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Abstract

A broadband center-fed reflectarray antenna is presented in this paper. Patch with slot ring on ground plane elements are used for bandwidth improvement. It is shown that quasi-linear phase responses with broad frequency band can be achieved by such a phasing element. An 11×1 elements reflectarray is designed and simulated. The results show that the simulated gain is 23.92 dB at the center frequency of 13.58 GHz with 3-dB bandwidth of 52%, which demonstrates significant broadband operation compared with that of conventional reflectarray.

Full Text

A Broadband Reflectarray Using Patch With Slot Ring On Ground Plane Elements

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ABSTRACT—A broadband center-fed reflectarray antenna is presented in this paper. Patch with slot ring on ground plane elements are used for bandwidth improvement. It is shown that quasi-linear phase responses with broad frequency band can be achieved by such a phasing element. An 11×11 elements reflectarray is designed and simulated. The results show that the simulated gain is 23.92 dB at the center frequency of 13.58 GHz with 3-dB bandwidth of 52%, which demonstrates significant broadband operation compared with that of conventional reflectarray.

1. INTRODUCTION

For most radar and long-distance communications, the need for high-gain antennas is inevitable. Parabolic reflectors and arrays have traditionally played an important role in these applications. However, parabolic reflectors suffer from several inherent disadvantages due to their specifically curved surfaces, including heavy weight, bulky structure, and non-planar geometry. On the other hand, high-gain array antennas equipped with controllable phase shifters generally become prohibitively expensive because of their complicated beamforming networks and high-cost amplifier modules. To overcome these limitations, reflectarray antennas have emerged as an attractive alternative, offering advantages of high gain, low profile and mass, low cost, and flat geometry. A reflectarray typically consists of an illuminating feed antenna and a flat reflecting surface composed of many microstrip elements.

The main limitation of reflectarray antennas is their narrow bandwidth, which is generally lower than 5% and even less for large apertures [1]. This bandwidth limitation arises primarily from two factors: the inherent bandwidth of the radiating elements and the spatial phase delay dispersion. However, for small or moderate-size reflectarray antennas, the element bandwidth factor plays the dominant role in determining overall array bandwidth.

Several methods have been presented in previous works to improve reflectarray bandwidth [2-7]. In [2], a novel single-layer cell consisting of three coupled circular rings with four quasi-spiral delay lines connected to the outer ring was presented, achieving a 1-dB gain bandwidth of approximately 16.5% for an 18×18 element reflectarray. In [3], significant bandwidth improvement in large reflectarrays was demonstrated using elements that provide true time delay. In [4], an optimization method to enhance bandwidth was proposed, and two single-layer large printed reflectarrays with multi-cross-loop elements of variable loop length were designed, showing significant improvement in radiation pattern and gain bandwidth. A multilayer approach combined with subwavelength element technique was presented in [5], demonstrating a 1-dB gain bandwidth of 19.1% for a double-layer reflectarray using elements with a periodicity of $\lambda/4$. In [6] and [7], multi-resonant structures were employed for broadband operation.

In this paper, a novel element structure using a circular patch with a slot ring on the ground plane is presented, which provides sufficient phase variation range with quasi-linear phase responses. An 11×11 element reflectarray is designed and simulated based on the proposed element, achieving a 3-dB gain bandwidth of approximately 52%, which demonstrates wideband operation for the present reflectarray antenna.

2. ELEMENT DESIGN

The configuration of the proposed reflectarray element consists of a circular patch with a slot ring on the ground plane, as shown in Figure 1 [Figure 1: see original paper]. The elements are etched on a Rogers 5880 substrate with

relative permittivity of 2.2 and thickness of h . The layer between the two ground planes is an air layer with relative permittivity of 1 and thickness of h . The lattice period of the element is $L = 13$ mm, which corresponds to 0.59 wavelengths at 13.58 GHz.

The phase response is obtained by adjusting the patch radius r . The relationships between the patch radius r , the outer slot ring radius r_1 , and the width of the slot ring g are given by $r_1 = k \times r$ and $g = k \times r$, respectively. After optimizing the dimensional parameters, the final design parameters are as follows: $h = 1.5$ mm, $h_1 = 1$ mm, $k = 1.7$, and $k_1 = 0.17$.

The equivalent unit cell waveguide approach [8] is used to obtain the phase responses for normally incident plane waves. The reflection phase analysis of the elements was carried out using HFSS, with periodic boundary conditions applied to account for interactions with identical neighboring elements. Reflection phase versus patch radius r for different frequencies (11.58–15.58 GHz) is shown in Figure 2 [Figure 2: see original paper]. The quasi-linear phase responses at different frequencies indicate the wideband property of the proposed element.

3. REFLECTARRAY DESIGN AND PERFORMANCE

To validate the wideband property of the proposed element, an 11×11 element reflectarray was designed using the proposed element and its performance was simulated. The reflectarray is center-fed by a linearly polarized pyramidal horn antenna. Figure 3 [Figure 3: see original paper] shows the radiation pattern of the pyramidal horn antenna at 13.58 GHz. The distance between the phase center of the horn antenna and the reflectarray is 143 mm, which corresponds to an F/D ratio of 1. All elements' reflection phases are adjusted to generate a beam in the direction of the Z-axis (the reflectarray is in the XY-plane). Figure 4 [Figure 4: see original paper] presents the structure of the proposed antenna.

Figure 5 [Figure 5: see original paper] shows the simulated radiation patterns of the reflectarray antenna in the E-plane and H-plane at the center frequency of 13.58 GHz. The simulated gain is 23.92 dB at the center frequency of 13.58 GHz. The simulated gains across frequencies from 11.08 GHz to 19.58 GHz are shown in Figure 6 [Figure 6: see original paper], which exhibits a 3-dB gain bandwidth of approximately 52% (11.58–18.58 GHz).

4. CONCLUSION

A novel element structure using a patch with a slot ring on the ground plane is proposed in this paper. Quasi-linear phase responses with broad frequency band have been achieved by changing the sizes of the patch and slot ring on the ground plane. A reflectarray with 11×11 elements was designed and simulated based on the proposed element. The simulated results show a 3-dB gain bandwidth of 52%. Experimental verification will be performed in the next step.

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