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Geodesic H-plane Horn Antennas

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Summary

This abstract describes a procedure that allows for a time-efficient design of fully metallic geodesic H-plane horn antennas using an in-house ray-tracing method together with an optimization algorithm. With all the propagation in the air, geodesic H-plane horn antennas are low-loss and highly efficient. The geodesic H-plane horn antennas provide a new degree of freedom, the height profile, to alleviate phase errors, realizing high gains and aperture efficiencies. Optimizations are implemented to design the height profile for a given target.

1 Introduction

With the development of modern information technology, higher frequency bands are considered to increase the data rate of wireless communications. In these high-frequency bands, especially millimeter waves and above, there is a demand for high-performance and cost-effective beamforming devices. Among all possible solutions, geodesic lenses are particularly attractive due to their low cost and high efficiency [1]. Geodesic lenses use the height profile of a curved parallel plate waveguide to introduce physical path-length differences that mimic an equivalent graded refractive index [2]. Therefore, geodesic lenses are ideal for high-frequency applications, avoiding the losses of dielectric materials.

Horn antennas, also simple and fully metallic, have the potential to be used as high-efficiency beamformers at high frequencies. They are realized by employing a metallic tapering to match electromagnetic waves from a waveguide to free space. When the tapering is applied only to the H-plane, the antenna is called the H-plane sectoral horn antenna. Compared to common pyramidal and conical horn antennas with bulky geometries, H-plane antennas with low profiles are especially useful in systems with space constraints. However, horn antennas have an inherent problem of phase errors in the horn aperture that reduce the aperture efficiency [3]. This problem hinders the use of horn antennas as highly directive beamformers.

To overcome the above problem, we propose the novel concept of fully metallic geodesic H-plane horn antennas, as well as a generic approach to design these antennas using an in-house ray-tracing method. The height profile of the H-plane horn antennas is carefully designed to control the path lengths of waves that arrive at different positions in the horn aperture. It allows us to alleviate the phase error problem and increase the gains and aperture efficiencies of H-plane horns.

2 Ray-Tracing Model

An H-plane horn antenna has a triangular geometry, gradually flared from the waveguide feed to the horn aperture. We assume that the height of the H-plane horn antenna is small enough to support only the fundamental mode. Commercial full-wave solvers are usually employed to analyze wave propagation inside the horn. However, these simulations require large computing resources and long times. Recently, ray-tracing techniques have been shown to be an alternative considerably more time-efficient and sufficiently accurate for analyzing geodesic lenses [4, 5]. In this work, we adapt the numerical ray-tracing method proposed in [5] to study horn antennas. The ray-tracing method can be described in the following steps.

1. Calculation of ray trajectories, or geodesics, traveling from the source point to any point in the aperture. The source point is located at the phase center of the horn antenna.
2. Evaluation of the phase distribution of the E-field in the aperture using the length of the obtained geodesics.
3. Obtaining the amplitude distribution of the E-field in the aperture using the ray-tube power conservation theory.
4. Computation of the far-field radiation pattern using Kirchhoff's scalar diffraction theory.

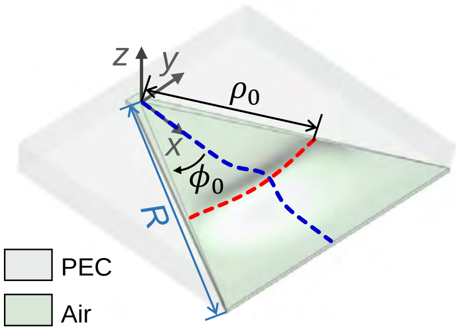

Figure 1. Illustration of the geometry of a geodesic H-plane horn antenna.

Note that in the ray-tracing model, the source point is displaced from the origin to coincide with the phase center. This displacement needs to be precisely defined and finely adjusted in the ray-tracing model to obtain a good match of the ray-tracing results with full-wave simulations. A good approximation of the feed model is also required to ensure the accuracy of the amplitude distribution of the E-field in the horn aperture.

3 Height Profile Design

To correct the path-length differences of waves travelling inside the horn, the devised height profile makes use of the z-direction geometry, letting rays in the center of the horn propagate extra lengths compared to those in the sides. As a result, we propose a height profile as

$$z(\rho,\phi) = A_h R \exp\left[-\left(\frac{\rho-\rho_0}{\eta}\right)^2\right] \times \left[\left(\frac{\cos\left(\frac{\pi\phi}{\phi_0}\right)+1+\delta}{2}\right)^p - \left(\frac{\delta}{2}\right)^p\right] \tag{1}$$

in which R and ϕ_0 determine the basic geometry of an H-plane horn, while δ is a constant, and A_h, ρ_0, η, and p are the four parameters for optimization. The height profile has a Gaussian distribution along the ρ-direction and a quasi-cosine distribution along the angular ϕ-direction with a maximum of $z(\rho_0,0) = A_h R\,[(1+\delta/2)^p - (\delta/2)^p]$, as illustrated by the blue and red dashed line in Fig. 1. Here, δ is a very small constant equal to 0.01 to avoid the numerical singularity 0^p as $\phi \to \phi_0$.

For a particular H-plane horn with design parameters R and ϕ_0, an optimization method with the ray-tracing approach is used to optimize an optimal height profile. The target is to get the narrowest beam width of the radiation pattern with a certain side lobe level, which corresponds to the highest gain and aperture efficiency.

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