Session 2632

Real Electromagnetics for Real Engineers – Really!

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Abstract

This paper describes a sequence of classes – *Engineering Electromagnetics I* and *II* that is offered every Fall semester to Junior-level Electrical & Computer Engineering students at Rowan University. The instructors were motivated by a strong desire to make the learning of electromagnetics relevant – not only to other concurrent and subsequent engineering classes that the students take, but also to post-baccalaureate experiences in industry and graduate school. Moreover, since this course has long been feared by students as one of the toughest in the curriculum, the instructors tried to make leaning electromagnetics fun. Instructional techniques that were employed by the professors were based on a significant laboratory component that included numerical modeling, visualization and experimentation. This paper describes classroom/laboratory activity during the Fall 2000 semester offering of this course sequence.

I. Introduction

One of the unique challenges in the new Electrical & Computer Engineering program at Rowan University is to create and effectively deliver courses in the curriculum in 7-week integrated laboratory-lecture modules. These courses complement the semester-long design projects known as "Clinics" that students are required to take every semester of their curriculum. As a team of instructors who teach the *Engineering Electromagnetics (EEMAG) I* and *II* sequence, we were motivated by a desire to create a set of courses, that require students to do real and relevant engineering electromagnetics – and utilize these skills effectively in later courses and clinic projects. It is difficult to tackle all topics in a 7-week period so care must be taken to emphasize key topics and strengthen understanding through real-world laboratory exercises. We present some examples of a successful implementation of these objectives in this paper. We discuss numerous real-world applications that are studied during our single semester sequence of courses. We also show how the topics covered in the *EEMAG I* course are utilized in other courses/projects in the curriculum.

In the first seven weeks of the semester, *EEMAG I* covers electrostatics, magnetostatics and quasistatics – details are provided in the course website[1]. In the second half of the semester, in *EEMAG II*, students tackle time-varying electromagnetic fields. Each of these courses contains an integrated laboratory component. The class meets every week for three 1-hour lecture periods and one 3-hour laboratory session. The following sections describe course objectives and implementation for each of these courses.

II. The First Seven Weeks

The catalog description for *EEMAG I* reads, "The first course in engineering electromagnetics covering applications of electrostatics, magnetostatics and quasistatics in contemporary electrical engineering practice. The course also covers numerical modeling of electromagnetic devices using appropriate software." We translated this to a *minimal* set of *significant* objectives that have *measurable* outcomes. These objectives are introduced to the student at the beginning of the course and constantly revisited as the course progresses. The objectives permeate almost every homework assignment, quiz, project and exam so that each student can assess his or her individual outcomes at each stage. The course objectives for *EEMAG 1* are:
"Given a contemporary stastic/quasistatic electromagnetic device/system, the student should be able to –

(a) Write down the Maxwell's equations that describe this device/system,
(b) Solve these equations for simple geometries using analytical techniques,
(c) Solve these equations for complex geometries using *MATLAB PDE Toolbox*.

The focus of this course is on applications of electromagnetics at a microscale level – inside and around devices such as MOSFETs, EEPROMs, etc. The key learning objectives translate to include the ability to calculate fields for exploring limitations of device size and the ability to calculate energy storage (capacitance, inductance) for exploring limits of operating frequency. A block diagram showing the course content can be seen in Figure 1.

The quizzes and exams contained questions that measured student aptitude for the knowledge and application of analytical techniques. In order to replicate a real-world engineering environment as closely as possible, the exams were not time-constrained – a time limit was suggested, but not enforced. In the laboratory component of the course, student teams did three projects that measured aptitude for the knowledge and application of numerical methods using commercial software, the *MATLAB Partial Differential Equation Toolbox*. There was heavy emphasis on 3-D static and dynamic (movie) visualization. Each project was related to a concurrent or subsequence course in the curriculum.

A discussion of the learning objectives and description of the student projects follows.

(i) Laboratory Project 1: Scalar & Vector Fields

This project is designed to provide the student with an introduction to calculating and plotting scalar and vector fields. This project has three parts. In part 1, students will generate surface/vector plots of static scalar and vector fields. In part 2, they will generate movies of time-varying scalar and vector fields. In part 3, they will compute the scalar and vector electromagnetic fields inside a parallel plate capacitor.

Expected Outcomes: Students learn how to visualize space and time-varying electromagnetic scalar and vector fields.

Relation to Other Courses: This is an introductory project, designed to provide students with some practice working in the *MATLAB* environment.

(ii) Laboratory Project 2: Numerical Modeling of Electrostatic Phenomena

This project is designed to provide the student with techniques to solve electrostatic boundary value problems using numerical techniques. Students will use *MATLAB Partial Differential Equation Toolbox* for computing solutions to Laplace's and Poisson's equations inside arbitrarily shaped 2-D geometries. This project has three parts. In part 1, they will use the *PDE Toolbox* to solve a simple boundary value problem for a rectangular geometry. In part 2, they will apply these solution techniques for calculating the fringe fields in a parallel-plate capacitor. In part 3, they will develop electrostatic models of an n-channel enhancement-mode MOSFET under various operating conditions.

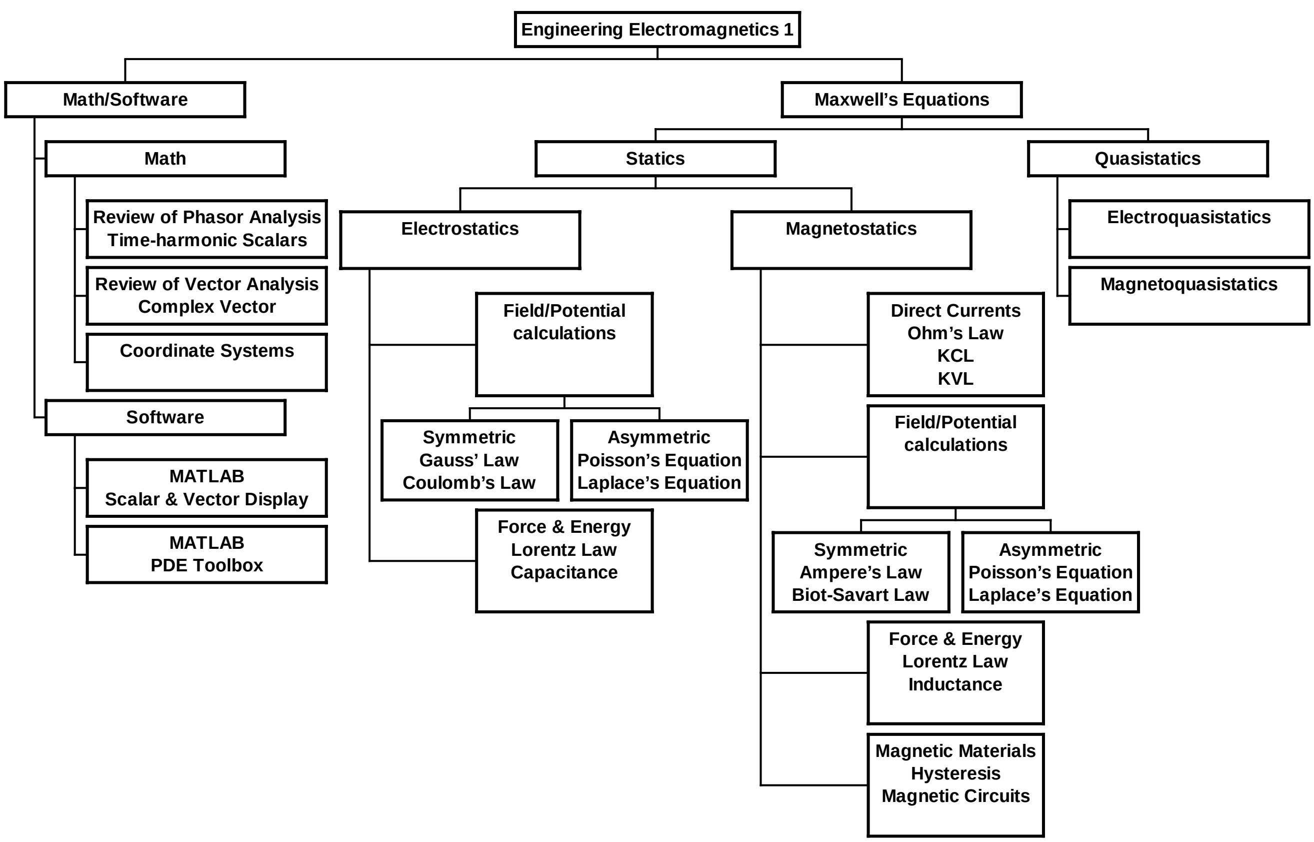

Figure 1: Engineering Electromagnetics I course content.

Expected Outcomes: Students should be able to convert real electrostatic field based devices into 2-D numerical models, assign material properties, apply appropriate boundary conditions and sources, post-process, visualize and interpret simulation results. They should be able to calculate capacitance for arbitrary geometries.

Relation to Other Courses: Learning to use the *PDE Toolbox* is a powerful skill in engineering practice, especially for modeling high-speed microelectronic devices. Students modeled the fields inside a MOSFET that they studied in a prior *Electronics I* course and will encounter again in a subsequent *VLSI Design* course. One of the students employed this tool in a concurrent Clinic design project for calculating the capacitance inside a MEMS-based accelerometer.

(iii) Laboratory Project 3: Numerical Modeling of Magnetostatic Phenomena

In this project students will use *MATLAB Partial Differential Equation Toolbox* for modeling magnetostatic phenomena. This project has four parts. Parts 1 through 3 are required. Part 4 is extra credit. In Part 1, students will compare magnetic fields calculated from analytical and numerical models of a current carrying wire. In Part 2, they will apply the model developed in Part 1, for calculating the magnetic interference fields generated from power lines. In Part 3, they will model a permanent bar magnet. In Part 4, they will simulate a nondestructive evaluation process that is prevalent in the gas pipeline inspection industry (this is extra credit).

Expected Outcomes: Students should be able to convert real magnetostatic field situations into 2-D numerical models, assign material properties, apply appropriate boundary conditions and sources, post-process, visualize and interpret simulation results. They should able to calculate interference fields for various geometries.

Relation to Other Courses: This project is especially relevant for modeling electromagnetic interference/compliance (EMI/EMC) situations. Skills developed in this course were used in the EEMAG 2 course and will be used in subsequent *Digital II*, *Wireless Communications* and *VLSI Design* courses.

III. The Second Seven Weeks

In the second half of the semester, students tackle time-varying electromagnetic fields. A subset of topics is chosen from the areas of transmission lines, plane waves, metal and/or dielectric waveguides and possibly antennas. Electromagnetics has the luxury that many current, real-world applications occur at the macroscale level and thus lend themselves to designing, building, and testing. For example, the PCI data bus, common in most desktop computer systems, relies upon the reflection of waves traveling down a controlled impedance printed wiring board. Students analyze and make laboratory measurements on this structure to increase their understanding of transmission line theory.

IV. Student Response

Although students complained about the fast pace of the courses and the heavy workload, the overall response was overwhelming positive. A total of 32 students took the course in the Fall 2000 semester offering – these were divided into 2 sections for the laboratory portion of the course; the lecture sessions were combined. A sample listing of student comment follows:

> *Labs and tests were very helpful in understanding the fundamentals of electromagnetics theory……*
>
> *Labs were very good but group review of them would be helpful……*
>
> *Even though the material and pace were difficult I felt that the instructor made the class interesting and excited me to learn the material well……*

Bibliography

1. URL: http://engineering.rowan.edu/~shreek/fall00/eemag1/; Engineering Electromagnetics I (Fall 2000).

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