A Pedagogical Approach to Teaching a First Course in Engineering Electromagnetics

Habib Rahman
Saint Louis University
Department of Electrical and Engineering
3450 Lindell Boulevard
Saint Louis, MO 63103, USA
rahmanmh@slu.edu

Abstract

This paper presents a pedagogical approach to the development and teaching of a course in engineering electromagnetics to undergraduate students in electrical and computer engineering at Saint Louis University. It also discusses myriad problems and challenges in offering this course to accommodate the changing discipline boundaries. Engineering electromagnetics, by nature, is not a very popular course to many students because they incorrectly think it is full of complicated mathematics with little or no applications in the real world posing an intellectual and educational challenge to them. It makes this course appear insurmountable, abstract and abstruse. With the evolution of state-of-the-art technologies in electrical and computer engineering, the understanding the fundamental concepts in electromagnetics has become increasingly important. This approach provides tools of accurate analysis through computer methods, in addition to closed-form methods used for design analysis and synthesis. Difficult three-dimensional vector differential and integral concepts are discussed when they are encountered with emphasis being on physical insight. The course is modernized by briefly introducing the finite-difference method, and thereafter, integrating some prewritten computer programs to demonstrate graphical representation of some problems of practical interests. As a result, the students really begin to find a measure of joy in this course and emerge as engineers equipped with the best of the closed-form and computer worlds.

1. Introduction

Saint Louis University, a private university under Catholic and Jesuit auspices, traces its history to the foundation of Saint Louis Academy in 1818, and was renamed Saint Louis University in 1832, becoming the first university established west of the Mississippi River. The University settled at its present site on Grand Boulevard in 1888. Saint Louis University is classified as Research Level II institution by the Carnegie Foundation. The University enrolls more than 13,000 students. Parks College of Engineering, Aviation and Technology, one of the twelve colleges or schools of Saint Louis University, prepares students for careers in engineering, aviation, computer engineering and related fields. The Department of Electrical and Computer Engineering was established in 1987, and is committed to excellence in undergraduate teaching and research. The Electrical Engineering Program, which offers B.S. in electrical and in computer engineering, is accredited by the Accreditation Board for Engineering and Technology (ABET). Currently, the Department offers this three-credit hour course in engineering electromagnetics as a required course to electrical engineering majors at the junior level and as an elective to computer engineering majors.

Engineering electromagnetics is a mature basic science, and is essential in the explanation of action at a distance. It is of fundamental importance to physicists, and to electrical and computer engineers, and appears indispensable in explaining electromagnetic phenomena and in understanding the principle of operation and the characteristics of electric, magnetic and electromagnetic engineering devices. The student is assumed to have completed typical lower-division courses in physics and mathematics as well as a first course in electrical engineering circuits. Understanding electromagnetics and appreciating its applications require a generally higher level of abstraction than most other topics encountered by electrical and computer engineering students. This warrants a systematic and novel approach to organizing topics in engineering electromagnetics in terms of range and depth of coverage. Many challenges and opportunities that are encountered in delivering this course are summarized by Whinnery [1] and Sadiku [2]. Challenges include the need to (1) maintain the student interests in spite of deceasing popularity of the subject of engineering electromagnetics and its reputation as a difficult and abstract subject, (2) cover most of the topics, in one-semester, that are fundamental and of essence to the practicing engineers based upon dynamic fields and their engineering applications, and (3) introduce the process of mastering the electromagnetic model [3] and associated rules of operation.

A solid and firm grasp of the basic principles is now more essential than ever before. An attempt is focused on maintaining a constant link with established as well as new emerging applications, while at the same time emphasizing fundamental physical insight and solid understanding of basic principles. Topics and extents of teaching engineering electromagnetics are chosen such that topics on the underlying principles—essential to practicing engineers and to students pursuing further study in this field—are covered in one-semester. The recommended course contents for a regular three-credit one semester course typically include static electric fields, steady electric currents, static magnetic fields, time-varying fields and Maxwell's equations. In so doing, topics on vector analysis, a language of engineering electromagnetics, are not formally covered in details. One important feature of this approach is to treat bulk of the topics through the use of the Cartesian coordinate system to keep the geometry simple and yet sufficient enough to learn the physical concepts and mathematical tools. It is attempted to maintain a good balance of mathematical rigor that will convince students without causing them to lose interest. The proposed course in engineering electromagnetics aims at the development and understanding of Maxwell's equations [3-8], requiring the extensive use of vector fields. It is this very step that makes the subject of engineering electromagnetics appear insurmountable to many students and turns off their interest. To overcome this difficulty, the topics of vector analysis are presented when it is necessary, and the importance of acquiring these mathematical tools in the study of engineering electromagnetics cannot be overemphasized.

This approach provides tools of accurate analysis through computer methods, in addition to closed-form methods used for design analysis and synthesis. The course is modernized by briefly introducing the finite-difference method, and thereafter, integrating some prewritten computer programs. As a result, the students really begin to find a measure of joy in this course and emerge as engineers equipped with the best of the closed-form and computer worlds. Some examples are included to demonstrate graphical representation of some problems of practical interests.

2. Recommended Course Contents

This course is specifically designed for a one-semester first course in engineering electromagnetics, nowadays typically the only required electromagnetic fields and waves course in electrical and computer engineering curricula. The recommended course content of ECE-340 for spring of 2013 at Saint Louis University is provided in Table 1.

Week #	Week	Activity
1	Jan 14 – Jan 18	Introduction, Coulomb's Law, Vector Analysis
2	Jan 21 – Jan 25	Martin Luther King Holiday: Jan 21 Electric Fields
3	Jan 28 – Feb 01	Electric Potential
4	Feb 04 – Feb 08	Gauss's Law and Applications
5	Feb 11 – Feb 15	Metallic Conductors
6	Feb 18 – Feb 22	Poisson's and Laplace's Equations Test I: Friday, Feb 22
7	Feb 25 – Mar 01	Capacitance: Dielectric Materials
8	Mar 04 – Mar 08	Boundary Conditions; Electrostatic Forces and Energy
9	Mar 11 – Mar 15	Spring Break: Mar 11 - 15
10	Mar 18 – Mar 22	Steady Electric Currents
11	Mar 24 – Mar 29	Biot-Savart Law and Applications Easter Break: march 28 – 29
12	Apr 01 – Apr 05	Easter Break Contd.: April 01 Ampere's Circuital law Test II: Friday, April 05
13	Apr 08 – Apr 12	Vector Magnetic Potential: Magnetization
14	Apr 15 – Apr 19	Inductors; Faraday's law; Magnetic Forces
15	Apr 22 – Apr 26	Maxwell's Equation; Displacement Currents
16-17	Apr 29 – May 10	Time-Varying Fields and Waves Final : Friday, May 10 at 12:00 – 01:00

Table 1. Recommended Course Contents

3. Vector Analysis

The fundamental laws of electromagnetics, expressed in compact form by the application of vector analysis, involve spatial relationships. Vector analysis deals with the formulation of fundamental laws involving two or more spatial dimensions. Many of the quantities encountered in the mathematical description of electromagnetic phenomena are vector, and can best be handled using vector analysis. Vector calculus treats those vector fields which change with respect to space and time.

In order to cater to new trends—teaching topics of engineering electromagnetics that are of essence to practicing engineers—the important topics of vector analysis and calculus are assigned as reading material at the beginning of the course. Students have usually been taught this material in mathematics courses, and are assumed to have background material that is required for a traditional course in engineering electromagnetics. As a result, the material does not have to be covered in lectures and thereby allows time to introduce the computer-based numerical methods of electromagnetic field analysis.

4. Computer-based Numerical Methods

The most recent trend in engineering electromagnetics is the introduction of computer-based numerical methods of electromagnetic field analysis. Solving electromagnetic field problems using compute methods have been very useful and efficient in recent days. In most of the universities, a first-year course in programming is a requirement for graduation. With this tool, students should be able to integrate their training and experience to gain more insights of electromagnetics by presenting graphic-based images of fields.

To emphasize the application of computer to visualize fields, the course briefly introduces the finite element method, the most important of all numerical methods for the solution of field problems. Students are exposed to prewritten computer programs that would require them only data preparation to explore the results of analysis. On example of the prewritten programs is the interactive *QuickField* finite element analysis system which is repeatedly used to illustrate various electromagnetic problems of practical interest. *QuickField* is easy to use and does not require a long training. Moreover, most of *QuickField* procedures are so intuitive and straightforward, that it is usually enough to see them once and avoid reading any written instructions. Therefore, one could find that it is most effective to learn *QuickField* basics by simply playing with examples provided.

Two examples are provided to demonstrate the scope of observing potential distributions and field gradients pertaining to (i) four infinitely long conducting strips of equal width, situated such that the cross-section of the arrangement is a square as shown in Figures 1 and 2, and held at zero potentials except for the top one held at 100 volts, and (ii) a geometry bounded by six infinitely long conducting strips of uniform width, situated such that the cross-section of the arrangement is represented as shown in Figures 3 and 4, and held at zero potentials except for the top three strips at 100 volts. Students completing these projects had very clear pictures of the potential distributions and field gradients for the prescribed geometries with the variation with two dimensions. As noted, the exact solutions of Laplace's equations with such boundary conditions are complex in nature.

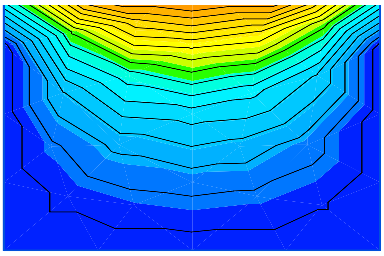

Figure 1. Potential distribution

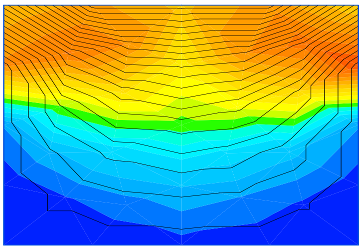

Figure 2. Field gradient

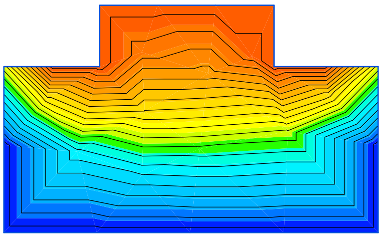

Figure 3. Potential distribution

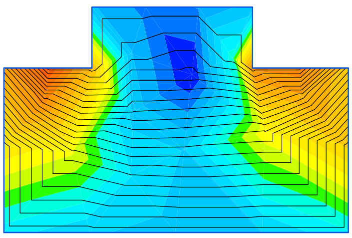

Figure 2. Field gradient

4. Conclusions

This paper addresses the challenges in teaching engineering electromagnetics in the undergraduate electrical and computer engineering curricula. It also outlines the pedagogical approach to face and overcome these challenges in order to deliver the course in one semester and cover those topics of elctromagnetics that are fundamental and of essence to the practicing engineers based upon dynamic fields and their engineering applications. The course concentrates on the underlying basic principles so that engineers, in their professional life, are prepared to handle new material with keen perception and proper understanding. In order to accommodate the desired topics, the essential topics on vector analysis—the language of engineering electromagnetics—are assigned as reading material at the beginning of the course thus freeing times for new computer methods. Students have usually been taught this material in mathematics courses, and are assumed to have background material that is required for a traditional course in engineering electromagnetics. As a result, the material does not have to be covered in lectures. Furthermore, the additional concepts on vector analysis are introduced using just-in-time approach. This novel approach of teaching electromagnetics treats bulk of the topics through the use of the Cartesian coordinate system to keep the geometry simple and yet sufficient enough to learn the physical concepts and mathematical tools. It is attempted to maintain a good balance of mathematical rigor that will convince students without causing them to lose interest. Solving many problems of practical interest by computer methods is addressed by briefly introducing the finite element method and, thereafter, using prewritten programs, such as, interactive *QuickField* finite element analysis system, which is repeatedly used to illustrate various electromagnetic problems particularly by presenting graphic-based images of fields. *QuickField* was liked by students as an extremely friendly tool, applicable for a variety of field problems, and for providing fast and accurate results. Students were required to write their own programs using any scientific languages to verify the results obtained by *Quickfield*. And, as a result, the students really begin to find a measure of joy in this course.

This novel approach of teaching was applied for the first time in the spring semester of 2013 in a clearer and more interesting manner than ever before. No formal assessment of the course was carried out; however, student evaluations at the conclusion of the semester provide enough positive comments and directions. It is our conviction that a new breed of engineers, in the field of engineering electronagnetics, will emerge through this training and experience exploiting the best of the traditional engineering electromagnetics and modernized computer applications.

5. References

1. A. B. Whinnery, “The Teaching of Electromagnetics”, *IEEE Transaction on Education*, 33(1); 3-7 (1990).
2. M. N. Sadiku, “Problems Faced by Undergraduates Studying Electromagnetics”, *IEEE Transaction on Education*, 29(1); 31-32 (1986).
3. Maxwell, J. C., A *Treatise in Electricity and Magnetism*, Claredon Press, Oxford, Vol. 2; 247-262 (1892).
4. L. Page, “A Derivation of the Fundamental relations of Electrodynamics from those of Electrostatics”, *American Journal of Science*, 34; 57-68 (1912).
5. Cheng, D. K., *Fields and Waves in Electromagnetics*, Second Edition, Addison Wesley Publishing Company (1989).
6. Inan, U. S., A. S. Inan, *Engineering Electromagnetics*, Addison Wesley Longman, Inc. (1999).
7. Elliott, R. S., *Electromagnetics*, IEEE Press, New Jersey (1993).
8. Jackson, J. D., *Classical Electrodynamics*, Second Edition, Wiley, Chapter 12, Section 12.2 (1975).