COMPARATIVE ANALYSIS OF CONTEMPORARY ELECTROMAGNETIC SOFTWARE FOR MICROWAVE POWER INDUSTRY

Vadim V. Yakovlev
Department of Mathematical Sciences
Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609

ABSTRACT

Sixteen commercial EM codes are considered as the contemporary database of software suitable for development and design of industrial systems of microwave thermal processing. Basic features of the codes are compared and discussed.

INTRODUCTION

The recent progress in numerical mathematics and computational technologies has resulted in a remarkable increase in the adequacy of modeling and accuracy of computations as well as in a certain decrease of the software and hardware costs. These circumstances have caused a notable growth of the use of advanced computer simulations to accelerate the design of wireless telecommunications equipment, semiconductors, computer systems, networking and a variety of other products.

Although industrial and food engineers dealing with microwave thermal processing also become more interested in modeling, for most this arena remains new and unexplored. The review of commercial EM codes [1] written for users in the telecommunications field does not include any evidence to what extent these codes are convenient/appropriate for modeling of microwave heating. Paper [2] published 10 years ago depicted the concepts of numerical methods suitable for microwave thermal processing and appeared to be the only one of this sort.

Although numerous cases of successful modeling in R&D projects have been reported, they have not specified the use of computer simulations in design of industrial systems. The microwave power community seems to be lacking both general information and specific technical data on current computational opportunities [3].

The combination of these factors has initiated a project in the Industrial Microwave Modeling Group at WPI to study the software market and discovering the capabilities of particular codes with respect to the needs of microwave power engineering. The present paper outlines the initial results of this study in the form of a database of software feasible for further analysis.

The existence of computer tools in computational electromagnetics implies that the possibility for the advanced simulation of microwave heating systems has also appeared. However, despite all the progress, processes of microwave thermal processing still cannot be modeled in their entirety. No modeling packages can provide complete information about processes, which necessarily involve thermal conduction. Neither can one take into account such phenomena as water transport, evaporation, mass transfer, chemical transformations and reactions, and other things. Corresponding research does exist, but there is no computer code implementing regular numerical solutions of all these problems at once.

Meaningful results can be obtained today from separate simulation of electromagnetic and thermal processes. Thus all software applicable to microwave heating can be divided into two groups in accordance with this feature. Another classification identifies academic and commercial codes.

Judging the latter appears to be difficult. Published information about academic software is far from complete. Quite often, they can be good tools in the hands of no one but the authors. So it would be unrealistic to think that much software from academia can be used in industry.

As for codes for analysis of thermal processes, they might be useful in practical situations even isolated from the electromagnetic packages. We, however, assume that the electromagnetic phenomenon plays the primary role in efficient microwave heating and is essentially responsible for the entire process.

Hence, the present review is focused on EM commercial codes. At the current stage of the study, the purpose was to figure out what software available in the market can be efficiently used to help analyze and design systems of MW processing.

CRITERIA

The market of relevant products appears to be not too large. All codes can be divided into two groups as implementing algorithms for low frequency and high frequency (HF) electromagnetics. Since at HF mathematics is more complicated, the number of packages applicable to this field is smaller (approximately 30%).

Among codes in this smaller group, there are packages dealing with 2D approaches and oriented on planar structures as well as codes addressing open problems and thus beneficial for electromagnetic compatibility, antennas, etc. If we give up these codes as irrelevant to the present study, the size of the market is reduced to a very limited number of codes.

The remaining packages were exposed to the criteria on the software capabilities. The characteristics determined by numerical methods can be listed in order of increasing complexity. The portion of the list relevant to problems of microwave heating may be presented as follows:

§ Lossy materials; phase and attenuation; eigenfields; power density;
§ Fields excited by the given source;
§ Dissipated power of the excited fields;
§ Level of coupling;
§ Specific absorption ratio (SAR) patterns.

It seems to be reasonable to suggest that for practitioners in the microwave power industry it would be feasible to have software with the capability of calculating *the dissipated power of the excited fields as a minimum*.

Finding eigenfields may not be enough for the purposes of industrial design since these data require certain interpretation; it might make more sense rather in R&D projects. This way researchers can use, for example, *FEMLAB*, *MathLab FEkit*, *FlexPDE*, and other extensions of the famous mathematical packages. Codes, which are essentially electromagnetic and able to determine at least patterns of dissipated power, are analyzed below.

ANALYSIS

Table I includes the names and main characteristics of these 16 full-wave 3D codes, which passed the selection criteria. Eight come from North America, 6 from Europe (including 4 from Germany), 2 from Japan. There are brand names (Ansoft, ANSYS, Agilent), products that have earned certain reputation in the microwave power community due to their successful practical applications (*MAFIA, XFDTD, QuickWave-3D*), as well as the names likely unknown in this context.

Each code exists in either one, or several versions for various operating systems. Today, 14 out of 16 packages work under Windows NT. A few years ago, UNIX associated with workstations or supercomputers was the only option for efficient EM codes. That was a big disadvantage for the industry, but now it is over.

The last column of Table I contains an indication on the software status in microwave power engineering. The term *Actual* means that it has been used at least once in some R&D or industrial project whereas *Potential* indicates that all capabilities outlined in the selection criteria are available. As of April 2000, the *Actual/Potential* ratio is equal to 8/8.

Kernel methods used in each code are referred to in the same column as well. FEM and FDTD prevail, but the method traditionally considered less powerful and flexible (Method of Moments) is also implemented in one package. Further, there are indications to the key parameters, which can be calculated and visualized: dissipated power and SAR. Currently, SAR is not available in all codes; however, vendors say that since calculating one on the basis of the other is simple, this would be added if any customers request it.

Interface, a highly important software element, appears to be very different in various codes. Agilent and Ansoft have developed for their codes the own advanced interfaces; this allows them to claim that their products do nothing, but computer design. *Microwave Studio*, *Empire*, and *QuickWave-3D* offer advanced functions for export/import data to work with some CAD software (like AutoCAD). *EMC2000-VF* merely works with another piece of commercial software, *HyperMesh*, serving as an interface.

Another important feature is an optimization option. *Agilent HFSS 7.0*, *Ansoft HFSS 5.5*, *QuickWave-3D 1.9*, and *XFDTD 5.1* possess it in some form. The option implements a certain procedure of computer optimization, that is, a subsequent solution for various scenarios with the choice of parameters supposed to be the best in accordance with some specified criteria. Running this option may take much time, and it cannot be called the genuine optimal design in the mathematical sense, but it might be useful.

Two vendors have implemented in their products practical solutions of how to overcome the major disadvantage the classical FDTD possesses in comparison with FEM: the stairs-like approximation of the mesh cells. The incorporation of the so-called perfect boundary approximation in *Microwave Studio* allows an accurate modeling of curvilinear regions. The conformal FDTD suggested by the authors of *QuickWave-3D* gives similar results (see Fig.1).

Interested users could work now with at least 3 vendors exploring an opportunity of solving the EM problems associated with the thermal ones. CST and WAI promote thermal packages completely compatible with their *MAFIA* and *EMFlex*. *JMAG Works* is merely built as the set of compatible units including the thermal code.

This review was composed, in part, interactively, and this gave data for working out the vendors' rating regarding their dedication to the MW heating

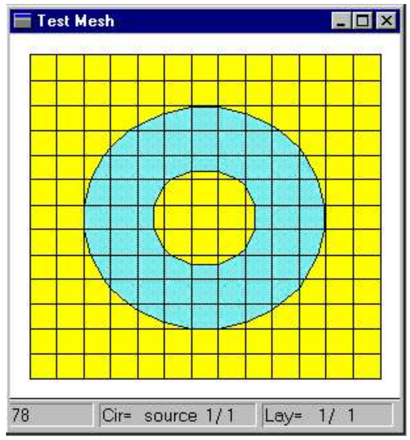


Fig.1. Meshing of the cross-section of a coaxial line by *QuickWave-3D*.
Courtesy of QWED, 1998.

applications. Such a characteristic appears to be important because if someone from the microwave power community decides do try a code in the microwave heating applications, work in close contact with its vendor is unavoidable, so it would be convenient to know what one may expect.

The 15 vendors covered by the present review have been grouped as shown in Table II. Agilent, Infolytica, Remcom and other vendors in the first column reveal very little interest in the area. The 2-star companies are aware of microwave heating applications and admit that they may have certain involvement in corresponding technical support and even further development of their products. Three European companies, CST, Matra S&I, and QWED, have a real interest in microwave heating applications and look forward to working for the field. They seem to be expecting to get a reasonable market there. Some features specifically appropriate for the microwave thermal processing have been already implemented in their codes, and this process goes on. For instance, QWED has recently announced plans for the development of special regimes for running EM solvers in applications including thermal changes of media parameters.

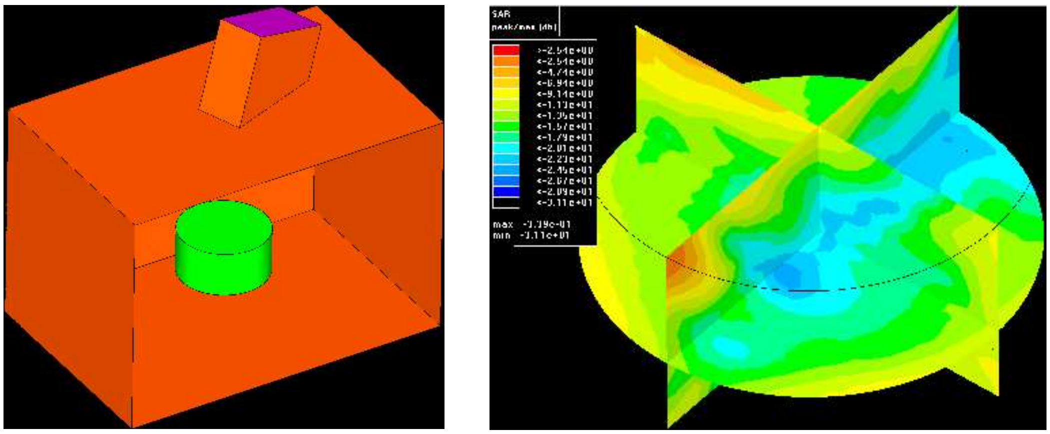
Basic financial information as of April 2000 is included in Table I. Since each code exists in a variety of options and configurations, the license costs depend dramatically on that and vary from \$9,000 to \$50,000 (with the average \$26,500). For the maintenance (technical support and upgrade), the cheapest option is zero for 2 years, the most expensive – \$5,300; the average here is \$3,000.

Table II. Rating of Vendors' Dedication to MW Heating Applications

☼	☼☼	☼☼☼
Agilent, CRC RI, Infolytica, JRI, Remcom, TU H-H	Ansoft, ANSYS, EMA, IMST, WAI, Zeland	CST, Matra S&I, QWED

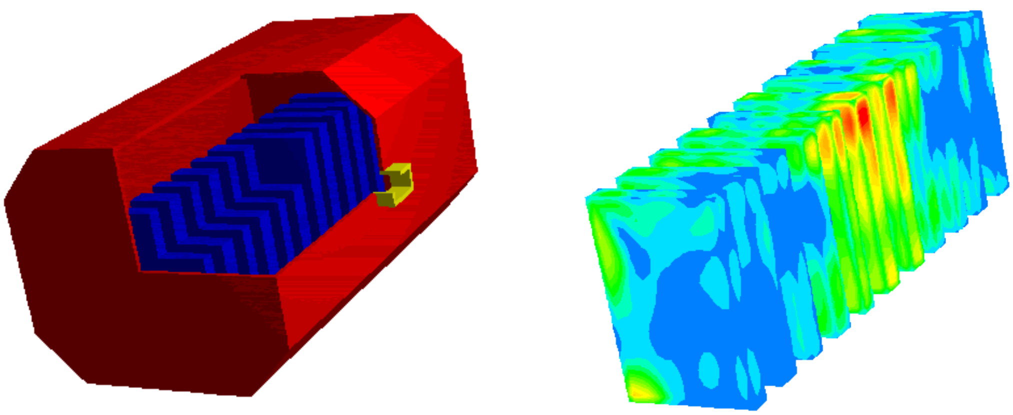
EXAMPLES

Examples included in this review and shown in Figs. 2-4 do not pretend to be meaningful simulation results, but rather simple illustrations of what commercial codes can provide. All the examples are about visualization of dissipated power or SAR patterns within the processed materials.



(a) (b)

Fig. 2. Fictional microwave oven with a sample of a non-centered food product ($\varepsilon = 45 - i15$) modeled by *EMC2000-VF*: (a) the interface image of the model; (b) SAR in three orthogonal cuts. *Courtesy of Aerospatiale Matra, 2000.*



(a) (b)

Fig. 3. Microwave oven for drying wet books in frequency range 1 – 5 GHz modeled by *MAFIA* 4: (a) the interface image of the cavity; (b) typical pattern of dissipated power on the surface of the book block at 3 GHz. *Courtesy of CST of America, 2000.*

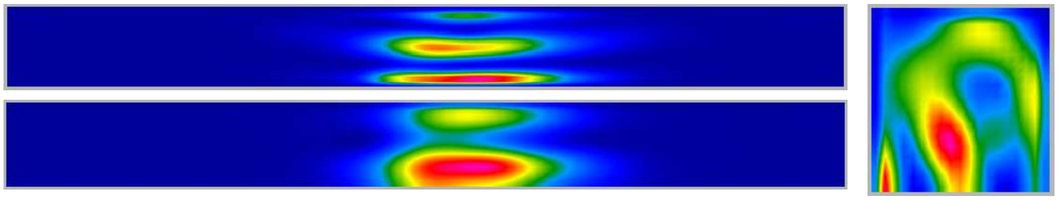


Fig. 4. SAR in a wood board processed in a microwave conveyor dryer at 915 MHz. The patterns computed by *QuickWave-3D* are shown in horizontal (top), vertical (bottom), and cross-sectional (right) cuts for specific values of moisture, density, and temperature.

CONCLUSION

All 16 full-wave 3D EM commercial codes applicable to microwave heating modeling have been originally developed for communication applications, so they are adapted to MW heating problems very differently and thus should be carefully considered in the context of the pending application. It is unlikely that there is one best piece of software equally good for all applications. One may find the costs still relatively high, but given the possibility to remarkably reduce the traditional expensive and inefficient cut-and-try phase in industrial design of the systems, the investment might be feasible. This review has no intention to recommend any of the codes; rather, this is an attempt to create a database, which may be *food for thought* for engineers and practitioners.

ACKNOWLEDGMENTS

The study was supported by the Center for Industrial Mathematics & Statistics (CIMS) at WPI.

The web site of Electromagnetic Compatibility Laboratory at the University of Missouri-Rolla (www.emclab.umr.edu/csoft.html) and the EM community Internet database EMLIB maintained by the Jet Propulsion Laboratory (emlib.jpl.nasa.gov) provided the directories to valuable information sources. The following software vendors delivered data regarding characteristics and features of their codes: Ansoft, Corp.; ANSYS, Inc.; CRC Research Institute; CST GmbH; EMA, Inc.; IMST GmbH; The Japan Research Institute; Matra Systemes & Information; Remcom, Inc.; QWED; TU Hamburg-Harburg; Weidingler Associates, Inc.; Zeland Software, Inc. Yang Cai, David Dibben, Erik Esveld, and Vyacheslav Komarov informed the author about particular issues relevant to the software considered.

REFERENCES

[1] M.S. Mitrotzik and D. Prather, How to Choose EM Software, *IEEE Spectrum*, **34** [12] 53-58, 1997.

[2] C. Lorenson, The Why's and How's of Math Modeling for Microwave Heating, *Microwave World*, **11** [1] 14-23, 1990.

[3] A. Palombizio and V.V. Yakovlev, Parallel Worlds of Microwave Modeling and Industry: a Time to Cross? *Microwave World*, **20** [2] 14-19 1999.

TABLE I. Commercial Electromagnetic Software of Actual/Potential Use in Microwave Power Engineering

Vendor	Code
Agilent Eesof EDA* www.tm.agilent.com/tmo/hpeesof	*Agilent HFSS Designer 5.5*
Ansoft, Corp. www.ansoft.com	*Ansoft HFSS 7.0*
ANSYS, Inc. www.ansys.com	*ANSYS/EMAG*
CRC Research Institute, Inc. www.crc.co.jp	*MAGNA/TDM*
CST GmbH www.cst.de	*MAFIA 4*
	CST Microwave Studio 2
ElectroMagnetic Applications, Inc. www.csn.net/~emaden	*EMA3D 3.0*
IMST GmbH www.imst.de	*EMPIRE 2.2*
Infolytica, Corp. www.infolytica.com	*FullWave*
The Japan Research Institute www.jri.co.jp	*JMAG-Works*
Matra Systemes & Information emc2000.matrasi-tls.fr	*EMC2000-VF*
Remcom, Inc. www.remcom.com	*XFDTD 5.1*
QWED www.qwed.com.pl	*QuickWave 1.9*
Tech University of Hamburg-Harburg www.tu-harburg.de/~tebr	*CONCEPT II 8.0*
Weidingler Associates, Inc. www.wai.com	*EMFlex*
Zeland Software, Inc. www.zeland.com	*FIDELITY 2.0*

DP = Dissipated Power. SAR = Specific Absorption Ratio. FEM = Finite Element Method. FETD = FE in Time Domain. FDFD, FDTD = Finite-Difference in Frequency Domain and in Time Domain. MoM = Method of Moments. FIM = Finite Integration Method. TLM = Transmission Line Method. TDFV = Time Domain Finite Volume. PBA = Perfect Boundary Approximation.

Operating System & License Price / Maintenance Per Year	Status, Major Technique, Performance, Requirements, etc.
UNIX, Windows 95/NT4 call vendor	Actual use. FEM. DP. OSA** optimization. PC-to-UNIX simulations.
UNIX, Windows 95/98/NT4 $42K / 12%	Actual use. FEM. DP, SAR (for plane wave). Eigenmode solver for anisotropic materials.
UNIX, Windows 95/98/NT4 $25-30K / call vendor	Actual use. FEM. DP. Compatibility with other ANSYS CAD codes, advanced animation.
UNIX, Windows NT4 call vendor	Potential use. FDTD. DP. 2 years on Japanese market; no English manual.
UNIX, Windows 95/98/NT4 $9-50K / 10%	Actual use. FIM. DP, SAR. PBA: up to 20 mil. cells. Optional temperature analysis.
Windows 95/98/NT4 $10-50K / 10%	Actual use. FIM. DP, SAR. AutoCAD export/import, full CAD design
UNIX, Windows NT4 $14-27K / $2.5-4K	Potential use. FDFD & FDTD. EMA-FAM*** interface
Linux, UNIX, Windows 95/98/NT4 $12-20K / from $1.5 K	Actual use. FDTD. DP, SAR. Auto CAD import (limited to 3D boxes). 300 MB hard-disk space
Windows 95/98/NT4 call vendor	Potential use. FEM. DP. Advanced interface
UNIX, Windows NT4 $35K / call vendor	Potential use. FEM & FDTD. DP. Thermal solver; 2GB hard-drive.
Windows 95/98/NT4 $15-20K (w/interface $30-35K) / 15%	Potential use. TDFV. DP, SAR. 4 GB hard-disk space. HyperMesh**** interface.
UNIX, Windows 95/98/NT4 $15K / $3K	Actual use. FDTD. DP, SAR. iSIGHT optimization*****. Multiprocessor for FDTD.
Windows 95/98/NT4 $15K / 15%	Actual use. Conformal FDTD. DP, SAR. 15 MB hard-disk space. ACIS export/import, AutoCAD import, optimization.
Linux, UNIX $26K / 2 years free	Potential use. MoM. DP, SAR. 100 MB hard-drive space
UNIX $40K / call vendor	Potential use. FETD. DP. Optional thermal solver.
Windows 95/98/NT4 $20K / call vendor	Potential use. FDTD. DP, SAR. 1 GB hard-disk space

* Formerly Hewlett Packard Eesof.
** Optimization Systems Associates, Inc.; purchased by Hewlett Packard in 1997.
*** FEGs, Ltd., www.fegs.co.uk.
**** Altair Engineering, Inc., www.altair.com.
***** Engineous Software, www.engineous.com.