Electromagnetism for Engineering Technology

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ABSTRACT

As the wireless revolution is maturing in its technological life cycle, the principles and concepts of electromagnetism (EM) have once again become a curriculum necessity rather than a curriculum novelty. The theory of EM continues as a core course in electrical engineering curricula and covers all the fundamental electromagnetic theory that is needed in later engineering courses. In engineering curricula, the EM course is supported by math courses in calculus and vector analysis and at least one engineering physics course in electromagnetic principles. In contrast, electronic engineering technology (EET) curricula tend to shy away from the fundamental EM concepts, choosing instead to offer courses in specific application areas of EM such as transmission lines, antennas, and/or RF electronics. The only EM preparation for EET students is basic calculus and an introductory physics course in basic electric and magnetic fields theory (typically algebra based). The dilemma facing EET curricula is providing a course that emphasizes EM principles with many practical examples within the structurally-mandated environment (state, institutional, and accrediting agencies) that most EET programs exist.

Introduction

One of the most profound achievements in classical physics was combining the laws of electricity and magnetism into the four equations known as Maxwell's equations.[1] These equations were published in 1873 and were deduced from experimental observations reported by Gauss, Ampere, Faraday, and others.[2] Maxwell's equations form the basis of electromagnetic theory. The equations (Figure 1) are so simple that they can be put on a T-shirt, yet sufficiently rich and dynamic to provide the emphasis for many of the modern developments in electrical engineering.

$$\nabla \bullet \mathbf{D} = \rho_v ,$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} ,$$

$$\nabla \bullet \mathbf{B} = 0 ,$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t} .$$

Figure 1. Maxwell's Equations

Although Maxwell's equations are the basis for EM and much of electrical engineering, EM has surprisingly had a roller coaster existence in engineering curricula. Maxwell's equations were seldom mentioned in engineering curricula before 1930.[1] The absence of Maxwell's equations from college curricula changed with the development of microwave during World War II. More recently, a uniform need for EM in certain engineering specialties has become less clear as electrical engineering has expanded and become more diverse.

While there is coverage of EM in traditional electrical engineering programs, the engineering technology (ET) programs have been hesitant about teaching EM.[3] In engineering curricula, the EM course is supported by math courses in calculus and vector analysis and at least one calculus based engineering physics course in electromagnetic principles. In contrast, EM concepts are incorporated in specific application areas of EM such as transmission lines, antennas, and/or RF electronics. The only EM preparation for EET students is basic calculus and an introductory physics course in basic electric and magnetic fields theory (often algebra based).

Mandates

Whether an engineering curriculum or an ET curriculum, increasing amounts of knowledge and new technology developments are pushing back subjects like EM in the curricula.[4] Likewise, regulatory environment (state, institutional, and accrediting agencies) put stresses on the curricula.

In order to reduce the State's portion of educational costs, the Tennessee Board of Regents (TBR) has mandated that they will fund a 120 semester hour curriculum. Engineering related curricula were exempted to a 128 semester hour curriculum in order to meet the 124 semester hour minimum established by the Technology Accreditation Board of the Accreditation Board of Engineering and Technology (TAC of ABET). This is a reduction from the previously 137 semester hours in most of the engineering technology programs at East Tennessee State University.

TBR has also mandated that 41 semester hours of the 128 semester hours will meet certain general education standards: English, math, science, history, art elective, social science elective, etc. The Department of Technology has mandated that all programs within the department are subject to a 19 semester hour technology core to fulfill Southern Association of Colleges and Schools (SACS) requirements. Likewise, TAC of ABET has some ancillary requirements related to specific program outcomes.

The Need for EM

East Tennessee State University (ETSU) offers two closely related programs: Electronic Engineering Technology (ENTC) and Biomedical Engineering Technology (BMET). The TBR mandates provided the opportunity to make wholesale changes in each of the programs. ENTC opted to develop a curriculum based on electronic specialties: general electronics, telecommunications, and instrumentation. BMET, already a specialty, opted to tinker with the requirements for graduation including the addition of an EM course.

Before the TBR mandates, two telecommunication courses existed: network systems and telecommunications. The network systems course is an introductory course emphasizing the physical layer associated with the seven layer model of data communications. The course is based upon the first course of the four course Cisco Certified Network Administrator (CCNA) certificate program. With so many community colleges and even high schools offering the CCNA, one of the intents of the course was articulation between the high school or community college and the four-year technology programs at East Tennessee State University. Other academic disciplines have shown a keen interest in network systems because of the boom in computer networks and wireless communications and because the network systems has no mathematical or technology prerequisites.

The telecommunications course is a much more mathematically intense course emphasizing the analysis of wireless communications systems. Emphasis is on transmission lines, Smith charts, noise, random processes, modulation, and antennas, especially at the higher frequencies. One of the curriculum stalwarts in BMET is medical imaging: X-ray, ultrasound, magnetic resonance imaging (MRI), and positron emission tomography (PET). Each is based on EM radiation.[4] MRI, for example, uses a strong superconducting magnet to align the magnetic moment of the hydrogen protons that exist in the water (H_2O) content of the body. This alignment (*equilibrium*) is in the *z*-direction (*laboratory frame*) and is known as *longitudinal magnetization*. A set of radiofrequency (RF) pulses (*transverse magnetization*) are applied that displace the magnetic moment of the protons from equilibrium conditions. Return to equilibrium results in emission of MRI signals proportional to the number of excited protons in the sample with a rate dependent on the characteristics of the tissues.

The weaknesses in the telecommunications specialty and medical imaging revolved around the depth of coverage. The depth of coverage was hindered by the lack of understanding that many ET students have of three dimensional analysis. Like many ET programs, the students at ETSU take two semesters of technical physics: mechanics and electromagnetism. These physics courses are also taken by non-technical majors (nursing, business, etc.). As a result, these physics courses have a broad scope and are algebra-trigonometry, two-dimensionally based with limited calculus and discussion of three dimensional systems. With such a broad scope, perhaps the so-called non-technical physics courses are not good for anyone.[6]

The ENTC concentration at ETSU felt that many of the concepts covered in the EM part of the physics sequence was a repeat of the material covered in the introductory electrical principles course in the ENTC curriculum. In order to allow greater depth of coverage in telecommunications and bioinstrumentation and electronics in general, the physics department was asked if they would develop a more intense EM course for the ET students. The physics department was unsupportive, suggesting that the ET students take the calculus-based sequence of physics courses as the prerequisite for their existing EM course. As result of the need for a more advanced EM course and the lack of support from the physics department, the EM course was developed as an ENTC course.

Although the ENTC program kept two semesters of physics as its TBR mandated general education requirements in science, the BMET program dropped one of the physics courses (electromagnetism) and added a chemistry course to satisfy its TBR mandated general education requirement in science and to meet TAC of ABET ancillary requirements related to BMET programs.

Course Curriculum

The EM course was developed using the book, Fundamentals of Applied Electromagnetics: 2004 Media Edition by Fawwaz T. Ulaby.[2] The book was relatively easy to follow and had several worked examples. The accompanying disk contained additional solutions to many of the problems at the end of the chapters as well as jpeg files of all of the figures in the book allowing for power point presentations that followed the book. The accompanying disk also provided several animations related to course material.

The EM course is required for the telecommunications specialty in ENTC and for all BMET students. The course was taught for the first time during the Fall Semester of 2004 with 12 students in the class. The course material included chapters 3, 4, 5, 6, and some material on optics from chapter 8. Presently, there is no lab associated with the course, but EM courses taught in ET programs at other colleges do offer labs.[3,6]

Chapter 3 is a review of vector concepts including the unit vector, vector addition and subtraction, and scaler and vector multiplication. The coordinate systems (Cartesian, cylindrical, and spherical) are covered along with vector calculus (integration—line, surface, and volume integrals—and differentiation). Chapter 4 is a study of electrostatics: Coulomb's law, Gauss's law, Joule's law, the electric field, charge, potential, current, resistance, and capacitance. Chapter 5 looks at magnetostatics: Lorentz's equation, the Biot-Savart law, Ampere's law, field density, and inductance. Chapter 6 investigates time varying fields: Faraday's law, Lenz's law, transformers, motors, and generators. Chapter 8 covers optics including Snell's law, fiber optics, polarization, and geometric optics.

Intended and Unintended Consequences

The major intended outcome was to develop an intermediate level EM course that would provide the EM concepts needed to allow more breadth in the existing telecommunication course and BMET curriculum. At the end of the course, each student completed a survey related to the course (Appendix A). Although the surveys were by no means scientific, overall the students seem to feel that they made improvements regarding many concepts related to EM. The area that seems to challenge the students the most was vector calculus. Surprisingly, most students seemed to be comfortable with coordinate systems and vector graphs.

Many of the students were simultaneously taking medical imaging. The students seemed to grasp many of the EM concepts much faster and much more thoroughly than those in previous sections. This allowed for more material to be covered in more detail. Because of the vector calculus covered in the EM course, the students were more comfortable with the Fourier integral than other sections have been. Although telecommunications course will not be offered until the spring of 2006, there is every confidence that the students that have taken EM will be able to cover more material in more detail.

One of the unintended consequences of the EM course is the ability to reduce some of the material covered in some of the earlier courses, especially the ENTC electrical principles course. The electrical principles course is the first electricity/electronic course for the ENTC curriculum. Because some manufacturing technology majors are required to take the electrical principles course, both direct current and alternating current circuits are covered. The amount of material that must be covered puts a premium on time in a course that is the foundation for all the other ENTC courses. The EM course covers many of the same concepts (current, voltage, resistance, capacitance, and inductance) that are covered in electrical principles. As a result, the instructor in principles can spend more time on the concepts that give electronic students problems (complex numbers, network theorems, circuit arrangements, etc.) while the EM course can develop the material related to electrostatics and magnetism.

Conclusions

The success and future of academic programs in engineering technology are related to the employability of its graduates.[7] At no time has the growth of technological knowledge been so profound. The reward for being technologically literate is strong career fields that typically provide steady employment, training opportunities, fringe benefits, and promotional opportunities.[8] With each new advance in technological knowledge, there is a corresponding demand for new, increasingly computer literate professionals. Much of the newer knowledge is related to higher frequency, wireless technology and requires some knowledge of EM.

New technical knowledge and new technical topics continue to pressure overloaded engineering and engineering technology curricula. The dilemma is how to teach ever expanding technological knowledge in shrinking curricula. An ET based EM course can stand alone in the curriculum or can supplement the concepts covered in a physics EM course. An EM course in an ET curriculum provides coverage of multivariate calculus, vector analysis, and multidimensional coordinate systems while providing an introduction to EM concepts and Maxwell's equations, the foundations of high frequency analysis. More important is the impact of EM on the rest of the curriculum where better prepared students can cover more advanced material more deeply.[3]

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Appendix A—Course Survey

1. Did the lectures and assignments provide the general principles, theories, concepts, and/or formulas associated with vector analysis?
   - Extremely valuable 20%
   - Very valuable 70%
   - Valuable 10%
2. Do you think that this course is more valuable than an algebra based electromagnetism course?
   - Extremely more valuable 10%
   - Much more valuable 40%
   - More valuable 30%
   - About the same 10%
   - Not more valuable 10%
3. How would you rate your understanding of vectors?
   - Very good 70%
   - Better 30%
4. How would you rate your understanding of magnetism?
   - Very good 70%
   - Better 20%
   - Uncomfortable 10%

5. How would you rate your understanding of electrostatics?

- Very good 50%
- Better 40%
- Uncomfortable 10%

6. Have you analytical abilities using calculus improved?

- Tremendously 10%
- Measurably 60%
- Somewhat 30%

7. What concepts did you have the most difficulty? (multiple answers)

- Vector algebra 0%
- Coordinate systems 10%
- Vector calculus 50%
- Electrostatics 30%
- Magnetostatics 40%
- Vector graphs 10%

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Wm. Hugh Blanton received the B.S. Technology degree in electronic engineering technology from the University of Houston in 1971, the M.S. in math/physics education from West Texas State University in 1979, the MBA from West Texas State University in 1986, and the Ed.D. in educational leadership and policy analysis from East Tennessee State University in 1992. He has taught electronic engineering technology at various colleges and universities since 1974 as well as worked as a biomedical technologist at Baylor College of Medicine, as a consultant in wind energy at the Alternative Energy Institute, and as a research engineer in instrumentation at Southwest Research Institute. He is currently the coordinator of the Biomedical Engineering Technology concentration and an assistant professor in the Department of Technology and Geomatics at East Tennessee State University. He is interested in applications of DSP, neural networks, and fuzzy logic to telecommunications and control systems.