Multilevel Fast Evaluation of Radiation Patterns for Lens and Reflector Antennas

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Lens antennas are gaining popularity in the millimetric and submillimetric ranges, for applications as diverse as mobile broadband communication and radioastronomy. For these applications, lenses are especially useful for multibeam or shaped beam antennas, and they are used either in combination with horns, or in open structure configurations, where planar antennas are printed at the back of substrate-lenses. On the other hand, reflector antennas are well established in a variety of applications. Here, we refer specifically to lens antennas while the proposed approach is directly applicable to all aperture radiation cases, including reflector antennas and radomes. Conventionally, the radiation pattern of a lens antenna is evaluated by employing the physical optics integral while assuming that the tangential electric and magnetic fields on the outer surface of the lens have been already computed. The latter computation is often effected by the Method of Moments (MoM) analysis of the feed followed by a ray tracing procedure and will not be discussed any further. Due to the large electrical dimensions of lens antennas, the computation time is often dominated by the surface integration time.

In this paper, we address the issue of numerically efficient evaluation of the pertinent integrals. The number of field sampling points N on the lens surface is proportional to its illuminated area (normalized to the wavelength squared). In order to sufficiently resolve the two-dimensional structure of the radiation pattern, the latter should be evaluated over a hemisphere at a number of points, also, proportional to the aperture area. Of course, the proportionality factors depend on the acceptable error level and the specific quadrature rule used, as well as, the desired level of oversampling of the radiation pattern. Thus, the computational cost of the straight-forward integration for $O(N)$ far-field directions each using $O(N)$ field samples amounts to $O(N^2)$ operations. On the other hand, the conventional Fast Fourier Transform (FFT) far field evaluation for planar apertures achieves an $O(N\log N)$ computational complexity. Recently, we proposed a novel domain decomposition approach aimed at achieving a high computational efficiency while removing the restrictions on the surface geometry (A. Boag and C. Letrou, *IEEE Trans. Antennas Propagat.*, vol. 51, no. 5, May 2003). This approach is based on the observation that the fields on the lens surface serving as the equivalent sources of radiation are sufficiently smooth, and we can safely assume that no "super-gain" distributions are present. Under these conditions, the radiation pattern can be "fully described" by its samples at a number of points proportional to the area of the surface domain comprising the equivalent sources. By "fully described" we mean that the pattern at an arbitrary point can be evaluated (with a prescribed error) by interpolation from the samples. Extending the proposed approach, we propose a multilevel computational algorithm based on a hierarchical domain decomposition of the aperture into subdomains. In this algorithm, the radiation patterns are first computed directly for the subdomains on the finest level of decomposition. The radiation patterns of the subdomains are evaluated over a very sparse grid of directions, thus providing the computational savings. Subsequently, the radiation patterns are progressively aggregated into the final pattern of the antenna as a whole. The aggregation steps involve phase correction, interpolation and addition. The multilevel algorithm attains the $O(N\log N)$ asymptotic complexity.