Design and analysis of dual-polarized reflectarray with low sidelobe level for wireless communication applications

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Abstract: A reflectarray with upper sidelobe level (SLL) suppression is proposed for the fifth generation (5G) wireless communications in this letter. A unit cell of the reflectarray is composed of a crossed-dipole element to realize dual-polarized operation. In order to validate the improvement of upper SLL, a 45 degree-beam-steering reflectarray, comprising $20 \times 10$ elements, operating at 28 GHz for quasi-millimeter-wave applications is designed and analyzed numerically. Simulation results demonstrate that the worst value of all upper SLL in radiation pattern of the reflectarray is reduced by about 10 dB as compared to that in previous design.

Keywords: reflectarray, 5G, SLL

Classification: Antennas and Propagation

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1 Introduction

Recently, quasi-millimeter-wave band such as 28 GHz band is officially used in the fifth generation (5G) wireless communications. However, blocking of radio waves from base stations of cellular mobile communications by high and dense buildings in urban areas is a serious problem, particularly in narrow streets, because it very much weakens the signal level and greatly affects the quality of communications. Many efforts were made to deal with this problem and the attendant poor signal noise ratio (SNR), which dramatically degrades the efficiency of data transmission between mobile users and base stations. The blockage of a propagation channel in a blind area may greatly decrease the channel capacity for a multi-input multi-output (MIMO) system. Generally, in cases where a direct microwave path cannot be established (i.e., None-Line-of-Sight [NLOS]) between two points, it is possible to reconstruct a path by using a repeater. The function of a repeater is to enable the microwave beam pass around or over the obstacle (e.g., a building or hill). Reflectarray [1, 2] are attractive candidates as a passive repeater to solve the problem due to their lower cost of manufacturing, operation, and maintenance compared with traditional active repeaters.

Although previous researches [3, 4] have demonstrated the effectiveness of reflectarray antenna to overcome the problem of blind areas, there is still an obvious disadvantage in these design, which is high upper sidelobe level (SLL). The upper SLL is the main source of network interference. Moreover, interference is a key problem for future 5G communication networks, particularly in millimeter-wave band. Therefore, it is essential to design a reflectarray with low upper SLL for reducing the intra-frequency interference with neighbor cells in a cellular network. In addition, Kennedy et al. introduced a concept of particle swarm optimization (PSO) method [5]. We think that the method can be applied to lower the upper sidelobe that radiates neighbor cells and improve the D/U ratio (the ratio of strength of useful signal to that of interference signal).

On the other hand, in order to suppress the multi-path fading effect and increase the channel capacity, polarization diversity technology have been widely applied in wireless communications. Therefore, it is necessary to design a dual-polarization reflectarray. A transparent reflectarray antenna integrated with solar cells was proposed for satellite communications in [6] using X-shaped dipole elements. A microstrip reflectarray with crossed dipoles was introduced to obtain circular polarization in [7]. In our works, a cross-shaped dipole element is adopted to realize dual-polarization operation.
In this letter, a reflectarray with low upper SLL is designed based on PSO method for 5G wireless communication systems. The reflectarray using $20 \times 10$ crossed-dipole elements is analyzed numerically to demonstrate the improvement of upper SLL.

### 2 Design of reflectarray with upper SLL suppression

The unit cell of the proposed reflectarray is composed of a crossed-dipole element to realize dual-polarized operation as shown in Fig. 1. CST Microwave Studio is applied to analyze the reflection phase characteristics of the unit cell. A similar analysis of the reflection phase can be found in [3, 8]. The analysis is carried assuming the operating frequency of 28 GHz. The period of the unit cell is $D = 5$ mm, which is equivalent to 0.47 wavelengths at 28 GHz. The substrate thickness is $t = 1.3$ mm, and the relative permittivity $\varepsilon_r = 3$. The width of the crossed-dipole element is $w = 1$ mm. Figure 1 shows that a phase variation range of 278 degrees can be obtained by adjusting the length $l$ of the element when the plane wave is incident normally to the element surface.

![Fig. 1. Reflection phase versus the length of crossed-dipole element.](image)

In the design of microstrip reflectarray, the required phase of the individual element is calculated generally as described in [1, 3]. Although a desired scattering angle can be obtained based on the method, high upper sidelobes are generated because of using a uniform phase shift. In our design, PSO method is utilized in order to suppress all upper SLL by optimizing the phase of each element in the reflectarray. Meanwhile, the required scattering angle also can be achieved. The resonant length of each element is determined according to the optimized phase and the reflection phase curve shown in Fig. 1.

Considering the 5G wireless communication system, we design a 45 degree-beam-steering reflectarray operating at 28 GHz for quasi-millimeter-wave applica-
tions. Figure 2 shows the geometry of the designed reflectarray with low upper SLL. The reflectarray is consist of $20 \times 10$ crossed-dipole element. Table as shown in Fig. 2 gives the dimensions of all crossed-dipole elements along the $x$- and $y$-axes. In the design, the incident plane wave arrived from $y$-axes direction of $(\theta_i, \phi_i) = (20^\circ, 90^\circ)$, and the reflected main beam is directed to $x$-axes direction of $(\theta_r, \phi_r) = (45^\circ, 0^\circ)$. Moreover, the incidence plane wave can be either TM or TE polarized due to the symmetric crossed-dipole design.

![Figure 2](image_url)

(a) Geometry. (b) Dimensions.

| Row | Column | Unit: mm |
|-----|--------|----------|
| 1   | 1      | 4.99     | 3.4  | 2.82 | 2.35 | 1.97 | 1.3  | 4.99 | 3.99 | 3.06 | 2.34 |
| 2   | 1      | 2.35     | 1.29 | 4.99 | 4.24 | 3.38 | 3.02 | 2.35 | 1.91 | 1    | 4.2  |
| 3   | 1      | 3.56     | 2.8  | 2.38 | 1.57 | 1    | 4.99 | 3.56 | 3.04 | 2.59 | 1.54 |
| 4   | 1      | 4.95     | 3.48 | 2.82 | 2.55 | 2.3  | 1    | 4.99 | 4.17 | 2.81 |
| 5   | 1      | 2.47     | 1.68 | 1    | 4.83 | 3.63 | 3.17 | 2.47 | 2.1  | 1    | 4.79 |
| 6   | 1      | 3.75     | 2.87 | 2.45 | 1.76 | 1    | 4.99 | 3.75 | 3.13 | 2.66 | 1.74 |
| 7   | 1      | 4.97     | 3.53 | 2.84 | 2.57 | 2.32 | 1    | 4.99 | 4.27 | 2.83 |
| 8   | 1      | 2.47     | 1.68 | 1    | 4.83 | 3.63 | 3.17 | 2.47 | 2.1  | 1    | 4.79 |
| 9   | 1      | 3.63     | 2.83 | 2.41 | 1.66 | 1    | 4.99 | 3.63 | 3.07 | 2.62 | 1.63 |
| 10  | 1      | 4.92     | 3.38 | 2.77 | 2.5  | 2.23 | 1    | 4.99 | 3.96 | 2.76 |
| 11  | 1      | 2.41     | 1.52 | 4.99 | 4.55 | 3.5  | 3.09 | 2.41 | 2.01 | 1    | 4.5  |
| 12  | 1      | 3.46     | 2.76 | 2.33 | 1.43 | 1    | 4.99 | 3.46 | 2.99 | 2.55 | 1.39 |
| 13  | 1      | 4.62     | 3.24 | 2.69 | 2.42 | 2.12 | 1    | 4.99 | 3.68 | 2.68 |
| 14  | 1      | 2.35     | 1.31 | 4.99 | 4.28 | 3.39 | 3.03 | 2.35 | 1.92 | 1    | 4.23 |
| 15  | 1      | 3.36     | 2.71 | 2.27 | 1.17 | 1    | 4.99 | 3.36 | 2.92 | 2.5  | 1.12 |
| 16  | 1      | 4.99     | 4.29 | 3.14 | 2.63 | 2.35 | 2.03 | 4.99 | 4.96 | 3.52 | 2.62 |
| 17  | 1      | 2.38     | 1.42 | 4.99 | 4.41 | 3.44 | 3.06 | 2.38 | 1.97 | 1    | 4.36 |
| 18  | 1      | 3.54     | 2.79 | 2.36 | 1.54 | 1    | 4.99 | 3.54 | 3.02 | 2.58 | 1.51 |
| 19  | 1      | 4.93     | 3.42 | 2.79 | 2.52 | 2.26 | 1    | 4.99 | 4.04 | 2.78 |
| 20  | 1      | 2.56     | 1.9  | 1    | 4.96 | 3.94 | 3.32 | 2.56 | 2.23 | 1.23 | 4.95 |
3 Simulation results

In order to verify the design, a simulation was performed for analyzing radiation pattern of the reflectarray in the $x_0z$ plane with an incident TE-polarized plane wave. The simulation results of a normalized bistatic scattering radar cross section (RCS) are shown in Fig. 3. The results show that the main beam is directed at 45 degree. Meanwhile, all upper SLL are suppressed to about 20 dB below peak. Compared with previous design in [3], the worst value of all upper SLL is reduced by about 10 dB. Thus, the reflectarray using the crossed-dipole element satisfies the requirements regarding the main beam position and low upper SLL very well. In addition, the performance for the TM-polarized incidence waves can be similarly obtained due to symmetry.

![Fig. 3. Simulated normalized bistatic scattering RCS of crossed-dipole reflectarray with low upper SLL.](image)

4 Conclusion

This letter presented a reflectarray with low upper sidelobe level (SLL) for wireless communication applications. The reflectarray using $20 \times 10$ crossed-dipole elements, which can be used for dual-polarized operation, was designed and analyzed numerically in order to confirm the improvement of the upper SLL. Simulation results indicated that the worst value of all upper SLL in radiation pattern of the reflectarray is reduced by about 10 dB as compared to that in previous design. This SLL reduction will increase the signal-to-interference-and-noise ratio in 5G millimeter-wave links, reducing interference.