Integrated Course-Lab-Studio Environment for Circuits and Electronics Courses at Elizabethtown College

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Abstract

In this paper we describe and critically review the sequence of Circuits and Electronics courses at Elizabethtown College. Supported by two grants from Tyco Electronics Foundation over the last five years, a class studio environment hosts a Circuits course and an Electronics course. Both courses integrate traditional classes, formal labs and studio setting for lectures, demonstrations, experiments, simulation and design. While in many institutions similar courses in circuits and in electronics are split between theory and lab components, these two four-credit, six-hour courses are centerpieces of the engineering curriculum at Elizabethtown College. The integrated classroom environment allows for a close vicinity and interplay between theory, simulation, design and lab activity. In addition, the courses, as they unfold, often mimic a real professional life routine when students are exposed to multi-tasking, team interaction, priority choices, and multidisciplinary participation. The recent addition of advanced semiconductor parameter analyzing tools, courtesy of a second Tyco Electronics grant, open the door for a strong initiation and integration of undergraduate research activity connected to the content of the courses. We propose and analyze this model for circuit and electronics classes, based on examples, performances and assessments. Strengths and weaknesses of this approach are identified and analyzed.

Introduction and short history

The Engineering Program at Elizabethtown College has significantly expanded, both in quantity and quality, over the last decade. It grew out of a small Physics Department, which comprised only two faculty members and a handful of Physics majors. Today the Department of Physics and Engineering has seven full time faculty members, about 75 students enrolled in a variety of programs including Physics, Engineering Physics, Computer Engineering and Industrial Engineering. Currently there are no Mechanical or Electrical Engineering majors; the department is moving to create a new Engineering major with emphasis in Mechanical or Electrical Engineering or in Applied Physics starting next year. The programs are not yet ABET accredited, but the department is proceeding with the preparatory work towards applying for accreditation, possibly in 2006. Some students graduate at Elizabethtown College after completing four-year curricula while others receive a double degree from Elizabethtown College and Penn State (or other universities) following a 3-2 program.

Sequence of courses and their place in the curriculum

The Computer Engineering curriculum requires a minimum of 123 credits, 91 for the major and 32 for the core. Similar loads are required in the other engineering majors offered.

All students in Physics and Engineering at Elizabethtown College undertake in their freshman and/or sophomore years three semesters in calculus-based physics. “College Physics II” (four credits) is dedicated mostly to electromagnetism. It includes a laboratory where students tackle experiments in electrostatics and magnetostatics, and build some devices; in these lab students also get an introduction to the oscilloscope and other basic lab measurement equipment, and a couple of sessions on simple circuits.

At the centerpiece for preparation in electronics for all engineering and physics students is the course “Circuit Analysis”, offered every fall semester. This four-credit course is prepared at a level appropriate for electrical engineering (EE) students, and, as such, it does abundantly exceed the level needed and usually offered to non-EE engineering majors in Engineering Schools at large. “Circuit Analysis” is a prerequisite for the higher level courses mentioned in the next paragraphs. A second four-credit course, “Electronics”, is required for computer engineering majors and is an elective for physics and other engineering majors interested in the topics. Additional relevant courses in the curriculum are “Signal and Systems” and “Control Systems,” required for computer engineering majors and elective for all other students. “Control Systems” is emphasized for Computer Engineering also in view of an extensive activity in robotics that is manifested though senior projects and participation in national College-team competitions. “Circuit Analysis” is usually taken by students in their sophomore or junior year, while “Electronics” is usually taken by junior or senior students.

Course content and format

College Physics II, as mentioned above, is dedicated mostly to electromagnetism. It includes a laboratory where students tackle some classic experiments such as Faraday’s ice pail experiment, build their own devices such as a capacitor, a can-based Van de Graff generator, and a system of radio, speakers and amplifier. The lab for Physics II also introduces the students to the oscilloscope and other basic lab measurement equipment.

The centerpiece courses “Circuit Analysis” and “Electronics” courses allow for six contact hours and include a variety of activities and requirements. Both courses integrate traditional classes, formal labs and studio setting for lectures, demonstrations, experiments, simulation and design.

The “Circuit Analysis” course roughly covers the basic of linear circuits, components, operational amplifiers, circuit analysis techniques, including time-domain and frequency-domain analysis of circuits, and an introduction to power analysis. The course is integrated by a number of lab activities, by simulations in PSpice, and by a few design labs/projects. Over the last few years the main text adopted for the course alternated between Dorf-Svoboda[1] and Nilsson-Riedel[2].

“Circuit Analysis” is usually taught during two days of the week, in two sessions of three hours each; each session is broken in different activities. Usually class begins with a lecture of no more than one hour and a quarter, integrated, when needed, by demonstrations and examples. After a short break, a variety of activities are undertaken during the remaining one and half hour, usually one or two per class. These activities include individual and group problem solving sessions, PSpice practice sessions, lab activities and design sessions.

The “Electronics” course is dedicated to the study of diodes, bipolar junction transistors, field-emission transistors, special diodes and other semiconductor devices. First, a brief introduction to the basic physics of each device is provided; then relevant circuits are studied. The course touches upon rectifier circuits, limiting and clamping circuits, biasing circuits, switching circuits, amplification and filtering circuits. Analysis of frequency response is expanded. An introduction to analog integrated circuits and a section on digital circuits complete the course. Laboratory activities, simulations and design projects integrate this course too. Over the last few years the text adopted for the course was Sedra-Smith[3].

“Electronics” follows approximately the same format as “Circuit Analysis”. Sometimes, instead of two three-hour blocks, the schedule is set to allow for two time slots of one hour and a half plus one session of three hours, and in this case the class meets three days a week. Larger amount of time is dedicated in class to discuss and implement design projects. Labs are usually more consistent and formal and require a longer time to complete, and are usually performed, but not always, during one three-hour block.

All the relevant courses, including “Physics II” and labs, “Circuit Analysis” and “Electronics” and all their activities are held in one integrated classroom-studio-laboratory. The physical setup of the class includes central benches for conventional lectures and, on the side, laboratory benches along three sides of the rectangular class. Eight lab stations can fit teams of two or three students and they include basic equipment such as digital oscilloscopes, power supplies, wave generators, networked computers, tools, supplies and additional specific equipment as needed. An elevated podium for the instructor includes a similar laboratory station for demonstrations or for leading and showing setups during lab experiments. A door opens from the podium side in the class to a storage room where electronic components, devices and other supplies are kept in marked storage cabinets.

In many institutions similar courses in circuits and in electronics are split between theory and lab components. The integrated classroom environment used at Elizabethtown College allows for a close vicinity and interplay between theory, simulation, design and lab activity. In addition, the courses, as they unfold, often mimic a real professional life routine when students are exposed to multi-tasking, team interaction, priority choices, and multidisciplinary participation.
Major points of decision and differentiation inherent to this format are:

- The offering of two four-credit courses that integrate labs, simulation and design activities, versus the splitting of each course in at least two components.
- The teaching of the course in an integrated class-studio-lab setup.
- The keeping of one course at a level usually fit for electrical engineering students for all engineering students in the department.

These choices spring from the philosophy and needs of the engineering education at Elizabethtown College, where a broad curriculum is viewed as a major strength and small size classes are usually offered. These choices are also compatible with the practical perspective of how many courses, overall, the department can teach with its current faculty.

Tyco Electronics / Amp Foundation support

The class-studio was made possible in part by a grant from Amp Foundation (Tyco Electronics) in 2000. A proposal submitted to the Amp foundation by Prof. Thomas Salem (currently at the U.S. Naval Academy) was funded and the main lab equipment for the class-studio-lab setup was purchased, including digital oscilloscopes from Tektronix, waveform generators and power supplies from HP/Agilent Technologies. The proposal was based on "ample evidence that the scientific community recognizes the need for integrated studio type of instruction and colleges and universities nationwide are being encouraged by funding agencies and common perception to incorporate these teaching methods throughout science, math, engineering and technology curricula. In an ideal studio classroom, students are presented with engineering concepts during short lecture periods. Students then engage in activity geared toward demonstrating this information by participating in hands-on laboratory activities that utilize computers and computer-interfaced laboratory equipment. Students work in teams of two-to-three under the guidance of an instructor. The studio approach allows for immediate application of theory, thereby creating a more effective learning environment for students."

A second grant, submitted to the Amp Foundation by the author in 2003, was funded as well. The second proposal came after the conversion to the integrated studio-lab-class and the successful implementation of the new format for the "Circuit Analysis" and "Electronics" courses. It addressed, in general, "enhancing the electronic lab and strengthening undergraduate research in Engineering at Elizabethtown College."

More specifically, the new proposal was submitted for the following goals:

- Providing the labs with equipment for advanced measurements of semiconductor device parameters, essential for completing the scope of the circuit and electronic courses.

- Using the same advanced equipment for fostering the continuation and expansion of lab course work into undergraduate research and design projects.

- Reinforcing the freshman lab for electromagnetism, the main prerequisite for the circuits and electronics courses, with computer interface and software.

The advanced piece of equipment requested was a semiconductor parameter analyzer. This tool allows for a set of new advanced measurements, among them precise I-V characteristics of semiconductor and optoelectronic devices at extremely low current and noise levels. It can be used for demonstrations within the two formal courses ("Circuit Analysis" and "Electronics") as well as for advanced junior and senior design/research projects.

In addition, the need to add the electromagnetic lab for "College Physics II" to the same integrated studio-class-lab was also addressed in this proposal. This course and its lab are prerequisites for the "Circuit Analysis" and "Electronics" courses. The students, as described above, learn electromagnetism and a number of basic experimental techniques. Purchasing interfacing and software for the relevant experiments helped completing the integration of this course into the same classroom and format as the two other courses. This proposal, once funded, did significantly improve the level of resources for the electromagnetic lab and boost the students' preparation for the higher-level courses.

At the same time the addition of sophisticated equipment will allow in the future for a wide range of experimental opportunities that will support and boost students' participation in undergraduate research and design projects. This last task is critical for a valid program in engineering. It is generally accepted that undergraduate research is a very important component of an engineering program. To expect valid contributions and advanced performances from undergraduate students, the class has to be motivated into research as early as possible, and opportunities for such activities should spring naturally out of, or in correlation with, course and laboratory work.

At this stage (end of fall semester 2004) the next "Electronics" class in spring 2005 will use for the first time the semiconductor parameter analyzer for projects linked to the course, building on the work of a student who is working on integrating and interfacing the equipment in the lab, in the context of a senior design project.

Critical analysis of course format

In this section we want to critically evaluate the decisions made with respects to the course format. This analysis reflects the experience during the last three years, since the author joined Elizabethtown College. During that period, "Circuit Analysis" has been offered three times and "Electronics" twice. The author had had prior experience teaching similar courses in different formats at different institutions. The following considerations also include points raised and debated in students' course evaluations or other surveys originated by the instructor.

The first decision is the offering of two four-credit courses that integrate labs, simulation and design activities, versus splitting each course in at least two components, theory and lab.
The great advantage of this approach is to have the students learn the theoretical material and perform lab, simulation and design activities in one integrated course and setup. Each component of the course builds on the other activities. Time proximity is insured between learning the topics and applying them to design activities and/or applications, and testing them with simulations and lab measurements. Each activity and experience reinforces the other ones in these instances, and enhanced learning through synergy can be expected.

It is possible to argue that a separated set of courses offers some advantages of its own, especially with respect to repetitive learning. Presumably, repetitive learning is important, at least for some students, in order to fully acquire knowledge and understand topics in depth. A serial, disjoint sequence of courses, the first one presumably theoretical in a class setting and the second one experimental in a lab setting, possibly taken a semester or even a year apart, provide opportunity for repetitive learning. Still, the benefits of the first scenario (integrated course) strongly outweigh the benefits of the second one (disjoint sequence of courses.)

There is one additional point worth considering and it pertains to a general, expanded set of educational goals. Beyond facilitating learning in individual courses and acquiring knowledge and skills, any engineering undergraduate curriculum should aim at preparing the student to professional life after graduation. Such preparation has to address a host of requirements, and has to prepare the engineer to function under different scenarios, within different teams, under various conditions including situations of pressure, of time constraint and of lack of resources. A senior project is usually one complex task that can help prepare the student to this multifaceted possible professional future. It is arguable that the integrated course scenario is another suitable tool for this same goal. In fact, these types of courses are usually very intense and require constant application in a number of different activities from the student. After all, this is in some way a compression process where two courses are squeezed into a single one. In a typical week a student does attend lectures integrated with demonstrations, software simulations and lab activities; and simultaneously he/she has to hand in homework, including problems, simulations, lab reports, and design challenges. Time management skills, teamwork and resilience do naturally emerge and possibly get enhanced in such an intense routine.

The second critical point of decision for the format of the "Circuit Analysis" and "Electronics" courses is strongly linked to the first point just discussed; it is the teaching of the course in an integrated class-studio-lab setup. Since the rational for and advantages of such a setup are connected and very similar to the ones discussed above, I will look at this feature from another perspective. In fact, recalling some wording used above, in an ideal studio classroom students are presented with engineering concepts during short lecture periods. Students then engage in activity geared toward demonstrating this information by participating in hands-on laboratory activities that utilize computers and computer-interfaced laboratory equipment. Students work in teams of two-to-three under the guidance of an instructor. The studio approach allows for immediate application of theory, thereby creating a more effective learning environment for students. The studio approach has been gathering recognition and subscriptions at large, both from academic institutions and from funding agencies, including NSF, during the last decade.

For a "Circuit Analysis" or "Electronics" course the studio approach works well if it is implemented with moderation and with flexibility, allowing for mixing with alternative traditional teaching paradigms, when needed. Some components in these courses are perfectly matched for the studio model, based on short lectures followed by immediate related lab activities and/or applications. Demonstrations by the instructor, visualization and recognition of electrical components, getting familiar with manufacturer data sheets, short PSpice simulation sessions, all-ready circuits for fast and simple measurements are all example of activities than fit very well in the studio model and should be used extensively. However, there is a fundamental lab-training component that is usually at odds with the model, and flexibility should be allowed to account for these contrasting educational needs.

In fact, from one hand, an agile transition from a theoretical session to an all-ready circuit that the student can measure in a short time, by just turning sideways and switching the measurement equipment on, is a very interesting and captivating activity that helps retention of the theoretical material just learned, and helps demystifying the abstract nature and difficulty of the subject. On the other hand, these courses are among the few ones that can and should impart to the students the attitudes, skills, philosophy and behavior of a true "experimentalist". These include the need to understand and experience, through preparatory work, that every experiment has to be studied and thought off in detail before lab time. In addition, students have to be given time to design, build circuits on a breadboard, struggle with apparent bugs and malfunctions, and, in general, develop that hands-on attitude so important for a sound engineering education. These requirements, by their very nature, are difficult to meet in an "ideal" studio model. However, the beauty of the integrated studio-lab-classroom is that we can enjoy both scenarios and both worlds! Some sessions are thus held in a traditional lab routine, including preparation, prelab work, calculation and design, prolonged circuit building and measurement in the lab, and post-lab final report with simulations and analysis. Sometimes the more advanced labs are allotted a full session of three hours, more so in the schedule of the "Electronics" course.

The third decision point, which I'll discuss only briefly, is the offering of a single course "Circuit Analysis", at a level fit for electrical engineers, for all engineering students at Elizabethtown College. This means that students who plan to graduate in any non-EE engineering discipline probably get a course at a substantially higher level than needed or required. We see this as strength of the program. The rational behind this curriculum imposition is the wish to enhance as much as possible the interdisciplinary skills of our graduating engineers and the recognition that electronics will play an ever increasing and important role integrated in all engineering projects and touching almost all engineering disciplines. The fact that this setup is also very helpful in the continuous struggle to offer additional elective courses, as many as possible, within a department limited in faculty size, by "saving" an additional course in circuits for non-ECE students does add to the rational of this decision.

Assessment

Assessment is sought from students in the course via IDEA forms, in line with the policy of Elizabethtown College. The scores and comments are used to analyze and improve the courses semester by semester. In addition, indirect external information helpful towards assessing the strength of the program in general and of the specific circuits and electronics courses is gathered in a number of ways. The best indicator for the soundness of the programs is a general satisfaction with our students involved in internship projects or other external commitments; also a general satisfaction with the performance of our graduates in their first jobs is apparent. More specifically for the circuits courses, most of our 3+2 students, upon reaching Penn State or other engineering schools for the second part of the 3+2 program, feel very well prepared for the courses they take in advanced electronics or circuits subjects; usually they also perform very well in their endeavors. The same scenario unfolds with those students who continue studying for graduate degrees at a number of different universities.

Examples and exhibits

To make full justice to many of the claims and discussions in this paper a large number of examples from the different teaching scenarios in the unfolding of "Circuit Analysis" and "Electronics" would probably be needed. This would be beyond the scope of this paper. Instead, in the following, I will present just two items, a minimal set of exhibits that might just convey a general sense and flavor of the course sequence in circuits and electronics at Elizabethtown College.

The first exhibit is the schedule of events as handed out with the syllabus to students during the last "Circuit Analysis" course in fall 2004. The second is an example of one of the lab handouts, specifically for design and measurement of second order circuits.

"Exhibit" 1: Schedule for EGR 210 – Circuit Analysis, Fall 2004

Day/Date CLASS #	**Text Reading, Chapter, Topics** Dorf-Svoboda: Introduction to Electric Circuits, 6th ed.	**ACTIVITIES: LAB DESIGN/APPL. PSPICE**
T Aug 31 LCT1A	Ch. 1 Introduction, Circuit Variables	Introduction to LAB Introduction to PSPICE
H Sep 2 LCT 1B	Ch 2 Circuit Elements	LAB: Instrumentation and components. Electric safety
T Sep 7 LCT 2A	Ch 2 Circuit Elements	LAB: Oscilloscope. PSPICE: Getting started
H Sep 9 LCT 2B	Ch 3 Resistive Circuits	LAB: Waveform generator, Lissajous figures
T Sep 14 LCT 3A	Ch 3 Resistive Circuits	PSPICE: Analysis of DC circuits LAB
H Sep 16 LCT 3B	Ch4 Methods of Circuit Analysis	DESIGN/LAB: Adjustable Voltage source
T Sep 21 LCT 4A	Ch 4 Methods of Circuit Analysis	PSPICE: Analysis of DC circuits LAB
H Sep 23 LCT 4B	Ch 4 Methods of Circuit Analysis	LAB Review for Test 1 / Group test
T Sep 28 LCT 5A	Ch 5 Circuit Theorems	**TEST 1**
H Sep 30 LCT 5B	Ch 5 Circuit Theorems	PSPICE: Variable DC Circuits LAB
T Oct 5	**FALL BREAK, NO CLASS**	**FALL BREAK, NO CLASS**
H Oct 7 LCT 6B	Ch 6 The Operational Amplifier	DESIGN/LAB: R2R Digital-to-analog converter

T Oct 12 LCT 7A	Ch 6 The Operational Amplifier	PSPICE: Variable DC circuits LAB
H Oct 14 LCT 7B	Ch 6 The Operational Amplifier	LAB: : Operational Amplifier
T Oct 19 LCT 8A	Ch 7 Energy Storage Elements	PSPICE: Operational Amplifier LAB
H Oct 21 LCT 8B	Ch 7 Energy Storage Elements	DESIGN/ PSPICE/LAB: Op-Amp circuits
T Oct 26 LCT 9A	Ch 8 RL and RC First-Order Circuits	DESIGN/ PSPICE/LAB: Op-Amp circuits
H Oct 28 LCT 9B	Ch 8 RL and RC First-Order Circuits	DESIGN/ PSPICE/LAB: First-order circuits
T Nov 2 LCT 10A	Ch 9 Second-Order Circuits	PSPICE: Time-domain analysis LAB: First-order circuits
H Nov 4 LCT 10B	Ch 9 Second-Order Circuits	LAB: Second-order circuits Review for Test 2 / Group test
T Nov 9 LCT 11A	**TEST 2**	**TEST 2**
H Nov 11 LCT 11B	Ch 10 Sinusoidal Steady State AC Analysis	DESIGN/ PSPICE/LAB: Second-order circuits
T Nov 16 LCT 12A	Ch 10 Sinusoidal Steady State AC Analysis	DESIGN/ PSPICE/LAB: Second-order circuits
H Nov 18 LCT 12B	Ch 10 Sinusoidal Steady State AC Analysis	PSPICE: Time-domain analysis
T Nov 23 LCT 13A	Ch 11 AC Steady-State Power	LAB: Steady state analysis
H Nov 25	**THANKSGIVING BREAK, NO CLASS**	**THANKSGIVING BREAK, NO CLASS**
T Nov	Ch 11 AC Steady-State Power	PSPICE: Analysis of AC

30 LCT 14A		circuits LAB: Steady state analysis
H Dec 2 LCT 14B	Ch 11 AC Steady-State Power	DESIGN/ PSPICE/LAB: Op-amp phase-shift circuit
T Dec 7 LCT 15A	Ch 13 Frequency response, Bode plots	DESIGN/LAB
H Dec 9 LCT 15B	Ch 13 Frequency response, Bode plots	Summary of course, review
FINAL EXAM	**Tuesday, DECEMBER 14, 2004**	**11:00 AM – 2:00 PM**

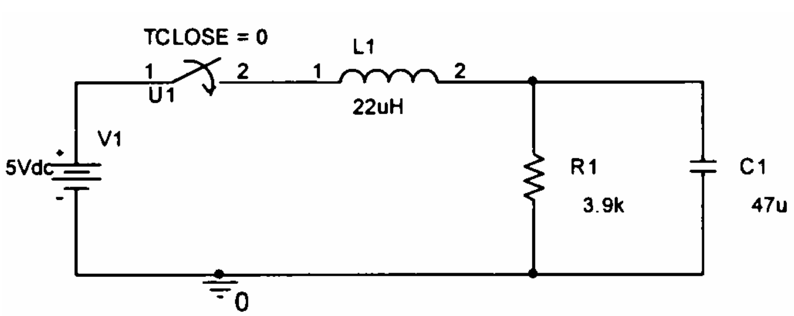
"Exhibit" 2: Example of Lab Handout

Circuit Analysis - Lab Activity 09: Second-Order Transients

The purpose of this lab activity is to evaluate and measure second order transient circuit response.

Procedure

1. Construct the circuit shown below using the solderless breadboards, resistors, jumper wires, and DC power supply.



2. Calculate the transient circuit response showing all of your work.

3. Estimate the time duration of the transient response.

4. Using the oscilloscope and the trigger function measure and record the transient phenomenon of voltage build-up across the capacitor. Be sure to include a printout of the data captured from the scope in your laboratory notebook. Use cursors and scope measurements and displays to experimentally extract all relevant parameters.

5. Repeat calculations and measurements with a parallel RCL circuit, using same value for the source, and R = 3 Ω, C = 5 μF, and L = 1 mH.

5. Compare your experimental results with your calculations and discuss errors or discrepancies.

6. Design build and measure an RLC circuit (either parallel or serial) using the same source of 5V switched to provide a step response, that will be overdamped and will reach 4V at a time 100 μs after switching. The design, calculations and PSpice simulations should be done in the prelab.

7. The prelab has to be completed before starting the experiment.

This is an example of a fully integrated class-studio-lab. The first circuit is provided in the figure of the handout and, following immediately the lecture on second-order transients, in a studio mode, each lab team calculates the expected results, simulates the circuit in PSpice and builds the circuit on the breadboard for measurement of the transient characteristics. Additional activities requested in the handout include designing an additional circuit according to specific requirements. This activity needs more preparatory work, thought and simulation, and is tackled in the next lab in a "traditional" extended session where prelab reports are required.

Conclusions

I have described and discussed the centerpiece sequence of courses in "Circuits Analysis" and "Electronics" for physics and engineering students at Elizabethtown College. Both courses integrate traditional classes, formal labs and studio setting for lectures, demonstrations, experiments, simulation and design. At least one of these courses is taught to all engineering majors at an advanced level fit for electrical engineers. The courses, as they unfold, can be also seen to mimic a real professional life routine when students are exposed to multi-tasking, team interaction, priority choices, and multidisciplinary participation. The studio setup and its state-of-the-art equipment were made possible, in part, by two grants awarded by the Tyco Electronics Foundation.

References

[1] Dorf, Svoboda, "Introduction to Electric Circuits," sixth edition, Wiley and Sons (2004.)

[2] Nilsson, Riedel, "Electric Circuits," sixth and seventh edition, Prentice Hall (2001.)

[3] Sedra, Smith, "Microelectronic Circuits," fifth edition, Oxford University Press (2004.)

Biographical Information

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