Overview of Electromagnetic Modeling Software

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Abstract: Computational electromagnetic modeling (CEM) software is widely used to model antennas, microwave circuits, circuit boards, components, shielded enclosures, cables, motors, sensors, actuators and a wide variety of electrical and electronic devices. The general features, capabilities and costs vary greatly among different codes and new codes are introduced on a regular basis. This paper provides an overview of currently available CEM codes grouped by type, cost and the specific numerical techniques they employ.

Keywords: Computational electromagnetic modeling, Method of moments, Finite element, FDTD

1. Introduction

With the advent of reasonably powerful computers in the mid-1960s, a new form of electromagnetic analysis emerged known as Computational ElectroMagnetic (CEM) modeling. Pioneers in this field such as Yee [1], Harrington [2], and others demonstrated that numerical solutions of Maxwell's equations could be used to accurately describe the electromagnetic behavior of real antenna configurations. For the first time, it became possible to analyze a wide range of structures and accurately determine current and field distributions without building and measuring these structures in a lab.

Of course, computers have come a long way since the 1960s, roughly doubling in speed and memory capacity every couple of years. Advances in CEM modeling techniques and software have also experienced exponential growth. This report provides an overview of EM modeling software that is currently available. Information for this report was obtained from responses to an online survey of EM software companies. The companies or were asked to complete an online form describing the general features, capabilities and costs of their products. Their responses are summarized in the following sections. Note that in some cases, the responses received on the survey forms were inconsistent with the information on the company's web site or other sources. The authors have done their best to insure that the information provided in the tables below is accurate as of the date of this publication. Updates will be posted to the web URL listed in [3].

2. Solution Steps

Generally, the process of modeling a particular configuration using numerical EM modeling software can be divided into 4 steps: defining the model, discretizing the geometry, obtaining the numerical solution, and interpreting the results. CEM software plays a critical role in each step of the process. For example, when defining the problem geometry, it is important to represent objects in a form that is compatible with the software's capabilities. Ideally, the software's graphical user interface should help the user define configurations that can be analyzed accurately and efficiently using the techniques employed by the solver. This section discusses each of the analysis steps and the role of CEM software.

A. Defining the Model

The first step in the modeling process is to construct a geometrical model of the problem to be solved. Most of the software in this survey includes a graphical user interface (GUI), which is capable of drawing 2D or 3D structures. GUIs also allow users to define the electromagnetic parameters of materials, source configurations and the desired output. Several codes (including most of the free codes) do not have an embedded GUI, but third-party GUIs are available for many of them.

Most of the codes in this survey allow importing third-party CAD databases, such as AUTOCAD, Pro/Engineer, CATIA, Solidworks, Inventor, ACIS, etc. This feature enhances the ability of these codes to be applied to very complex geometrical models. Unfortunately, none of the GUIs evaluated by the authors prevent the user from defining geometries that the code is incapable of analyzing correctly.

B. Discretizing the Geometry

Most CEM software employs some type of mesh generator in order to discretize the volumes and/or surfaces of the structure. The meshing process is usually iterative or adaptive. Some mesh generators are capable of automatically or manually refining parts of the model where additional detail is required. Normally, those parts are either critical to the structure's electromagnetic performance or much smaller than other parts dimensionally. Mesh generators have limited abilities to automatically identify these parts. Therefore, it is important for the user of the software to be familiar with the analysis techniques being used by the software and the effect that the mesh has on the calculations.

Table 1: Software that employs the boundary element method

Software	**Company**	**Description**
Ampere/Coulomb/Faraday	IES	3D quasi-static
Antenna Model	Teri Software	wire structures
AXIEM	AWR	modeling planar circuits
CableMod	CST/Simlab	2D cable modeling
CONCEPT-II	TU Hamburg-Harburg	3D full-wave
efield	Efield AB	3D full-wave
Electro/Magneto/Oersted	IES	2D quasi-static
EM3DS	MEM Research	MMIC Modeling
EMC Studio	EMCoS	3D full-wave
EZNEC Pro	EZNEC	wire structures
FEKO	EMSS	3D full-wave
GEMACS	Adv. EM	3D full-wave (wires-plates)
IE3D	Zeland	3D full-wave
Momentum	Agilent	2D high frequency
NEC2	Open Source	3D full-wave (wires-plates)
NEC4	L. Livermore	3D full-wave
Open FMM	Open FMM	Large scattering problems
OPERA 2D	Vector Fields	2D quasi-static
OPERA 3D	Vector Fields	3D quasi-static
PCBMod	CST/Simlab	2D circuit board structures
PhysPack	Physware	3D full-wave
Q3D Extractor/Q2D	Ansys/Ansoft	2D/3D quasi-static
Sonnet Suit	Sonnet	3D full-wave
Trace Analyzer	Trace Analyzer	R/L/G calculator
WIPL-D Pro	WIPL-D	3D full-wave

C. Obtaining the Numerical Solution

The strengths and weaknesses of a particular CEM code depend on many factors, but perhaps the most significant of these factors is the specific technique that is employed by the code to solve Maxwell's equations. Generally, numerical electromagnetic modeling techniques can be categorized as either time-domain or frequency-domain depending on whether the analysis is done by stepping in time or frequency. Another significant classification is partial differential equation (PDE) techniques vs. integral techniques. PDE techniques solve the differential form of Maxwell's equations and generally require a volume mesh. Integral techniques solve an integral form of

Table 2: Software that employs the finite element method

Software	Company	Description
AMaze-Aether	Field Precision	3D full-wave
AMaze (HiPhi/Magnum)	Field Precision	3D quasi-static
Analyst	STAAR	2D & 3D full-wave
Comsol – RF Module	COMSOL	3D full-wave
CST M. Studio –FDS	CST	3D full-wave
EMDS	Agilent Technologies	3D full-wave
EMS	ElectromagneticWorks	3D quasi-static
FEMM	David Meeker	2D quasi-static
Flux2D/3D	Magsoft	2D & 3D quasi-static
HFSS	Ansys/Ansoft	3D full-wave
HFWorks	ElectromagneticWorks	RF component analysis
JCMsuite	JCMwave	optics
MagNet / ElecNet	Infolytica	3D quasi-static
Magneto / Oersted	Integrated Eng. Software	2D quasi-static
Maxwell	Ansys / Ansoft	2D/3D quasi-static
Opera 2D/3D	Vector Fields	2D/3D quasi-static
pdnmesh		2D quasi-static
QuickField	Tera Analysis	2D quasi-static
Tricomp (EStat/PerMag)	Field Precision	2D quasi-static
Tricomp-WaveSim	Field Precision	2D high-frequency

Table 3: CEM modeling codes that use the FDTD method

Software	Company	Description
AMDS	Agilent	3D full-wave
ApsimFDTD	Applied Simulation Tech.	3D full-wave
CST M. Studio - TS	CST	3D full-wave
EMA3D	Electromagnetic Appl.	3D full-wave
EM Explorer	EM Explorer	solver for periodic structures
EMPIRE XCcel	Empire	3D full-wave
EMPLab	EM Photonics	3D quasi-static
EZ (EMC/FDTD)	EMS-Plus	3D full-wave
Fidelity	Zeland Software	3D full-wave
GEMS	2COMU	3D full-wave
LC	Cray Research	3D full-wave
MEEP	MIT	3D full-wave
PAM-CEM	ESI Group	3D full-wave
SEMCAD X	Schmid & Partner Eng.	3D full-wave
Speed2000	Sigrity	multi-layer packages and PCBs
Toy	The CEMTACH Group	3D full-wave
XFDTD	Remcom	3D full-wave

Maxwell's equations and employ a surface mesh.

The most popular frequency-domain, integral technique is the Boundary Element Method (BEM). BEM codes are often called Moment Method codes, because they employ the method of moments to solve integral equations. BEM software generally excels at modeling open radiation problems, particularly when the geometry includes resonant length wires or large metallic surfaces. Table 1 lists various CEM modeling codes that employ the Boundary Element Method.

Perhaps the most popular frequency domain, PDE technique is the Finite Element Method (FEM). Finite element codes typically excel at modeling configurations that have complex or inhomogeneous materials in a bounded space. Perhaps the greatest advantage of this technique over others described here is its ability to model geometries with both coarsely meshed and very finely meshed regions. Table 2 lists CEM codes that employ the Finite Element Method.

The most popular time-domain technique is the Finite Difference Time Domain (FDTD) method. This is a PDE technique, which (like FEM) is good

Table 4: Hybrid codes

Software	Company	Description
CONCEPT-II	TUHH	Hybrid BEM and PO
efield	Efield AB	hybrid FDTD-FEM-TD hybrid MoM-MLFMM-PO
EMAP5	Clemson	BEM-FEM
FEKO	EMSS	BEM-FEM-PO
GEMACS	Adv. EM	BEM-FDFD-UTD
Singula	IES	BEM-PO
SuperNEC	Poynting Antennas	BEM -PO

at modeling complex and highly inhomogeneous structures. FDTD techniques do not create a large system of linear equations and therefore do not require a matrix solver like BEM and FEM techniques. As a result, FDTD tackles very large problems relatively efficiently. As a time-domain method, it is very good at solving problems with a relatively wide bandwidth. Table 3 lists various CEM modeling codes employing an FDTD solver.

Hybrid codes combine the features of two different modeling techniques in order to be able to model a wider range of problem geometries. Unlike CEM software suites that bundle different codes in the same package, hybrid codes are capable of simultaneously applying different numerical solvers to different regions of the geometry. Table 4 lists various CEM codes that combine two or more solvers.

D. Interpreting the Results

No software is particularly useful unless the solution can be visualized, post-processed or exported. Often the solver does not calculate the quantity desired directly. For example, a code may solve for a set of equivalent currents on a fictitious boundary, while the user wants to know the field strength at a particular distant point. Post processing software can be as complex as the numerical solver and can have an equally limiting effect on the accuracy and usefulness of the code. Most of the software surveyed allows the exporting of data in one format or another. Popular export formats include text files, Excel spreadsheets and Matlab files.

Table 5: General purpose 3D full-wave codes

Software	Company	Technique	Comment
AMaze-Aether	Field Precision	FEM	
ApsimFDTD	AST	FDTD	IC and package analysis
CST MS-TS	CST	FDTD	part of a suite of tools
CST MS- FDS	CST	FEM	part of a suite of tools
RF Module	COMSOL	FEM	part of a suite of tools
EMA3D	EMA	FDTD	
EMC Studio	EMCoS	BEM	
EMDS-for-ADS	Agilent	FEM	
emGine	Petr Lorenz	TLM	free for non-commercial use.
EMPIRE XCcel	Empire	FDTD	
EZ-EMC	EMS-Plus	FDTD	
EZ-FDTD	EMS-Plus	FDTD	
EZNEC Pro	EZNEC	BEM	wire and wire-grid modeling
Fidelity	Zeland Software	FDTD	
GEMS	2COMU	FDTD	
HFSS	Ansys/Ansoft	FEM	
LC	LC	FDTD	
MaX-1	John Wiley & Sons	GMT	includes 2D and 3D FDTD solvers

MEEP	MIT	FDTD	Free software under the GNU GPL
MEFiSTo-3D Pro	Faustus Scientific	TLM	
NEC2	open source	BEM	
NEC4	L.Livermore	BEM	U.S. export controlled
PAM-CEM	ESI Group	FDTD	
PhysPack	Physware	BEM	chip-package-board simulation
SEMCAD X	Schmid & Partner	FDTD	package includes quasi-static solvers
Sonnet Suit	Sonnet	BEM	
Toy	CEMTACH Group	FDTD	for educational use
ToyTLM	CEMTACH Group	TLM	for educational use
WIPL-D Pro	WIPL-D	BEM	
XFDTD	Remcom	FDTD	

3. Other Concerns

A. Software Applications

CEM modeling codes can be categorized by their intended application. Some codes are optimized for specific applications, while others try to be more general. Table 5 lists general purpose full-wave codes.

In many situations, it is better to use a quasi-static modeling code to model components that are small relative to the wavelengths of interest, even when these components are used at RF or microwave frequencies. Generally, quasi-static modeling codes are more powerful and more efficient for modeling complex electrically small geometries than full-wave codes. The codes listed in Table 6 are electrostatic and/or magnetostatic modeling codes.

Table 6: 3D quasi-static codes

Software	Company	Technique	Comment
AMaze - HiPhi	Field Precision	FEM	electrostatic
AMaze - Magnum	Field Precision	FEM	magnetostatic
Amperes	IES	BEM	magnetostatic
Coulomb	IES	BEM	electrostatic
AC/DC	COMSOL	FEM	electrostatic, magnetostatic
ElecNet	Infolytica Corporation	FEM	electrostatic
EMS	ElectromagneticWorks	FEM	electrostatic, magnetostatic
Faraday	IES	BEM	magnetostatic
Flux3D	Magsoft	FEM	electrostatic, magnetostatic
Opera 3D	Vector Fields Inc.	FEM	electrostatic, magnetostatic
MagNet	Infolytica Corporation	FEM	magnetostatic
Maxwell	Ansys/Ansoft	FEM	electrostatic, magnetostatic
PCBMod	Simlab GmbH	2D BEM or 3D PEEC	electrostatic
Q3D Extractor	Ansys/Ansoft	FEM	electrostatic, magnetostatic

B. Price

Price is another important factor that affects the user's decision to choose a specific software tool. There are a few free codes, but they generally offer little if any user support. Most software titles list for more than $10k, but nearly all of the software companies responding to our survey offered significant discounts for academic users. Table 7 lists software titles sorted by price.

Table 7: CEM modeling software sorted by price

Price	Software
FREE	Antenna Model, FEMM, LC, MEEP, OpenFMM, pdnmesh, Radia, Toy, Scatlab
$200-$1000	EZNEC Pro, GEMACS, Tricomp-EStat, Trace Analyzer
$1000-$10,000	AMaze (HiPhi/Magnum/Omnitrak/Aether), CONCEPT-II, ElecNet, MS, EM3DS, EZ-FDTD, EZ-EMC, EZ-PowerPlane, EM Explorer, EMPLab, EMS, FlexPDE, Flux2D, GSolver, MaX-1, MEFiSTo-3D Pro, Opera, SuperNEC, Tricomp (PerMag/Trak/WaveSim)
> $10,000	AMDS, Amperes/Coulomb/Electro/Faraday /Magneto/Oersted/Singula, Analyst, ApsimFDTD-SPICE, AXIEM, CableMod/ PCBMod, Compliance, Comsol, CRIPTE , CST, efield, EMA3D, EMC Studio, EMDS, EMFlex, emGine Environment, EMPIRE XCcel, Fidelity, FEKO, GEMS, HFWorks, HFSS, IE3D, JCMSuite, OptEM Cable Designer, OptEM Inspector, Magnet, Microwave office, Momentum, PAM-CEM, PhysPack, Q3DExtractor, SEMCAD X, Sonnet, WIPL-D Pro, Xenos, XFDTD, XGtd

C. Operating Systems

As shown in Figure 1, most of the available codes support Windows 32-bit or 64-bit. Some codes can also run on Linux and Mac OS. Trace Analyzer is written purely in Java, which is platform independent, although an installer is provided for Windows.

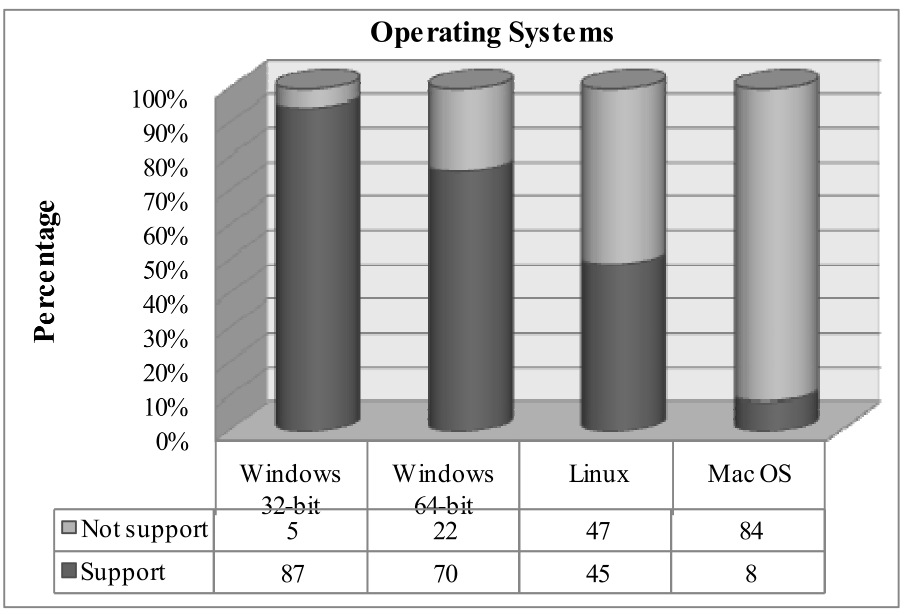

Fig. 1. Operating systems supported by the numerical modeling codes.

D. Technical Support

Almost all the modeling software surveyed provides technical support by phone, web and/or email. Some codes also have internet user groups that share hard-won knowledge. External commercial support is also available for several codes. Free codes generally have little or no technical support, though some support is available for the NEC codes through the NEC-List internet mailing list [4].

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