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Profile Inversion and Closed form Formulation for Inhomogeneous Metalenses

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We introduce novel formulations for flat radial GRadient INdex (GRIN) lenses allowing for the optimal lens design through closed form expressions of both inhomogeneous refracting index and aperture efficiency. The validity of the proposed formulation covers a very large range of GRIN lens design parameters (focal length, lens thickness and maximum refractive index). For non-vanishing focal length (Fig. 1a), the formulation is based on a Geometrical Optics (GO) derivation of a new form of non-linear integral equation representing the equalization of all the optical ray-path lengths, denoted as Regularized Ray Congruence (RRC) equation, and on its closed form solution. For zero-focal length (Fig. 1b, namely, with integrated feeder) the optimal refractive index is retrieved by an inversion of a truncated Abel Transform. An analytical form of aperture efficiency is given for standard feed patterns for both non-zero and zero focal length. The application of the formulas presented here allows for an instantaneous design for medium/high gain antennas with controllable total aperture efficiency till 80%. The accuracy of the formulation is tested by a full-wave analysis and compared with other formulations available in the literature. For non-zero focal length, we found that the new formulations proposed here significantly reduce the phase error in a wide range of the lens parameters, thus allowing for a more efficient, accurate and flexible design for GRIN lenses. Practical examples of GRIN lens antennas will be shown including lens antenna for operation in E-band (60-90 GHz), and practical design of GRIN horn-type lenses by using holes of different shapes in a dielectric ABS/Teflon host media.

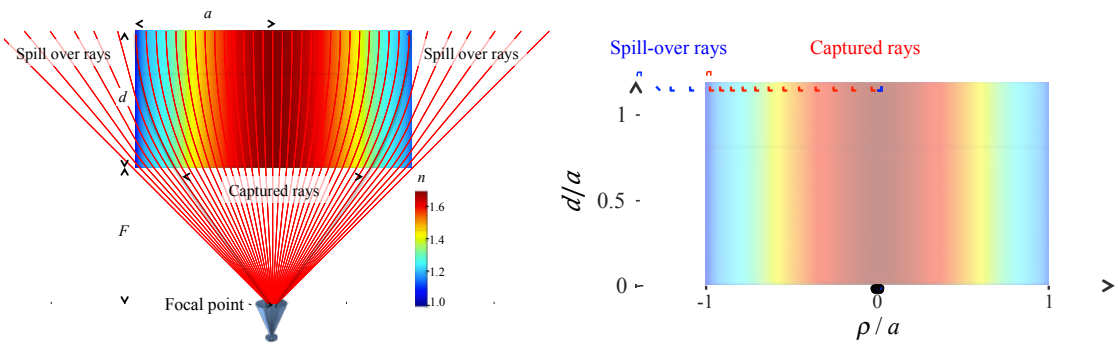

Fig. 1 Geomery of the Graded Index Lens with (a) focal length different form zero; (b) zero Focal Length