AC 2010-1862: PROJECT-BASED INTRODUCTORY ELECTROMAGNETICS COURSE FOCUSED ON INCREASING STUDENTS' INTEREST AND MOTIVATION

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Project-Based Introductory Electromagnetics Course Focused on Increasing Students' Interest and Motivation

Abstract

This paper discusses course material being designed under the National Science Foundation's (NSF) Course, Curriculum and Laboratory Improvement (CCLI) grant # 0632842 "Developing Leadership and Innovation in Engineering Students Through Undergraduate Courses in Applied Electromagnetics Built Upon Novel Educational Concept" to specifically address the problem of students' declining interest in electromagnetics (EM), while applications of EM continue to permeate many areas of electrical engineering both in the industry and academia. The new approach to teaching introductory course of EM aims to spark students' interest to the subject via offering them several real-world problems. The project has its major emphasis on increasing students' motivation for studying electromagnetics by re-developing the course flow. The educational concept being explored is based on breaking down the course into 4-5 lecture/lab mini-projects, each focused on a particular theme of interest to engineers and researchers nowadays. As part of this project, a senior capstone research on Wireless Electricity Transfer was implemented during 2007-08 by a computer engineering student. The paper will present the results of this and several other projects designed and developed under the NSF CCLI grant and discuss the students' changing attitudes to electromagnetics.

Introduction

"Electromagnetics is hard." This is probably one of the most common first thoughts that come to mind whenever electromagnetics (EM) is invoked. The real meaning of this phrase is often even more discouraging: EM is widely believed to be overly theoretical, unintuitive and a little irrelevant in today's engineering world. And this is, typically, an opinion of a person who is somewhat familiar with EM, e.g. a graduate engineering student who took electromagnetics during their junior or senior year (and never looked back ever since). For undergraduate students who take their first course in EM the picture usually looks even more dismal. Allow me to quote some of the students who took Applied Electromagnetics class with me last semester – these are their responses to the question "What is your perception of EM?" posed during the first class meeting:

- "…I was apathetic towards EM. I knew it was very math and physics intensive and I thought that it would be very boring."
- "…I actually was very interested in EM…and found it to be the only part of physics that was not so predictable…I couldn't think of many applications off the top of my head."
- "…I was very intimidated by the subject. When I glanced through the book [and] read the first few pages…I think I was more confused afterwards."
- "…I thought we would be working with electromagnets and motors. For example, the electromagnetic locks, which can be seen as the black boxes that say Locknetics above some of the doors."

Those were the answers from good engineering students with average GPA well above 3.0. The same students who expressed keen interest in “more applied” subjects, like circuit analysis and signal processing before. Although somewhat discouraging – clearly, my course’s topic wasn’t the most exciting in any student’s schedule at the beginning of the semester – the assessment was also incredibly thought provoking. After all, the truth of the matter is that EM is a much applied discipline, with myriad of examples in the industry and academia. In a way, it is actually quite unique in that it permeates many boundaries of traditional subjects, such as circuit analysis, signal processing, and more applied fields – radar engineering, remote sensing, signal integrity, industrial engineering (e.g. induction heating) and bioengineering/biophysics (e.g. EM field effects on a live organism). So, how does one make sure that the students who come to their first class on EM are aware of these benefits and appreciate the strong applied nature of EM in today’s world?

After reflection on these observations, we came to a conclusion that a good way to address the question above would be to gain experience in (and test-run) Project-Based Learning (PBL). It appears that engineering has inherent appeal due to its strong “hands-on” component – we have not met a student of engineering yet who wouldn’t be fascinated by the applied nature of the subject, which translates into “building something” or “seeing something work.” PBL is also advantageous from the perspective of structuring the coursework to maximize its impact on the students’ ability to a). Find a desirable job, and b). Succeed in it – and it’s no secret that present-day industry operates in terms of projects. Thus, it has been decided that our teaching project will focus on the concept of PBL as a centerpiece of an introductory course on EM.

PBL has been studied quite extensively in the engineering community in recent years and it continues to command attention[1–3]. It is especially advantageous when applied to courses which serve as introductions – not necessarily first-year oriented, but those courses that provide the first look into a sub-discipline, such as electromagnetics. Also, as an introduction, a good review of PBL and PBL-related research is available[4], along with definition and characteristics of PBL: “Project-based learning (PBL) is a model that organizes learning around projects. According to the definitions found in PBL handbooks for teachers, projects are complex tasks, based on challenging questions or problems, that involve students in design, problem-solving, decision making, or investigative activities; give students the opportunity to work relatively autonomously over extended periods of time; and culminate in realistic products or presentations.”

Project Descriptions

Arguably, the most challenging aspect of PBL is design of projects. The projects should be viewed not as peripheral to the course material – in fact, auxiliary projects exist in many engineering courses, for example as laboratory exercises – but central to it. Below are descriptions of several projects which were particularly successful in garnering students’ interest and motivation. These projects were implemented over the 2007-09 academic years and we continue to develop new ones, with an eventual goal of creating a multi-project database.

A. WiTricity: Wireless Power Transfer Installation

The concept of wireless power transfer has been investigated ever since the early 1900's when Nikola Tesla started experimenting with the idea. The team of researchers at MIT in 2006 took his experiments one step further to determine that evanescent resonant coupling is ideal for efficient wireless power transfer in the near-field[5]. Our project utilizes MIT's research to create a strong coupling regime between an oscillatory circuit and a resistive load. Our goal is to wirelessly power an electronic device first through a set of identical coils resonating at equal frequencies and then take it a step further to decrease the receiver coil, while maintaining the efficiency of power transfer. The senior capstone project focused on experimental concept of a wireless charging device – for example, to charge an electric car without actually plugging it in. System prototype was built and tested at very low power levels (enough to light up an LED), thus proving the feasibility of such an implementation.

The project consisted of two stages – each one semester long. The first phase was simulation modeling of the transmitting and receiving coils using a software simulator. The first phase began with the breakdown of our exact coil parameters. Prior to determining the exact parameters for the set of identical coils to be created, the effects of each parameter on the resonant frequency was needed to be understood therefore each parameter selected would be ideal. The implementation of the second phase with the decreased receiver coil required a complete understanding of exactly which parameters had the greatest impact on the resonant frequency, therefore the selected parameters would cancel the alteration of the resonant frequency and kept it constant.

Ansoft High Frequency Structure Simulator (HFSS) was utilized to run numerous simulations to determine the most influential parameters with respect to the resonant frequency. Ansoft HFSS offered a 3D full-wave Finite Element Method (FEM) to compute the electrical behavior of high frequency components. Four parameters were selected to isolate and run simulations to determine their influence on the resonant frequency: the cross sectional radius, helix radius, helix pitch, and the number of turns. Each parameter was altered and tested by comparing the increase and decrease of the selected parameter to a control. The control was chosen from the parameters that MIT utilized and then three larger increments and three smaller increments of the parameter were run comparing each alteration to determine the overall effect of the isolated parameter on the resonant frequency. Figure 1 illustrates the simulation setup and the topology drawn in Ansoft HFSS and the simulated dependence of the resonant frequency of the helix coil structure on the helix radius.

The second phase of the project was experimental design and test of a wireless electricity transfer module. A full-scale model was erected and measurements were performed. A simple laboratory generator was used to power the transmitter coil, thus practical implementations were not part of the procedure; a light-emitting diode (LED) was used to correlate measurements with theoretical data – i.e. when the resonant frequency was optimal the LED would shine brighter. The samples of collected data and the installation itself are illustrated in Figures 2 – 3.

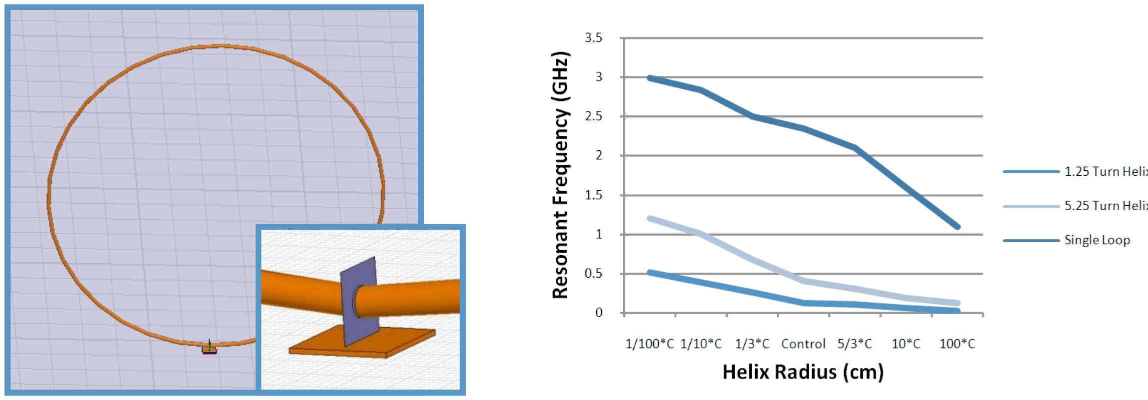


Figure 1 Topology drawn in HFSS (left); Simulation result showing resonant frequency dependency on helix radius (right)

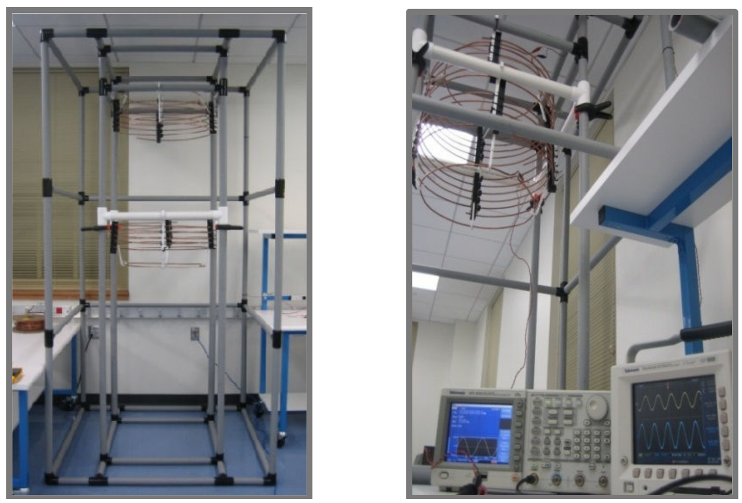
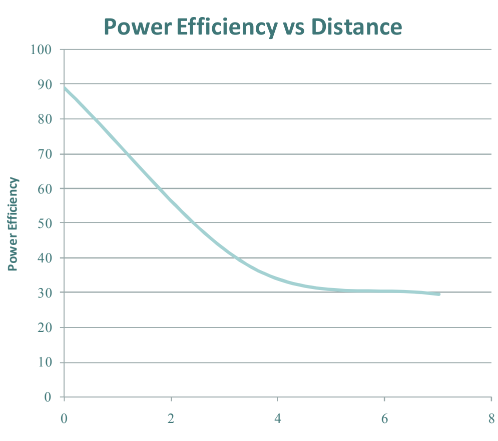


Figure 2 Experimental setup with coil separation ~ 1 meter (left); experimental setup with zero coil separation and signal generator/oscilloscope visible (right)



Distance	% Efficiency
0 ft	88.97
3.5 ft	34.33
7 ft	29.20

Figure 3 Measured power transfer efficiency as a function of distance between the coils.

B. Capacitive De-Ionization (CDI)

Another project took place as a class project in Spring 2009: capacitive de-ionization (CDI) of brackish water, which is based upon the principle of electrostatics, as illustrated in Figure 4.

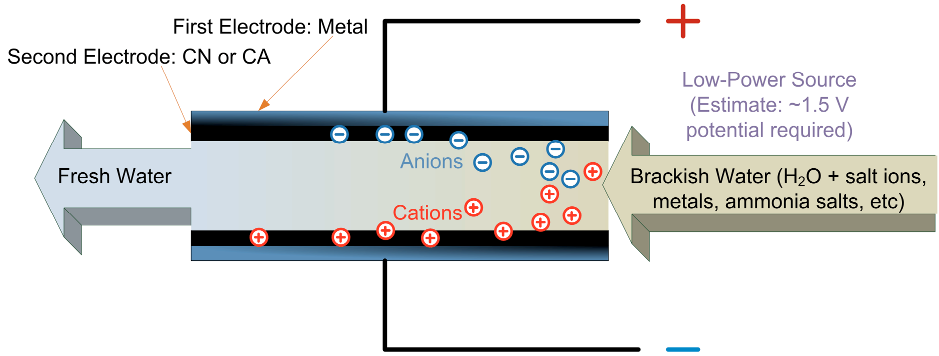


Figure 4 CDI concept illustration

The goal of this project was to design, analyze and construct a water desalination device method and prototype based on CDI technology. CDI is a relatively new technology, which was first proposed about half a century ago. It is still considered a novel method, alternative to the widely implemented mechanical methods, such as reverse osmosis, which require high water pressure, frequent changing of membranes and are generally regarded as not very power-efficient[6,7]. Due to material limitations CDI was not developed commercially, however, it received a significant boost in the late 1990's when carbon aerogel (CA) – invented about a decade earlier – was proposed to be used as ion absorber in a CDI cell. In general, CDI is deemed very efficient in many aspects – perhaps most important of which is its low energy use. In addition, a CDI system does not require high water pressure and it can be implemented without any membranes. These characteristics make CDI much more suitable for small-scale system implementation, which is relatively inexpensive to manufacture and maintain, facilitating access to water purification in remote and/or poor areas. This is of increasing importance due to a number of factors: Earth's population growth, which places unprecedented demands of water supplies; the desire to solve water desalination problem more energy-efficient ways; changing climate and demographics in many parts of the world, which may further induce the R&D efforts to create a portable, cheap, and low-energy water purification/desalination system concept. CDI technology works best for brackish water[8], which has lower salinity than regular ocean/seawater. Because of this, it can be utilized in remote areas with brackish water supplies, where energy requirements can be satisfied by using renewable energy sources, such as solar or wind power. The examples of areas with significant supplies of brackish water, but relatively low economic potential for building industrial water desalination plants based on conventional technology are underground saline lakes in New Mexico and West Texas, brackish water lagoons of Southern India, brackish springs in Jordan and other areas in the Middle East, and brackish water lakes in coastal regions of Africa. The concepts used to devise the system are deceptively simple and accessible to a high school graduate. Behind the initial simplicity, however, lies an enormous opportunity to expand the topic in a number of directions – solar power implementation, novel material research, fluid mechanics, chemical analysis (can anything else besides the salt be filtered this way?), and entrepreneurship, among others. Applicability of EM and its static fields sub-topic is readily evident. One can envision the initial system prototype being developed into a manufacturable device that can be used in field tests and, eventually, serve the goal of providing inexpensive, portable water desalination technology to the underdeveloped areas with brackish water supplies.

A preliminary result obtained by the 12-student-strong team in Spring 2009 is that, indeed, CDI can be implemented and successfully tested in student laboratory conditions. An illustration of the initial lab setup and the measured data, showing the efficiency of salt removal, is shown in Figure 5.

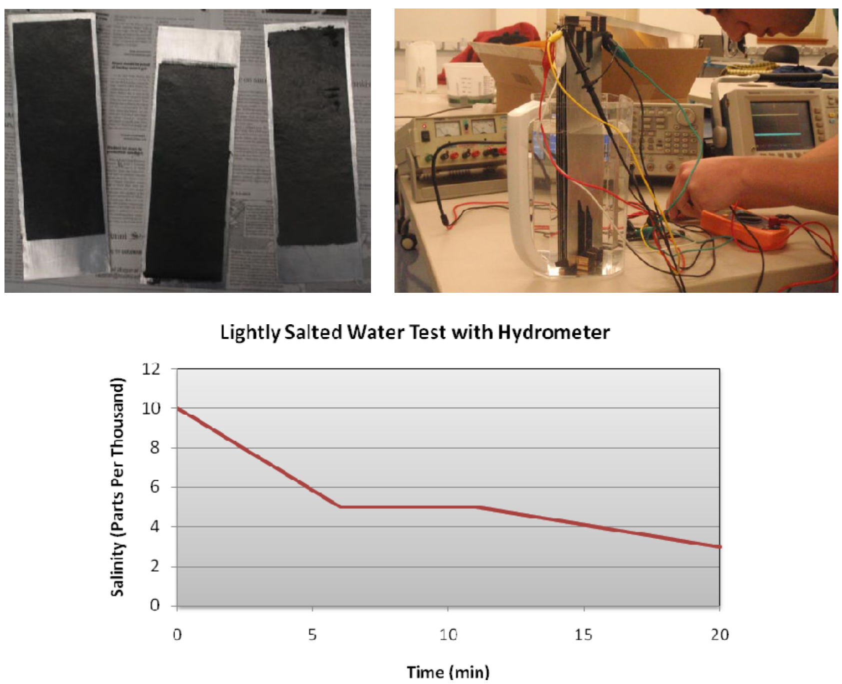


Figure 5 Carbon nanofoam paper electrodes atop aluminum plates (top left); System prototype test installation (top right); Measured test results for lightly salted (brackish) water (bottom).

C. Student Feedback

The reception of these and other developed projects (more will be presented in the final paper) was very good. Below are statements written by the students at the end of the semesters as part of the anonymous questionnaire on course and instruction efficiency.

- "…I am interested in taking higher level EM courses…I can see how EM can be factored into many – if not all – EE job opportunities."
- "My interest in EM has definitely increased after taking this course…Getting to use Ansoft and being able to build a device that uses the principles of electric fields to accomplish a task helped tie in-classroom learning to real world applications…"
- "My interest in EM has certainly been heightened by this course if only for the reason that…the gap between theory and reality was so solidly filled. It's very comforting to know that I can look at cell phones, antennas and computers and know the underlying principles behind their operation rather than just take them for granted."
- "I now know that most of the class deals with electric and magnetic fields as well as transmission line crosstalk and interference. My interest in EM has been heightened, because I have been introduced to a new field within electrical engineering where crosstalk, which I'll admit was somewhat ambiguous before, is analyzed and explained clearly."

Subjectively, the students described the course as "interesting and applicable." All of the students (12) "strongly agreed" or "agreed" that the contribution of the course to their education was "apparent" and all have rated the course as "excellent." 11 of the 12 students have "strongly agreed," while 1 student has "agreed" with the following statement: "This course has significantly improved my understanding of modern Electromagnetics and engineering practices, challenges, techniques and solutions." 10 of the 12 students "strongly agreed" and 2 have "agreed" with the following statement: "This course has heightened my interest to EM and made me aware of benefits of studying it." Overall, the course was a success, with many students sharing their increased appreciation of electromagnetics in peer conversations and trying to apply EM principles in engineering problems associated with other courses and projects.

Conclusion

PBL is a viable educational instrument, which has become a centerpiece of this NSF-supported project. The students' reactions to course projects have been overwhelmingly positive, and external evaluations solicited and received from other faculty have indicated that PBL has the potential to revive the subject of electromagnetics. The challenging aspect of PBL is the development of relevant, timely and manageable projects, which have a good student appeal. The subject of electromagnetics is highly multi-disciplinary, and it is desirable to develop the projects to reflect this aspect. The work will be continued and new projects will be reported in the future.

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