Level-set based Topology Optimization of MM-Wave Large Aperture Lens Designs

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Design of imaging sensors has been an important focus within mm-wave electromagnetic applications. Motivated from the field of optics, lenses are known alternatives capable of collimating, directing and focusing high frequency waves. The process of standard lens design follows fundamental rules of designing electromagnetic imaging systems. However, one key issue to be considered is that as their aperture size is being increased to increase image resolution, a side effect of image distortion known as lens aberration is introduced, the effect of which is pronounced at higher frequencies. Aberrations can decrease overall imaging system performance significantly because of unwanted ray intersection combinations. To address this issue, in this paper a novel topology optimization procedure will be developed to design optimal lens geometry for millimeter-wave applications with minimum amount of aberration. Topology optimization is the most powerful approach for concurrently designing geometrical and topological/material distributions, i.e. the design of novel device topologies from scratch. Originally developed within the Mechanical Engineering community for minimizing compliance, the field has expanded significantly, addressing many practical engineering problems including automotive applications and design of extreme material properties. More recently, the method was applied to piezoelectric actuators, electrostatic applications, photonic crystals, antenna design problems and radar cross sections [H. Yigit, PIERS, 2011]. From a theoretical perspective, recent studies have shown that integration of the level-set method within standard topology optimization applications has the potential to solve problems such as computational cost, getting trapped into local minima and inconvenient compatibility for complex geometrical problems, when compared with the classical method of shape sensitivity (or boundary variation). The level-set method has been devised for numerically tracking fronts and free boundaries and it is used in many applications as fluid mechanics and image processing. In this paper, we apply it to the design of an optical lens with minimum aberration and maximum aperture size. Towards that goal, the electric field distributions behind the lens, where the focus lies, can be represented via an integral equation based on a kernel describing radiation induced source points, which strictly dependent on surface geometry. The challenge will be to determine the sensitivity of the kernel's response to the change of the lens surface boundary in order to apply the level-set based topology optimization procedure. More specifically, the derivative of the object function is needed to determine the evolution of the geometry's boundary speed by solving the Hamilton-Jacobi equation. The main idea is based on the implicit expression of a material boundary that evolves to its optimum with this speed function. Level set based classical electric field integral equation formulation was presented earlier by the author. Here, we will demonstrate that for the dielectric lens, a similar procedure can be followed by overcoming the additional challenge of the original derivative term existing in the Kernel of a homogeneous dielectric lens. We propose a simple integral equation kernel based on Snell's laws to overcome this challenge. Diffraction, reflection and transmission of rays will be defined by this kernel at the dielectric surface boundary. Since these terms will not yield the complete field amplitude distribution, we combine ray tracing with Gaussian beam approach to resolve this issue. Initial results show that the proposed level set based topology optimization method is powerful in synthesizing the geometry of a dielectric lens with minimal aberration.