Physical Optics Applied to Parallel-Plate Lens Antennas

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1 Extended Abstract

The Physical Optics (PO) method is applied to compute the radiated electric far fields of parallel-plate waveguide (PPW) lens antennas, including planar graded-index and geodesic lenses. When combined with ray-tracing (RT) techniques, the resulting RT-PO algorithm is able to calculate very efficiently the radiation pattern and directivity of PPW-based lens antennas that operate with a transverse electromagnetic (TEM) mode. Figure 1 illustrates the underlying geometry to evaluate the radiated electric field at the observation point $\mathbf{r}$ from a vertically polarized electric field $\mathbf{E_a}(\mathbf{r}')$ in a thin aperture. The field $\mathbf{E_a}(\mathbf{r}')$ in the lens aperture is obtained using the RT technique reported in [1], where the ray length gives the phase and the amplitude is evaluated applying the ray tube power conservation theory. As a result, for the k-th target point in the aperture, the electric field takes the form of $\mathbf{E}_k = A_k \mathrm{e}^{-\mathrm{j}\Phi_k}\hat{\mathbf{y}}$, where A_k and Φ_k are the amplitude and phase, respectively. The magnetic field in the aperture can easily be related to the electric field by a uniform plane wave relationship $\mathbf{H}_a = \hat{\mathbf{n}} \times \mathbf{E}_a/\eta_a$, where η_a is the wave impedance in the aperture.

Starting from the fields in the lens aperture, the radiated field at the observation points ($r \gg r'$) can be obtained applying the PO method [2]. The lens aperture S' is assumed to be surrounded by a screen where the tangential fields are assumed to be null. Under this assumption, the far-zone electric field can be computed from the equivalent magnetic and electric currents ($\mathbf{J} = \hat{\mathbf{n}} \times \mathbf{H}_a$ and $\mathbf{M} = -\hat{\mathbf{n}} \times \mathbf{E}_a$) as

$$\mathbf{E}(\theta,\phi) = -\mathrm{j}k\frac{\mathrm{e}^{-\mathrm{j}kr}}{4\pi r}\hat{\mathbf{r}} \times \left[\eta\widetilde{\mathbf{J}} \times \hat{\mathbf{r}} - \widetilde{\mathbf{M}}\right] \tag{1}$$

where the symbol $\widetilde{\cdot}$ stands for

$$\widetilde{\mathbf{J}}(\theta,\phi) = \int_S \mathbf{J}(\mathbf{r}')\mathrm{e}^{\mathrm{j}\mathbf{k}\cdot\mathbf{r}'}\mathrm{d}S' \qquad \widetilde{\mathbf{M}}(\theta,\phi) = \int_S \mathbf{M}(\mathbf{r}')\mathrm{e}^{\mathrm{j}\mathbf{k}\cdot\mathbf{r}'}\mathrm{d}S'\,. \tag{2}$$

From the far-zone electric field in (1), the radiation pattern and directivity of the lens antenna can be directly determined. This specific implementation of the RT-PO approach is not only fast but also precise, making it a suitable analysis and design technique for PPW-based lens antennas.

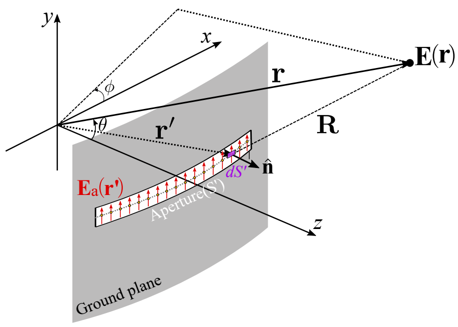

Figure 1. Illustration of radiated electric fields from a thin aperture.

References

[1] Q. Liao *et al.*, "Ray-tracing model for generalized geodesic lens multiple beam antennas," *IEEE Trans. Antennas Propag.*, vol. 71, no. 3, pp. 2640–2651, Mar. 2023.

[2] S. J. Orfanidis, *Electromagnetic Waves and Antennas.* (Open access), 2013.