

Ray-Tracing Model for Dielectric Lens Arrays Combined with Meta-Domes

Hairu Wang⁽¹⁾, Mingzheng Chen⁽¹⁾, Francisco Mesa⁽²⁾, and Oscar Quevedo-Teruel⁽¹⁾

⁽¹⁾ Division of Electromagnetic Engineering and Fusion Science, KTH Royal Institute of Technology, Stockholm, Sweden

⁽²⁾ Department of Applied Physics 1, Universidad de Sevilla, Sevilla, Spain

Planar phased array antennas (PAAs) are crucial in modern terrestrial communications and satellite systems because of their simplicity of design, low profile, and beam steering capabilities. However, their beam-scan capabilities are inherently limited as a result of a reduced projected aperture area, especially at large angles. To enhance large-angle scanning performance, the integration of dielectric lenses with PAAs has been proposed. Although this integration offers a certain degree of flexibility, the extent of improvement is often constrained by the possible lens shapes and dielectric constant distributions, which limits uniform gain enhancements over the entire scanning range. This work aims to tackle these challenges by introducing a hybrid model that integrates dielectric lenses with metadomes, significantly enhancing the performance of the PAA.

As illustrated in Fig. 1, the metadome is integrated into the inner surface of the dielectric lens and positioned in front of the PAA. The radiation from the PAA can be controlled by adjusting the shape and material parameters of the dielectric lens as well as the phase and amplitude distributions of the metadome. This integration enhances design flexibility beyond what separate dielectric lenses offer, and reduces the stringent design requirements typically associated with using the metadome alone. Creating meta-elements that perform well over a broad frequency range and maintain a consistent response across different incidence angles presents a significant challenge. However, pairing these elements with dielectric lenses alleviates the demand for high-performance metadomes, allowing them to prioritize their role in augmenting the dielectric lenses for targeted improvements.

The use of commercial full-wave simulators to optimize the combined PAA + dielectric lens + meta-dome is computationally intensive and time consuming. To streamline the analysis and design process, this study introduces a ray-tracing (RT) model for the combination of the three parts. The proposed model first uses phase predistortion to enable proper array element excitations at different scanning angles. Then physical optics, specifically Kirchhoff's scalar diffraction theory, is used to calculate the far-field radiation pattern. The proposed RT model greatly accelerates the design process, simplifying the optimization of the dielectric lens and metadome configuration for specific PAAs, thereby enhancing the efficiency of PAA-based communication networks.

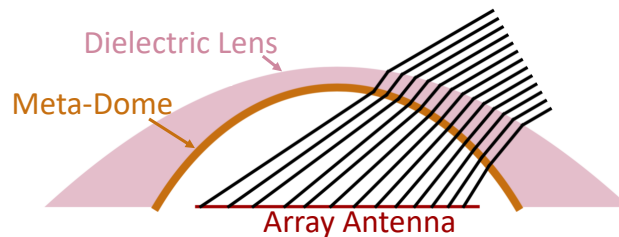


Figure 1: Scheme of the RT technique for the analysis of combined PAA, dielectric lens, and meta-dome.