

Visual Electromagnetics (VEM): A Student Learning Tool

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Abstract

Visual ElectroMagnetics (VEM) is a 2-D static electromagnetic simulator designed as a visualization aid for students in undergraduate electromagnetic courses. VEM utilizes finite difference techniques in conductive, dielectric, and magnetic environments. The VEM code, written in MATLAB for Windows 95/98, provides an inexpensive, user-friendly graphical interface that is platform independent. VEM consists of a structure window in which the user enters electromagnetic materials and sources via common drawing tools and pop-up menus. The solver button generates the system matrix, solves it, and activates the solutions window in which the results are displayed in a variety of user-selected viewing modes. Though the solution region is finite in extent, a compact simulation of the open boundaries of infinite extent is achieved via the Transparent Grid Termination (TGT). Preliminary evaluations of the enhancement of student learning by VEM are promising. A full demonstration of VEM will be included in the presentation.

1. Introduction

Traditional analytic methods are at the heart of many electromagnetic courses. They provide the mathematical basis upon which the theory of electromagnetics is based and provide conceptual views that offer insight into the behavior of electromagnetic fields. However, they are not effective in solving the variety and complexity of modern industrial applications. With industry leading the way, numeric tools have become the very heart of modern electromagnetics. With this in mind, introductory courses in engineering electromagnetics and the accompanying textbooks¹ are changing to include numeric techniques, not just the tools, but the underlying principles as well. This paper focuses upon the requirements, implementation, and results of using an appropriate numeric electromagnetics simulator in introductory courses.

2. Application Software Requirements

Many numeric electromagnetic application packages offer sophisticated and accurate solutions. Quite obviously, the overall goal is to enhance students' learning experiences. But which package is most appropriate for student use? Our deliberations lead to seven basic requirements.

- A) Easy to Learn: The software should not take significant time to learn. The more intuitive the better since time taken to learn the software is time taken from the course.
- B) Simple to Use: Problem setup should take only a few minutes. This process consists of making a rough sketch of the geometry and filling in material and sources.

- C) Quick Calculations: A typical solution should be obtained in a minute or less.
- D) Reliable Solutions: Reasonable accuracy of the data so that students have confidence in the results.
- E) 2-Dimensional Structures: Full 3-D solvers are not needed in introductory courses.
- F) Rich variety of Graphical Displays: The structure and the solution can be viewed in many modes – equipotentials, potential surfaces, field intensity and flux density vectors, flux lines, and background colors.
- G) Inexpensive Software and Hardware: The simulator should use readily available software and operate on “standard” machines.

3. Choosing an Electromagnetic Simulator

A rich array of electromagnetic simulator packages is available with wide variations in capabilities, prices, and hardware platforms. For the most part, the electromagnetic simulation software has advanced remarkably over the past decade. No doubt this is driven by the need of industry to solve increasingly complex electromagnetic problems. The user interface is one of the most observable improvements. Of course, the calculation routines and speed have made rapid advances as well. They are a pleasure to use and, in the hands of a skilled engineer, they are quick and versatile. In short, the electromagnetic simulators have become a genuine design tool with many “what if” options.

Simulator	Solution Method	Special Features	Notes
OPERA-2d ²	Finite Element Analysis	Thermal/Mechanical	GUI menu, PC
QuickField™ ³	Finite Element Analysis	Thermal/Mechanical	Free Student Edition, PC
Sonnet® Lite ⁴	Finite Element Analysis	High Frequency	Free, PC
Maxwell2D ⁵	Finite Element Analysis	DC/low Frequency	
Gemini ⁶	Finite Element Analysis	Magnetics	

Table 1 – 2-Dimensional Electromagnetic Simulators

Unfortunately, most of the packages are much more sophisticated and versatile than is required by students in introductory electromagnetics. In short, they are overkill! The learning curve is so long that the inclusion of these simulators significantly reduces the course coverage of concepts and principles. In response to this situation, a student-oriented electromagnetic simulator was developed. A decade of development of this package and its many features are described in the following sections.

4. EMAG

The original simulator, EMAG (A 2-D Electrostatic and Magnetostatic Solver in MATLAB) developed by Manke⁷ as a menu-based, networked MATLAB implementation. Quick calculations and reasonable accuracy were obtained by the finite integral (FI) method. For homogeneous materials this reduces to the finite difference (FD) method. Solutions were restricted to rectangular grid structures, i.e., Cartesian systems with z-invariance. At the time, memory limitations were considerable and two solution methods were available: iterative solutions using initial guesses or coarse grid calculations and direct matrix inversions utilizing

the built-in sparse routines of MATLAB. EMAG operated from two basic menus—a structures or geometry window and a display window. A hallmark of this application was the use of the Transparent Grid Termination (TGT)⁸ that enabled essentially open boundary conditions. This means that solutions to sources in free space need not be distorted by the presence of artificial boundaries at the edge of the solution region. The essence of the TGT method is that the effects of a Dirichlet boundary condition far removed from the solution space can be expressed in terms of a set of TGT coefficients. The TGT coefficients express the effects of the potential on any one node at the edge of the solution boundary on any other node on the boundary due to far-removed Dirichlet condition. The TGT coefficients are pre-calculated and substituted into the nodal coefficient matrix at the time of solution. In addition to preserving the open boundary, the TGT coefficients do not increase the size of the coefficient matrix. However, the TGT method substitutes a non-zero value into a relatively small number of the original zero-valued coefficients.

EMAG 2.0 was created by Wells⁹. The essence of EMAG including most MATLAB routines was retained within EMAG 2.0. However, the geometric versatility was expanded by EMAG 2.0 to include cylindrically invariant structures and the associated TGT coefficients. Moreover, the calculation effort for generating the TGT coefficients was reduced in EMAG 2.0 due to development of an optimal placement of the Dirichlet boundary relative to the solution region.

5. VEM

With Visual Electromagnetics (VEM) Garner¹⁰ transformed the menu-based EMAG 2.0 to a Windows[®] environment of the majority of computer platforms. Though VEM is built upon many of the underlying numeric routines of EMAG 2.0, they were streamlined to make quicker solutions possible. As a result, it became practical to generalize the solver to handle larger grid sizes. Corresponding TGT coefficient matrix generations for various grid sizes were added. In addition, the user interface was completely redesigned to build upon students' familiarity with common Windows features, especially the drawing commands, buttons, and pull-down menus. The data entry menu of EMAG 2.0 was replaced by a structure window and the display menu by a solution window. VEM included a rich variety of display modes including equipotential contours, potential surfaces, field and flux vectors, and background colors. The VEM interface was designed for "intuitive" operations by new users.

Most recently, Tierney¹¹ has completed VEM 2.0 with the enhancements that include user editing of material properties and the inclusion of conductive materials in the structure window. The display window was upgraded to include flux lines and a 3-D display of potential surfaces. In addition, the flux density along and the total flux crossing a boundary have been included. Unseen to the user, the storage requirement of the TGT coefficients has been reduced significantly in VEM 2.0.

The salient features of VEM 2.0 are summarized below:

- Cartesian (z-invariant) and Cylindrical (rotationally symmetric) structures;
- Conductive, Dielectric, and Magnetic materials;
- Finite differences method;
- Typical Windows[®] drawing commands;

- User edited material properties;
- Display modes that include equipotential contours, potential surfaces, field and flux vectors, flux lines, background color with structure;
- Flux through a specified surface; and
- Open boundary conditions.

A typical solution window is shown in Figure 1.

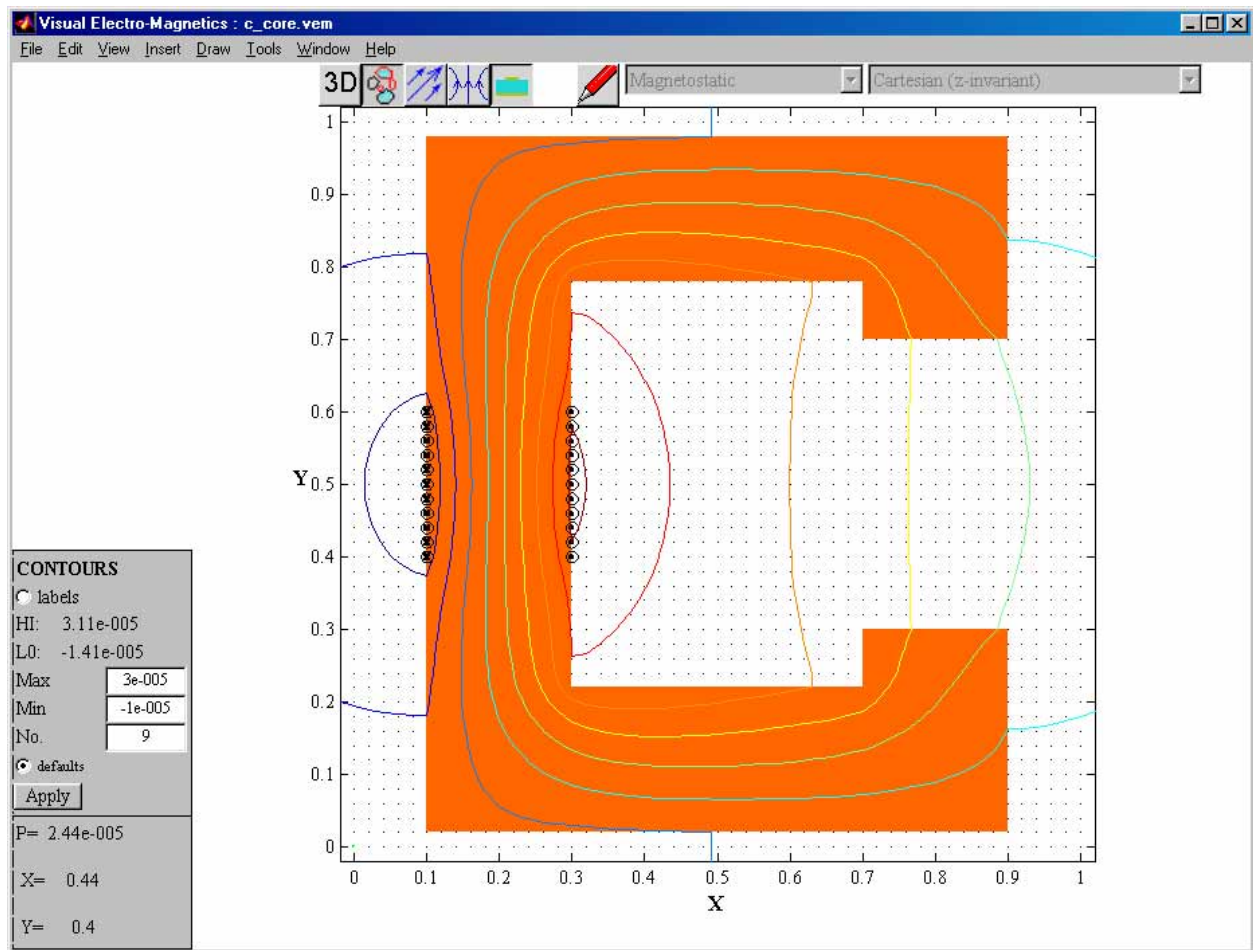


Figure 1 – Typical Solution Window for VEM 2.0

VEM 2.0 in the Classroom and as a Study Aid

Currently, VEM 2.0 is used in a classroom environment in which all students have laptops with MATLAB and network connections. Projection systems enable the instructor and students to display their solutions to the entire class. VEM 2.0 is most often used to supplement the numeric and graphic methods emphasized in the introductory electromagnetics course. From the instructor's point of view, it is a delightful teaching tool.

To date, VEM 2.0 has not been required for students, but is readily available for their use as desired, especially in “what if” homework situations. Preliminary student reaction to VEM 2.0 is very positive. Definitive assessment of the effectiveness as a learning tool is currently underway.

Bibliography

1. Voltmer, D. Undergraduate Electromagnetics: Discrete, Numeric, and Continuous, Proceedings of Progress in Electromagnetic Research, Cambridge, MA, July 2000.
2. URL <http://www.vectorfields.com/op2d.htm>
3. URL <http://www.quickfield.com/>
4. URL <http://www.sonnetusa.com/lite/index.htm>
5. URL http://www.ansoft.com/products/em/max2d/max2d_brochure.html
6. URL <http://www.infolytica.qc.ca/products/gemini/>
7. Manke, Jr, R.P. EMAG: A 2-D Electrostatic and Magnetostatic Solver in MATLAB, M.S. Thesis, Rose-Hulman Institute of Technology, October 1992.
8. Melton, M.R., Manke, Jr., R.P., Wong, P.B., & Lebaric, J.E. Transparent Grid Termination-Open Boundary Conditions for Finite Differences, Session WP13, Digest of the Fifth Biennial IEEE Conference on Electromagnetic Field computation, Harvey Mudd College, August 1992.
9. Wells, D.P. Enhancement of EMAG: A 2-D Electrostatic and Magnetostatic Solver for MATLAB, M.S. Thesis, Naval Postgraduate School, September 1994.
10. Garner, B.D. VEM: An Electromagnetics Visualization Aid, M.S. Thesis, Rose-Hulman Institute of Technology, May 1998.
11. Tierney, W. Enhancement of Visual Electromagnetics (VEM): Flux Lines and Conductive Material Solutions, M.S. Thesis, Rose-Hulman Institute of Technology, May 2000.

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