired reflection phase at the centre frequency $f_0 = 15$ GHz. The contour interval is 45°. The lengths l_1 and l_2 of dual-element are determined from design charts prepared corresponding to illumination angles in addition to Fig. 6. Figure 8 shows the top view of designed reflectarray with the width $w = 0.625$ mm, the unit cell dimension $d_x = 10$ mm, $d_y = 16$ mm. Also, the close-up photograph in the middle of fabricated reflectarray is shown in Fig 9. The fabricated reflectarray consists of dipoles of thickness 18 μm printed on a thin dielectric film (Polyimide) of thickness 125 μm by using the photo-etching technique, and also the interval between the film and ground plane is kept by a foam substrate (dielectric constant $\epsilon_r = 1.07$) of thickness $h = 3$ mm.

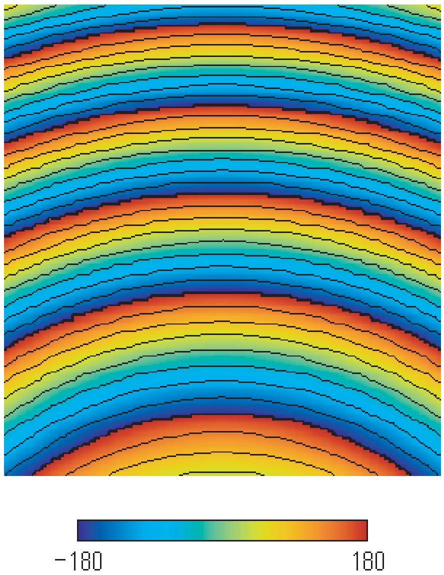

Fig. 7. Contour map of desired reflection phase.

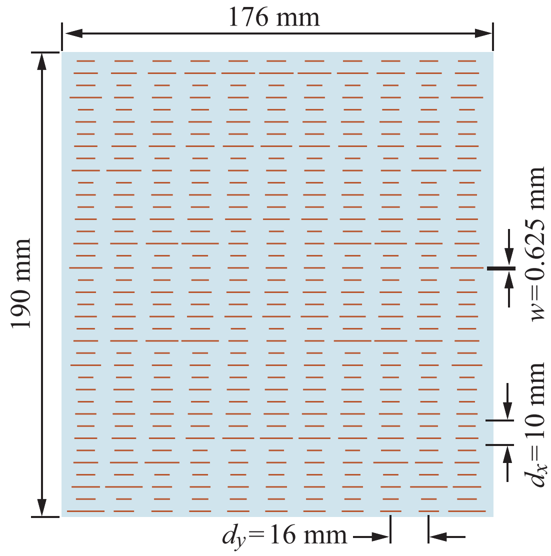

Fig. 8. Top view of designed reflectarray with dual-resonance elements (the element spacing in x-direction: $d = 4.38$ mm).

The far-field measurements were performed at 14 GHz and 16 GHz in an anechoic chamber. In Fig. 10, measured H-plane radiation patterns indicated by the solid lines are compared with calculated ones obtained by the aperture-field method. The reflection phase of each dual-element is approximated by infinite reflectarray analysis based on the method of moments. Although an increase of sidelobe level is caused by the alignment error of the feed, some errors in the fabrication and approximations in the design procedure, it was confirmed that the proposed reflectarray provides good radiation patterns with the main beam in the direction $\Theta = 0°$.

4. Conclusions

We have presented the single-layer reflectarray based on dual-resonance behavior to suppress the specular reflection. The performance of the proposed reflectarray has been verified by the numerical evaluation and the experiment for the fabricated antenna. The detail discussion on frequency characteristics of the reflectarray will be presented at the talk.

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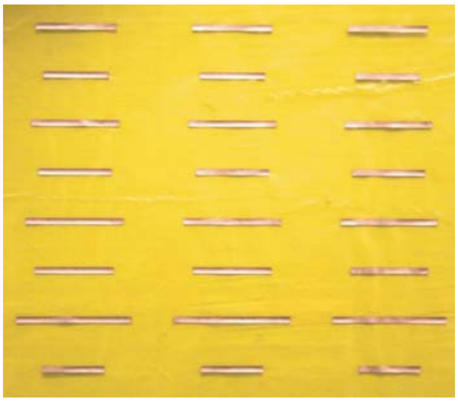
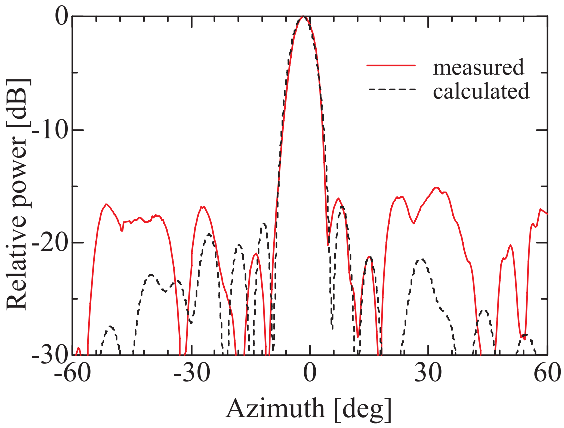
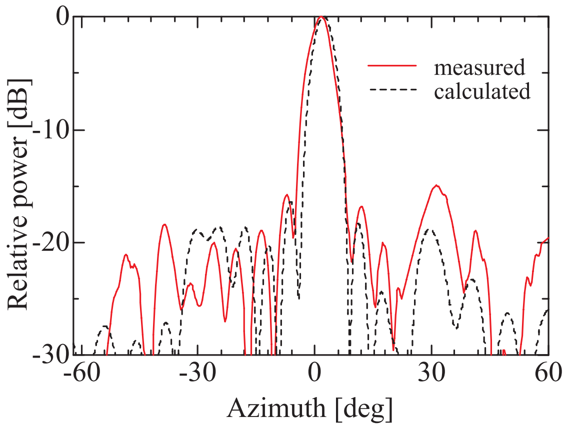


Fig. 9. Close-up photograph in the middle of fabricated reflectarray.



(a) 14 GHz.



(b) 16 GHz.

Fig. 10. Comparison between measured and calculated H-plane radiation patterns.

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