

AC 2007-2065: TEACHING AND MENTORING RESEARCH EXPERIENCES FOR UNDERGRADUATES IN POWER ELECTRONICS

Doug Sterk , Virginia Tech

Douglas Sterk is a PhD candidate in the Bradley Department of Electrical and Computer Engineering at Virginia Tech and has received his BSEE and MSEE from Virginia Tech in 2000 and 2003, respectfully. He is currently working at the Center for Power Electronic Systems researching high frequency dc/dc power conversion, resonant power conversion, integrated magnetic designs and semiconductor device optimization.

Tim Thacker , Virginia Tech

Timothy Thacker is a PhD candidate in the Bradley Department of Electrical and Computer Engineering at Virginia Tech and has received his BSEE and MSEE from Virginia Tech in 2003 and 2005, respectfully. He is currently working at the Center for Power Electronic Systems doing research on the interconnection and control of distributed generation to the electric utility grid.

Elizabeth Tranter, Virginia Tech

Elizabeth Tranter received the M.A. from University of Wisconsin-Madison. She joined the Indiana University faculty in 1992, with an emphasis on course coordination and teaching assistant training. In 1996, she joined an academic publishing house, where she worked as a language specialist as an associate developmental editor. She has been affiliated with Virginia Tech since 1998, and joined the Center for Power Electronics Systems in 2000, where she serves as Administrative Director and Education and Outreach Program Director.

Richard Goff, Virginia Tech

Richard M. Goff is the Pete White Chair for Innovation in Engineering Education, Associate Professor, and Assistant Head of the Department of Engineering Education at Virginia Tech. An award winning teacher, his main areas of research and teaching are design and design education.

Janis Terpenney, Virginia Tech

Janis Terpenney is an Associate Professor in the Department of Engineering Education with affiliated positions in Mechanical Engineering and Industrial & Systems Engineering at Virginia Tech. She is co-Director of the NSF multi-university Center for e-Design. Her research interests focus on methods and representation schemes to support early design stages of engineered products and systems. She is currently a member of ASEE, ASME, IIE, and Alpha Pi Mu. She is the Design Economics area editor for The Engineering Economist journal.

Teaching and Mentoring Research Experiences for Undergraduates in Power Electronics

Abstract/Introduction

This study examines the National Science Foundation's (NSF) Research Experiences for Undergraduates (REU) program and REU for Louis Stokes Alliance for Minority Participation (LSAMP) Scholars at the Center for Power Electronic Systems (CPES) at Virginia Tech.

The REU program “supports active research participation by undergraduate students in any of the areas of research funded by the National Science Foundation. REU projects involve students in meaningful ways in ongoing research programs or in research projects designed especially for the purpose. [...] Undergraduate student participants [...] must be citizens or permanent residents of the United States or its possessions.”¹

The CPES REU program seeks to: provide experiences, develop expertise in experimental laboratory research among undergraduates prior to their senior year of undergraduate study, and to encourage participants to pursue graduate studies in science, technology, engineering and mathematics (STEM) programs. The NSF Engineering Research Centers (ERC) Program, which is designed to foster multi-institutional, interdisciplinary, and systems-oriented approach to collaborative research, is a favorable environment for development of a rich REU experience.

Following completion of a successful three-year REU program at Virginia Tech and the University of Puerto Rico Mayaguez (UPRM), CPES successfully proposed a three-year continuation of the program at both universities. During this period, CPES also sought to broaden its approach to the REU program goal of expanding linkages to curriculums designed to increase participation of students from under-represented populations in STEM fields. As multi-institutional centers with a 10-year potential NSF funding cycle, ERCs are well suited to foster inter-institutional collaboration with core and outreach partner institutions over the course of many years. To encourage the development of programmatic linkages as part of each Center's diversity strategic plan, the NSF offered all active ERCs the opportunity to submit proposals for the development of programs which create linkages between research centers and large-scale NSF human resource development initiatives. For CPES, this program solicitation represented the opportunity to expand linkages with the NSF's Louis Stokes Alliance for Minority Participation (LSAMP) program. The LSAMP program “is aimed at increasing the quality and quantity of students successfully completing STEM baccalaureate degree programs, and increasing the number of students interested in, academically qualified for, and matriculated into programs of graduate study. LSAMP programs support sustained and comprehensive approaches that facilitate achievement of the long-term goal of increasing the number of students who earn doctorates in STEM fields, particularly those from populations underrepresented in STEM fields. The program goals are accomplished through the formation of alliances.”²

In 2004, CPES successfully proposed to build on a growing collaboration between the ERC program and the LSAMP program in order to develop an REU in power electronics targeted to LSAMP participants. The purpose of this program is threefold: 1) to provide additional

opportunities to ERC students to obtain a rich undergraduate research experience, including consecutive summer experiences, for interested students; 2) to extend ERC resources to non ERC students; and 3) to encourage the participants' pursuit of engineering research activities and graduate study after completion of the REU program. Opportunities to expand collaboration are further enhanced by the consortium organization of the Louis Stokes Alliances, which provide access to several institutions through each regional alliance.

The structure of the CPES REU and LSAMP REU programs are unique in their integration into the Center's diversity strategic plan, which specifies the goals, commitments, and results for each partner campus in the areas of student recruitment and undergraduate program development. Through the CPES Education Program, REU and LSAMP REU participants have the opportunity to apply for short-term travel scholarships, which enable their continued participation in Center-related research during the academic year. This has proved an effective mechanism for continued engagement of undergraduates in Center programs, and occasionally, for integration of summer research into the student's undergraduate capstone design project(s). The Center's consortium format also allows participants from partner universities to establish a faculty contact at their home campus following the summer research experience.

The REU program at CPES is an eight-week summer program for undergraduate students expressing interest in the field of power electronics. This program spans the disciplines of electrical engineering, computer engineering, mechanical engineering and materials science engineering. The 2006 projects selected by the participating students consisted of digital control design, system-level electromechanical analysis hardware implementation and testing of an experimental test-bed. The graduate mentors guided the undergraduates with evaluation and selection of the types of research pursued. The REU students also attended a unique introductory course taught by a graduate instructor over the program's duration. Though not a required NSF REU element, this course is important for students' success and continued participation in the field.

As a multi-institutional ERC, CPES was also challenged to integrate the REU as a supporting structure for intercampus collaboration for the Center. For CPES, which included core partner campuses with emerging power electronics, both curriculum and research program development were priorities. CPES made a special effort to recruit REU students from partner institutions which were in the process of establishing upper-level undergraduate and graduate-level curricula, as well as research programs in power electronics. The summer course was customized to articulate with VT's basic power electronics course, or its equivalent courses which had been developed at partner campuses and modeled after the VT course. In order to enhance the summer research experience, a summer program for graduate students was offered in parallel to the REU, and was utilized by graduate students from the same home institutions as the undergraduate researchers. Through course articulation, the shared research experience of undergraduate and graduate students and research program coordination within the Center, CPES strengthened the mechanism for sustaining their summer experience into the following academic year.

Details of the students' activities and progress throughout the summer are described in this study. The course instructor and research mentor coordination between class and work in the laboratory was essential and is reviewed and analyzed.

The program's effectiveness is dually assessed by: 1) evaluating achievements during the program through a survey given to recent REU graduates and 2) correlations made on the grades of the students who took a power electronics courses the following semester(s) compared, relatively, to students who did not participate in the REU programs.

Lectures and Classroom Portion of the REU Program

The REU students, though coming from diverse backgrounds, all were either Electrical or Computer Engineering undergraduate majors, thus had basic knowledge of EE/CpE theories and concepts. Though partnered with a mentor that guided them on their research project (see following section for research details), the students were also required to attend a lecture series on basic Power Electronics three days a week for the duration of the program.

The classroom aspect of this program is unique from other REU programs, firstly by its existence alone, but also in its purpose. The lecture series allows the students to become familiar with the basic concepts and practices of power electronics to perform research; without having a mentor spend the time explaining fundamental concepts and ideas. This allows the research mentor to concentrate on helping the students with advanced concepts and research, which greatly accelerates the students' progress toward successfully completing a research project by the end of the program.

Through this class/lecture series, the students reviewed familiar concepts that they had previously been exposed to, as well as being introduced to more advanced concepts and practices in Power Electronics design. The lectures were paced quickly at first, reviewing the previously learned material, then began to slow down and track what they were working on in their research projects. The lectures were generally 2-3 days ahead of the types of things they were working on in their research. This allowed the students to become familiar with the theories needed for research before hand; which in turn allowed a quicker progression in their research projects. Once the review material was covered, the students began learning basic modeling techniques and the principles behind how power electronic converters work. This gave them a jump-start in their research project selections and an understanding of the ultimate goals to achieve throughout the program. The lectures then turned to more advance modeling techniques that improve the accuracy of the design; as well as control techniques for getting the converters to give the desired output. The bulk of the lectures were spent on these advanced topics, with various examples and homework problems assigned to the students to reinforce the concepts learned in the lectures. Though the coursework was accelerated and compacted to fit the duration of the program, the examples and homework problems given to the students helped keep them up to speed and absorb the knowledge presented to them.

Toward the end of the program, the students were introduced to a few practical examples of how these converters are used in the real world by going through full design examples, and observing an advance experiment in power electronics research at Virginia Tech.

Laboratory Research Portion of the REU Program

During the first days, the students were given a tour of the laboratories at CPES at Virginia Tech's campus and met with three graduate mentors. The mentors explained the many areas of Power Electronics research, and what topics they could pursue for their summer work. The mentors did not lead the students in any one direction over another, but allowed the students to ask questions and pursue the area of research that most interested them. The students were then split into groups of two, based upon the areas of research they decided to engage in, and paired with one of the graduate mentors.

After the REU students, were paired with their respective graduate mentors, the students and mentors spoke about what type of research project would be beneficial to study. This year there were three major projects carried out. The first project entailed building an advanced voltage regulator module to power future microprocessors, the second project involved digital modeling and designing a digital control algorithm for a single phase inverter, and the final project required designing, building, and testing a test bed for a future high voltage distributed power system. The students first chose the research project that sounded interesting to them, without any prior background or information about the subject, and then decided what specific topic of the project they would like to study for the summer. Within the first few days of the program, the mentor supplied the students with a tentative schedule of work to adhere to and a suggested a list of goals for completion of the project. The schedules made were closely aligned with the course material taught in the lecture section of the program.

Scope of the research project

The schedule of the research project was an imperative part of the research experience in general; without it the students would not know where to begin and where to end. The first two weeks of the program the students had to read many papers about the research topic that they chose. The mentors supplied the initial papers on the research topic. The mentors were tasked with teaching the undergraduates how to perform a literature search on a topic in order for the students to find subsequent articles.

The mentors also taught the students several software packages that were necessary for completion of their research project. The software programs taught were SABER and SIMPLIS for circuit simulations and ALTIUM/Protel for printed circuit board (PCB) layout.

The next few weeks of the REU program the students learned how to model the hardware in a circuit simulation program. The mentors attempted to give the students a first hand feel for the circuit's functionality and to show potential problems that might occur when the actual hardware is tested. Intentionally placed in the student's idealized models were parasitic components and non-idealities that would be observed in a real life simulation. Typically, in undergraduate courses, the homework and projects assigned use only idealized circuit models, and in this context was the first time that the students had encountered these types of non-idealities

After exploring the circuitry that would be used for their research project, the students then designed the PCB that would later be populated for hardware demonstration. Printed circuit board design is a technique that is rarely taught in an undergraduate course, making it a unique experience for the students. When the PCB is returned from the manufacturer, the students then soldered the surface mount components down on the board for testing. As such, the mentors had to teach the students the proper methods of soldering devices so the students would not destroy the silicon devices or detach the copper traces from the PCB.

Finally, the students built and tested their hardware and compared results to the simulated model. Before the students energized their circuits the mentors had to demonstrate how to test and debug a live circuit board and reiterated the laboratory safety protocols.

Student Evaluation

The success of the REU program at Virginia Tech, as mentioned above, has been dually assessed. The first assessment is by a survey completed by the students that have graduated from the REU program. The second assessment is of the final grade score of the REU students that took introductory power electronics class the following semester compared to those students who did not participate in the REU program.

The survey, shown in appendix A that was given to the REU graduates, shows an overwhelming endorsement of the REU program. The majority of the survey respondents stated that they continued on to take an introductory power electronics class, and more importantly the program gave the student confidence that they could pursue a graduate degree and influenced many of the students to pursue a career or graduate degree in power electronics.

Due to the fact that the lecture portion is unique portion to the CPES REU experience, several questions in the survey were directed at assessing the effectiveness of the lecture portion of the REU program. A generalization can be made from the responses that the lecture portion of the program helped the participants understand their research quicker. It was also indicated that without the lecture, much time and effort would have to be spent between the student and mentor learning and teaching the fundamentals.

Having the lecture sections allowed information to be rapidly delivered to the REU students all at the same time rather than have each mentor teach each pair of students in parallel. This, in turn, freed up time for the mentors to prepare the laboratory sections of the program. There was a response from a student that had previously taken an introductory power electronics course prior to the REU program and they stated that the lectures help clarify the lessons learned in their previous power electronics course.

In the survey there were also several questions that pertained to the mentoring portion of the REU program. In summary, the students expressed the notion that the hands on laboratory experience of the REU program far exceeded any other traditional undergraduate laboratory experience. The students stressed that one of the major benefits of the REU program that they were exposed to and learned where the new tools that would not otherwise learn before entering industry. Some of the tools taught to the students during the program were performing general,

as well as an exhaustive, literature search, effective presentation skills for a wide variety of audience members, electronic test equipment usage, soldering techniques, and hardware debugging techniques. This program also gave the students confidence that they could pursue a graduate degree and perform high-level research. The overall acceptance of the REU program's format, from the students' perspective, is evident by the survey results.

The only suggestion made by the students to improve upon the program, was that it be made longer. The students showed such enthusiasm for the program and repeatedly expressed their interest that it last two weeks longer than originally planned, because they enjoyed it and the surroundings tremendously.

However, there was another significant measure of the program's success: by a comparison of the REU participants' versus non-participants' final course grades for the following semester's introductory class in power electronics. Shown in Figure.1 is a relative comparison of final grades. The students that participated in the REU program all had grades that were 91 percent or above, which commonly indicates an "A" letter grade. The students that did not participate in the REU program had a wide distribution in final score with the mean grade being 87 percent and with a standard deviation of 9.9 percent, while the REU students' grades had a mean value of 95.2 percent with a standard deviation of 3.5 percent. The difference in the mean student score from non-participant to participant is 8.2 percent.

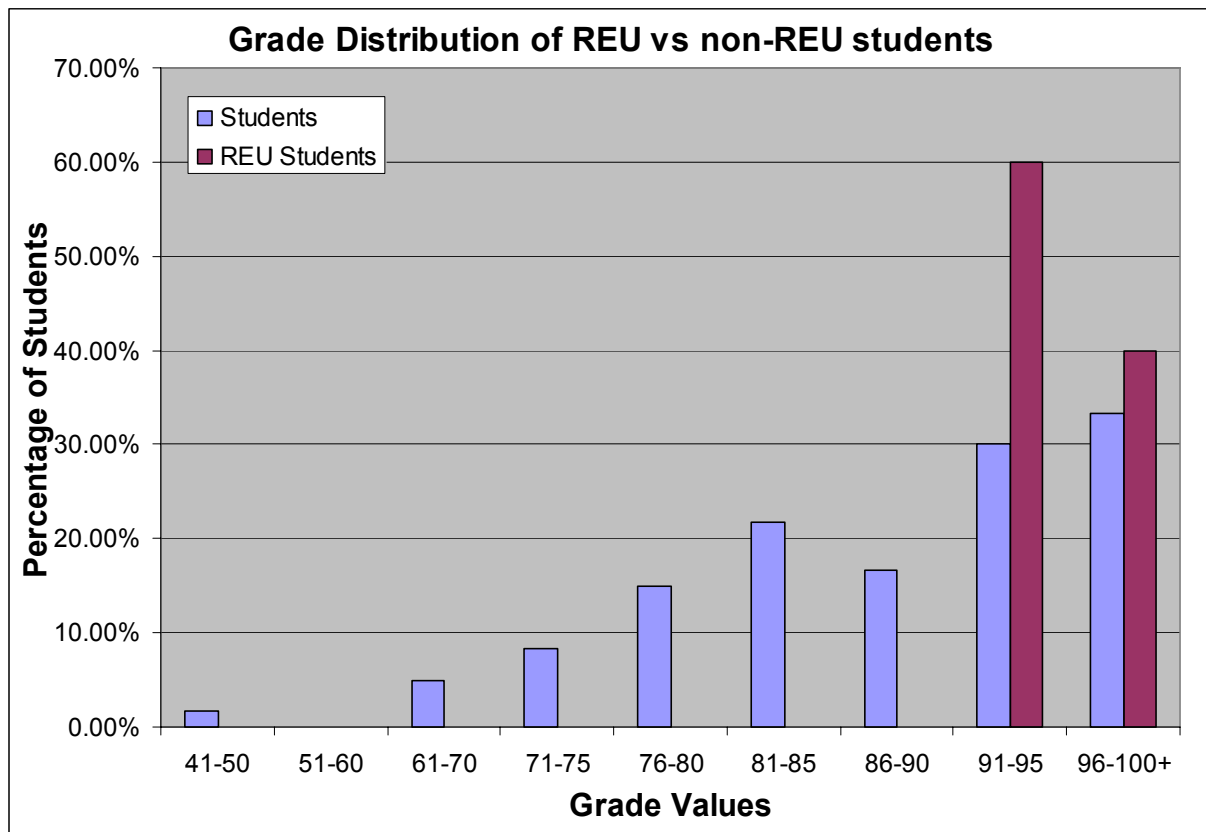


Figure 1. Grade distribution of the REU Participants' final grades vs. non-participants final grades for the Introduction to Power Electronics course

Conclusions

From observing the 8 percent improvement in the mean final grade score of the REU program students in the introductory power electronics course, and then combining this with the overall opinion of the REU program by the students themselves, one can conclude that the REU program is a very successful entity at Virginia Tech.

The students learned not only valuable research skills and were introduced to new design techniques, but also gained experience in using advanced testing equipment and procedures, conducting research reviews and surveys, and bolstered their presentation skills. The unique course to which they attended over the program's duration allowed the students to learn basic concepts and design techniques at an accelerated rate, while also allowing them to make advancements toward their research goals. This was key to the completion of their projects because they no longer had to spend the time alone or with their mentor learning fundamental concepts, which allowed them to focus more on research and result interpretation.

By forming and expanding alliances with other schools, the CPES's REU program is able to reach a wide-variety of students from various institutions. Through this outreach the program is able to provide learning opportunities not available through traditional undergraduate studies, and to influence students to continue their education and pursue a graduate degree by instilling the confidence in them that they have the capability to succeed beyond the undergraduate level.

As mentioned before, the only real improvement suggested by the students to be made was that the program last about two weeks longer because they enjoyed the experience so much. Other possible improvements to be made could include more in-depth assignments for the classroom portion of the program, as well as possible tours to other labs and area facilities that use and/or design power electronics equipment for various applications.

References

- 1 – NSF Program Solicitation: Document: NSF 05-592, <http://www.nsf.gov/pubs/2005/nsf05952/nsf05952.htm>
- 2 – NSF Program Solicitation: Document: NSF 03-520, <http://www.nsf.gov/pubs/2003/nsf03520/nsf03520.htm>

Appendix A – Survey Questions

- 1) In what year did you take the REU Program?
- 2) Did you take an introduction to power electronics course following the REU program? If so how long afterwards did you take the class? How did the REU class prepare you for future power electronics classes?
- 3) Did the classroom course help further your fundamental knowledge of power electronics? If so, how? Was the class relevant to the research performed? If so, how?

- 4) Would the lack of such a course (the classroom sessions) have negatively impacted your summer research experience? If so, how?
- 5) Which part of the REU program do you feel was the most beneficial to you and why?
- 6) Were the research projects you worked on engaging and meaningful? Which aspects of the REU projects were the most engaging and meaningful to you?
- 7) Have you had any research experiences before attending the REU program? If so can you summarize what they were?
- 8) How do you feel helped you in performing research in your everyday career whether it be graduate/undergraduate work or non-academic work?
- 9) How did your experience in the REU influence your decision to pursue (or not pursue)...
 1. ... Graduate studies in the field?
 2. ... continued study of power electronics?
- 10) Was your interest in performing research impacted by your participation in this program? If so, how?
- 11) Have you engaged in research activities following your participation in the REU? If so, please describe the project.
- 12) Please provide below any suggestions you have to change or alter the REU program for the future.