Engaging Underrepresented Community College Students in Engineering Research

Hao Jiang[1], Jose Carrillo[2], Alam Salguero[2], Ellaine Talle[2], Enrique Raygoza[2], Xenia Leon[2], Ben Lariviere [1], Amelito G. Enriquez[2], Wenshen Pong[1], Hamid Shahnasser[1], Hamid Mahmoodi[1], Cheng Chen[1]
[1]School of Engineering, San Francisco State University, San Francisco, CA
[2]Cañada College, Redwood City, CA

Abstract

One of the effective methods to engage and excel underrepresented minority (URM) students in the STEM field is to "replace standard laboratory courses with discovery-based research", as mentioned in the 2012 PCAST report [1]. Funded by 2012 NASA CIPAIR (Curriculum Improvements and Partnership Award for the Integration of Research) award, five underrepresented minority (i.e., 4 Hispanic and 2 female) students from Cañada College participate in a ten-week research of designing a world smallest power harvesting apparatus for implantable medical devices (IMDs). Two of the five students engage in circuit simulation using LT-SPICE to predict the device's performance. Two students are involved in programming the micro-controller, which controls the operation of the power harvest apparatus, and characterizing its performance. Another student designs and winds spiral coils that is used to harvest time-varying magnetic field. After students are familiar with the system, they are asked to improve the existing device by re-designing the electronic circuitry using the printed circuit board (PCB) technology altogether. At the last week of the summer project, they have the opportunity to characterize the device that is designed and made by students. During the ten-week summer research, students from Cañada College have the opportunity to experience entire engineering development flow: idea > design > prototyping > validation. In addition to learning the electronics design using the state-of-art electronic design automation (EDA) tool, the students are exposed to the challenges in designing electronic systems for biological systems. The interdisciplinary thinking could benefit their future STEM careers. The feedback from the students shows that the NASA CIPAIR is an effective method to engage URM students from community college in engineering research.

Introduction

Closing the persistent ethnic and racial gap among engineering students plays a pivotal role in reaching the goal proposed in the Engage to Excel by the President's Council of Advisors on Science and Technology (PCAST) [1]: "producing, over the next decade, approximate 1 million more college graduates in STEM fields than expected under current assumptions". In California, Hispanics make up about 37.6 percent of the total population [2], and only about 6 percent of the total engineers [3]. Increasing under-represented minority (URM) students in the STEM field will not only answer the call of producing more STEM graduates, but also improve the overall well-being of the society.

Recent reports [3, 4] indicate a great achievement gap among various ethnic groups. In California, only one in four students wanting to transfer or earn a degree/certificate did so within six years. African American and Hispanic students have even lower rates of completion; only 14% of African American students and 20% of Latino students completed a degree or certificate within six years, compared to 29% of white students, and 24% of Asian students. These low success and completion rates among URM students at community colleges are even more crucial since almost three-fourths of all Latino and two-thirds of all African-American students who go on to higher education begin their postsecondary education in a community college.

"Replacing standard laboratory courses with discovery research" is one of the five effective methods to engage and excel underrepresented minority students in the STEM field in the 2012 PCAST report [1]. However, in the community college setting, students are not exposed to STEM research. To facilitate community college students, especially whose from underrepresent minority groups, to participate STEM research, Cañada College, a Hispanic serving community college, join force with San Francisco State University, a four-year university with an active master program, to create an internship program that integrate underrepresented minority students into research. Supported by NASA 2012 CIPAIR program, five students join the Electrical Engineering research program in SFSU.

The critical challenge to integrate community college students into research is to assign the activity at an appropriate level, so that students are actually involved in the research and make contributions. The approach here is to let students understand the research by pre-packaged computer simulations, and contribute to the project by hands-on tasks.

Project Background

The research project is to optimize an AC-DC boost converter for wireless powered miniaturized biomedical implant. Biomedical implants are highly anticipated by medical community to dramatically improve the healthcare quality with the potential to lower the associated costs. Delivering electrical power to implants wirelessly has a profound impact on implant's efficacy. Inductive coupling based wireless power delivery realized by two face-to-face coils has been the primary technology for last several decades [5]. One of the critical challenges is that the receiving coil must be large enough (in cm range) so that its induced voltage can be significantly higher than the diode's turn-on voltage (about 400~700 mV in silicon technology). Otherwise, the power conversion efficiency (from the induced AC power to the usable DC power) is low [6].

The research group in SFSU has proposed a new approach to efficiently convert the received low-voltage AC power to a high-voltage DC power, when the induced voltage of the receiving coil is low (500mV when the coil is open). The operating principle of the proposed AC-DC boost converter is illustrated by a simplified circuit that handles the half period of the induced AC power, as depicted in Fig. 1 (a) and (b). In this particular design, the circuit operates the following three consecutive modes during half of the input AC period. First, the switch is turned on to short the receiving coil by itself, as depicted in the dashed line in Fig. 1(a). During this period, the induced current stores the magnetic energy into the coil. Second, the switch is off. Because the disruption of the coil current is dramatic, the receiving coil will generate a high voltage across the receiving coil. The voltage across the coil is high enough to overcome the diode's turn-on voltage and the DC output voltage. Thus, a charging current is produced, depicted as the dashed-arrow in Fig. (1)(b). The charging current will only last for a very short time until the coil voltage is lower than the sum of the output voltage and the diode's turn-on voltage. At last, both the switch and the diode are off. The circuit waits for next charging. The operating principle of the circuit is similar to the traditional discontinuous conduction mode (DCM) DC-DC boost converter that raises a low voltage DC input to a high voltage DC output [7]. With this design, a very low induced voltage AC power at the receiving coil (500mV when the coil is open) can be converted into DC and raised to >5V in DC. The ability of converting low-voltage AC power into high voltage DC can alleviate the requirement of large receiving coil. Thus, the receiving coil, which is the largest component in most implants, can be miniaturized without the sacrifice of the power conversion efficiency.

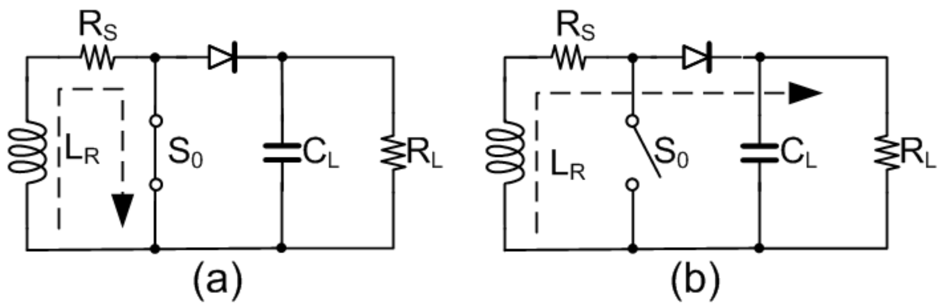

Figure 1: A simplified equivalent circuit to illustrate the operating principle. (a) energy storing mode, (b) charging mode

To validate the proposed circuit, a discrete components based electrical circuit is built, as shown in Fig. 2(a). The circuit diagram is shown in Fig. 2(b). A microcontroller that samples the input waveform using a separated auxiliary coil is used to produce the control signal for the main switch, S_0. The measurement setup is shown in Fig. 3(a). Rotating permanent magnets is just a convenient way to generate a strong, low-frequency time-varying magnetic field to characterize the AC-DC boost converter [8]. The system is able to generate a magnetic field varying at 100 Hz. The disk magnet shown in Fig. 3(a) is made of neodymium iron boron (NdFeB) with 19 mm diameter and 3 mm thickness [9]. The hexagonal rotor driven by a DC motor [10] is made of steel so that all the disk magnets can be attracted to the surface. Each adjacent disk magnet has the opposite polarity. When the rotor rotates 60°, the receiving coil could experience the maximum variation of the magnetic flux. When the open-circuit induced voltage is as low as 500 mV, a >5V DC output is produced as shown in Fig. 3(b).

Before the undergraduate research team join the research, the AC-DC boost converter, though have many jumpers on the board, is constructed by the graduate students. The characterization setup is also established. The project goal for the undergraduate research team is to (1) optimize the existing electronics to improve its performance by reducing the parasitics and its reliability by removing the jumpers; (2) carry out systematic measurements to fully characterize the proposed circuit.

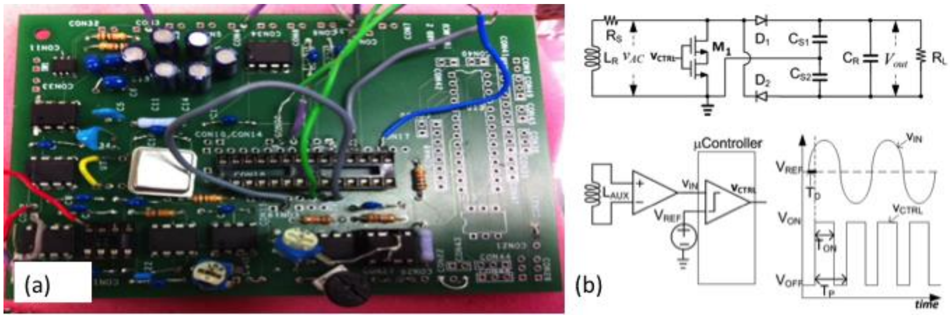

Figure 2: (a) The first circuit implementation of the proposed switching based AC-DC boost converter; (b) The circuit diagram of the boost converter

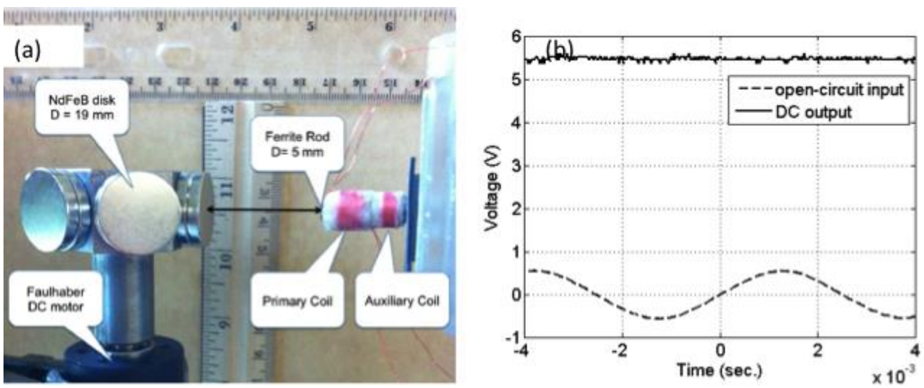

Figure 3: (a) the measurement setup; (b) input open-circuit AC and output DC.

Project Description

Five students (i.e., 4 Hispanic and 2 female) students from Cañada College participate in a ten-week research of designing a world smallest power harvesting apparatus for implantable medical devices. The project is divided into three phases

Phase 1: Understand the research project via computer simulations

All five students simulate the describe circuit using LT-SPICE [11], as shown in Fig. 4. By changing the value of each circuit component, students have thorough understanding of the AC-DC boost converter. The students are asked to present their findings after two weeks when they have exhausted all the possible design variation. Because computer simulations are able to illustrate the voltage of every node and the current of every branch, the exercise is an effective tool to help students understand the operating principle of the described AC-DC boost converter.

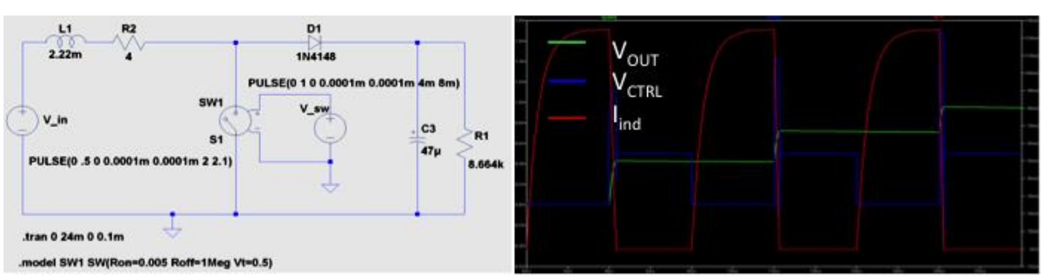

Figure 4: LTspice simulation, schematic and simulation results

Phase 2: Improve the existing circuit and the testing setup

Once students are familiar with the desgin, they are divided into three groups to work on the research. Group 1 (2 students) is to optimize the circuit, Group 2 (2 students) is to improve the measurement setup, and Group 3 (1 student) is to wind multiple coils to facilitate the characterization.

Group 1: Improve the existing circuit

The circuit shown in Fig. 2(a) has many redundancies and errors that are circumvented by jumper wires. The goal of the undergraduate research team is to improve the circuit design by reducing the redundancies and fixing all the wiring errors. As shown in Fig. 5, students create the new schematic and the layout of the described AC-DC boost converter.

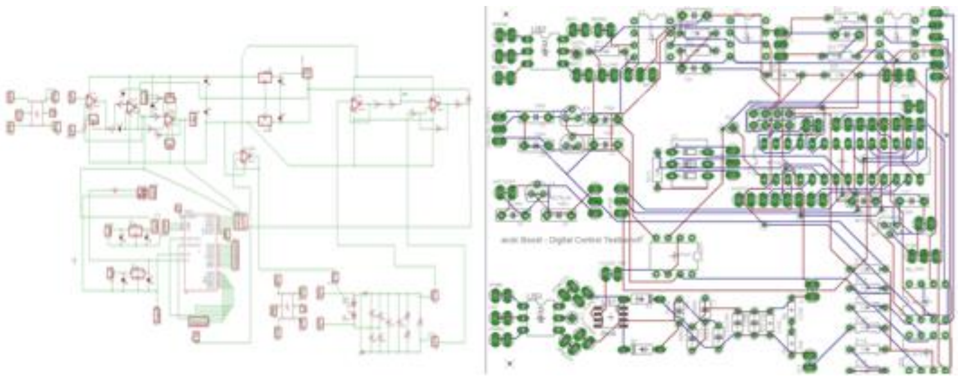

Figure 5: The schematic and layout of the AC-DC boost converter

Group 2: Improve the measurement setup

The measurement setup has been established before students join the research. However, the C-program that is used to produce the control signal from the microcontroller is not flexible enough to accommodate various testing modes. Two students in the undergraduate research team are asked to rewrite the original C-program so that it can dial out various duty cycle based on the original program. Because students are exposed to various programming language before, completing the task does not require a steep learning cliff.

Group 3: Design and wind inductive coils

One student is asked to wind various inductive coils to facilitate the test. The student is also responsible to measure the characteristics of an inductive coil.

Phase 3: Characterize the improved AC-DC boost converter

The improved AC-DC built based on the students' modification is used to fully characterize the circuit performance. In Fig. 6, the DC output is measured and plotted versus the duty cycle of the control signal that is applied to the main switch S_0. Two coils are measured. Coil A has the inductance of 0.4 mH and the resistance of 1.2 Ohm, and Coil B has the inductance of 2.16 mH and the resistance of 4.0 Ohm. The open-circuit voltage of both coils is 500 mV and the load resistance is kept at 8.62 KΩ. The DC output of Coil A peaks at 8.98 V when the duty cycle is 52%, and the DC output of Coil B peaks at 5.85 V when the duty cycle is 56%, as depicted in Fig. 6. The characterization results indicate that the proposed AC-DC boost converter is able to produce high DC output with the low-voltage AC input. The electronics modified by the undergraduate research team works well.

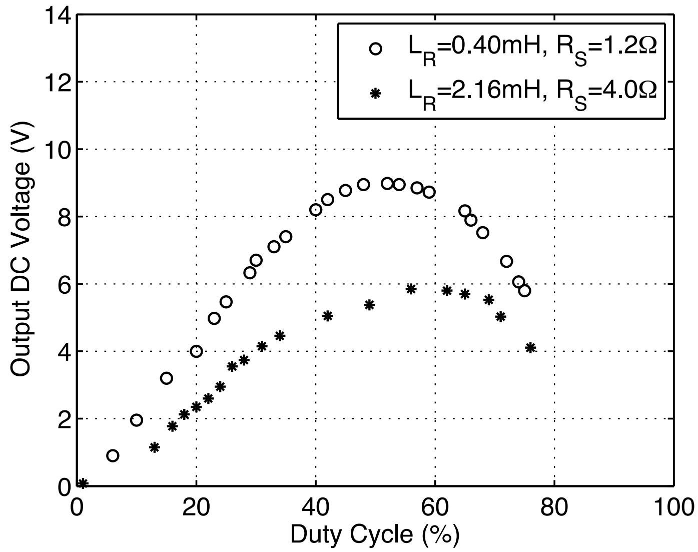

Figure 6: The DC output voltage is measured at various duty cycle of the main switch S_0's control signal

In the traditional AC-DC boost converter design, the switching frequency is 10 ~ 50 × higher than that of the input AC [12, 13], therefore, the timing between the switching pulse and the input AC is not critical to the converter's performance. In this low switching frequency AC-DC boost converter, the timing between the control signal and the input AC power is important. In the experiment, the DC output voltage across an 8.62 kΩ load resistor is measured and plotted in Fig. 7, when a delay time is inserted before the rising edge of the control signal, whereas the falling edge is kept at the 60% of the input AC's half-cycle. In Fig. 7, the delay time T_D is normalized to the control signal period, T_P. The measurement result indicates that the DC output voltage drops less than 10% when the rising edge of the switching pulse is ~20% behind the zero-crossing of the input AC. This measurement suggests that the low-frequency AC-DC boost converter has a large timing tolerance on the comparator, and has the potential to work with high-frequency input AC.

Project Assessment and Future Improvement

Students who participate in the research on the design and optimization of an innovative power harvest device for miniaturized biomedical implant are very enthusiastic about the selected project, and highly motivated to learn electrical engineering. The future improvement suggested by students is to extend the internship into a longer period of time.

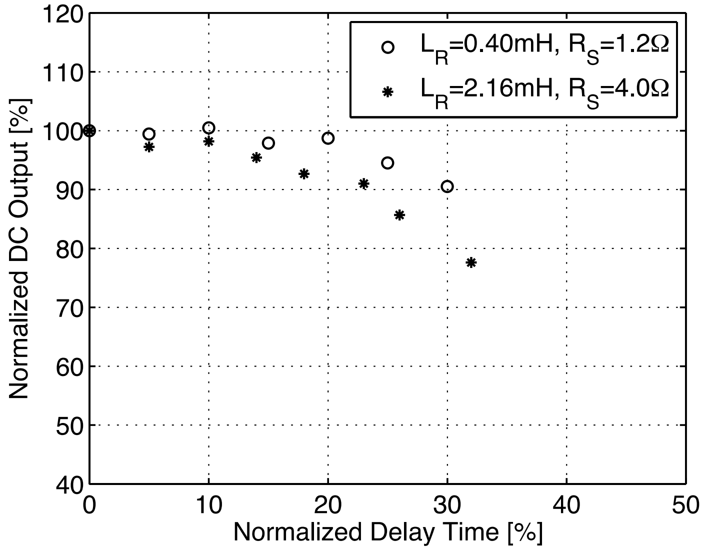

Figure 7: The DC output voltage versus the delay time that is inserted before the rising edge of the pulse.

A survey is conducted after the internship to obtain the assessment of the project. The survey includes four questions that students were asked to rate their level of agreement with each question in a five point scale (1 – Not at all useful; 2 – A little; 3 – Some; 4 – Quite a bit; 5 – A lot), and three questions that students were asked to write their comments. The survey is conducted anonymously so that students are able to express their opinions freely.

Students in the internship program are very enthusiastic about the research, although they just finished engineering preparation courses in the community college and are ready to transfer to a four-year college. Table 1, which extracted from the survey, clearly indicates students' enthusiasm towards the research.

Table 1: Students' responses on the results of the internship program
Question: As a result of your participation in the program, how much did you learn about each of the following?

Activity	Average Rating
Performing research	4.69
Designing/performing an experiment	4.85
Creating a work plan	4.77
Working as a part of a team	4.85
Writing a technical report	4.85
Creating a poster presentation	4.62
Making an oral presentation	4.54

When asked the question "what do you like most about the NASA CIPAIR Internship Program?', Electrical Engineering students' responses are: "*I like the opportunity to conduct research and* *experience how theoretical concepts learned in class can be apply to real world situations. I like the environment created by adviser, mentor, and group mates. We could work and learn as we have some fun*", "*It gave us practice with researching a topic*.", and "*being able to implement all my knowledge that I have learned in my engineering classes to a research*".

Students who participate the program are very committed in electrical engineering. Students put down comments like: "*I liked how each day I had the chance of learning something new about my major and the principles that goes with Electrical Engineering. Also that the internship was research based*." and "*I like that we got to work with the EE department and we got to work on a project that interest me*." These comments show students are interested in electrical engineering.

When asked "*Give at least one suggestion for improvement of the NASA CIPAIR Internship Program?*" The most-likely response is that students want to extend the program to a longer period of time. The suggestions are: "*Increase the number of weeks in the summer projects*"; "*Maybe offer one during a semester. Give more time maybe. like 15-20 weeks*."; "*The only change that I would consider is if possible is to try to extend the internship longer because 10 weeks is not adequate to comprehend everything*."; "*Extending the program for a couple more weeks in order to allow the interns more time to understand the material and be able to present a better final report."*. These comments suggest that students are very interested in research experience.

Summary and Conclusion

The NASA CIPAIR program has successfully integrated the underrepresented minority students from community college into the state-of-art electrical engineering research. With some careful planning, students who participated in the program have indicated that the program has exerted a positive influence in their future STEM learning and practicing.

Acknowledgement

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1. Dr. Hao Jiang joined San Francisco State University in 2007. Between 2000 and 2007, Dr. Jiang worked as a radio-frequency devices and circuits in Conexant Systems, Jazz Semiconductor and Broadcom Corporation. His recent research in the general area of analog integrated circuits, particularly in ultra-low-power electronics system for biomedical implants. He has served as faculty advisor for the IEEE SFSU chapter since 2008.

2. Dr. Amelito Enriquez has been a tenured professor in the Engineering and Mathematics departments at Cañada College since 1995. He has been an active member of the California Engineering Liaison Council since 1997, and has been serving as the Vice Chair, Community College of the ASEE Pacific Southwest (PSW) section since 2008. He has received awards for his accomplishments related to teaching and enhancing student success. He also received the 2010 NSF Presidential Awards for Excellence in Science, Mathematics, and Engineering Mentoring (PAESMEM).

3. Dr. Wenshen Pong joined the engineering faculty of SFSU in 1998. As a committee chair of over 40 graduate students' culminating experience, Dr. Pong works closely with his students to ensure that they successfully produce and complete quality research work. He was named Faculty of the Year by the engineering societies of the School of Engineering at SFSU in 2000. He also served as Graduate Coordinator from 2001 to 2007. He has been civil engineering program head since 2007 and currently serves as Director of the School of Engineering at SFSU.

4. Dr. Hamid Shahnasser has been teaching and carrying out research at SFSU for the past 22 years. He has received ten NASA related grants and fellowships, and has been working at NASA Ames Research center since 1990. He has advised and mentored many students and successfully introduced some of them to NASA Ames summer internship programs as well as careers at Ames and other NASA sites.

5. Dr. Hamid Mahmoodi is currently an associate professor of electrical and computer engineering in the School of Engineering at San Francisco State University. He was a recipient of the 2008 Semiconductor Research Corporation Inventor Recognition Award, the 2006 IEEE Circuits and Systems Society VLSI Transactions Best Paper Award, 2005 Semiconductor Research Corporation Technical Excellence Award, and the Best Paper Award of the 2004 International Conference on Computer Design. He is a technical program committee member of International Symposium on Low Power Electronics Design and International Symposium on Quality Electronics Design.

6. Cheng Chen joined SFSU in 2009 and he is currently an assistant professor in civil engineering at the School of Engineering at SFSU. He has a strong research background in hybrid simulation and earthquake engineering, and he has published more than twenty technical papers in professional journals and conference proceedings. He has served as faculty advisor for the ASCE SFSU chapter since 2009. He is also a technical committee member of ASCE on structural control and seismic effects.

7. Mr. Ben Lariviere is currently a senior undergraduate student in electrical engineering at SFSU. He has been an undergraduate researcher in the Bioelectronics Lab at SFSU since Nov. 2011.

8. Jose Carrillo, Alam Salguero, Ellaine Talle, Enrique Raygoza, Xenia Leon and Amelito G. Enriquez were student participants of the CIPAIR program from Cañada College. Mr. Carrillo, Mr. Salguero, Mr. Raygoza and Ms. Leon are currently enrolled in electrical engineering in Cal Poly at San Luis Obispo. Ms. Talle is currently a material science student at University of California at Irvine.