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Incorporating Software Simulation into Electric Circuit Experiments

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Abstract- A number of laboratory experiments in a sophomore electrical engineering course, Circuits and Devices, were revised to accommodate students' needs during COVID-19. This was accomplished while ensuring that a reasonable level of hands-on experience with electrical components and basic laboratory equipment still took place. During the semester, students completed three hands-on experiments on campus, six experiments that involved analysis and software simulation, and a final project with an oral presentation. Some final projects included hardware and software while others were limited to circuit design and software simulation. This paper briefly describes six remotely performed exercises that used Multisim to perform circuit analysis and simulation and help students learn the course material. While there were several challenges, overall students were able to perform the experiments and successfully complete a final project.

Introduction

A report by the United Nations estimated that closures of schools and other learning spaces due to the COVID-19 pandemic impacted 94% of the world's student population in 2020 [1]. This included a severe impact on higher education, as many universities closed their premises and replaced face-to-face lectures with an online learning environment [2] – [3]. A similar effect was experienced in the case of summer events such as camps and research experiences for undergraduate students where some institutions selected to cancel such programs while others held them remotely or in hybrid formats [4] – [5]. In most cases, online delivery of courses required some adjustments of course material and pedagogy and faculty responded with a variety of approaches to adapt to the situation [6] – [9]. In laboratory courses, there were additional unique challenges due to the difficulty in providing some level of hands-on experimentation, teamwork opportunities, and social interactions among students [10].

At Penn State University-Harrisburg, most courses during the 2020-2021 academic year were offered remotely while some included a mixed-mode delivery mode. In laboratory courses, in particular, a combination of in-person and online experimentation was a reasonable option. This is based on the general understanding that hands-on experimentation is crucial to the learning process and simulation cannot be a substitution for the experience of building and troubleshooting a circuit on a breadboard. In Circuits and Devices, a sophomore electrical engineering course, a number of laboratory experiments were revised to accommodate students' needs while ensuring that a reasonable level of hands-on experience with electrical components and basic laboratory equipment such as power supplies, multimeters, still took place. To accomplish this objective, the laboratory portion of the course included three hands-on experiments that students completed on campus, six exercises that involved software simulation, and a final project with an oral presentation. Some final projects included hardware and software components while others involved only design and software simulation. This paper provides brief details about the remotely completed experiments using Multisim, a National Instruments Software package. Most students accessed the software remotely through the University while others selected to purchase the Student Edition of Multisim. While there were challenges in accessing the software remotely, one positive outcome of this experience is incorporating Multisim in several experiments in a very meaningful way. When teaching the course in-person in the future, Multisim would be further integrated into the course with additional improvements. Experiments would be revised to include two phases: (1) Completing a pre-lab that involves theoretical analysis and software simulation, and 2) Building and testing the circuit on a breadboard.

Laboratory Experiments

Throughout the semester, students completed a total of 9 experiments in addition to a final project. The experiments were designed to complement the material covered in the lecture part of the course [11]. Three experiments were completed in the laboratory on campus and six experiments were completed using a software package, Multisim. The Multisim exercises were performed during weeks 1, 2, 4, 5, 7, and 9 during the semester while the hands-on experiments were performed during weeks 3, 6, and 8. There were 25 students in this course and they worked individually throughout the semester. The hands-on experiments focused on (1) Constructing electric circuits on a breadboard and becoming familiar with resistor, voltage, and current measurements by applying KVL and KCL, (2) Applying nodal and mesh analysis to a circuit with two voltage sources and taking measurements of nodal voltages and branch currents, and (3) Designing, constructing, and testing a "high voltage level" indicator using an Op-Amp and other electronic components. The following paragraphs briefly describe the six software exercises that were completed remotely.

<u>Exercise 1:</u> The purpose of this exercise was to help students become familiar with Multisim and use it for current, voltage, and power measurements. Students were asked to create and analyze several simple circuits.

<u>Exercise 2:</u> The purpose of this exercise was to help students learn about the four dependent sources: (1) Current-Controlled Voltage Source, (2) Current-Controlled Current Source, (3) Voltage-Controlled Voltage Source, and (4) Current-Controlled Voltage Source. Students used Multisim to construct four relevant circuits and make measurements to verify their operation.

<u>Exercise 3:</u> In this exercise, students used the circuit shown in Fig. 1 to learn how to apply and examine DC Sweep Analysis using Multisim.

DC Sweep Analysis simulates a circuit multiple times, sweeping the DC values over a predetermined range for a specified variable. For sweeping over a range, the following values need to be specified: start value, stop value, and increment.

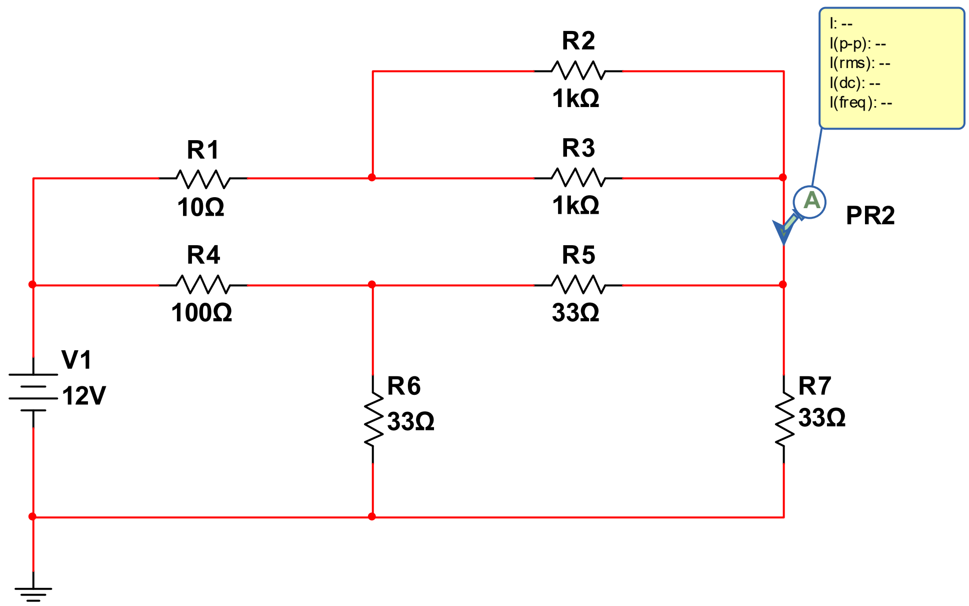
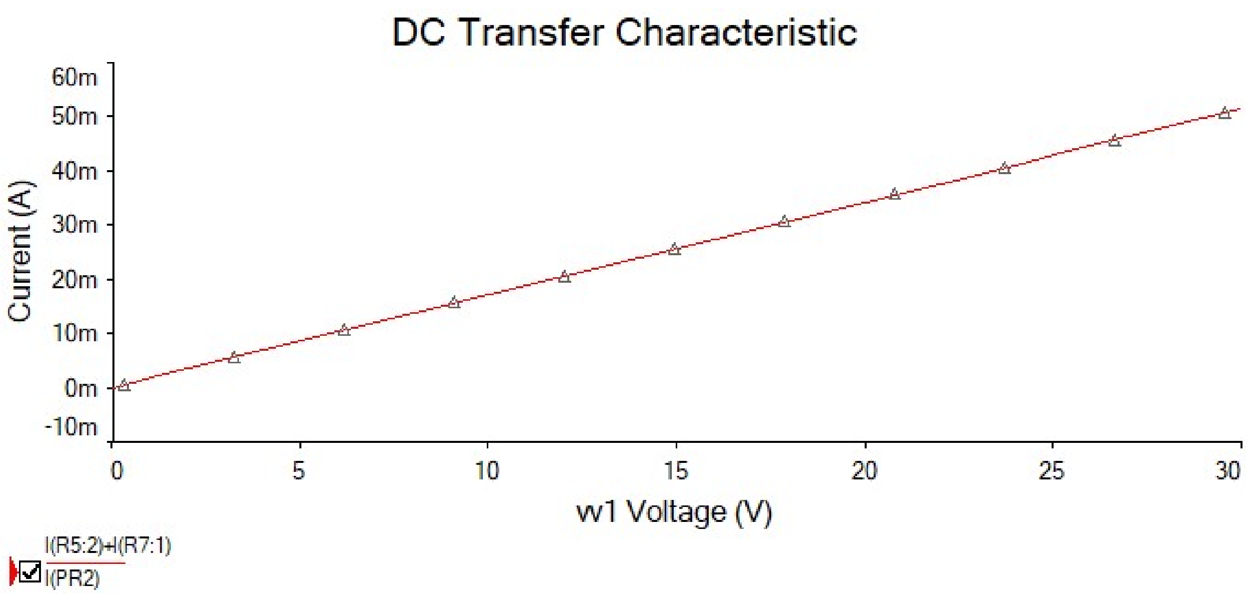


Fig. 1 Resistive circuit with one voltage source

To analyze the circuit manually, students needed to apply delta to Y conversion to produce a simplified circuit. The following graph shows a sample test with the source voltage being "swept" from o to 30 V.



Exercise 4: In this experiment, students used the circuit shown in Fig. 2 to examine resistor tolerance effects by performing Worst Case Analysis.

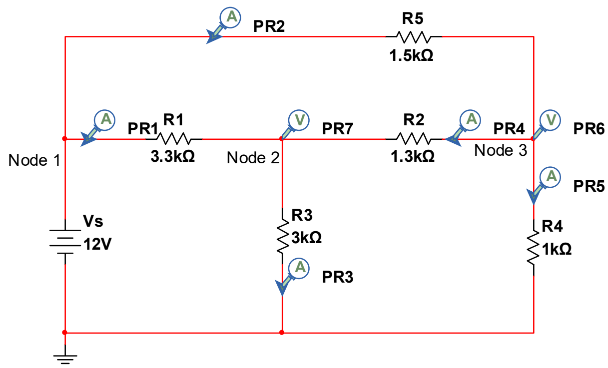
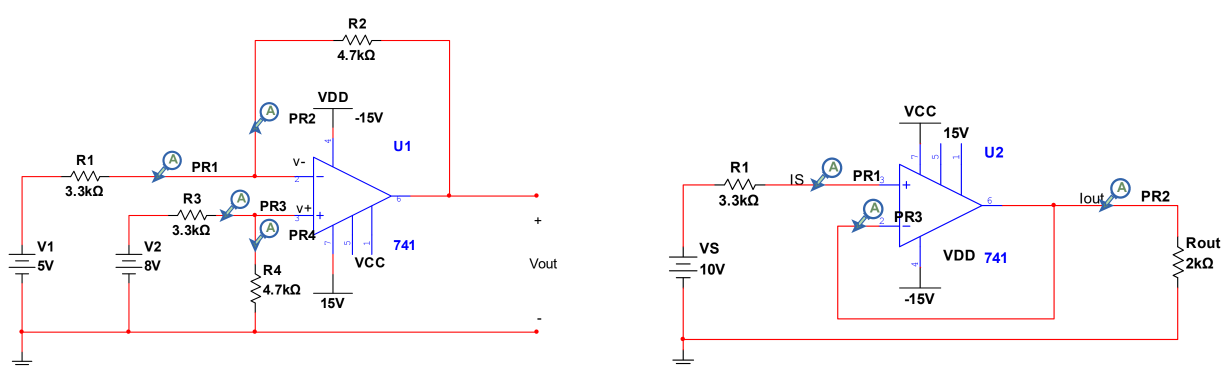


Figure 2. Resistive circuit with one voltage source and several nodes

Different tolerance values were assigned as follows: R_1 and R_2 (10%), and R_3, R_4, and R_5 (5%). Once entering tolerance data is completed, one needs to specify the analyzed variable, V(2) in this case. Both extreme values, V(2)max and V(2)min, were identified. Students recorded the Nominal and Worst-case values.

<u>Exercise 5:</u> In this exercise, students explored Op-Amp applications. Two circuits, a voltage difference op-amp circuit and a voltage follower circuit, were used to accomplish the goals of this lab. For the circuit in Fig. 3(a), students manually derived the output voltage (Vout) in function of V1, V2, R1, R2, R3, and R4, then used the 741 Op-Amp model in the Multisim library to create and simulate the circuit. The measured output voltage, Vout, was compared with manual calculations.

For the circuit of Fig. 3(b), students created the circuit, measure Vout, and compared it with the source voltage VS. In addition, the currents going into terminals 2 and 3 were measured as well as the current flowing out of pin 6. Students were asked to answer a few critical questions about the operation of the circuit and its usefulness.



(a) (b)

Figure 3 (a) Voltage difference Op-Amp circuit (b) Voltage follower Op-Amp circuit

Exercise 6: This exercise involved determining the Thevenin equivalent circuit and experimenting with dependent sources. This was done manually and using Multisim for the original circuit shown in Fig. 4. Since the circuit contains a dependent source, students needed to use the open-circuit and the short-circuit measurement approaches.

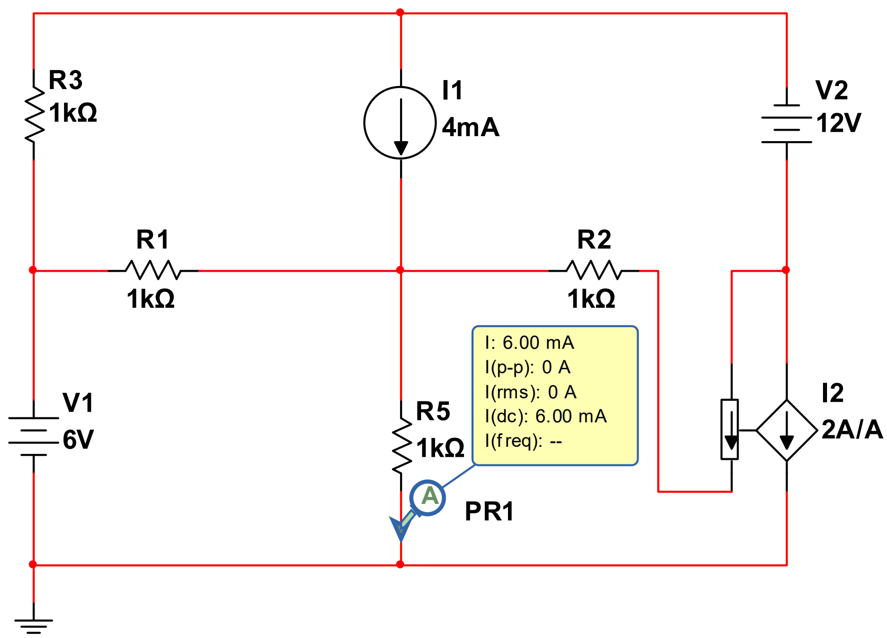
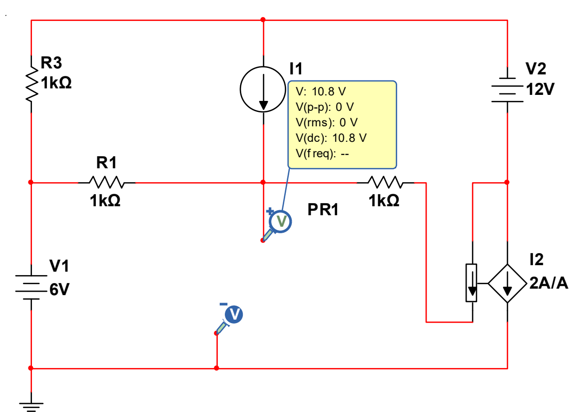
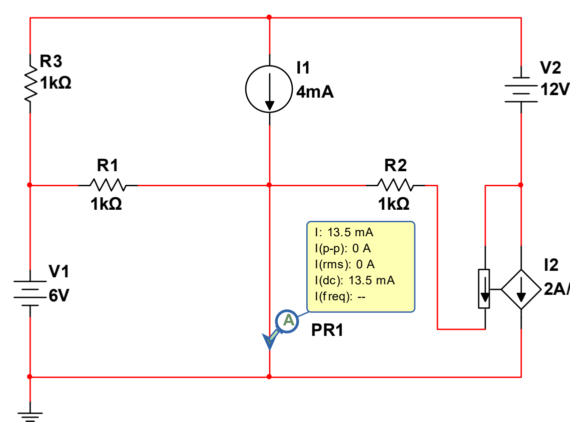


Figure 4. Measurement on the original circuit

To use Multisim to determine Vth and Rth, one needs to determine the open-circuit voltage and the short-circuit current to be able to compute Rth. The open-circuit measurement is shown in Fig. 5 (a) and the short-circuit measurements is shown in Fig. 5 (b).



(a)



(b)

Figure 5. (a) Circuit for open-circuit voltage, (b) Circuit for short-circuit current

Student Feedback and Future Plans

Students were encouraged to provide written feedback at the end of the semester as part of the final report and/or through the official course evaluation forms administered by the University. Feedback was in general positive, but a number of students recommended more hands-on experiments. Some students also made comments about the need for a hands-on tutorial to learn how to use the software. Although a lab session was devoted to going over the basics of Multisim, some students found the handouts and the online tutorials to be a little challenging. This feedback will be taken into consideration to improve this laboratory course.

Conclusion

Laboratory experimentation is an essential component of a comprehensive learning experience in engineering and engineering technology programs. This paper describes a set of software simulation exercises that were developed to complement the limited hands-on opportunities in Fall 2020 due to the COVID-19 pandemic. The exercises ranged from simple circuits that illustrated the use of Multisim to more complex and practical circuits that covered Op-Amp applications, dependent sources, and the Thevenin theorem. In general, we were successful in achieving the course objectives but there is room for improvement. Future plans include integration of the software into every experiment in this course while increasing the number and complexity of the hands-on experiments. Experiments would be revised to consist of two phases: (1) Students would complete a pre-lab that involves theoretical analysis and software simulation, and 2) Students would build and test the circuit in the laboratory. The final project was well-received by students and is expected to continue to exist in a similar format where students were encouraged to include both software simulation and hardware construction and testing.

References

[1] United Nations, "Policy Brief: Education during COVID-19 and beyond August 2020," [Online]. Available: https://www.un.org/development/desa/dspd/wp-content/uploads/sites/22/2020/08/sg_policy_brief_covid-19_and_education_august_2020.pdf.

[2] Andreas Schleicher, *The Impact of COVID-19 on "Education – Insights from Education at a Glance,"* The Organisation for Economic Co-operation and Development (OECD), 2020, [Online]. Available: the-impact-of-covid-19-on-education-insights-education-at-a-glance-2020.pdf (oecd.org), accessed on 9/24/2021.

[3] Seema Nazneen, G. Vishal, "*The Impact of COVID-19 on Education*" International Journal of Science and Research (IJSR), Volume 9 Issue 5, May 2020, 647 – 650. [Online]. Available: https://www.ijsr.net/search_index_results_paperid.php?id=SR20506142725.

[4] Weickenmeier, J. (2020, November), "*Running A Virtual Summer Undergraduate Research Program: Lessons learned*" Presented at 2020 Fall ASEE Mid-Atlantic Section Meeting, Virtual (hosted by Stevens Institute of Technology). https://www.jee.org/36054.

[5] Lim, L. (2021, January), "*From Residential to Remote: Adapting Summer Bridge Practices (Millennium Scholars Program),*" Presented at 2021 CoNECD, Virtual, https://www.jee.org/36058.

[6] Shekoyan, V., & Dehipawala, S., & Kokkinos, D. S., & Taibu, R., & Tremberger, G., & Cheung, T. (2020, November), "*Assessment of Experiential Learning in Online Introductory Physics Labs during COVID-19,"* Presented at 2020 Fall ASEE Mid-Atlantic Section Meeting, Virtual (hosted by Stevens Institute of Technology). https://strategy.asee.org/36041.

[7] Lieber, S. C., & Borgaonkar, A. D. (2020, November), "*Focusing on the Silver Lining: How COVID-19 Pandemic is Influencing the Pedagogy of Mechatronic Course Delivery to Support the Industrial Role of a Mechanical Engineering Technologist," P*resented at 2020 Fall ASEE Mid-Atlantic Section Meeting, Virtual (hosted by Stevens Institute of Technology). https://peer.asee.org/36047.

[8] Li, J., & Ramos-Salas, J., & Li, C. (2020, July), "*Experience of Teaching Introduction to Electrical Engineering with an Online Platform," P*resented at 2020 First-Year Engineering Experience, East Lansing, Michigan. https://peer.asee.org/35758.

[9] Modenbach, A. A., & Peterson, M. M. (2021, July), *Lessons Learned From a Covid-impacted Capstone* Paper presented at 2021 ASEE Virtual Annual Conference Content Access, Virtual Conference. https://peer.asee.org/37437.

[10] Javaid, M., & Wittenmyer, E. L., & Henriquez, O., & Pritchett, L. D. (2021, July), *Undergraduate Engineering Laboratories During COVID-19 Pandemic* Paper presented at 2021 ASEE Virtual Annual Conference Content Access, Virtual Conference. https://peer.asee.org/37948.

[11] J. David Irwin and R. Mark Nelms, "*Basic Engineering Circuit Analysis,"* 11th Edition, Wiley, 2015.