INNOVATIVE LENS ANTENNAS FOR MM AND THZ RANGE ELECTROMAGNETIC WAVE SYSTEMS

Objective and scope

The project objective is basic research into the physics, design and optimization of wavelength-size dielectric lenses used for the collimating, focusing, un-focusing, or beam steering of electromagnetic waves, depending on the applications under consideration. This will be achieved by the mathematical and numerical study of the corresponding wave scattering problems as the boundary-value problems for the set of Maxwell's equations with exact boundary, edge, and radiation conditions. Underlining concept is the use of boundary integral equations, which do not imply small-contrast or high-frequency approximations and lead to convergent, stable, and efficient numerical algorithms. Directivity of radiation, efficiency of focusing, wavelength dependences, and the field patterns in the near and far zones will result from this analysis, and the ways to improve these characteristics will be elaborated and analyzed. In the long-term, rigorous electromagnetic synthesis of such structures is the ultimate challenge.

State of the art

To increase signal capacity and security, microwave terrestrial and space communication systems are evolving into millimeter-wave ones. This also enables one to arrange a frequency re-using within a smaller indoor or urban-space area. Due to smaller wavelength, mm-wave antennas rely heavily on the quasioptical principles. Here, dielectric lens antennas take upper hand over reflectors and play a key role as components able to provide both the high density of the electromagnetic power and the integration with receivers and signal-processing circuits. E.g., such antennas have been reported for broadband point-to-multipoint distribution systems, automotive radars, and radio astronomy [G. Rebeiz, *Proc. IEEE*, 80, 1748, 1992; X. Wu, *IEEE Trans. MTT*, 49, 431, 2001]. In the domain of even shorter waves, commonly labeled terahertz range, one can see a rapid development of various systems and instruments [P. Siegel, *IEEE Trans. MTT*, 80, 910, 2002]. Most notable of them are T-ray imaging [D. Mittelman, *Appl. Phys.*, 4, 1999], time-resolved T-spectroscopy [J. Rudd, *et al.*, JOSA-B, 19, 319, 2002], and environment sensors [R. Jacobsen, *et al*., *Optics Lett.* 21, 2011, 1996]. Cylindrical and rotationally symmetric lenses are also widely used here. Preliminary computer-aided analysis and synthesis of these devices is a well-known way to reduce the cost and the time of their design. However, today modeling of the dielectric lens antennas is based on quite rough analysis tools, which are either analytical Geometrical Optics (GO) and Physical Optics (PO) solutions or finite-difference time-domain (FDTD) numerical codes. Either of them fails to provide high accuracy, especially if the distances to the lenses and their dimensions are comparable to the wavelength. E.g., staircasing of scatterer boundaries and back-reflections from the virtual boundaries of computational windows are well-known sources of errors in the FDTD [G. Hower *et al.*, *IEEE Trans. AP*, 41, 982, 1993]. If the designers could work with more accurate and economic full-wave tools for the electromagnetic analysis and synthesis of lens antennas, they would develop high-performance and lower-cost mm-wave and terahertz circuits with a higher degree of integration.

Problem statement

Dielectric lenses are crucial components of major mm-wave and all terahertz range communications and instruments systems. Their design and manufacturing would be much faster and cheaper if one could avoid costly prototyping and measurements. Computer-aided analysis and synthesis is a well-known key to succeed in this direction. However so far it has been based entirely on optical approximations. Therefore the effects of finite size, realistic material, and feed parameters on the electromagnetic performance of lens antennas still need to be accurately incorporated into the design tools. This implies a development of accurate mathematical and numerical modeling methods, writing and testing of computer codes, and investigation of the physical features of electromagnetic wave propagation, scattering and absorption. Lenses are to be considered as uniform or layered transparent scatterers having specific shape (e.g., elliptic with specially designed eccentricity, truncated elliptic, 2D or 3D arbitrarily shaped, etc.), and the size comparable to the wavelength

Method

The methods of analysis and computer-aided simulation of dielectric lens antennas will be based on rigorous uniquely solvable integral-equation (IE) formulations. This implies reducing each original boundary-value problem to an equivalent IE whose class of solution is determined by the corresponding edge and radiation conditions. Especially attractive are the boundary IEs, as they enable one to reduce the complexity of the problem by seeking only the surface currents. Unlike frequently used GO, PO, and geometrical theory of diffraction (GTD) methods, such full-wave IE models have not been used in the simulations of quasioptical and microwave lens antennas. The full-wave IEs are always of singular type. Therefore they should be either first converted to the Fredholm second kind IE by using the *Method of Analytical Regularization* (MAR) and then discretized, or directly solved numerically with the *Method of Discrete Singularities* (MDS). Both methods have been greatly developed in Kharkov since the 1970's. Each of them has its specific merits and the both have guaranteed convergence and controlled accuracy – unlike FDTD, GO, PO, GTD and other approximations. On solving IEs, one obtains the surface or polarization currents, near and far optical-field patterns, and can easily compute overall lens antenna characteristics such as directivity, sidelobe level, and focusing efficiency.