BOOK REVIEW

Book: EMI/EMC Computational Modeling Handbook, 2nd edition, 311 pages

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Publisher: Kluwer Academic Publishers, 2001

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There are many books on computational electromagnetics, but this book specializes in the usage of computational electromagnetics for EMC problems. Most EMC/EMI engineers come from the testing world (where EMC was started with the nascence of testing requirements and standards) and some come from the abstract world of electromagnetic theory. Both groups have learned to apply what they know to the often misunderstood concepts of EMC and EMI. But complexities of EMI problems have rendered the analytical approaches to the solution of interference and compliance problems very difficult to implement.

Now, the art of computational electromagnetics comes to the rescue! For years, such computational techniques have been used for different types of EMI problems with different degrees of success (unless you understand the EMI problem, you can't model it properly). This book serves as a bridge for those in the EMC world who want to learn about modeling EMI problems via computational electromagnetics (CEM). It may also be useful to experienced CEM modelers who want to know about the EMI world. The book is introductory in the level of difficulty and is light in mathematics. The purpose of the book is the teaching of the art of modeling for EMI rather than the details of CEM techniques.

The book is divided into eleven chapters. Chapters 4, 5 and 6 deal with the most commonly used CEM techniques such as FDTD, Method of Moments, and FEM respectively. The rest of the chapters (Chapters 7 through 11) deal with the application aspects of EMC. The first two chapters are introductory in nature. For the experienced CEM modeler who wants to know about the applicability of CEM to EMI, I suggest starting with Chapter 1, then proceed with Chapters 7 through 11. For the EMC engineer who is starting to learn about CEM, a cursory reading of the book from Chapters 1 through 11 is recommended.

Chapter 1 introduces the reader to the basic principles of EMI and to the state of the art in EMI modeling. The "tool box" approach, as described in the chapter, allows the EMC engineer to look at an EMI problem and choose the appropriate CEM tool (FDTD, MoM, or FEM) to analyze the situation. The choice of the appropriate CEM tool requires some intuition and experience. A successful modeler is one who has intuition of the nature of the interference/compliance problem and is one who has some experience with what each CEM can deliver for each particular situation. The chapter ends with a brief description of FDTD, MoM, and FEM. Chapter 2 introduces the reader to the basic concepts of electromagnetic theory and eases the reader into CEM techniques resulting from manipulation of the mathematics embedded in Maxwell equations.

The introduction to CEM techniques starts with Chapter 3 where the FDTD method is discussed in detail. The chapter is devoted to the details of FDTD. Two and three dimensional FDTD is discussed, with emphasis, of course, in the 3D approach as outlined by the Yee cell. The chapter covers modeling of radiation sources and inherited dispersion issues that are part of every FDTD modeling approach. The chapter ends with mesh truncation techniques and sources of FDTD modeling errors. Chapter 4 covers the method of moments which is used less in EMI analysis than is FDTD. This is because it is more complex mathematically and is used for surface currents, and is more complex for inhomogeneous media. Therefore, from the EMI point of view only those problems in EMI where there is a need to calculate current distributions (e.g antenna emission problems) does this method of solution provide an advantage. The material discussed in Chapter 4 is MoM for perfectly conducting surfaces. Chapter 5 addresses the finite element method. The chapters covers the basic principles of

FEM, such as creating the finite element matrix, matrix assembly, matrix solution and the solution of two-dimensional Helmholtz equation

Chapter 6 prepares the reader for the world of EMI modeling, where the first consideration is how modeling tools can be used. Depending upon the frequency range and the physical size of the device to be modeled, quasi-static or full wave tools may be more appropriate. If the geometry of the problems permits, two dimensional models may be used to avoid model complexity and the higher computer resources necessary for full three-dimensional models. If detailed frequency responses are desired, the use of time domain tools is advantageous, because a wide bandwidth is modeled with a single run instead of the multiple runs that are required with frequency domain methods. Therefore, it is up to the reader to weigh the pros and cons of the main CEM techniques for a given EMI problem, based on the data available for the problem and on what is needed as a solution.

Chapter 7 presents the steps required to create practical EMC models for different computational techniques. In addition, examples of practical problems are presented to illustrate the use of modeling and to show some of the most critical areas. Good geometries are important to the construction of models, especially if such geometries are well defined. However, it is always important to realize that EMI models are often unusual in their requirements and applications, and often require further attention to assure that the problems being solved are of interest, and not those for a perfect model.

Every modeling task has its own priorities and criteria and the creation of EMI models can often be a difficult process. However, a guide to the steps needed to prepare for modeling, using the three main CEM techniques, is provided here. Chapter 8 covers a wide range of modeling topics of interest to EMC engineers. Multiple stage models can be used when several sections are separable electromagnetically, and the modeling techniques can be varied to allow each individual stage to be optimized. Test sites can be evaluated before construction to show effects of changes to typical recommendations. Antennas and other measuring probes can be modeled as part of the evaluation process or as a method to allow their effects to be included into the overall results. Chapter 9 discusses EMI modeling validation and the usage of different techniques, depending on which is most appropriate. Validation is important in order to ensure the correctness of models and to help one understand the basic physics behind the model. Measurements can validate modeling results, but extreme care must be used to ensure the model correctly simulates the measurements.

Chapter 10 covers standard EMI/EMC modeling problems. A set of well defined and designed modeling problems can be used as test beds for new software and can serve as an important tool in the process of selecting an appropriate modeling technique. Taking time to consider the actual uses for such software and creating suitable problems is the key to getting the most value from such problems. The objective is to have problems that are not only representative of the challenges of an EMC engineer, but also problems are not so complex that the answers can not be verified. Several examples, shown in the chapter, can be used as standard EMI modeling problems. These benchmark problems can be used to evaluate present and future modeling tools that may show up in the market. The last chapter in the book, Chapter 11, addresses advanced modeling techniques. The chapter describes the PEEC and TLM modeling techniques. These techniques are relatively new to EMC modeling activities, but can be extremely useful for certain modeling applications. The PEEC technique is an equivalent circuit technique better suited than SPICE. PEEC is a full wave simulation tool because includes propagation delay. It is suited for EMC problems that include lumped circuit elements, such as power/ground plane decoupling, including capacitors, via inductance, and other printed circuit board related EMI problems. PEEC is also very suitable for interfacing directly with traditional quasi-static TEM based signal integrity tools, to provide the full-wave solution for traces running over splits in ground-reference planes, or traces with connectors between boards. The TLM converts the electromagnetic problem into a series of transmission lines. It is similar, in some aspects to FDTD; however, TLM has the ability to model voltage and currents in each node, located at the same point in space, which is an advantage when changing cell size or modeling very thin objects.

Expert MININEC Classic

James C. Logan

Introduction

***Expert* MININEC** is an advanced engineering tool for the design and analysis of wire antennas. Antennas are represented by an arbitrary collection of electrically thin, straight wires in free space or over an infinite, perfectly conducting, flat ground plane. A method of moments approach is used to solve for the current distribution on the wires, from which useful parameters (e.g., impedance/admittance, charge distribution, and near and far fields) are computed. Special options for analysis of commercial broadcast antennas have been added. ***Expert* MININEC** is fully integrated with the Microsoft Windows environment (i.e., including Windows 98 and Windows NT) and includes the usual on-line help features typical of most Windows applications. Anyone already familiar with other Windows applications and the application of the method of moments to antenna modeling should have little difficulty in exploring the attributes of ***Expert* MININEC.**

Because of the similarity in names, it has often been stated that MININEC is but a personal computer (PC) version of its big brother, NEC [Burke and Poggio, 1981]. Some of this confusion is described in Murray and Austin [Murry and Austin, 1994]. However, this could not be farther from the truth. There are significant differences between these two codes. Both codes use the method of moments to solve for currents on electrically thin wires. However, each code starts with a different version of the integral formulation for the currents and fields for wires. Then, each follows significantly different algorithms for implementation of the method of moments.

The authors are herein announcing the release of ***Expert* MININEC Classic**. The Applied Computational Electromagnetics Society (ACES) will distribute ***Expert* MININEC Classic**.

Historical Development

The original version of **MININEC** was written in BASIC for use on a limited desktop computer with 16K memory with 8-bit word length (e.g. an Apple II). John W. Rockway wrote the first version in his spare time while on vacation. Subsequent work by Alred J. Julian and James C. Logan eliminated bugs and proved the utility and accuracy. It was first published in 1982 as Naval Ocean Systems Center Technical Document 516 [Julian, Logan and Rockway, 1982].

A significantly improved version, **MININEC (2)** was published in 1982 as one of 25 computer programs (in BASIC) in an Artech book [Li, Logan and Rockway, 1984]. Again the improvements to the code were done in spare time on home computers.

Working on an Army funded project, the authors added a few capabilities and made other improvements, such as changing the input format. The improved **MININEC(3)** was published in 1986 as Naval Ocean Systems Center Technical Document 516 [Logan and Rockway, 1986]. It was designed to run under DOS on a PC. All third-party commercial and "free" versions are based on **MININEC(3)**. **MININEC(3)** was written in BASIC using a Galerkin solution routine with pulse basis functions. (Galerkin is a moment method procedure using identical expansion and testing functions).

Various people have produced some **MININEC(3)** versions in FORTRAN and C. In at least one case, parts or all of the program were converted to machine language. All of these versions were virtually a one-for-one translation from the BASIC code. In BASIC the complex arithmetic is part of the code. Complex arrays are handled as two separate real number arrays. The translations into FORTRAN, for example, did not take advantage of the complex arithmetic of the language. Many of these versions were not as accurate, longer (requiring more lines of code and storage) and generally slower. In the PC environment of the times, BASIC seemed to provide the best all-around performance.

In 1988, the **MININEC** authors published a new version with Artech House [Rockway, Logan, Li, and Tam, 1988]. The **MININEC System** used BASIC and sported a significantly improved user interface. Unfortunately, the work was completed just prior to the release of the Microsoft Windows Operating System. Although this work was a significant improvement, it could not take advantage of the Windows operating environment. When this version went out of print, Artech House returned the copyright to the authors.

In 1995 and 1996, the authors published new "Windows" versions of **MININEC** [Rockway and Logan, 1995] [Rockway and Logan, 1996] [Rockway and Logan, 1996]. The computational engines of the **MININEC Professional Series** were written in FORTRAN. The user interface was in Visual BASIC. These codes were integrated into Windows. The user-interface provided on-line context sensitive help with entries in multiple input windows or dialog boxes. The solution was accomplished in a Galerkin procedure but using triangular expansion functions rather than pulses. This results in improved accuracy and stability. The FORTRAN computational engines were executed automatically from a DOS level command for greater speed.

In 1999, the authors published another improved set of codes, the ***Expert* MININEC Series** [Rockway and Logan, 1999] [Rockway and Logan, 1999] [Rockway and Logan, 1999]. The new series features "*Expert*" assistance in selecting appropriate input dialog boxes while constructing a model. Context sensitive help is still an important feature. Further advancements include programs dimensioned for larger problems and faster computations. The computational codes have been compiled with newer FORTRAN 90 compilers that have resulted in faster computations. Finally, significant use of the **MININEC Professional Series** has provided feedback on suggested improvements. These improvements have been implemented in ***Expert* MININEC**.

Intended Application

The ***Expert* MININEC** is a series of capabilities that include:

> ***Expert* MININEC Broadcast Professional**
> ***Expert* MININEC Professional**
> ***Expert* MININEC Classic**

The user interface to ***Expert*** **MININEC** is through Microsoft Windows. Input data screens provide format sensitive entry boxes in individual windows with tabular data displays. ***Expert*** **MININEC** modeling geometry constructs include:

Cartesian, cylindrical and geographic coordinate systems
Meters, centimeters, feet or inches selection
Straight, helix, spiral, catenary and arced wires
Wire meshes
Automated canonical structure meshing
Node coordinates stepping
Symmetry options
Rotational and linear transformations
Numerical Green's Function
Automated convergence testing

Electrical description options include:

Free space, perfect ground, and imperfect ground environments
Frequency stepping
Loaded wires
Lumped loads
Passive circuits
Transmission lines
Voltage and current sources
Plane wave source excitation

Solution description options include:

Near fields
Radiation pattern
Two-port coupling
Medium wave array synthesis

Output products are displayed in both tabular and graphics forms. The integrated graphics of ***Expert*** **MININEC** include:

3-D geometry displays with rotation, zoom and mouse support.
3-D currents, charges and pattern displays.
Linear, semilog and log-log plots of currents, coupling, near fields, impedance and admittance.
Smith Chart plots of impedance and admittance.
Linear and polar pattern plots.

Input and output data screens are fully interfaced to Windows printer drivers as well as other window applications, such as word processors and spread sheets. On-line, context sensitive help is also provided.

The computational intensive algorithms are implemented in FORTRAN for greater speed and make maximum use of available memory to set array sizes. The formulation has been changed from earlier versions of the MININEC to use triangular basis functions. This results in greater accuracy. The short segment limit is a function of machine accuracy. Square loops and Yagi antennas may be solved with confidence. In addition, a Fresnel reflection coefficient approximation improves the calculation of currents in the vicinity of real ground. As a summary ***Expert* MININEC** solves for:

Currents and charges on wires (peak or RMS)
Impedance, admittance, S_{11} and S_{12}
Effective height and current moments
Power and voltage losses
Multi-port (antenna-to-antenna) coupling
Near electric and magnetic fields
Radiation patterns (dBi or electric fields, power or directive gain)
Medium wave array design
Auxiliary calculations of ground wave, stub matching, and tower footing impedance

Not all of the capabilities of the ***Expert* MININEC** are available in all of the series options. A list of ***Expert* MININEC capabilities** is given in following Table.

List of ***Expert*** **MININEC** options and Capabilities

	Classic	**Professional**	**Broadcast**
Geometry description			
Canonical mesh structure		X	X
Convergence test			X
Dimensions, Environments, Coordinates	X	X	X
Geometry points	X	X	X
Geometry points iteration	X	X	X
Helix/spiral		X	X
Numerical Green's Function			X
Straight wires	X	X	X
Symmetry		X	X
Text file input	X	X	X
Transformations		X	X
Wire arc		X	X
Wire mesh		X	X
Spiral sort of wires		X	X
Electrical description			
Frequency	X	X	X
Ground	X	X	X
Loaded wires	X	X	X
Lumped loads	X	X	X
Passive circuits			X
Plane wave source			X
Transmission lines		X	X
Voltage/current sources	X	X	X
Solution description			
Near fields	X	X	X
Radiation pattern	X	X	X
Two-port coupling		X	X
Medium wave array synthesis			X
Planar antenna phased array			
New array definition			X
Source/load modification			X
Auxiliary calculations			
FCC ground wave			X
Stub matching			X
Tower footing impedance			X
Antenna matching			X
Impedance interpolation			X
Problem limits			
Number of wires	500	2000	4000
Number of unknowns	1250	5000	10000

Technical Approach

Integral Equation

In ***Expert*** **MININEC** the solution for currents is based on the numerical solution of an integral equation representation of the electric fields. The solution depends on several assumptions, which are valid for thin wires:

The wire radius is very small with respect to the wavelength and the wire length.
The wire is subdivided into short segments so that the radius is small with respect to segment lengths.
The currents can be represented by axially directed filaments (i.e., there are no circumferential currents on the wires).

The electric field is formulated in terms of its scalar and vector sources [Harrington, 1968]. These sources are the vector magnetic potential and the scalar electric potential. The two potentials are calculated from potential integrals, which are solutions to the Helmholz vector and scalar wave equations. In the potential integrals, the integrands are the wire current and wire charge distributions of assumed forms. The current and charge are linked via the equation of continuity.

Expert **MININEC** makes use of the boundary condition that the tangential electric field on the surface of a perfect conductor must be zero. Since the wires are assumed to be electrically thin, this forces the total axial electric field on the wire to zero. The three sources of tangential electric field on the wire are:

Currents and charges on the wires and on nearby wires.
Incoming waves from distance or nearby sources.
Local sources of electric field on the wire.

The local sources are in the form of voltage sources or current sources that are applied to or connected to the wires. By summing the tangential electric field components at each segment on the wire antenna and enforcing the zero total value, an integral representation for the currents and charges is obtained.

The Numerical Procedure

The moment method solution in ***Expert*** **MININEC** is a numerical procedure for solving the electric field equation. Triangular basis functions are chosen to represent the unknown currents. Triangular testing functions are chosen to enforce the integral equation on the surface of the wires. A matrix approximating the integral equation results from the choice of the basis and testing functions. When this matrix is inverted and multiplied by the local sources of electric field, the complex magnitudes of the current basis functions are derived. In ***Expert*** **MININEC**, Gaussian elimination is actually used to solve the matrix equation. All antenna performance parameters are computed from the derived current distribution.

The Ground Plane

Ground planes are accommodated by the method of images. Where a wire attaches to the ground plane, a current basis function is automatically added to the wire end point connection to ground to maintain current continuity to the image.

Loads

Lumped parameter impedance loading can be added in series to selected junctions between connecting segments. The load impedance is added to the self-term of the solution matrix for the corresponding matrix element.

Radiation Pattern

Radiation patterns are calculated from the electric field in terms of the structure currents, in the classical closed-form solution.

Real Grounds

Real grounds are approximated using the reflection coefficient method [Wait, 1969]. In computing the radiated fields in a given direction, the specified ground media is determined where the ray from each current node reflects. The reflected ray is computed using the appropriate ground parameters and height of the ground associated with the specified ground media. When a cliff is specified, the diffraction from the cliff edge is not included. The ***Expert* MININEC** solution evaluates the field of the image multiplied by the appropriate Fresnel plane wave reflection coefficients. The method should not be used for current segments close to ground. Reasonable engineering estimates have been obtained when current nodes are located greater than 0.1 to 0.2 wavelengths from ground.

Near Fields

A method of virtual dipoles is used for the computation of electric and magnetic near-fields [Adams, et al., 1973]. Near electric fields are calculated at a given point in the vicinity of a wire structure by placing a small virtual dipole at the observation point. The open circuit voltage is calculated from knowledge of the structure current distribution and the mutual impedance between the virtual dipole and the antenna. For the magnetic near field, the current distribution and the difference between the appropriate components of the vector magnetic potential are used.

User Interface and the Modeling Process

There is a systematic process to the successful application of ***Expert* MININEC** to wire antenna design and analysis. There are five steps to this process:

Geometry description – definition of wire endpoint coordinates and radii.
Electrical description – definition of sources.
Model validation – verification that model fits constraints.
Solution description – definition of the desired output.

Output display – graphical and tabular display of computational products.

The user interface mirrors this process. The interface provides a real-time "*Expert*" to assist in selecting appropriate input dialog boxes while constructing a model. The "*Expert*" opens supporting windows when needed. Data can be easily transferred from the supporting windows to the dialog entry boxes with a click of the mouse. Context sensitive help is available anytime from any open dialog box.

Summary

***Expert* MININEC Classic** is ideal for the novice, student and hobbyist. ***Expert* MININEC Professional** is suitable for the experienced student and the professional engineer. ***Expert* MININEC Broadcast Professional** is a tool for the advanced student and the professional broadcast engineer.

For further information on the attributes of the "***Expert* MININEC Series**", please see the EM Scientific, Inc. web site at http://www. Emsci.com/.

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ACES is preparing to distribute *Expert* MININEC Classic to members. At the March Conference, we will have the software available for attendees and will commence shipment to members for the cost of materials and reproduction only. The costs are being determined and information will be posted on the ACES web site by 18 March, conference time. This distribution of the latest version of MININEC is the second package of CEM software ACES has distributed. The last software was NEEDS 2.0, in the late 1980's.

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