PICS # 3721

Design and optimization of miniature integrated focusing devices for ultra wide band communication systems

Context and motivation: Today many research teams in Europe work on finding optimal designs for dielectric lenses widely used to improve the sensitivity of receivers in the millimetre, sub-millimetre and THz ranges, and raise the radiation efficiency and directivity of integrated to them printed elements with diodes, local oscillators, etc. Such lens-coupled antennas are already widely used in indoor/outdoor and satellite broadband communication systems (in Q-band and V-band), radar applications (e.g. commercial automotive radars at 77GHz), quasi-optical systems, imaging systems for surveillance and security applications, etc. However, the available electromagnetic simulators used for the antenna preliminary analysis are commonly based on the time-consuming FDTD codes and sometimes suffer from uncontrollable accuracy and unclear domain of validity. Therefore they cannot be used for efficient numerical optimization. Existing optimization tools are based on the geometrical and physical optics and loose accuracy for lenses comparable in size with the wavelength. This calls for development of more accurate and efficient approaches to the lens analysis and synthesis. These new design tools will allow designing innovative lens antennas, including ultra-compact lenses for embedded electronic systems, beam steering lens antennas and reconfigurable lens antennas.

Objectives and target applications: The main goals of the project lie in basic and applied research:

1. Development of novel CAD tools for the numerical analysis and synthesis of homogeneous dielectric lens antennas of complicated shape,
2. Fundamental study of electromagnetic properties of finite-size homogeneous dielectric lenses including quasi-optical effects such as focusing and wave-like effects such as internal resonances,
3. Design of optimized lens antennas. The main target millimeter wave applications are the following:
    i. High-performance 4^{th} generation automotive radars (76-82 GHz),
    ii. Broad communication systems (High-altitude platforms, indoor communications, on-board satellite lens antennas) and electronic scanning imaging systems.

   These applications require compact radiating structures with a very high aperture and radiation efficiency and innovative beam steering / multiple-beam functionalities. Lens antennas are very likely one of the best antenna technologies for such applications because they combine unique features of planar antennas (low-cost, integration of active circuits and receivers) and quasi-optical technologies.

Methods: To achieve the formulated objectives, we plan to implement and use an efficient in terms of computational time and resources algorithm based on the combination of the uniquely solvable Muller boundary integral equations and a genetic algorithm which is a well-know “global” numerical-optimization method.
In the beginning, we shall study a 2-D model of a convectional hemielliptic lens whose size is about several wavelengths in free space. Further efforts will be concentrated around the arbitrary shaped lenses made of various materials and illuminated by plane waves and aperture sources in the receiving and emitting modes, respectively. Both E- and H- polarizations will be considered. The accuracy of relevant lens CAD design tools available at the European level will be assessed in the framework of the Network of Excellence ACE-2 (“Antenna Center of Excellence”). Then, the joint optimization of the primary feed(s) and lens will be considered for the first time. Our preliminary results obtained with high-frequency techniques have demonstrated that such a strategy is really promising and must be studied in-depth. Finally, some lens antennas will be designed and optimized from the specifications of the above-mentioned target applications.

Expected results: First, we expect to clarify the effect of the lens shape and finite size on its focusing properties as well as study the resonance phenomena due to multiple internal reflections. Then we will introduce new designs of reduced-size arbitrary shaped lens antennas with improved radiation and focusing characteristics for diverses emerging applications involving multiple-beam antennas, beam switching antennas, beam forming antennas and reconfigurable lens antennas.

Preliminary research: Scientific collaboration between IRE and IETR started almost 9 years ago. Recent results obtained in the course of joint research (Programme PECO NEI Grant #17111 for 2004-2005 and Programme DNIPRO Grant #82 for 2005-2006) cover the development of accurate mathematical and numerical tools, based on the boundary integral equations, for advanced analysis of two-dimensional models of dielectric lenses. They have been presented at a number of international conferences in France, The Netherlands, Russia and Ukraine. High estimation of these results from the European electromagnetics community is proven by the 1st Prize in the Young Scientist competition at the MSMW-04 symposium in 2004 (sponsored by the European Microwave Association) and the 2nd place in the nomination to the Young Engineer Prize at the EuMC-2005.