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Description of Light Focusing by a Lens using Vector Diffraction Theory

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Abstract: For a plane wave incident on a spherical lens at normal incidence, the field distributions in the focal region are calculated using vector diffraction theory showing the effects of aberration.

Description of practical lenses used in the laboratory using full vector diffraction theory is not easily available in the literature, possibly because of the large computation time involved in the evaluation of multiple integrals through two surfaces. Moreover, the propagation equations for light originating on a curved surface of a lens are not easily available in the literature in a simple form although they can be derived from the general vector form of Kirchoff diffraction integrals [1,2]. For a plane wave incident on one curved surface of a lens, the electric and magnetic field components at all points on the second lens surface can be calculated by evaluation of the integrals. Reapplication of the diffraction formalism on the second surface allows the evaluation of the field distribution at all points external to the lens.

The diffraction integrals have been expressed in normalized coordinates and in terms of dimensionless parameters, so that the formalism can be applied to a wide variety of lenses. One key parameter that characterizes the degree of the computational challenge is the quantity defined as $p_1 = (2 \pi n R)/\lambda$, where λ is the wavelength of light, n is the refractive index of the lens medium and R denotes the radius of curvature of a lens surface.

Focusing by a commercially obtained plano-convex glass lens (Newport KPX010) for which the value of p_1 is 47,500 for the curved surface, at a wavelength of 0.633 μm will be described. The calculations of the integrals to obtain field distributions on the plane surface take about two days on a Compaq SC-45 computer (1 Gigabyte Memory per Compute Processor, 8 Terabyte Workspace, AlphaEV 1 GHz 6.8 Chip). The electro-magnetic field distribution thus obtained are re-propagated from the plane surface to the focal region to determine the field distributions near focus. Detailed three dimensional distribution of intensity near focus will be presented.

[1] J.A. Stratton, Electromagnetic Theory (McGraw Hill Book Company, New York, 1941).
[2] E.J. Rothwell and E.J. Cloud, Electromagnetics (CRC Press, Boca Raton, FL, 2001)