REMOTE WIRING AND MEASUREMENT LAB

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Abstract *— This paper describes a system composed of hardware and software to allow an individual to create an electronic circuit using a web interface. The user interface would simulate an electronic breadboard, such as students usually use in a typical undergraduate electronics lab. A matrix of relays would allow the actual components to be connected in any manner that the user specifies over the web. In this way, a user will be able to remotely wire up a variety of circuits and take measurements without needing to physically be in the laboratory.*

Index Terms — electronics laboratories, virtual laboratories, web based instruction.

INTRODUCTION

This paper represents a work in progress report for the development of a remote wiring and measurement laboratory. A prototype of the circuits and systems to accomplish this project were demonstrated at the 2001 American Society of Engineering Educators (ASEE) national conference in Albuquerque, NM. [1]. This paper gives a description of the hardware and software necessary to effect the physical wiring of circuits using web based access.

SOFTWARE

The presentation to the user appears like a standard electronic breadboard (a "virtual breadboard") similar to those typically used in undergraduate electronics laboratories. A pictorial representation of the various components available for the laboratory are also presented on the side of the screen. In some components, color-coded bands are displayed to indicate the appropriate values of the component. For example, resistors look like the actual color-coded resistors. For other components, a tool tip is used to display the appropriate value or perhaps display a data-sheet.

The user is able to drag any components around the virtual breadboard as desired to accomplish the necessary wiring.

When the user completes the circuit and presses a "Done" button, the software analyzes the circuit to determine which hardware leads are connected together. These connections represent nodes. The software first sends a reset signal to clear all the physical relays. The software then sends a digital code associated with each lead/node combination sequentially through the hardware.

HARDWARE

As described in [1], a digital/analog embedded controller from Xecom Corporation is used to run the website where the user configures the chosen circuit. This device incorporates a multi-tasking operating system and TCP/IP stacks with Ethernet access. The controller allows the setting and resetting of up to sixteen dedicated TTL signals.

As described above, the software running on this website sends a clear signal, then sequentially sends the digital code associated with each lead/node combination through the dedicated TTL signals. These signals are decoded by a CPLD (Complex Programmable Logic Device) and routed to appropriate relay latches. The latches in turn drive electronic LED-based relays. When a relay is set, it physically connects a leg of the component to a node. Any other components connected to that node are then also physically in the circuit.

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The Ongoing Quest for the Perfect First Course in Electrical Engineering

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Abstract -- Efforts to fully integrate a home laboratory into the introductory circuit course (EE215) in electrical engineering at the University of Washington are presented. The home laboratory is a laboratory exercise that can be completed outside of university laboratory facilities with a limited set of portable measurement equipment and is intended to supplement the current course content and objectives by improving hands-on skills, self-confidence, and exposure to the broad specialty areas in EE early in the program. Home laboratories at the introductory level are the focus of presentation in this paper, rather than the topical area (circuit analysis, analog signal processing, digital signal processing, etc.) under which they are constructed. Feedback from students and instructors has clearly shown the difficulty in achieving the correct balance among appropriate student workload, reinforcement of course topical content, development of hands-on skills and self-confidence, and significant exposure to the broad specialty areas of electrical engineering. In this paper, we present the second major revision of home laboratories for the first course in EE as we proceed toward more closely achieving this balance.

Index terms: laboratory development, electrical engineering

INTRODUCTION

The debate over the best way to bring students into an electrical engineering undergraduate program is ongoing; digital signal processing is a popular topic to replace the more traditional introductory circuit analysis course in this day and age where digital circuits dominate the electronics industry; however, the costs, in parts, facilities and technical background, of providing a meaningful DSP course at the introductory level are often alarming to young students as well as to curriculum coordinators. Seminar introductory courses provide a broad overview of EE but frequently fail to provide the student with an in-depth understanding of the skills required to successfully complete an undergraduate EE program and engage in a meaningful career in the field. Many creative efforts have been directed at integrating curricula to make the transition into the EE curriculum more elegant and efficient. In large public universities that have a significant community college transfer component, integrated curricula at the freshman level are often impractical to offer to the bulk of the EE undergraduate community. It is evident from the many approaches that various programs take to the introduction of EE to undergraduates that no single correct approach exists. Objectives in the introductory course or course sequence typically emphasize providing students a meaningful exposure to the field of electrical engineering while building the skills required to facilitate successful completion of their undergraduate program.

Hands-on skills are a necessary part of completing any engineering program and the undergraduate electrical engineering program at UW is no exception. Self-confidence plays a role in determining how well students can proceed toward developing adequate competence in hands-on activities. By providing home laboratories early in the curriculum, we intend to create a "safe" environment, free from potentially negative peer influences, for students to develop hands-on skills at their own pace and in their own style. Other skills such as spatial reasoning abilities certainly contribute to building self-confidence as well; hands-on experimentation activities have been shown to contribute to the development of spatial reasoning skills[1] which in turn improve self confidence. A host of other factors, including the significant impact of instructor practices and techniques[2] and cross-verification exercises[3] contribute to the complex process of developing self confidence in the introductory engineering courses. The home laboratories, a series of laboratory exercises to be completed individually with a minimum set of portable measurement equipment, is not a single solution to the development of self-confidence; rather, it is a supplemental tool for developing the self confidence that can play such a critical role in determining student success especially for students in particular minority groups

In addition to supplementing the development of self-confidence and hands-on skills early in the curriculum, the goals of the home laboratories also focus on exposure to electrical engineering as a career within the context of introductory circuit analysis. In our effort to more fully introduce young undergraduates to what it means to be an electrical engineer as early in the curriculum as possible, we have introduced a relatively simple, straightforward and streamlined suite of home laboratory exercises into the introductory EE course. The home laboratory does not place any additional demands on strained laboratory resources used for junior and senior courses. Rather, laboratories are designed to be performed at home with a simple infrastructure consisting of batteries, handheld multimeter, and breadboard. Hands-on home laboratories have been successfully tried and demonstrated in other fields such as mechanical engineering for concepts in solid mechanics[4] and reverse engineering [5]. Virtual experiments and animated software simulation of experiments for home use have also been attempted in a wide

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range of topics including transmission line theory[6], digital circuits[7], control engineering[8], and others. The topics of the home laboratory sequence in the UW introductory electrical engineering course begin by falling hand in hand with basic circuit analysis techniques; students determine currents and voltage using standard circuit analysis techniques and verify a portion of their answers by building the corresponding circuits in their homes using simple breadboard and voltmeters as their laboratory infrastructure. From this introduction to circuits and devices at the hands on level, the home laboratories progress to more sophisticated circuits, each of which exposes the student to three of the remaining specialty areas of the undergraduate EE curriculum: communications, signal and image processing, and energy systems. Future revisions of the home laboratories as part of a core curriculum redesign effort are expected to expose students to all specialty areas of electrical engineering at the introductory level.

BACKGROUND

In the undergraduate EE curriculum at the University of Washington, EE215 is the first course that pre-engineering students take as they apply for admission or are accepted to the department. The course has traditionally focussed on fundamental circuit analysis. The possibility of moving to an introductory course that reflects digital systems concepts or provides a broader overview of the specialty areas within electrical engineering has been extensively discussed. The core curriculum is currently in the process of redesign by an internal departmental committee with extensive input from industry, faculty, and students. An experiment in home laboratories for the introductory course, EE215, began in the Summer 2000 quarter. The primary focus of the home laboratories during the initial offering in Sum00 was to expose students more fully to the seven specialty areas of electrical engineering during their first course in the department. One of three lectures per week was dedicated to the laboratory and the associated specialty area in EE (electronic circuits and devices, digital systems, electromagnetics, power systems, robotics and controls, signal processing, and communications). In response to student feedback from the initial offering, home laboratories have been revised to more closely connected with mainstream lecture material and circuit analysis topics while introducing specialty areas as appropriate. The home laboratories, at the present time, continue to undergo continuous improvement as links among EE speciality areas, traditional circuit analysis, and hands-on and critical thinking skills development continue to be strengthened.

LABORATORY DESCRIPTION

Home laboratories are currently structured to allow experimentation and verification of results in basic circuit analysis techniques and to expose the student to at least four specialty areas of electrical engineering (ECDT (electronic circuits and devices), energy systems, signal processing, and communications). Students meet these objectives on an individual basis, using a minimal set of portable equipment (handheld multimeter, breadboard, wiring kit) in a working environment of their choice. The lab manual provides instructions on constructing and performing the requisite experiments, insight as to how these experiments relate to a corresponding specialty area, and information regarding the specialty area (including an overview of the job market, history of the specialty area, and opportunities to do undergraduate research). Teaching assistant and instructor assistance are plentiful; laboratories are not only supported during regular office hours but also by up to one hour of a two hour recitation section every week. The eight laboratories are linked to lecture content in fundamental circuit analysis via the following topics:

Laboratories 1-3 (specialty area is ECDT)
- Lab 1: Introductory circuit analysis including resistors, capacitors, inductors and diodes in DC circuits and an analysis of parasitic resistance (in the breadboard itself).
- Lab 2: Extended DC Circuit Analysis including nodal and mesh analysis and the use of switches and non-linear components such as diodes and transistors (bipolar junction) in circuits.
- Lab 3: Thevenin and Norton Equivalents including internal resistance of voltage sources.

Laboratory 4 (specialty area is Energy Systems)
- Lab 4: Power in the home including AC and DC power sources.

Laboratory 5 (specialty area is Signal Processing)
- Lab 5: Low pass and high pass filters including time-domain RC and RL circuit analysis.

Laboratory 6 (specialty area is Communications)
- Lab 6: Remote control tester including operational amplifier circuit and digital signal modulation.

Each of the laboratories can be completed with a handheld digital multimeter, breadboard and batteries. Since students require no stationary laboratory facilities to complete the labs, they often construct and initially test experiments at home, followed by troubleshooting them in groups at school. This structure not only alleviates the burden on overcrowded undergraduate EE laboratory facilities, it also allows students to develop hands-on skills with a great deal of guidance (from instructors, TAs and lab manuals) but with minimum pressure to perform. Pressure on the student is reduced because neither are the stringent time requirements, inherent in the traditional lab section format, present nor are influences from more proficient peers as significant. The difficulty in designing these home laboratories is in achieving the correct balance among:

- (a) providing a meaningful hands-on experience at an acceptable level of difficulty for beginning students;
- (b) aligning the laboratory material sufficiently with lecture topics;
- (c) providing a meaningful introduction to other specialty areas in electrical engineering that do not rely as heavily on circuit analysis as the ECDT area.

Finding the correct balance among these conflicting objectives is an ongoing process, requiring quarterly modification of laboratories. However, in the long term, through the continuous improvement process facilitated by ABET 2000 requirements and resulting changes in department processes, it is our hope that the home laboratory format will provide students weak in hands-on skills the opportunity to advance their abilities to a level more comparable with their peers. More equivalence in hands-on skills reduces student piggy-backing in advanced laboratory courses, as more students are equal participants in laboratory, design, and analysis efforts. In the current curriculum, as students advance through the program, more and more discrepancy of student participation is seen in laboratory and design work as the hands-on skills of the stronger students become stronger and those of the weaker students diminish or remain stagnant due to lack of participation.

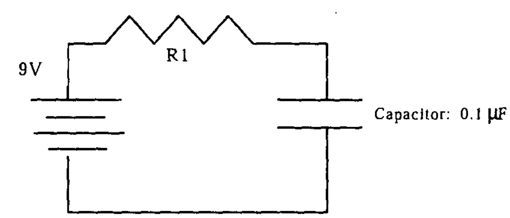
LABORATORY EXAMPLES

Circuit difficulty progresses in the laboratories, starting with such simple circuits as the straightforward three component experiment in Figure 1 and ending with a far more complex, application-oriented circuit such as the remote control tester shown in Figure 2 for Lab 6. The objective of the representative circuit shown in Figure 1 for Lab 1 is to evaluate the performance of the capacitor and inductor under DC conditions. Typically, since this is the first circuit that many of the students have ever constructed on a breadboard, this experiment takes a significant amount of time, as students must travel a relatively steep learning curve toward understanding and using the breadboard layout. Once the circuit is constructed, however, the measurements are simple and the related questions fairly straightforward. Open-ended questions are avoided at this point to provide the student the opportunity to develop confidence in their circuit construction capability. The representative circuits shown in Figure 1 are accompanied by three other procedures and circuits of comparable difficulty directed at introducing the student to breadboard layout and basic voltage and resistance measurements.

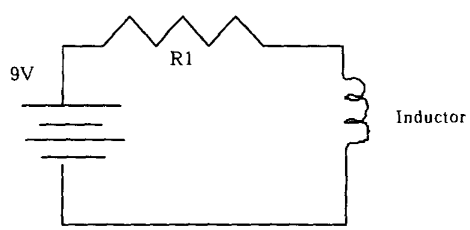
In the particular example shown in Figure 1, measurements and calculations are as follows:

- Measure: voltage across resistor and capacitor
- Calculate: current through resistor and capacitor
- Measure: voltage across resistor and inductor
- Calculate: current through resistor and inductor

Students find that no current is flowing through the capacitor under DC conditions and will use this experimental information to reinforce their understanding of capacitors in time-domain analysis and phasor analysis later in the quarter. Capacitors and inductors are only briefly introduced at the beginning of the quarter via basic current-voltage relationships in the context of DC circuit analysis.



(a) *Laboratory 1, Procedure 3*



(b) *Laboratory 1, Procedure 4*

Figure 1.0: Representative Circuits from Lab 1
Students are asked to evaluate the behavior of (a) a capacitor and (b) an inductor under DC conditions as part of Laboratory 1. The circuits for all procedures in Laboratory 1 are kept to a minimum of components and wiring while still enabling students to examine and verify introductory circuit analysis concepts. Voltages across each component are measured and currents through each component are calculated.

The second circuit example from the home laboratories (Figure 2) is a fairly complex circuit that demonstrates a system level application (remote-control tester). This laboratory is coincident with lectures on operational amplifier analysis; however, a variety of other concepts are demonstrated in this laboratory. To facilitate confidence in circuit construction and proficiency in troubleshooting, students assemble this complex circuit in stages, testing each stage with an infrared remote-control:

- Subcircuit 1 (basic sensing circuit including infrared phototransistor and pull-up resistor): students measure the output voltage at the node between phototransistor and resistor as a function of distance between remote-control and phototransistor. Digital pulse modulated remote control outputs are too fast to be captured by handheld voltmeters. Instead, the voltmeter displays an average output corresponding to a particular code (button) on the remote control being displayed. Basic light-current-voltage characteristics remain the same as if the (infrared light) input to this sensing circuit were constant.
- Subcircuit 2 (basic sensing circuit and amplifier): students compare the sensing circuit output with the amplified output, calculating the gain of the amplifier and comparing it with ideal op-amp calculations.
- Complete circuit (basic sensing circuit, amplifier and display output): the display output enables the student to see the pulsed characteristic of the remote-control input; while digital pulse modulation is not an appropriate topic for EE215 as it is currently structured, students gain a basic intuitive understanding of what signal modulation means through this experience.

The remote control tester is clearly a real-world application of a simple amplifier circuit, enabling the transduction of light to analog information (IR photo transistor) and the transduction of analog to digital information (bar graph display driver). Students discover experimentally the nature of the light sensor (by evaluating the photo transistor current as a function of remote control distance from the sensor), the basic operation of the inverting amplifier, and the pulsed nature of the remote control signal (using the bar graph display and driver).

Evaluation and Assessment

Evaluation of student home laboratories is done on an individual basis. To receive credit for the laboratory, the student must turn in completed laboratory procedures and demonstrate one or all of the circuits to the TA during recitation section. Demonstrations are done at one time, to minimize the possibility of cheating. Students are advised to complete the laboratories well in advance of the due date to avoid last-minute complications and frustrations. Students at this introductory level exhibit a minimum of procrastination in relation to the home laboratories. Last-minute crises are rare and this surprising result is likely tied to the student's lack of experience with laboratory exercises.

In the first offering of the home laboratories (Summer 2000), student feedback indicated that the home laboratories were not sufficiently integrated with the course topical material and that they incurred prohibitive additional workload. This series of student feedback which coincided with instructor feedback from summer and fall quarters facilitated the second major revision of these home laboratories. Preliminary feedback from the second round of revisions indicates that most students do not spend more than three hours per week on the laboratories and that the laboratories continue to supplement their understanding of the course.

Future Development

Future effort in the development of home laboratories will focus on further streamlining the laboratories to meet the topical content of the existing introductory core course (EE215) and in using them as an integral part of achieving the industry/student/academic objectives of the new core, currently under development. Achieving a balance where home laboratories approach a seamless bond with individual instructor teaching style, technique, and organization as well as the credit hour limits of the course is a difficult process. This process will require at least one more major revision before settling into a pattern where long-term evaluation results can be assessed.

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