1. Introduction

Recent years have witnessed a phenomenal growth in our ability to numerically model, simulate the performance of, and design complex electromagnetic systems. Nonetheless, as designers, we continue to be challenged by the need to solve even larger and more complex problems than we have been able to handle in the past, e.g., antennas mounted on satellites, aircrafts or ships, as well as communication antennas used in various applications. There are many competing Computational Electromagnetics (CEM) approaches at our disposal for solving very large problems, principal among which are the asymptotic techniques such as the GTD, which often offer the only viable approach to dealing with objects whose dimensions are very large compared to the wavelength. However, it is well known that while the asymptotic methods can handle smooth perfectly conducting objects with relative ease—regardless of how large they may be—the methods do suffer from several inherent limitations, especially when dealing with arbitrarily shaped, inhomogeneous, and multiscale objects. Some of these limitations are attributable to the fact that the diffraction coefficients are available only for a limited number of canonical geometrical shapes, such as PEC wedges and smooth surfaces with large radii of curvature; resonant structures, such as cavities, or Frequency Selective Surfaces (FSSs) that are not amenable to convenient analysis via asymptotic methods, regardless of their size; multiscale and material inhomogeneities are always problematic because they do not lend themselves to asymptotic analysis owing to the fact that the wave phenomena in these structures do not satisfy the ansatz upon which the asymptotic methods are based. Many attempts have been made in the past to embellish the GTD, either by using techniques such as the Physical Theory of Diffraction PTD [1] or by hybridizing it with rigorous numerical methods [2], and varying degrees of success have been reported. However, either these approaches do not fully overcome the fundamental limitations of the GTD—alluded to above—or they are not sufficiently robust. This backdrop, coupled with the phenomenal growth in the computing power that we have witnessed in recent years, have prompted us to develop algorithms[3-6] that can complement the GTD and enable us to expand the scope of our problem-solving capabilities by venturing into territories, that have been off-limits to asymptotic methods, with relative ease. Prominent among them is the Fast Multipole Method (FMM), which is now one of the most widely used MoM-based technique for solving large problems with Degrees o Freedom (DoFs) reaching millions of unknowns. There are several excellent commercial CEM tools available in the market today that are based on these methods, and are being routinely used for modeling and simulation of a wide variety of electromagnetic structures. However, a close examination of the FMM and similar algorithms reveals, however, that they too have some drawbacks that limit their applicability to CEM problems. One of these limitations arise from the fact that the FMM is kernel-dependent and, hence, is primarily useful for handling either PEC objects, or can be modified to apply to homogeneous dielectric bodies. Furthermore, the FMM relies exclusively on iterative algorithms to solve problems with a large number of DoFs, and convergence of such algorithms can be problematic when the associated MoM matrix for the problem is ill-conditioned, even with the use of a preconditioner.

Recently, a novel approach, called the Characteristic Basis Function Method (CBFM)—for a bibliography on CBFM and related methods see [7-49]—has been introduced in the literature, which takes a cue from the asymptotic methods and by borrowing the concept of localization—that forms the cornerstone of these methods—and yet fully preserves the rigors of numerical techniques. Some of the important features of this algorithm are: (i) it is general-purpose and not kernel-dependent; (ii) it leads to a relative small-size matrix that can be solved directly by using L-U decomposition without using iteration and/or a preconditioner; (iii) it handles multiple right hand sides efficiently without resorting to a restart of the problem from scratch, as do the iterative techniques; (iv) it works equally well for both microwave circuits as well as open region radiation and scattering problems; (v) it is not limited just to MoM, but has also been extended to Finite Element Method (FEM) and the Finite Difference Time Domain (FDTD), with appropriate modifications; (vi) the algorithm is eminently suited for parallelization. We observe at this point that there is a rapidly growing trend in Computational Electromagnetics (CEM) that is significantly impacting the computing landscape, namely the use of highly parallel computers to address large and complex problems. Thus the ease of parallelization, mentioned above, is an important salutary feature of CBFM, not readily available in other MoM- or FEM-based algorithms.
The paper details how a large problem is reduced to a manageable size by using the principle of localization, which also forms the foundation of Domain Decomposition (DD) methods. However, unlike the commonly-used strategy of employing Jacobi or other iteration algorithms to handle the problem of interaction between the various subdomains, CBFM derives a reduced matrix, which preserves all of the coupling effects rigorously when it is formed, and subsequently solves this matrix directly without resorting to iteration. Following the domain decomposition of the geometry, carried out in the usual manner, the CBFM generates high-level or macro basis functions in these subdomains—that capture all the local information—by illuminating the subdomains with a spectrum of incident fields. Next, a Singular Value Decomposition (SVD) is applied to the set of CBFs, so generated, to reduce the redundancy by setting a threshold in the SVD algorithm. Finally, the Galerkin procedure is used to generate the “reduced matrix” whose size is orders of magnitude smaller than the original MoM matrix, which, incidentally is never generated in full at any stage of the iteration. The solution of this reduced matrix, which can be used for all the incident waves without any modification, except, of course, its RHS, provides a very efficient way to solve the problem for a multitude of incident waves, even though they may not have been used to generate the CBFs in an earlier step mentioned above. For microwave circuits, we employ an alternative to generating the set of CBFs by using plane waves incident from multiple angles, and use port excitations instead. We also resort to the use of the concept of primary and secondary type of CBFs, as opposed to “all primary” types that we typically use for scattering problems.

The paper will begin by detailing the CBFM, and providing some examples that illustrate its capabilities and demonstrate the size reduction it achieves for a number of representative problems. Next, the parallelization aspect of this algorithm will be discussed, and the time advantage gained via this technique will be documented. Finally, we will review how the original CBFM has been evolving and the embellishments that have recently been incorporated in the original version introduced several years back. These include:

a. The use of PO for the CBFs, which bypasses the initial step of matrix solution in the individual subdomains to generate the CBFs.
b. Mitigation of the truncation effects that manifest themselves into spurious singularities in the CBFs, in the vicinity of the artificial edges that are introduced in the process of domain decomposition.
c. Speeding up the operation of matrix-vector product, required during the formation of the “reduced matrix,” by using Adaptive Cross Approximation (ACA) or interpolation techniques.
d. Multi-level CBFM algorithms.
e. LM/CBMoM—code based on locally-modified CBFM for efficient solution of problems in which only a local region is modified.
f. Extension of CBFM to handle objects with apertures.
g. Frequency sweeping in CBFM.
h. Extension to FEM and FDTD.

The reader is referred to the bibliography on CBFM for further information.

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3. REFERENCES


