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THE FUTURE OF NEC-LIKE MODELS

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Introduction

The method of moments (MoM) was the basis of the earliest large scale, general purpose EM modeling codes, and the Numerical Electromagnetics Code (NEC) [1] traces its ancestry to one of the first of these large codes, AMP. A number of EM codes is now in use, some much larger than NEC, based on MoM, GTD, the finite-difference solution of Maxwell's curl equations or a combination of techniques. Substantial progress has been made in modeling techniques, and further large gains have been derived from the growth in available computing power. Still, one does not need to get too involved in computational electromagnetics to find that the available modeling tools often fall short of the user's needs. Some of the gaps in the modeling capabilities available to the typical code user might be met now by making more of the developments of recent years available in documented and supported codes. For other problems, advances in techniques are needed, such as pushing MoM to larger problems, possibly involving thousands of unknowns, and developing hybrid models so that optimum methods can be used on each part of a complex structure.

NEC has been under continuing development, and a new release of the code is planed that will correct some problems in the present version in areas of wire modeling and code structure. Still, it remains basically a wire modeling code with some capabilities for surfaces. The present features of NEC and improvements planed for the next release are summarized below, followed by a discussion of some possibilities for extending the capabilities of NEC or similar codes.

The Present and Immediate Future of NEC

Two versions of NEC are currently in use. The latest, NEC–3, is restricted for release beyond the U. S. Department of Defense and contractors, however it has now been released in a number of other countries. NEC–2 offers all of the features of NEC–3 except that of modeling wires buried in the ground, and has no distribution restrictions. Principal features of NEC–3 are summarized below:

- MoM model for wires with spline current expansion as $A + B\sin(ks) + C\cos(ks)$ where $k = \omega\sqrt{\mu\epsilon}$, and point matching of the electric field. Surfaces (closed and perfectly conducting) are modeled by solution of the magnetic field integral equation with delta function current expansion and weighting. Wires may connect to surface patches.
- Lumped or distributed R-L-C loads on wires, or loading computed from finite conductivity of a round wire.
- Implicit models for ideal transmission lines and nonradiating two-port networks through matrix operations that do not modify the main MoM matrix.
- Accurate model for wires above or buried in earth based on the Sommerfeld-integral solution, with table lookup and model-based least squares approximation to reduce evaluation

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time [2]. Fast approximation for wires above earth, using Fresnel plane-wave reflection coefficients. Image treatment for perfectly conducting ground.

- Structure symmetry (discrete rotational or reflection) reduces the time to fill and factor the MoM matrix and the matrix size. A special version NEC-GS is optimized for wire bodies of revolution with uniform excitation, specifically for monopoles on radial-wire ground screens.
- Partitioned-matrix algorithm for adding to a previous solution (Numerical Green's Function.) The NGF can also be used to take advantage of partial structure symmetry.
- Input via batch-mode command file. Structures are defined from straight wires, arcs and surfaces. Shift, rotation and reflection commands aid in the generation of complex structures. An auxiliary PC program IGUANA [3] supports interactive-graphics input of model description.
- Computation of near E or H fields, ground wave, radiated field, power or directive gain and average gain.
- Maximum coupling (minimum isolation) between antennas is computed for simultaneously matched loads.

The next release of NEC, NEC–4 due in about a year, will retain the same basic modeling capabilities of the present code, but will incorporate several improvements to the wire algorithms and code structure. New features of the code will include:

- Revisions to the wire modeling algorithm to avoid loss of precision with electrically small structures [4].
- A new field evaluation and treatment of charge in the basis functions to accurately model steps in wire radius and junctions of tightly coupled wires.
- Up to 50 percent faster filling the MoM matrix for wires.
- Generalized excitation allowing multiple incident waves and voltage sources.
- Command to compute monostatic cross section over a range of angles.
- Calculation of maximum coupling for structures involving nonradiating networks or transmission lines (previously done incorrectly.)
- Revised code structure, using Fortran 77 constructs, with greater modularity and internal documentation; easy adjustment of array dimensions and full documentation.

In addition, versions of NEC have been developed for modeling insulated wires in air or earth [5], and to use constant basis and weighting functions on small loops [6]. We probably will not be able to include these features in NEC–4, but hope to in a subsequent release.

Areas for Future Development

NEC now offers a reasonably complete capability for modeling wire structures, and NEC–4 will correct some remaining problems. However, NEC is weak in modeling surfaces and offers nothing for penetrable volumes. A large amount of work has been done in modeling surfaces and volumes with MoM, some of which is reviewed in [7]. Most such MoM techniques can be coupled together for a hybrid capability, although the ease of such coupling depends somewhat on the compatibility of the basis and weighting functions. The usefulness of NEC would be particularly enhanced by addition of a surface modeling capability based on solution of the electric field integral equation, and including an accurate treatment of ground.

Reduction of computation time is a continuing goal in MoM, since it permits modeling larger objects, finer sampling for a more accurate solution, and facilitates repetitive solutions as are needed in optimization and synthesis. One means of reducing time is to exploit symmetries in the structure and excitation. While NEC uses rotational and reflection symmetry, more could be gained in this area, particularly in filling the matrix, where repetition patterns do not need to hold through the entire matrix. Simply filling by diagonals rather than by rows should yield many successive identical matrix elements which need not be recomputed for structures composed of straight wires or uniform surfaces. Specialized codes such as NEC-GS can be designed to model a particular class of structures in minimum time.

Matrix solution algorithms offer a number of possibilities for reducing computation time. For large models, iterative solution methods can reduce the N^3 dependence of inverting or factoring a matrix, which becomes a prohibitive barrier for very large models. Near-neighbor approximations, neglecting interactions over large distances, must be considered for very large models, both to reduce time to fill the matrix and to obtain a sparse matrix. The effect of such approximations on solution accuracy is sometimes difficult to determine, however.

With small to moderate sized models, solution by LU factoring may remain advantageous since the N^3 operation is independent of excitation, and partitioned-matrix techniques can be used to add to a solution matrix. To go a step beyond the NGF procedure in NEC, a new LU factored matrix could be derived from the original factors and an added structure. This process, which can be called a concatenated NGF, could then be repeated (until error accumulation became a problem.) The same method can be used to delete parts of a structure, with the matrix order then reduced. The LU-factored impedance matrix can also be solved together with a separate matrix representing networks or transmission line connections (now done in NEC) or for impedance loads on a limited number of segments (a special case of networks.) The ability to update or augment the solution matrix is particularly valuable when a MoM model is used in antenna synthesis or optimization.

Model Based Parameter Estimation (MBPE) [8] offers a means to build known physics of a problem into an otherwise brut-force numerical solution. An example in NEC is the use of a model based on the asymptotic ray solution for evaluating the field transmitted from ground to air. Parameters in this model are adjusted to fit numerically computed Sommerfeld-integral values. The model then provides an effective interpolator for field values at ranges where the direct asymptotic solution would not be sufficiently accurate. It is shown in [8] that a rational function, representing a pole series, is much more effective than polynomials for interpolating quantities such as current and impedance versus frequency. This application of MBPE can greatly reduce the number of frequency evaluations to obtain wide-band data. Among other possibilities for applying MBPE are evaluation of the interaction fields, choice of basis and weighting functions and evaluation of radiation patterns.

An obvious way of expanding the versatility of a model is to combine several techniques. MoM lends it self to this approach, since any solution for fields of a point source in some environment can be incorporated into the Green's function for the kernel of the integral equation. GTD complements MoM in being suited to modeling electrically large structures, and is easily incorporated into the integral equation kernel.

Finite difference algorithms (FD) have advantages over MoM for modeling arbitrary media within the solution region, and offer solution time proportional to the number of cells in a time domain solution. Also, when formulated for the total field, FD can provide much greater dynamic range than MoM for interior coupling problems. MoM, on the other hand, appears preferable to FD for modeling thin wires or slots, and for modeling exterior-regions of resonant sized structures. The code GEMACS [9] currently takes advantage of some of these factors by combining a MoM model similar to NEC with GTD and a frequency domain FD model for interior regions.

Conclusions

NEC has become a widely used modeling code largely due to its continuing support and development. A new version is being prepared with improved accuracy and code structure. The most immediate need for NEC seems to be a surface model based on solution of the electric field integral equation. Much more must be done to extend the versatility of NEC or similar codes. A greater variety of antenna types and environments must be modeled, and applications to synthesis and optimization should be supported. Developments of interactive graphics systems for input and output are also important to increase the utility of codes. While much progress is being made in modeling technology, limited documentation and support seem to be delaying the transfer of modeling capabilities to the community.

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