A Wideband Reflectarray Antenna for Millimeter-Wave Applications

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***Abstract*—In this paper, a waveguide-type reflectarray element is designed and used to form a 16 × 16 reflectarray antenna which generates a pencil beam pointing to the broadside direction. The element consists of a dielectric filled waveguide, and copper wires that reflect the incident waves. The simulation results indicate that the reflectarray antenna can achieve stable high-gain beam from 25 to 35 GHz with low sidelobe level (SLL). The merits of high gain, low profile and wide bandwidth make the proposed reflectarray antenna a promising candidate for millimeter-wave applications and 5G.**

Keywords—millimeter-wave antenna, reflectarray antenna, wideband antenna.

I. Introduction

With the development of wireless communications, the operating bandwidth is extended to millimeter-wave band to obtain high data rate. However, at millimeter-wave frequencies, a high gain antenna is normally required to compensate the high propagation loss. One suitable candidate for realizing high antenna gain is using the reflectarray antenna, which combines the advantages of parabolic antenna and phased array antenna [1].

On the other hand, the dramatic increase of system capacity inevitably drives the research of broadband reflectarray antennas [2]-[3]. In this paper, we design a waveguide-type reflectarray element to realize broadband reflectarray antennas which work at millimeter-wave band. The simulation results show that the reflectarray can achieve stable high-gain beam from 25 to 35 GHz with low sidelobe level.

II. Antenna Design and Operating Principle

A. Design of the Proposed Element

Fig. 1 shows the geometry of the proposed reflectarray element. The dielectric post is embedded with four identical copper wires, and copper foil with thickness T = 0.05 mm is pasted around the dielectric post to form the proposed waveguide-type reflectarray element. The dielectric material has a loss tangent of tanδ = 0.0135 and a relative permittivity of ε_r = 3.3. The geometrical values of the reflectarray element are as follows: L = W = 5 mm, H = 8 mm, Wr = 0.25 mm, Wgap = 2 × Gap = 1.25 mm, Wh = 3.26 mm to 7.74 mm. The reflectarray element is simulated by setting periodic boundary condition and Floquet port. And the reflection phase shift curves at different frequencies are obtained. The phase shift is changed by adjusting the height (Wh) of the copper wires in the dielectric post. The phase shift range is over 360° from 25 GHz to 35 GHz. If a dielectric post with high dielectric constant is used, the phase shift range can be further extended.

The average reflection phase can be written as

$$\boldsymbol{Phase'(Wh)} = \frac{\sum_{f=f_1}^{f_N} \boldsymbol{Phase(Wh)}}{\boldsymbol{N}} \tag{1}$$

where N is the number of frequencise ($f_1 \sim f_N$). Fig. 2 shows the reflection magnitude and phase at 30 GHz and average reflection phase of the element. As shown, the element has a stable reflection magnitude over 0.9. In particular, the difference between the reflection phase shift curve at 30 GHz and the average reflection phase curve is less than 29°. Therefore, the reflection phase shift curve of 30 GHz is used to compensate the phase distribution to obtain a wideband reflectarray antenna as described in Ⅲ.

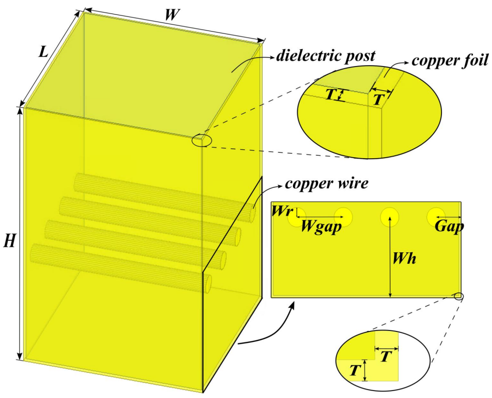


Fig. 1. Geometry of the proposed waveguide-type element.

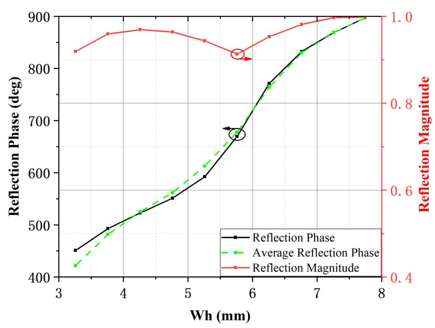


Fig. 2. The reflection magnitude and phase at 30 GHz and average reflection phase of the proposed waveguide-type element.

B. Design of the Reflectarray Antenna

The configuration of the proposed antenna is shown in Fig. 3. The horn antenna emits a beam onto the reflectarray. In order to reflect the beam pointing to the desired direction, not only the phase distribution which generates a desired beam, but also the phase difference caused by the different paths from horn antenna to each element must be compensated. In order to emit a beam pointing at the (θ, φ), the desired phase shift of each unit cell can be written as

$$\phi(x_i, y_j) = -k_0 \sin\theta (x_i \cos\varphi + y_j \sin\varphi) + k_0 R_{ij} \qquad (2)$$

where k_0 is the wave number, (x_i, y_j) is the position of the element and R_{ij} is the distance between the unit cell and the phase center. To reflect a beam pointing to (0°, 0°), the phase distribution can be calculated by (2). The desired phase distribution is shown in Fig. 4(a).

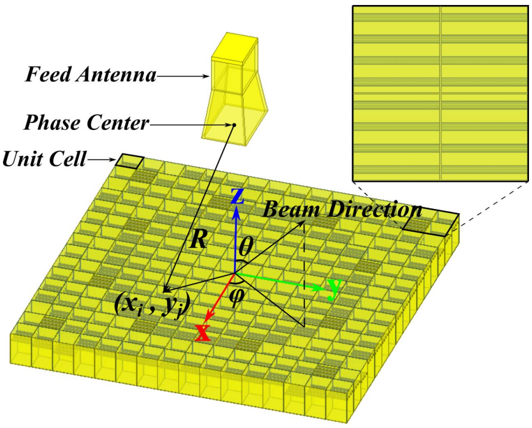
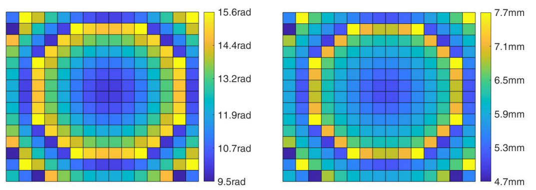


Fig. 3. The configuration of the reflectarray antenna.



(a) (b)

Fig. 4. (a) The phase shift distribution and (b) the Wh distribution of the proposed reflectarray antenna.

III. Simulation Results and Discussion

Using the reflection phase curve at 30 GHz and the phase shift distribution, the Wh distribution shown in Fig. 4(b) can be obtained. The Wh distribution can be used to model and simulate the 16 × 16 reflectarray which generates a pencil beam to (0°, 0°) as shown in Fig. 3. The simulated 3D radiation pattern at 30 GHz is shown in Fig. 5. Fig. 6 shows the normalized simulated radiation patterns of the proposed antenna. As shown in Fig. 6, the proposed antenna can achieve good pencil-shaped beams across a wide bandwidth of 25-35 GHz with -20dB sidelobe levels. The simulated aperture efficiency and gain of the proposed reflectarray antenna are given in Fig. 7. As shown in Fig. 7, the simulated maximum aperture efficiency is 48.98％ and simulated gain is over 23 dB.

IV. Conclusion

In this paper, a waveguide-type reflectarray element is proposed and used to form a 16 × 16 reflectarray antenna which generates a pencil beam pointing to broadside direction. The simulation results show that the reflectarray can achieve stable high-gain beam from 25 to 35 GHz with low sidelobe level (SLL). The merits of high gain, low profile and wide bandwith make the proposed antenna a promising candidate for millimeter-wave applications and 5G.

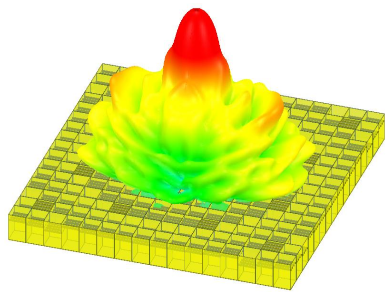


Fig. 5. The simulated 3D radiation pattern at 30 GHz.

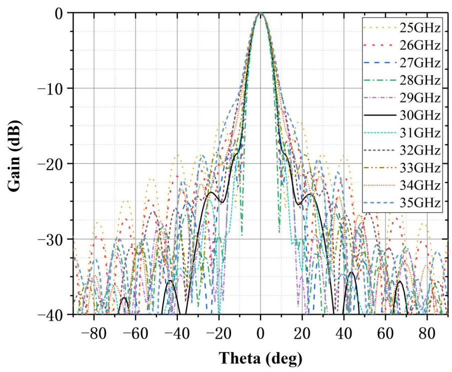


Fig. 6. The normalized simulated radiation patterns of the antenna (phi = 0°).

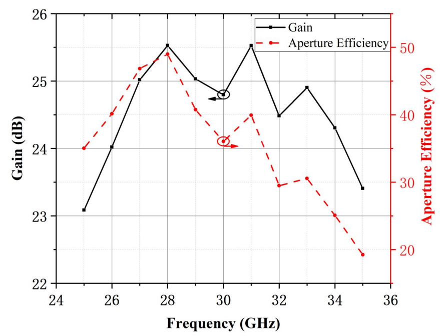


Fig. 7. Simulated aperture efficiency and gain of the proposed reflectarray.

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