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Combination of Array Antennas and Dielectric Lenses for 6G Communication Systems

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Summary

In this work, we propose the combination of a phased array antenna with dielectric lenses to have a flexible and cost-effective antenna system for 6G terrestrial communications. This study includes the exploration of three different scenarios: outdoor street scenario, ceiling mounted indoor scenario and gain enhancement in a wide scanning area. For the first design, a gain improvement of up to 0.5 dBi from 0° to 30° is achieved. The second design increases the gain up to 0.9 dBi from 65° to 80°. Finally, in the third design, the gain is increased up to 0.4 dBi in the range 0°-30° and 55°-70°.

1 Introduction

The sixth generation (6G) of mobile communication systems aims to provide high data rates to different scenarios [1]. Consequently, 6G requires flexible antenna systems in terms of directivity, beam steering and efficiency. One of the antenna types that can meet these requirements is phased array antennas (PAAs) [2]. PAAs have the advantages of low profile and low cost in mass production, so they have been widely applied to mobile communications, satellite broadcasting, etc [3]. However, as the frequency increases, the feeding network of this type of antenna has high design complexity and losses [4], so designing different PAAs for different scenarios becomes costly.

To overcome this, one PAA can be combined with different lenses, whose design process is more cost-effective. For example, in [5], a dielectric radome is used to extend the scanning performance of the array. In [6], a lens is used to increase the directivity. Alternatively, radomes can also be used to reduce the grating-lobe-level [7].

The focus of this study is exploring the possibility of using different dielectric lenses to change the capabilities of a PAA working in the Ka-band. Dielectric lenses are chosen due to their broadband performance. Here, we use rotationally-symmetric dielectric lenses whose profile satisfies the conics equation, as proposed in [5]. Three different scenarios are considered in this study: gain increase near the broadside direction for outdoor street scenario (from 0° to 30°), gain increase in extreme angles for indoor ceiling mounted scenarios (from 60° to 80°), and gain increase in a wide scanning range (from 0° to 70°).

2 Antenna design process

In this work, the design process is done using *CST Microwave Studio*. To simplify the simulations, an array antenna of ideal open waveguides is used. The array antenna has 24 elements with spacing of 0.45λ along the x-direction and 8 elements with spacing of 0.75λ along the y-direction. An illustration of the XZ-plane of the lens is shown in Fig. 1. As proposed in [5], the lens inner and outer surfaces follow the conics equation

$$z = h_i + \frac{c_i \rho^2}{1+\sqrt{1-(1+K_i)\,c_i^2\rho^2}} \tag{1}$$

where h_i is the height, c_i is the curvature factor and K_i is the conic constant. The subscript $i = 1$ represents the inner surface of the lens and $i = 2$ represents the outer surface. The permittivity of the lens is $\varepsilon_r = 2.53$. To reduce the reflections at the interface of the different media, matching layers, with permittivity $\varepsilon_{ML} = 1.7$, are added on the inner and outer surfaces of the lens.

When no lens is used, the PAA requires a linear phase distribution, which can be calculated theoretically as $\alpha = -kd\cos(\frac{\pi}{2} - \theta_o)$, where α is the phase difference between adjacent array elements, k is the propagation constant in free space, d is the repetition period of array elements, and θ_o is the relative angle between the target radiation direction and the broadside direction [3]. On the contrary, when the PAA is combined with the dielectric lens, the inverse excitation method is used to get the required phase distribution. This is done by simulating a plane wave excitation at the targeted angle impinging on the lens and some observation points placed at the array position. The obtained phase distribution at the observation points will later be used in a second simulation to obtain the radiation pattern.

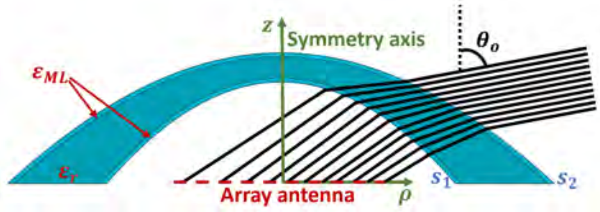

Figure 1. Schematic diagram of the conical shaped dielectric lens.

3 Numerical results

The design process is done by adjusting first the geometrical parameters of the outer surface of the lens, and then the geometrical parameters of the inner surface. For each iteration, two simulations are needed: one to obtain the phase distribution of the array and another to obtain the gain.

Three different designs are done. The first one, is aimed for outdoor street scenarios. The dielectric lens increases the gain of the array antenna by about 0.5 dBi in the range of 0°-30°. The second design is for ceiling mounted indoor scenarios. By combining with the lens, the gain of the array antenna is increased up to 0.9 dBi from 65° to 80°. The third design could be applied to scenarios requiring wide scanning range. Compared with the case of array only, the lens increases the gain up to 0.4 dBi in the range 0°-30° and 55°-70°.

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