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# Board 109: Moving Towards a Fully On-line Laboratory in Electric Circuits Course

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# Moving towards a fully online laboratory in Electric Circuits course


## Abstract

The Department of Engineering Technology at Daytona State College seeks to offer a completely online Bachelor of Science program in Electrical Engineering Technology. Currently, all lectures are delivered online for all department courses; however, some laboratories still require campus facility attendance. As an alternative, some lab courses rely on simulators, which sometimes provide a limited reproduction of the conditions. Such is the case of the EET 3085L Electricity and Electronic Lab course, a sophomore-level class with increasing enrollment over the years. An online and an in-lab section of EET 3085L are offered concurrently. Both sections cover the same experiments, with the difference being that online students use circuit simulation software (Multisim) to complete the labs. However, this alternative leaves lab experience limited to the use of a simulator. Given that an Engineering Technology graduate should have accrued substantial hands-on experience, the skills obtained from a simulator are no substitute for those obtained with real-world hands-on experiments. To mitigate this experience deficiency in EET 3085L, we propose an approach to allow online students to complete the same experiments in a way that is equivalent to those done by in-lab students.

In this paper, we examine the adoption of alternatives to enable online students to complete the set of labs programmed for EET 3085 at home under realistic conditions and propose guidelines to achieve this goal. We consider the adoption of lab kits and a module that provides the functionality of lab instruments such as multimeters, oscilloscopes, and waveform generators. There are several options with a lab module that, when plugged into a computer, delivers a multi-instrument setup conveying the functionality of the above devices. The first step, which is the objective of this work, is to select the appropriate lab module based on its capabilities to adapt and reasonably convey the experiments programmed for the EET 3085 class at an affordable cost. This work is still in progress; future activities will tackle the plan to deploy the referred laboratory platform.


## Background

The Daytona State College Engineering Technology program has been progressively transitioning from a hybrid to an online format in less than sixteen years. Though one hundred percent of the lectures in each course are already online, not all the laboratories have similarly converted formats. One example of a fully online lab is CET 3198 Digital Systems. Since 2013, CET 3198 Lab can be completed either in the lab or at home. Both options cover the same set of labs and experiments using FPGA boards. The availability of low-cost FPGA boards makes it possible for students to buy the required equipment and complete the labs at home.

As stated in the course outline, EET 3085 provides a comprehensive treatment of traditional topics in DC analysis, suitable for electrical/nonelectrical engineering technology majors. While the course emphasizes the development of analysis skills, it also provides examples and exercises that can teach practical applications and troubleshooting. Since most practical circuit analysis is performed in support of one of these two activities, it is appropriate for technology students to gain experience developing the mental processes needed for problem-solving in such contexts.

The learning objectives for EET 3085 are as follows:
Upon completion of the course,

1. Students will be able to state and utilize the current-voltage relationships of resistors, capacitors, inductors, independent and dependent current, and voltage sources in solving DC circuits and calculating power and energy.
2. Students will be able to apply the fundamental laws and theorems of electric circuits, such as Kirchhoff's voltage and current law and Thevenin, Norton, and Superposition theorems, to analyze complex DC and AC linear circuits.
3. Students will be able to explore through hands-on experimentation and prove fundamental laws and circuit theorems.
4. Students will be able to adequately operate basic instruments such as multimeters, power supplies, oscilloscopes, ammeters, voltage meters, signal generators, and simulators.

Given learning objectives 3 and 4, a significant portion of the course effort is expected to be based on hands-on experiments. A semester of EET 3085L expects the completion of twelve laboratories:

1-A **Math Review and Calculator Fundamentals DC**: Students will work on diverse math problems that review key mathematical concepts and skills required to effectively complete the lab's circuit analysis. This laboratory assignment is to be completed individually outside the lab.

1-B **Multisim:** This lab introduces the students of both sections, live and online, to Multisim. Students will be acquainted with the techniques required to work with Multisim by solving simple circuits.

2 **Resistors and the Color Code**: In this lab, the student will familiarize themself with the physical characteristic of resistors and the measurement instruments: Ohmmeter, Voltmeter, and Ammeter. Students will learn how to identify the resistance value given by the bar color and calculate the deviation (the maximum and minimum values) of the resistance (tolerance).

3 **Ohm's Law**: In this lab, students will experimentally demonstrate the validity of the Ohms Law. Students will use the measurement instruments (Ohmmeter, Voltmeter, and Ammeter) and power supply to verify Ohm's Law by measuring current and voltage and obtaining the I-V for a resistance.

4 **Series DC Circuits**: In this lab, students will experimentally validate Kirchhoff's Voltage Law by measuring currents and voltages of a series' DC circuit. Students will also test and validate the voltage and current divider rule.

5 **Parallel DC Circuits**: In this lab, students will experimentally validate Kirchhoff's Current Law by measuring currents and voltages of a series of DC circuits and then test and validate the current divider rule.

6 **Series-Parallel DC Circuits**: In this lab, students will validate experimentally the electric properties of series-parallel circuits by applying Kirchhoff's Current and Voltage laws, entailing measuring currents and voltages of a series-parallel DC circuit. Students will test and validate current and voltage divider rules in a series-parallel DC circuit.

7 **Methods of Analysis DC**: In this lab, students will experimentally validate the application of branch-current-analysis, mesh (loop) analysis, and nodal analysis techniques.

8 **Superposition Theorem (DC)**: In this lab, students will experimentally verify the superposition theorem for both voltage and current and show that the superposition theorem does not hold in the case of non-linear DC circuits.

9 **Thevenin's Theorem and Maximum Power Transfer (DC):** In this lab, students will verify experimentally Thevenin's theorem and validate the procedures to determine $E_{Th}$ and $R_{Th}$. Also, students will validate experimentally that the maximum power transfer to a load is defined by the condition $R_L = R_{Th}$

10 **Pulse Waveforms (Oscilloscope)**: In this lab, students will determine the R-C response to a square wave and note the effect of the time constant on an R-C circuit's pulse response. Students will gain experience using the function generator and oscilloscope.

12 **R-L DC circuits**: Students will examine R-L circuits' properties and transient response using a pulse (square wave).

In the in-lab EET3085L Electricity and Electronic course, most experiments are conducted under real-life conditions using actual components and measurement instruments and following the conditions outlined in each lab as stated in the lab manual [1] [2]. The online section is offered for those students unable to attend the live session. In both sections, students prepare and submit similar pre-laboratory tasks. The online section completes the set of laboratories in a virtual environment using Multisim. Online students are given "measured values" as parameters, typically a set of measured resistance values, entered into Multisim to run the simulations. Each student analyzes, discusses, and reports results from their simulations.

Although the simulation alternative produces correct results, the hands-on skills gained are not comparable to those obtained through real-life experiments. The virtual tool provides an ideal environment that masks actual conditions, such as equipment and component imperfections, noise, and changes in external conditions. Part of an engineer's training involves acquiring skills to perform in real-life environments subject to these events.

To address the lack of real-life environment experience, we must provide an experimental environment where students can deal with actual conditions. Low-cost electronic modules are available in the market to simulate real-life conditions for completing experiments related to electric and electronic circuits. Most of these modules are combined with a computer that serves as an interface between the module and the user, providing a complete set of measurement instruments such as voltmeters, current meters, signal sources, power supplies, etc.

This work proposes an alternative for online students to perform the complete set of experiments outlined in the syllabus in a real-life environment, using actual components and instruments to measure realistic conditions, thereby enabling accurate data analysis. In this regard, online and face-to-face sections will complete the same labs, achieve the same learning outcomes, and be assessed similarly.

**Literature Review**

There are multiple documented projects supporting online labs for electrical engineering. An example of one of the earliest is iLabs, part of iCampus [5], a research collaboration program between Microsoft Research and MIT initiated in 1999. iLabs permits students, using their personal computers' web browsers, to gain access to remote lab equipment to design, control, and collect data from experiments. iLabs allows access to sophisticated lab equipment. The type of users attracted to this project were labs from graduate courses such as Microelectronics Devices.

There are more experiences in remote labs with schemes similar to those of iLabs. One is the remote lab at BTH (Blekinge Institute of Technology) [7] [8], known as VISIR (Virtual Instrument Systems in Reality). VISIR is an improved version of The Open Electronics Lab at BTH. Their architecture is client-server architecture, in which measurements are carried out on a server, and the instrument front panel commands are displayed on the client's computer screen. Initially, the experimenter had to set the circuit in a "virtual breadboard," using a set of components that the instructor installed in a circuit board on the server side. The same board connects virtual instruments displayed on the experimenter's side. This scheme advanced into a more sophisticated platform with the VISIR initiative. The initiative involved a group of cooperating universities worldwide. The project's overall goal was to increase students' access to experimental equipment in many areas without significantly raising the running cost per student for the universities. VISIR uses grid architecture, which allows multiple concurrent lab sessions with students from around the world.

A different approach for moving the Electricity and Electronic labs to an online format is documented in the paper by Astatke, Scott, and Ladeji [6]. They have converted most of the laboratories using a portable module Mobile Studio™ I/O board, combined with equipment accessed remotely. Mobile Studio™ I/O Board is an IC board that is relatively small in print and inexpensive (around $150). The Mobile Studio Desktop's software module configures the unit with measurements and other equipment's capabilities (like oscilloscope, function generator, power supplies, voltmeters, etc.) that may cost around $10,000.00 [7] when acquiring the equivalent real instruments. The Mobile Studio project was launched at Rensselaer Polytechnic Institute (RPI) in 2008. The project was conceived as part of the STEM initiative, exploring science, technology, engineering, and mathematics as educational principles. It was first used in an Electric Circuits course in 2008. Over the years, the use of Mobile Studio gained widespread acceptance in other classes, such as Electronic Instrumentation. Further assessments to document and validate uses and outcomes, conducted by independent evaluators, reported the successful use of Mobile Studio in multiple instructional and student settings.

Considering our requirements for moving the EET3085 lab online, we observe that using a solution based on remote labs like iLabs or VISIR will not satisfy the requirement of working in a natural, hands-on environment of EET3085 labs since the interaction between the student and the equipment is virtual. In contrast, a solution based on a Mobile Studio I/O board with Mobile and Mobile Studio Desktop or similar seems like a good fit for our purposes. Such a solution would allow students to complete all labs without attending the lab using a portable, inexpensive module. After the success of Mobile Studio, similar modules have appeared on the market. We aim to create a platform based on inexpensive modules to offer a real-life, hands-on experience.

## Methodology

The first step compares similar experiences in moving laboratory courses in Electricity and Electronics to an online system. Comparing the experiences of other institutions, specifically focusing on the technology selected, the process of equipment endowment, software requirements, and issues with implementation may offer great value.

The second step involves reviewing the options available in equipment and software in the market. Each option was appraised and evaluated in terms of its capability to adequately convey each of the laboratories listed above within a reasonable price. This step may later include testing and evaluating the capabilities of each option according to their claimed nominal performance and their actual performance when carrying out the experiments.

In the third step, once the module and other equipment are selected, we will analyze the possible alternatives to provide students with the equipment and components. We will consider either having students acquire the chosen kit of instruments and components or requesting the college to purchase the kit and loan it to the students for a limited time. Concurrently, with the activities of this step, each of the labs will be converted and tested on the new platform. Each lab module will be documented for the specific kit, and videos will be available for each experiment.

The fourth step consists of gradual implementation. A pilot program would allow the introduction of corrections and improvements. A delivery verification process and a loan agreement shall be implemented should the college acquire and distribute the kits. An introduction video explaining the setup of the experiments with the kit will be available to the students.

The last step consists of continuous improvements. Periodically, we set a goal for the completion of labs and compare each lab outcome with the goal. Any differences will be analyzed, and the respective improvements will be applied until we reach the goal.

## Description of Alternatives

In this work, we propose adopting an affordable experimenter module to serve as a platform to complete the online labs under real-life conditions. We have successfully used a similar approach in other online labs at Daytona State College. For example, in CET 3198L (Digital Systems Lab), an FPGA experimenter board was introduced in 2013 as an alternative to online labs [3]. In the case of moving EET 3085L to an online system, we have searched the market for an option to adopt as an alternative. This module should offer the required features to perform the set of labs programmed for EET 3085L with minor adjustments to the conditions set for the currently used labs. The module should provide measurement instruments such as a voltmeter, ammeter, ohmmeter, oscilloscope, and a DC power supply and function generator as minimum requirements. We found four candidates: MyDAQ from National Instruments, Analog 2 Discovery from Digilent, and ADALM2000 and ADALM1000 from Analog Devices. Some available modules, such as a spectrum analyzer and Bode plotter, have advanced functionality. However, we will focus on the functionality required to complete the experiments: voltmeters, ammeters, ohmmeters, oscilloscope, power supply, and signal generator.

Table 1: Comparison of modules according to features and cost.

| Features | MyDAQ (with NI Elvis) | Analog 2 Discovery | ADALM2000 | ADALM1000 |
|---|---|---|---|---|
| Price in US$ | $ 371.00 | $ 279.00 | $ 149.00 | $ 40.00 |
| Voltmeter: DC | 200 mV, 2 V, 20 V, 60 V | ±25V | Two-channel voltmeter (AC, DC, ±20V) | 0 V to 5 V |
| Voltmeter: AC | 200 mVrms, 2 Vrms, 20 Vrms | ±25V | Two-channel voltmeter (AC, DC, ±20V) | –200 mA to +200 mA |
| Ammeter: DC | 20 mA, 200 mA, 1 A | NA | NA | YES |
| Ammeter: AC | 20 mA rms, 200 mA rms, 1 A rms | NA | NA | YES |
| Ohmmeter | 200 Ω, 2 kΩ, 20 kΩ, 200 kΩ, 2 MΩ, 20 MΩ | NA | NA | NA |
| Oscilloscope | Elvis Scope 2 channels: 5 V, 2 V, 1 V, 500 mV, 200 mV, 100 mV, 50 mV, 20 mV, 10 mV | Two-channel USB digital oscilloscope (1MΩ, ±25V, differential, 14-bit, 100MS/s, 30MHz+ bandwidth - with the Analog Discovery BNC Adapter Board) | Two-channel oscilloscope with differential inputs | Two channels |
| Oscilloscope Time Base | 200 ms to 5 μs. | NA | NA | 100 kSPS |
| DC outputs | ± 15 V, +5V Max Power 500 mW.(*) | 0…+5V, 0…-5V 700 mA | Two programmable power supplies (0…+5V , 0…-5V) | 5 V (200 mA) 2.5 V (200 mA) |
| Function Generator | Elvis Two Channels DC offset. Sine, square, triangular | Two-channel arbitrary function generator ±5V | Two-channel arbitrary function generator | 100 kSPS |

| | | | | |
|---|---|---|---|---|
| | 0.2 Hz to 20 kHz | | | |
| Powered | USB | USB | USB | USB |
| Max Power | 500mW | 500mW / 2.1W max with external power supply | 500mW | 500mW |

(*) My DAQ offers an interface board that plugs into the I/O ports into a protoboard and a 9-volt battery case.

Table 1 displays a comparative table with the relevant parameters for the experiments described above for the four modules mentioned. As observed, only one of the offered modules complies with complete functionality: MyDAQ, which is the only module equipped with an ohmmeter. It should be noted that the maximum DC output voltages are limited to ± 5 V, except for MyDAQ, which offers ±15 V. The lack of an ohmmeter is not a limitation since a multimeter may be purchased for a reasonable price. Similarly, all modules but Analog2 Discovery have a maximum output power of 500 mW. This limitation is a direct consequence of the power source used by all modules (the USB interface). To overcome the limitation on total output power, Analog 2 Discovery provides a separate power input that can be connected to an external power supply and increases the total output power to 2.1 W.

Most of the labs listed above use power supplies with values that exceed the ± 5 V limit. Limitations in maximum output voltages, currents, and power severely constrain the idea of using the same set of labs in the new environment. Therefore, it will be required to redesign each lab to comply with the restrictions imposed by power and voltage limitations without losing the purpose and pedagogical objectives for which each lab was conceived. Another limitation is that some labs (lab 7, lab 8, and lab 9) use multiple power supplies. MyDAQ would eventually supply two power supplies.

**Proposed plan for moving online EET308L labs to real-life experimentation**.

We propose a plan in two steps:

1. Redesign the labs based on the adoption of the new equipment.

The first step, redesigning the labs, will require a thorough review of each current experiment and their adaptation to the new environment. Such review involves scaling (up and down) values of components and input sources, testing prospective circuits using different alternatives of modules, checking that the difficulty and time to complete the experiments are within the expected range, verifying that the power values are within the range, and ensuring that the results are consistent with the purpose of the experiments. We foresee having a first version of the course material that includes the selected module and kit of components to distribute to students, a complete set of documents (lab guides, support material, and lab assessments), and a set of videos. Assuming that, on average, the production of each lab takes two weeks, the estimated time to complete the first step is around 24 weeks. In this step, the funding arrangement for the project should be clarified.

2. Proceed with a pilot program to validate and assess the pedagogical effectiveness of the online labs for EET 3085L.

Once the experiments and resources are available, a pilot program for a complete 2023-2024 academic year cycle will be implemented. A multidisciplinary committee of representatives from the Engineering Technology, Online Studies, and School of Education will validate the effectiveness during three semesters. Throughout the entire cycle, the outcomes and findings will be continuously reported to the committee so that corrections can be made. It is relevant to mention that a peer review committee periodically assesses each online course to evaluate the course's effectiveness and the quality of the learning process. Additionally, online instructors must complete 45 hours of Online Faculty Training, including 20 hours on Applying the Quality Matters Rubric, as recommended in [10].

**Results**

During the 2022-2023 academic year, we began utilizing some available options to complete labs with students attending live laboratory sessions at the school. This approach allowed us to monitor the performance of live students under natural conditions. It enabled the instructors to manage the adjustment process under realistic conditions. In these labs, we utilized two MyDAQ modules, one Analog Discovery 2, and multimeters from the lab. The total number of experiments listed were conducted using the modules, components, and boards from the Electricity and Electronic laboratory. Some of the original experiments were modified to overcome the limitations of the modules, such as the module's maximum voltage level and the experiments' nominal values.

The same approach was taken to satisfy the requirements of a hands-on lab, completed remotely for a different class, Linear Integrated Circuits Laboratory (EET 4158L), a senior class in the bachelor's program of Electrical Engineering Technology. EET 4158L requires the completion of eleven laboratories, all of which use operational amplifiers. We have been utilizing the same approach as EET 3085L, with some modules, MyDAQ and Analog Discovery 2, to complete the total of EET 4158 labs offering a hands-on experience.

**Illustated Example**

In this section we present an example of a selected lab completed with MyDAQ kit. We selected lab number 10, Pulse Waveforms (Oscilloscope). As mentioned above In this lab, students will determine the R-C response to a square wave and note the effect of the time constant on an R-C circuit's pulse response. Students will gain experience using the function generator and oscilloscope.

Figures 1 and 2 show  the MyDAQ kit consisting on DAQ module, connectors and probes and a MyProtoboa rd for NI MyDAQ

Figures 3 and 4 show the response of the RC circuit (in blue) to square wave input (in green). We can notice the effect of the frequency in the shape of the dapacitor response.

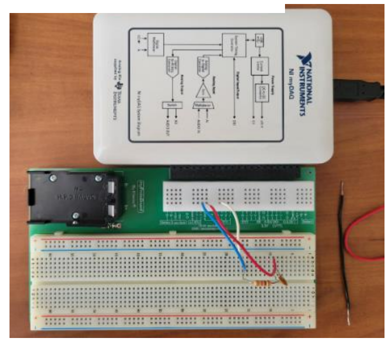
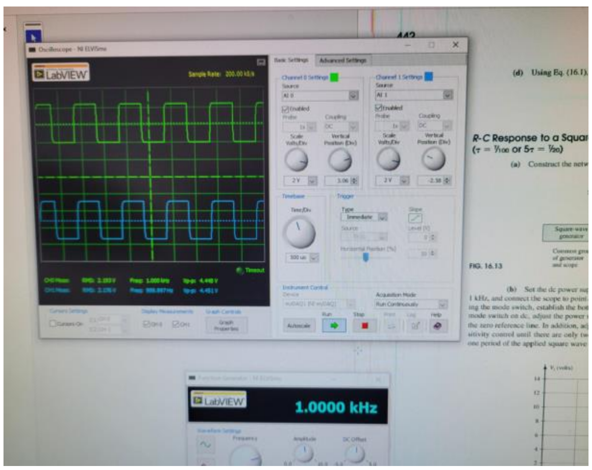


**Figure 1: MyDAQ Kit and My Protoboard**

**Figure 2: RC circuit under test mounted in My Protoboard**



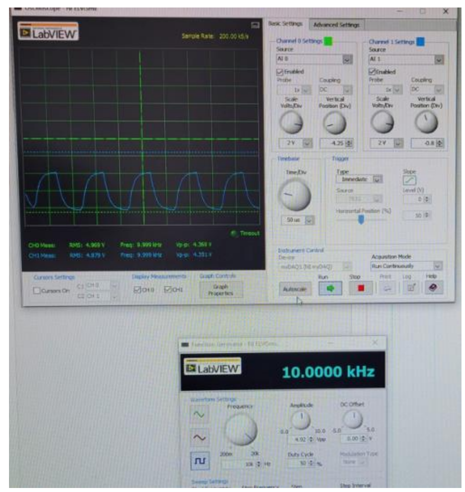




**Figure 3: Sqare waveforms of source and capacitor at 1KHz**

**Figure 4: Squarewaveform of capacitor frequency response at 10 kHz**

## Conclusions

One of our goals as educators of future engineers is to ensure that graduates acquire experience in dealing with real-life events. An engineer should identify essential real-life elements such as components and current voltages, not only as numbers in equations or values in a matrix. Numbers in equations and values in matrices are easy to forget; however, hands-on experience with real-life equipment and components contributes to the lifelong learning process of an Electrical Engineer. EET 3085L Electricity and Electronic Lab is the perfect opportunity to provide future electrical engineers with experience gained as genuinely as possible by working in a real-life, hands-on laboratory. This work is a proposal to provide electrical engineering students with an experience that should not be limited to students who attend the laboratory to complete the labs, and it is possible to offer such a substitute. We present an action plan and guidelines to move EET 3085 to a genuine, hands-on, experiment-based approach.

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