UTD Fields Radiated by Electrically Large Hexagonal Arrays with Realistic Current Distributions

***A.A. Serra*[1], *P. Nepa*[1], *G. Manara*[1] , *T. Celandroni*[1] , *O.A. Civi*[2]**

[1]Dept. of Information Engineering, University of Pisa
Via G. Caruso 16, I-56126 Pisa, Italy
ph: +39-050-2217511, fax: +39-050-2217522
andrea.serra @iet.unipi.it, p.nepa@iet.unipi.it, g.manara@iet.unipi.it, tommaso.celandroni@iet.unipi.it

[2]Dept. of Electrical and Electronics Eng., Middle East Technical University
Ankara 06531, Turkey
ph. +90-3122104564, fax: +90-312-2101261
ozlem@metu.edu.tr,

Abstract

Uniform Geometrical Theory of Diffraction (UTD)-based efficient descriptions of the field radiated by electrically large linear and rectangular planar phased arrays have been developed under the hypothesis of uniform current distributions. More recently they have been extended to relatively arbitrary current taperings by resorting to a Discrete Fourier Transform (DFT) representation of the array current excitation. In this paper, the DFT-UTD based technique is extended to deal with the efficient evaluation of the near- and far-field radiated by hexagonal arrays made of free-standing dipoles in a triangular lattice. To face with arrays on hexagonal lattices, the Hexagonal DFT (HDFT) is exploited.

1. Introduction

Electrically large arrays with more than thousand of elements are often and often being applied in advanced radars, in remote sensing systems, as well as in modern satellite communication systems. Due to the huge number of radiating elements, ray techniques for either the analysis or the synthesis of arrays radiating in the presence of close by obstacles become rapidly inefficient when an element-by-element summation is used to combine the scattered field contributions generated at reflecting surfaces or diffracting edges nearby the antenna. To speed up both iterative synthesis and analysis techniques for electrically large arrays, high frequency expressions for the field collectively radiated from the whole array have been investigated. Carin and Felsen [1] represented the field radiated by a linear array (1D problem) as the summation of truncated Floquet-based wave contributions plus diffracted-like contributions excited at the array ends. Since in practical large arrays the interelement distance is smaller than the free-space wavelength, the Floquet wave expansion is fast convergent and only very few terms are needed when the observation point is located in the far field region of each array element and a few wavelengths from the array boundaries. The above UTD-based approach is based on the utilization of the Poisson's summation to transform the element-by-element summation to a Floquet series expansion. Then, for each integral term of the Floquet summation a high frequency expression can be derived by extending standard asymptotic techniques to the case of inhomogeneous plane wave illumination (Kouyoumjian et al., [2]). Starting from the work in [1], high frequency expressions for the field radiated by rectangular planar arrays of free-standing dipoles have been derived, when a uniform current excitation is considered (except for a linear phase shift) [3]. Specifically, these ray fields are associated with, first, the local periodic structure Floquet modes whose fields are truncated in space because of the finite number of array elements. Second, there are additional rays which arise from the diffraction of those propagating and evanescent Floquet modes at the truncation of the finite array (edges and corners). The resulting ray field representation for the near field radiated by electrically large phased arrays is very accurate, and usually only the propagating Floquet modes must be considered (often only the dominant mode must be considered since grating lobes are avoided in practical antennas). Non-rectangular arrays of free-standing dipoles with a skewed grid have also been considered. In [4-5], the arbitrary polygonal array has been decomposed in linear arrays, whose contribution can be evaluated asymptotically as in the previous works for 1D arrays [1]. A more efficient approach has been presented in [6], where the decomposition in linear arrays has been avoided and a ray field representation has been derived which has the same structure as that originally derived for planar rectangular arrays.

The ray description of the field radiated from large arrays can be introduced in UTD based numerical codes (as for instance, the Basic Scattering Code) for an efficient evaluation of the effects of obstacles, which can be located in the near field region of electrically large array antennas. However, most of the existing ray solutions for large arrays [3-6] are strictly valid for uniform array current distributions, except for a linear phase shift that can account for the main beam steering. Conversely, arrays for advanced systems (multibeam and shaped beam arrays, low side-lobe-level antennas) are always characterized by tapered current distributions. Due to the mutual coupling effects, even standard corporate-feed arrays with a uniform voltage excitation do exhibit a non uniform current excitation with a relatively large ripple in the close-to-edge regions. It is then apparent that the application of the above high frequency expressions to realistic arrays do require their extension to arbitrary current distributions. In this context, an elegant approach is based on the introduction of a slope-like contribution to account for weakly tapered distributions [7]. Another attempt to extend the UTD to deal with highly non-uniform excitations is based on expanding the current distribution over the finite array in an exact fashion through a finite set of its spectral components, namely the traveling waves (TWs), by resorting to the Discrete Fourier Transform (DFT) [4, 8-9]. The DFT synthesized array current distribution (the latter being a finite discrete sequence) allows us to represent the field radiated by non-uniform array distributions as the sum of the fields radiated by uniform distributions, so that the procedure in [3-6] can be easily applied for each of them. It is worth noting that the number of the spectral components equals the number of array elements. Nevertheless, the compactness of the DFT spectrum for real antenna current distributions renders the DFT-UTD expressions very efficient. Indeed, it has been shown in [8-9] that less than 25 % of the total DFT spectral components can be sufficient to recover the main beam and the first side lobes for most practical phased arrays. Specific attention has been devoted to the accuracy of the DFT-UTD solution in evaluating the field radiated by a phased array in its near field region. Moreover, the DFT approach is valid for arbitrary current distributions thus allowing the application of the DFT-UTD based approach to provide efficient iterative procedures for synthesizing desired large array antenna distributions in the presence of any obstacle, as for instance radomes or reflectors, lying in their antenna near field region.

The DFT-UTD approach is based on a TW expansion of the array current sequence, where the finite set of vector wavenumbers are constrained along specific spectral directions dictated by the number of array elements. More recently, an approximate traveling wave expansion for the UTD analysis of large arrays has been proposed in [10] to represent the array current distribution as a summation of a few uniform linearly phased current distributions. It is worth noting that the number of TWs required by the approximate TW expansion in [10] is usually less than that required by a truncated DFT expansion, to obtain the same accuracy. On the other hand, the determination of the vector wavenumbers and complex amplitude of each TW component requires the implementation of parameter estimation algorithms that are more complex than a standard DFT (or Fast Fourier Transform, FFT). Finally, it is worth noting that the increasing of the number of the TW terms in a DFT expansion will guarantee the convergence to the actual array current sequence, so resulting in a robust approximate technique.

In [11], the DFT-UTD representation of the far-field radiated by large arrays has been combined with a standard synthesis algorithm for generating a contoured beam in satellite antenna planar arrays. The approach employs the DFT representation for the actual array amplitude distribution; each DFT global basis set for the array distribution radiates a local radiation basis function (spot beam) which can be expressed in closed form and interpreted in terms of the UTD ray concept. The advantages of the approach are that only a few spot beams are sufficient to synthesize a contoured pattern. In the context of array synthesis procedures the decomposition of the far-field in a finite summation of spot beams is not new, and some advanced decompositions based on more effective basis functions has been proved to enable a faster converge of synthesis algorithms. However, the DFT representation has the major advantage of allowing for a combination with a ray representation of the field radiated by an array uniformly excited [3-5]. Moreover, each term, namely a spot beam, has a clear physical interpretation which can be determinant in the estimation of the effects of obstacles located in the array near-field region.

2. HDFT-UTD Analysis of Large Hexagonal Arrays

It is well known that by arranging the elements of a phased planar antenna array in a triangular grid (namely, a hexagonal array lattice) rather than a rectangular grid, the number of elements needed in the array is reduced (a hardware saving of at least 13.4% can be achieved). Moreover, the hexagonal arrangement effectively suppresses grating lobes.

A UTD representation of the field radiated by hexagonal arrays with a triangular lattice has been derived in [6] for the most general case of a polygonal planar array. The field expressions, which are strictly valid for uniform current excitations, are similar to those derived for a planar rectangular array [3] except for a more complex term related to the Floquet-wave induced vertex diffraction. The extension of the expressions in [6] to actual arrays with realistic non-uniform current taperings can be obtained by representing the arbitrary current excitation (which is a finite sequence of complex values) as a finite summation of uniform current distributions with a linear phase shift. This can be done by using the HDFT which has been extensively studied in the past for its interesting properties in two dimensional signal processing [12-16].

In this paper, the current excitation on a large hexagonal array is calculated through a full-wave moment method code, for some common voltage taperings. Then, by combining the UTD expressions derived in [6] with a HDFT representation of the above current sequence, an accurate evaluation of both the near-field and far-field is obtained by resorting to a few HDFT components, due to the high-directivity feature of electrically large arrays. Numerical results will be shown with reference to current taperings which guarantee specific pattern performance. The interesting features of the HDFT when applied to array antenna problems will be discussed.

The availability of efficient and accurate HDFT-UTD ray descriptions of the near field of an electrically large hexagonal phased array constitutes an appealing tool for the analysis and synthesis of arrays mounted on complex platforms. For example, it can be applied in an iterative pattern synthesis procedure that account for the field scattered from obstacles located in the near field region of the same array. Moreover, it can be used in conjunction with a ray tracing analysis of the transmission properties of curved dielectric radomes enclosing large phased arrays. In all these applications, it is expected that the HDFT-UTD based expressions for the near field are more efficient than the conventional element-by-element summation. Specifically, the HDFT-UTD can account for completely arbitrary current distributions without any restriction to array current sequences, including also the cases in which the latter cannot be approximated by continuous functions with a weak spatial variation. Moreover, a HDFT-UTD based numerical code can be applied to evaluate the near field with any degree of accuracy, as it is sufficient to run the same code just increasing the number of DFT terms, finally obtaining the exact results if all of the HDFT terms (namely a number of elements equal to the number of array elements) is included. However, this will never become necessary, since the compactness of the HDFT spectrum of an array current distribution is intrinsically related to the fact that an electrically large array is always designed to provide a narrow pencil beam.

Finally, the HDFT-UTD approach can be combined with either a MoM code or a generalized forward-backward method to derive a full-wave numerical tool for the efficient analysis of electrically large hexagonal arrays, as already done in [17-18] for rectangular planar arrays.

3. Conclusions

An efficient HDFT-UTD representation of the field radiated by a hexagonal array of free-standing dipoles in a triangular lattice has been addressed, Sample of numerical results will be presented at the conference to show the accuracy and the efficiency of the HDFT-UTD method for calculating the near-field radiated by hexagonal arrays with realistic current distributions obtained from a method of moment full-wave analysis. Work is in progress to extend this technique to hexagonal planar arrays of printed antennas.

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5. References

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