Experimental Centric Pedagogy in Circuits and Electronics Courses at 13 Universities

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Abstract

This paper presents the initial pilot findings from a multi-year project that is initiating experimental centric approaches to learning in electrical engineering courses via the use of an Analog Discovery Board (ADB). The specific audience emphasized in the paper reflects participants in circuits-content courses; the majority of students are 2nd and 3rd year EE students; the unique audience represents students enrolled in HBCU colleges. Within this context, collaborating partners used portable hands-on hardware coupled with a model of pedagogy (i.e., blended learning - a combination of lecture and hands-on activities in class; traditional - hands-on activities are completed outside of class time; etc.) to provide instruction in their courses. Outcomes indicated a positive impact of the interactive ADB methodology within a number of methodological contexts.

Keywords

Analog Discovery Board, ADB, HBCU, Electric Circuits.

Introduction

This paper presents the outcomes of the implementation of mobile hands-on devices into college level circuits courses through different pedagogical models, to measure student learning, and facilitate instructor adoption of the mobile hands-on learning device (the ADB), supporting an effective way of learning concepts and skills which have repeatedly been shown to be based on constructivist principles[1,2]. Within this context, collaborating partners used portable hands-on hardware coupled with a model of pedagogy (i.e., blended learning - a combination of lecture and hands-on activities in class; traditional - hands-on activities are completed outside of class time; etc.) to provide instruction in their circuits' courses. Research suggests that on average, engaging in overt activities, particularly ones that require knowledge construction by the student, especially through the implementation of differentiated active- constructive-interactive activities particularly in engineering classrooms[3]. One area where this is especially important is in STEM related learning and instruction; especially in engineering where the ability to solve and visualize problem, and do hands-on work is essential. In this case, the learning process is guided by the professor and supported by the technology of an ADB, which provides the opportunity to relate new concepts to what students already understand, and to 'play' with new ideas using trial and error to develop understanding.

Understanding learner characteristics can also assist course developers in the creation of materials with the optimal goal of structuring the instructional conditions in a manner that will facilitate internal learning and information processing within each learner's zone of proximal development or scaffolding level[4,5]. This perspective supports research which highlights outcomes based on the use of technology in STEM related areas for adult learners that appear to differ by learning style[6]. The importance of matching teaching methodology to the learning style preference of students is well documented[7].

According to Yousuf, Wong and Eden's[8], the Introduction of Electrical Circuits I course in the freshman year of an Electrical Engineering program is important because it will enhance interest in Electrical Engineering. Additionally, Meehan and Fritz[9] indicated that the motivation that drove the development of a laboratory course was the recognition by the faculty members that students were not learning the basic concepts in electric circuit theory and after collecting input from students, it became clear that the level of abstraction with limited real-life applications during lectures was extremely high in the introductory circuits course, which made learning important material difficult for those who are visual learners[9]. The research covered in this paper focuses on the importance of the constructing engineering knowledge at a higher, more in-depth level by using the hands-on methodology of the ADB.

Purpose of the paper

The purpose of this paper is to present findings from a series of pilot studies that investigated the use of hand held devices, more specifically ADBs, as part of experimental centric instruction on circuits' content within second level engineering classes. The mobile hands-on device discussed in this paper is the ADB, which consists of an Input/Output (I/O) board to replace the large laboratory equipment in taking electronic measurements, instructional materials (e.g., laboratory guides, training guides), and software designed for installation on laptop computers that simulates the computational aspects of the larger laboratory equipment. Data sources included post surveys from 271 students at 9 selected institutions, observations of student use in the classrooms and labs, and interviews with faculty/instructors and students. Dependent variables of interest in the pilot studies were those related to affective pre-cursors of learning, immediate classroom outcomes, initial long-term indicators, and professional ABET variables.

Background

In 2013, Howard University, in collaboration with Alabama A&M University, Florida A&M University, Hampton University, Jackson State University, Morgan State University, Norfolk State University, North Carolina A&T State University, Prairie View A&M University, Southern University, Tennessee State University, Tuskegee University, and University of Maryland Eastern Shore, received funding for an National Science foundation (NSF) grant entitled "*Experimental Centric Based Engineering Curriculum for HBCUs*". The project advances a process which will create a sustainable "HBCU Engineering Network" that is focused on the development, implementation, and expansion of an Experimental Centric-based instructional pedagogy in engineering curricula used in these HBCUs.

The goal of the project was to increase the number of highly qualified and prepared African American engineers, and all students, to have a better understanding of technology and its role in STEM education and the policy associated with it. Another key goal for the grant is to promote wide spread dissemination of portable hands-on mobile devices through proactive collaboration between educational institutions and industry partners. Collaborating partners are each using portable hands-on hardware coupled with a model of pedagogy (i.e., blended learning - a combination of lecture and hands-on activities in class; traditional - hands-on activities are completed outside of class time; etc.) to provide instruction in their courses.

Implementation of use in circuits classes

Process:

The ADBs and supporting curriculum modules were piloted in a variety of instructional settings with students similar to those currently enrolled in general circuits, level one and level two circuit classes, and supporting laboratory experiences. Experiences vary by institution however most instructors indicated that the Electrical Circuits courses and or laboratory are required courses for all engineering majors and they are generally taken at the second semester of the sophomore year. According to participating instructors the significance of electric circuits courses and their content as the basic engineering science courses is very important.

For example, during typical circuits' laboratory experiments, students analyze the response of an RC circuit and measure the time constant of the circuit for different combinations of resistances and capacitances. First, students are required to conduct the experiment using the traditional method, i.e. capturing the RC response by collecting voltage reading using multi-meter and timer or using readings from oscilloscope. Then, the students take their lab readings and plot the responses and calculate the time constant of the RC circuit. Next, the ADB was introduced to the students with instructions on how to use the board. The students repeated the same laboratory under the supervision of the instructor and his assistant. This process helped students view, capture and save responses of their RC circuit in a file using the software and the ADB. Students were also shown how to measure approximate value of the time constant of their RC circuit using the Digilent WaveForms software. Instructors also indicated that their process changed due to students' enthusiastic response to the use of the ADB. The Digilent WaveForms software provided a platform for redesigning additional experiments for conducting and analyzing the RL and the RLC circuits and all three revised experiments are now a permanent part of the Circuits I Laboratory. (Appendix A: Figure 1).

Another example of the introduction of the ADB included the support for Ohms' law modules which were developed as an introductory lesson for students. Because most students understand ohm's law, these modules allowed students to focus on understanding how to use the ADB. Students are able to quickly build the circuit as they were forced to familiarize themselves with board connections and computer interface. Once the students are comfortable with the boards, they are able to move on to modules that reinforce the concepts covered in class. By the third module, students are expected to develop their own procedures to verify concepts. Students have the option of designing their own experiment or completing the activity developed by Digilent. Students are required to complete a formal report for this module (Appendix B).

Another example of using in one of the participating Universities is shown in Appendix C for Thevenin's, Norton's, and Maximum Power Transfer Theorems. The students built the circuits solderless board, tested them using the ADB and Waveforms, and using portable digital multi-meter, then compared the measurements with the results they obtained from calculations and B2 Spice. The procedure of this experiment was divided into three main parts: (1) calculation using Circuits' theorems and laws, (2) circuit simulation using B2Spice, and (3) real circuit connection and measurements using the breadboard, Analog Parts Kit, ADB, Waveforms, portable multi-meter, and computer. According to the instructor, students can do all the practical part without the need of being at the laboratory. They just need to schedule appointments with the instructor to show their work and discuss any problems. This is considered one of the main advantages of using ADB that it makes it possible to teach electrical engineering labs like Circuits online, which opens the gate for offering online EE degree.

All electrical engineering students at partnering universities are required to take both circuits I & II and laboratory courses (ECEN 200, 300, and 306), and all non-electrical engineering majors are required to take one circuit course in their undergraduate study (Appendix D). Students in both circuits I & II and laboratory courses (ECEN 200, 300, and 306), and all non-electrical engineering majors were introduced to the ADB at the beginning of the semester through in class demonstration and online videos in order to enhance students learning through hands on experiments. Students then were asked to build a particular circuit and then measure voltages and currents at different points of the circuit using the ADB. They were then required to verify their experimental results with the theoretical results and try to explain any differences. According to colleagues, circuits can be used to model various physical devices, which help in the development of complex systems. KVL and KCL Circuit Analysis Transient Analysis of First Order RC Circuit and Op-Amp Circuit Analysis are some of the major topics that can be covered using the ADB. As previously noted, instructors are redesigning modules as students are more engaged in the process.

Participants:

Research results and conclusions include findings from 271 students across 9 institutions, 5 terms, 10 separate course sequence numbers, 14 sections of teaching, and 11 instructors. The majority of students were male (77%); 75% self-reported ethnicity as Black, 3% as Hispanic, and 4% as multi-racial; the remaining students reported as Asian (6%) or White (11%). Of the students involved, 17% indicated that English was not their primary language. Participating students were 2nd year, 3rd year, and senior students; 61% of the enrollees in the circuits related classes were majoring in electrical engineering; 21% reported as computer science or mechanical engineering majors. The remaining students generally reported majors related to other STEM majors for which the course served as an elective or to fulfill a minor requirement. Table 1 presents the overall demographic of participants.

Table 1: Student Demographics Circuits Class Pilots*

Gender	Gender %	Discipline of Study	Major %
Male	77	Electrical Engineering	61
Female	22	Computer Science	11
Ethnicity	**Ethnicity %**	Mechanical Engineering	10
Black	75	Other**	18
Asian	6	**Degree Progress**	**Degree %**
Multi-racial	4	1st year	1
White	11	2nd year	33
Hispanic	3	3rd year	40
English Primary Language	**Language %**	4rd year	18
Yes	82	Graduate/5th year	8
No	17		

**n=271*

Instructional Uses: Application of the ADB:

Use of the ADB, as a tool to support experimental centric learning practices within circuits' content, was shown to be successful across a variety of instructional settings and uses. Verification and validation of these uses is based on instructor description, student identification and evaluator observations. The different settings included the following: a traditional classroom (the instructor used lectures and exploration/hands-on work took place in lab setting, frequently with a different instructor); studio classrooms (instructor lectures were followed by direct implementation within the classroom with the same instructor working with students); comparative labs (students worked with the ADB as part of lab, outside direct instruction, use was an "add-on" or a comparison with traditional equipment); integrated labs (students worked with the ADB as part of lab, outside direct instruction, sometimes with a different instructor, but use was part of the required coursework and supplemented/supplanted traditional equipment) and out of the class situation (students were assigned tasks on the ADB that were to be accomplished outside either classroom or lab; some of these exercises were part of the traditional grade, some were volunteer, and others were for extra credit.) Each of these approaches was found to have potential impact on learning outcomes.

The typical student experienced a median use within an electric circuits related classroom of 3 times per term while use within lab settings usually occurred 3-5 times per term. Additionally, within circuits' content use, students typically had 3-5 uses of the ADB as part of their assigned homework (See Table 2). Overlapping or simultaneous use of the ADB varied by institution: At most new pilot sites, the primary use was within a laboratory setting and was incorporated into the lab experiments as supplemental or substitution assignments. In these lab settings, use was part of a typical experimental effort with standard reports generated to support use. The instructor for the lab might not be the content course instructor; teaching assistants varied on degree of experience with the ADB and with experimental centric instruction. In some settings the TA had prior experience with the ADB and independently developed manuals, experiments, and "tinkering" exercises. Students reported a need to have the lab use tied back to traditional course content when the use was not correlated by faculty.

Use as independent homework was found to support both traditional class instruction and lab work. In newer use settings, this homework often was for extra credit or exploratory purposes and was an extension of regularly assigned work. As use of the ADB became more embedded and the instructor(s) became more familiar with it, inclusion in homework reflected advanced opportunities to practice/learn material.

Table 2: Use of ADB in Varied Instructional Modalities: Median Reported Use

Instructional Modality	Median Response
Location/Setting of Use*	
In a class setting	3 times
In a lab setting	5+ times
As part of homework assignment	5+ times
Method of Use*	
Instructor Demonstration	3-5 times
Cooperatively with a peer	>5
Independently	>5

**selection of multiple responses allowed*

Data from Table 2 indicated that cooperative use of the ADB, described by instructors and TA, and observed by evaluators, usually reflected dyad and triad exploration, most frequently in a structured-goal based setting. This occurred in both classroom and lab settings. Typical students experienced this type of use at least 5 times per term. Some homework assignments also were completed in cooperative dyad/triads; students reported that this use was not as successful if they only had access to one ADB; if each had access, students reported greater collaboration and sharing of finding instead of just cooperation across assigned tasks.

While a similar number of students reported independent use, (at least 5 times a term) interpretation of these findings are less clear as this also may include those students who were part of cooperative groups or who took the lead in lab experiments. Use of the ADB as a support for experimental centric instruction via instructor demonstration also was found to occur at least 3 times per term for the typical student. Instructor and student interviews, evaluator observations, and a review of module descriptions indicate that in many cases these instructor demonstrations were used as advance organizers to increase student interest and motivation, to prepare students for use in lab settings, and to review potential uses in the real world. The most frequently used method of instructor demonstration supported content with case studies and examples followed by hands-on practice.

Students viewed this use as a positive experience. Most of the students (80%) agreed/strongly agreed that use of the ADB allowed them to practice course content. Similarly, approximately three of four students saw their practice with the ADB as relevant (70%), reflecting course content (78%), and reflecting real practice (77%). Similarly, they approved of the opportunity to practice their content and noted that the hands-on use reflected their learning needs.

Table 3: Student Perceptions of the Process of Use

Instruction and Supplementary Materials*	% Agree
The ADB provided opportunities to practice content	80
The use of the ADB reflected course content	78
Use was relevant to my academic area.	78
The use of the ADB reflected real practice.	77
The time allotted for ADB use was adequate.	72
The use of ADB suited my learning needs.	70
Introduction to the ADB/Supplemental Materials	
Instructions on ADB use were relevant.	70
Instructions on ADB use were helpful.	68
Handouts necessary for ADB use were provided.	69
The visual aids (e.g. diagrams) used with the ADB were clear and helpful	65

**Number represents percentage of participants who responded "Strongly Agree"/"Agree"; n ranged from 265 to 268*

According to survey results outlined by Table 3, a majority of students enrolled in circuits' related content courses reported general satisfaction with instructions and supplemental materials that were used to support the above uses. This satisfaction increased as instructor familiarity increased. Surveys of first time users and interviews of faculty and students did indicate a need for more introductory materials, videos, and visual aids that would facilitate first time use. Several sites reported developing site and content specific videos and introductory materials that helped students become familiar with start-up use. Several sites also reported that 4th year students helped with this development.

Outcomes

As part of its implementation of the mobile ADB approach within circuit classes, independent evaluation and validation of use was conducted to document outcomes. The following is a summary of current findings for the Mobile Studio ADB as it supports instruction and learning.

Short-term Outcomes:

Multiple domains of short-term learning known to influence constructivist experimental learning were shown to be supported during these pilots within circuits' content as illustrated by Table 4. These included pre-requisite affective changes need for learning to occur. Approximately 75% of students reported changes relative to attention of/to the need to learn as reflected by growing perceptions of importance of knowledge of the ADB in preparing to become an engineer, followed by increased motivation to learn the content supported by a growing confidence in learning/working in the content. Correlated to these changes was a perception that knowledge had increased. This is reinforced attention, motivation and confidence in learning, creating an increasingly positive cycle of affective support.

Table 4: Initial Changes Reported by Students

	Perceived Changes	% Agree*
Immediate Learning	My knowledge has increased as a result of use.	78
Pre-requisite to Learning	The hands-on ADB is important in my preparation as an engineer.	77
Pre-requisite to Learning	My confidence in the content area has increased because of use.	73
Pre-requisite to Learning	Using the ADB motivated me to learn the content.	71

**Number represents percentage of participants who responded "Strongly Agree"/"Agree" on post-survey; n=267*

When queried, a notable 84% of the students enrolled in circuits classes reported that the use of the ADB helped them to learn more (See Table 5). Subsequent follow-up questions as to how the process of use helped to support this learning actions related to both affective pre-requites of learning and immediate outcome received high agreement scores.

Table 5: How Method Supported Learning

	Areas of Growth	%*
General Outcome	Helped me to learn more	84
Immediate Learning	Develop skills in problem solving in the content area.	78
Immediate Learning	Think about problems in graphical/pictorial or practical ways.	75
Immediate Learning	Learn how AC and DC circuits are used in practical applications.	74
Immediate Learning	Recall course content.	73
Immediate Learning	Improve grades	70
Pre-requisite to Learning	Develop confidence in content area	75
Pre-requisite to Learning	Become motivated to learn course content.	71
Pre-requisite to Learning	Develop interest in the content area.	69
Pre-requisite to Learning	Confidently complete lab assignments.	69

**Number represents percentage of participants who responded "Strongly Agree"/"Agree" on post-survey; n=267*

Actions related to affective pre-requisites include helping students to develop interest (69%), to become motivated to learn content (71%), to become confident in learning course content (75%) and more specifically to become confident in completing lab assignments (69%). Specific areas of learning noted included recalling course content (70%), learning about practical applications of AC/DC circuits (74%), thinking about problems in graphical/pictorial/practical ways (75%), and developing skills in problem solving within the content area (78%). These skills were reported by 70% of the students as helping to directly improve their grade.

Long-term Outcomes:

Changes in support of sustained learning also were noted as illustrated in Table 6. Students self-reported improvements in working collaboratively with fellow students, enhancing their professional abilities and developing attitudes of self-direction and self-responsibilities. Students also self-reported effects directly related to problem solving and transferring skills related to problem solving. This included developing different ways to solve problems, being able to apply course content to new problems and transferring their knowledge and skills to problems outside the course. During interviews, many students noted that they were aided in this transfer due to their ability to pictorially remember their use of the board and that they had an increased confidence in their ability to work in new or varied domains because of the "practice" applications that had helped them to experience failures and ultimately success.

Table 6: Initial Long-term Outcomes

General Effects of Use of the ADB	% Agree
Work collaboratively with fellow students.	77
Enhanced my professional abilities	76
Develop different ways of solving problems	75
Apply course content to new problems.	74
Transfer knowledge/skills to problems outside the course	74
Develop attitudes of self-direction and self-responsibility	73

**Number represents percentage of participants who responded "Strongly Agree"/"Agree" on post-survey; n=267*

ABET Indicators:

As part of the documentation of student growth directly related to professional outcomes students were asked to respond to a selected series of ABET outcomes (See Table 7). Because of the relationship of affective pre-requisites and potential outcomes, students were asked to indicate the importance of learning each outcome and their preparedness in performing that outcome after exposure to and use of experimental centric learning via the ADB. Results of this comparison indicate that at the end of their experience, approximately sixty percent of the students perceived the ABET tasks as very important to learn with only approximately 40% reporting that they were very prepared to exhibit these skills.

Further examination of the data indicate that areas viewed as highest in importance reflect specific goals of experimental centric learning (e.g. designing experiments, analyzing data, solving specific problems, and directly applying scientific processes). General professional goals (e.g. knowledge of contemporary issues, ability to work with multi-disciplinary teams, and ability to communicate in public settings) were not viewed as important and were rated as less important; these skills are cross course outcomes, and while important to the experimental centric model are not always identified with circuits content.

Table 7: ABET Outcomes

General Effects after use of the ADB	% Very Important	% Very Prepared	% Difference
Ability to apply scientific knowledge to engineering tasks	62	36	26
Ability to design experiments	59	40	19
Ability to interpret data	61	41	20
Ability to design system, component, process to meet desired need	63	39	24
Ability to function effectively on multi-disciplinary team	57	42	15
Ability to communicate effectively as a public speaker	52	39	13
Knowledge of contemporary issues	48	32	16

**Number represents percentage of participants who responded "Very Important" or "Very Prepared" on a 4 point scale (n=234-265)*

Ratings on preparedness of these skills were found to be consistently "below preparedness". The most notable of these responses was needed to have knowledge of contemporary issues. This skill was rated as least important and as the lowest in preparation. This finding was contrary to instructor comments. Instructors frequently referred to "real world" applications as highly important. Both stakeholder groups indicated that a positive benefit of current and future use of the ADB was its application to current settings. This finding may be related to the use of the process as a pilot and may change as faculty become more familiar with the device. During interviews with faculty, classroom observations, and review of modules, it was noted that those with more experience in use of the ADB, and specifically the experimental centric approach to instruction, used more real world descriptions of problems.

Benefits, Barriers, and Needs Related to Continued Use

Faculty, administrators, students, and local assessment personnel reported multiple benefits, barriers, and needs related to the use of ADB in circuits' related classes. Presented in Table 8 is a summary of these responses.

Table 8: Sustainability-Benefits, Barriers and Needs

	Student Responses	Faculty/TA Responses
Benefits	• Increased knowledge about circuits • Provided good visual representations • Facilitated hands-on experience • Visualization of real-world/practical applications • Allowed opportunity to "play" and "practice"	• Increased hands on opportunities transferred learning • Real world application increased motivation and transferability • Flexibility for use in different contexts • Allows the faculty member to try out different ways of teaching material
Barriers	• Partnership use—hard to use as homework when shared; one person tends to get most "access" when used in lab • Wanted to take home/opportunity to practice • First time use difficult • Not all students had a laptop/MAC issues	• Want at the beginning of class, want introductory materials so can spend more time teaching content • Application issues with Mac computers • Voltage issues • More examples • Need time to play and develop their own style of use
Suggestions for future	• Provide clearer instructions on the ADB • Require individual possession or a semester long checkout • Get it at the beginning of the semester • In-class demonstrations on how to use ADB for projects • Increase in-class use blended with lectures • Make it a part of the class • Make sure the TAs and faculty know how to use it • Tie use into Sr. Project, internship and future job possibilities	• Boards available prior to the beginning of the semester • Help in involving more faculty and content; courses rotate and want continuity • Professional development for themselves and colleagues • More devices for faculty and TAs • More modules; more specific use/assessment tie-in • Give the students more time to "play"

Benefits noted by participants included increased knowledge and greater creativity resulting from the hands-on use; increased confidence; and more real-world knowledge as theory is tied to practice. Both students and faculty noted the value added to learning when hands-on practice and the opportunity to play and practice were included and expanded. Students specifically noted the benefits accrued from working on real-world problems, as they grew more experienced in its use. Faculty noted the flexibility of the ADB and the applicability of experimental centric approaches in different instructional contexts and through use of different instructional modalities as most beneficial.

Barriers to either continued or expanded use included the need to provide one ADB per student, availability of curriculum and resources that support full semester and take-home use; lack of introductory materials (videos, instructions, etc.); and equipment specific limitations. Both faculty and students wanted more use across all levels of settings. Students in circuits classes wanted their own ADB as a means of increasing their involvement in experimental centric practice; cooperative learning exercises were viewed as favorable if each student had his/her own set of tools. Faculty wanted the resources needed to expand use throughout entire circuits' courses and curriculum that would support differentiated levels of learning. They also noted a key barrier to current successful use was their own lack of familiarity with the ADB and experimental centric learning. Instructors observed the decline of this barrier as they began to work together to learn and share information.

All participants identified future needs to enhance sustainability. Students and faculty noted the need for less expensive boards; more integration within introductory as well as advanced classes; and use in blended class formats. Faculty specifically noted the need for additional refined, standardized curricula that would allow for more integration with less faculty development time, assessment tools that could be used to support these changes in teaching/learning goals; and professional development that would allow time for practice and more opportunities for hands-on sharing of curriculum. Students wanted more help in initial introductions to experimental centric approaches so that they would know what the goals were what was expected of them, and why this approach was important. They also desired a cross match between experiences and skills that would be expected in circuits, other classes, and the real world.

Summary

This paper has presented initial pilot findings from a multi-year project that is initiating experimental centric approaches to learning in electrical engineering courses via the use of an ADB. The specific audience emphasized in the paper reflects participants in circuits-content courses. The majority of students are 2nd and 3rd year EE students enrolled at HBCUs.

Preliminary data indicate that faculty and students are benefiting from the use of the ADBs. Students and faculty report increases in constructs reflecting required affective pre-requisites to learning including interest in content, motivation to learn, and confidence in ability to learn. Increases in these variables appear to be yielding positive student perceptions of their current knowledge and ability level and these in turn are increasing interest, motivation and confidence to learn. Immediate outcomes, reported by students, and verified by faculty include gains in course specific content knowledge, ability to transfer information to new setting, better problem solving, and increased professional characteristics.

As the research in this area continues, faculty and students have noted several barriers to use of the process and have suggested potential means of meeting these barriers. These include ensuring that more standardized approaches and expanded curriculum modules are piloted, that use of the ADB as a support for experimental centric learning allow for more independent use both in the classroom and as homework, that use of the approach be integrated in both class and lab settings, and that use be expanded to course pre-requisites as well as follow up/advanced courses.

According to Anderson et al.[10] achievement of higher level cognitive, affective and psychomotor skills are essential for a successful and fulfilling career[11]. Overall, the use of experimental centric approaches to learning and teaching appears to offer a promising method of increasing and enhancing the construction of engineering knowledge at a higher, more in-depth level by using the hands-on methodology of the ADB based in circuits classes so that future engineers will be better able to meet the needs of a rapidly changing world. Further research is needed on the role of faculty teaching style, specific course content, and long-term achievement outcomes.

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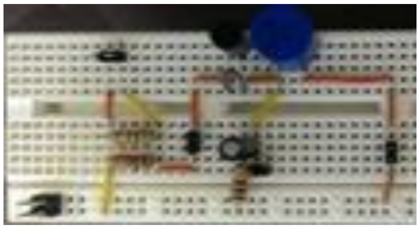
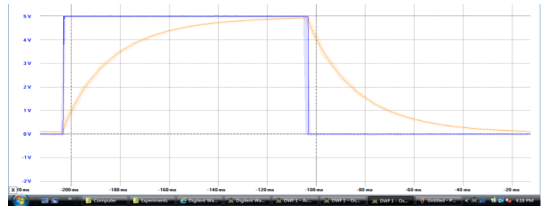
APPENDIX A
Tennessee State University

In Lab Example

During every semester Fall and Spring at Tennessee State University, the ADBs have been used by students in the ENGR 2001- Electrical Circuits Laboratory which is required sophomore level laboratory. We have developed and implemented several experiments using ADBs for the purpose of this lab, e.g., nodal and mesh analysis, superposition, Thevenin's and Norton's theorems, analysis of operational amplifiers and transient analysis of RC, RL and RLC circuits. At the beginning of the semester ADB is introduced and explained to the students in the Lab. Then in a different setting the use of the ADB are demonstrated to the students by the Teaching Assistant during a lab setting. The students are required to understand the significance of the time constant in electrical systems. Figure 1 shows a sample RC circuit setup and the voltage responses the students typically acquired using the ADB's two channel oscilloscope.



(a)



RC-Circuit Response C = 40 µF R = 500 Ohm

(b)

Figure 1. Sample of the RC Circuit Setup and the Obtained Responses

Pre-Implementation

Before adding the ADB, typically these laboratories used standard desk top based and standalone test equipment. Experimental experiences, is the goal of the department and included the use of PSpice and NI ELVIS-II simulation kit. In a typical circuit's laboratory, after testing and analyzing simple circuits to validate fundamental laws, experiments are conducted by students to analyze RC, RL RLC circuits. These experiments are used to measure the time constant of the RL and RC circuits, and let students understand the significance of time constant. In the traditional approach, the students are first asked to conduct an experiment for recording the voltage reading across the capacitor at specific time intervals by using a watch or using readings from an oscilloscope. Then the students plot the responses and calculate the time constant of the RC circuit.

Post Implementation

Since the beginning of HBCU-ECP program, we have integrated the use of the ADBs into three laboratories and courses. We have developed and implemented experiments using ADBs in demonstrating transient analysis using RC and RL circuits in the required EECE 2001- Circuits I laboratory. Two sections of the Circuits I Lab are offered every semester for electrical and non-electrical engineering students. For example 24 students were attending the circuits I Lab during the fall 2014 semester. Similar number of students took the lab last spring 2015 and used ADB in the circuits-I lab. However, the number of experiments and students involvement in using ADB increased significantly during Spring 2015.

APPENDIX B
Norfolk State University

Example 1: Ohm's Law

The key concept covered in this module is the relationship between voltage and current. The relationship is analyzed by constructing a basic circuit like the one shown in Figure1. At this point in the semester, students are not very familiar with the ADB. Therefore, step by step instructions with pictures are used to help students complete the module. Some examples of the procedures are listed below:

1. Gather the following components
    a. Unknown Resistor
    b. Breadboard
    c. Multi-meter
    d. ADB
2. Plug in the ADB into a computer. Open up the WaveForms program. Verify that an ADB is connected. Click on WavGen. Under Analog, switch from sinusoid wave to straight line.
3. Use Figure 1 to understand the pin layout of the ADB.

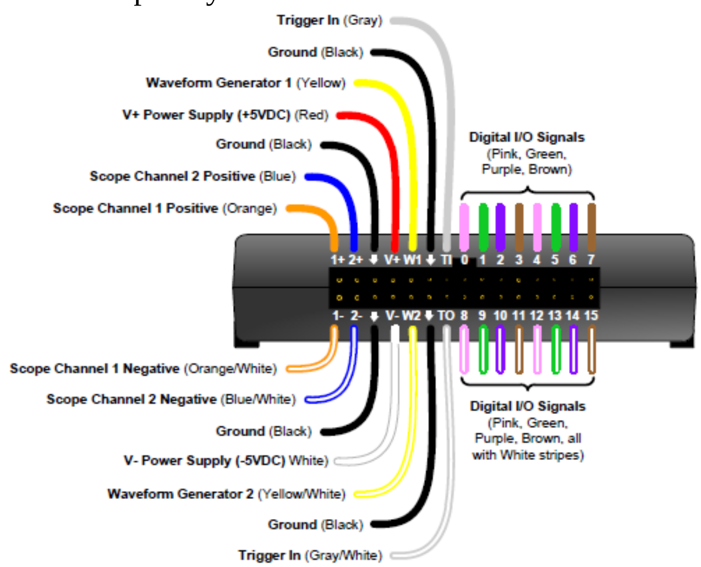


Fig. 1. ADB Pin Diagram

4. Verify ohm's law by constructing the circuit in Figure 2.

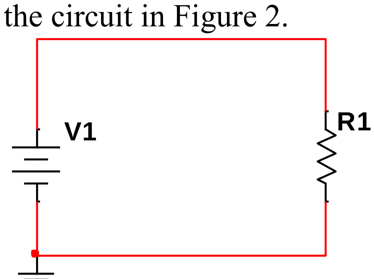


Fig. 2. Circuit Diagram

    a. Apply voltage to an unknown resistor by using the Waveform Generator 1 from the ADB. Place ammeter in series with the resistor. As shown in Figure 3.

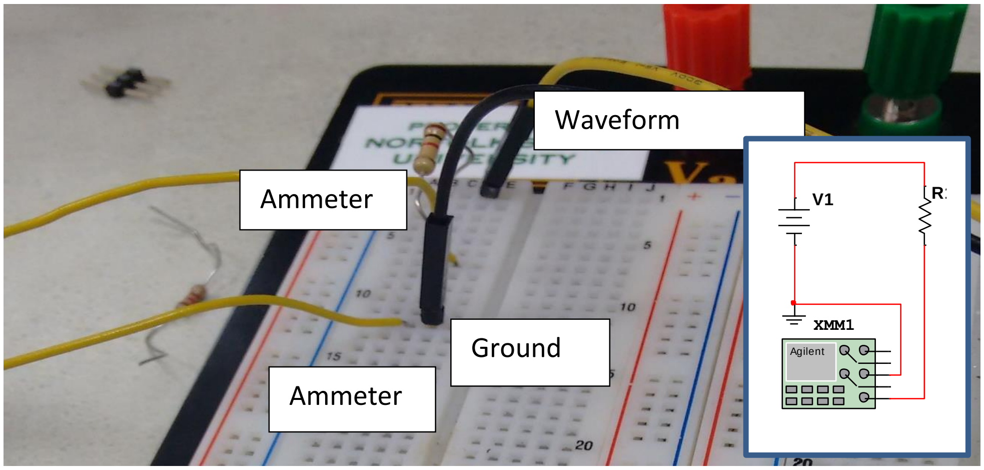


Fig. 3. Circuit on the Breadboard

By using the WaveForm program, adjust the voltage to 0 V. Then use the ammeter to measure the current in the circuit as shown in Figure 3.

Example 2: KVL Module

Now that students are more familiar with the ADB, the modules procedures that are given to them are less detailed. The goal is to reinforce the concept covered in class. Kirchhoff's Voltage Law states that "the algebraic sum of all the voltages *v* around any closed path in a circuit equals zero". Therefore, students are given circuits with more than one resistor to verify this law. Below are some of the steps from the module:

1- Connect two resistors in series as shown in Figure 4
2- Apply voltage to the circuit using the ADB.

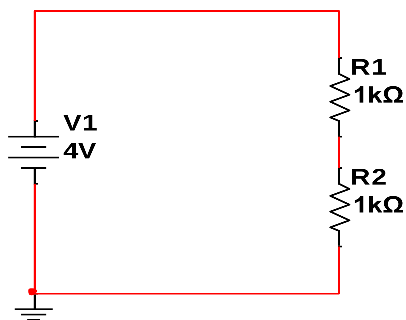


Fig. 4. KVL Circuit

3- Measure the voltage using the ADB oscilloscopes.
4- Add the measured voltages.

So according to KVL the final result that you would be getting is Vs=VR1 + VR2.

So your circuit should look something like Figure 5.

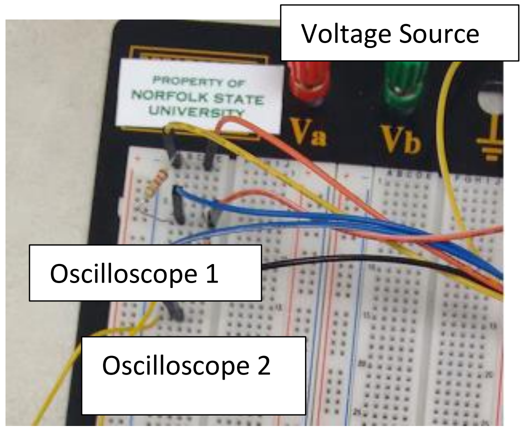


Fig. 5. Breadboard view of KVL Circuit

Given the following parameters:
R1 = 1.2 KΩ, R2 = 3.6 KΩ, Vs = 8 Vpp

The result should be similar to those shown in Figure 6.

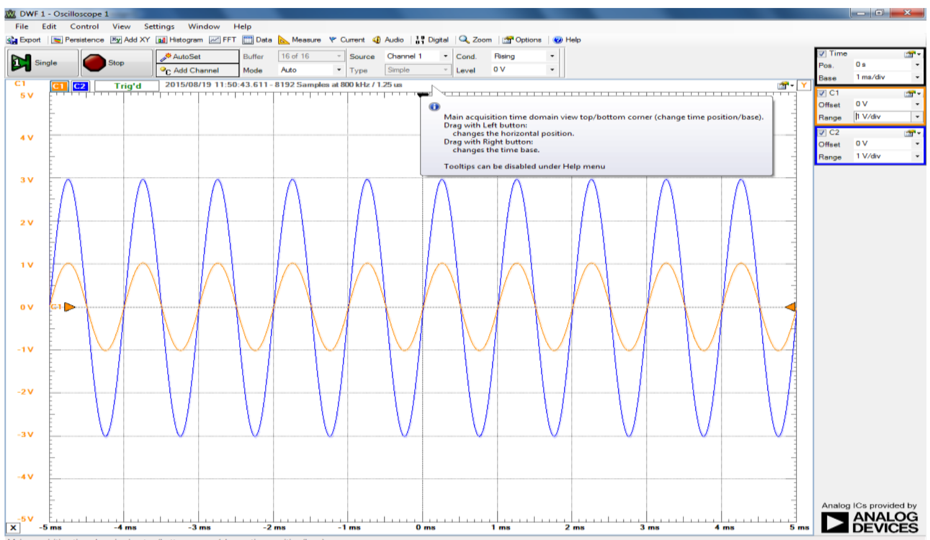


Fig 6: Measure voltage from KVL circuit.

Example 3 – Thevenin's Equivalent Circuit Module

By the time students complete this module, they are expected to develop their own procedures for verifying this concept. Students have the option of designing their own experiment or completing the activity developed by Digilent. Students are also required to complete a formal report for this module.

APPENDIX C
Jackson State University

Thevenin's Equivalent Circuit

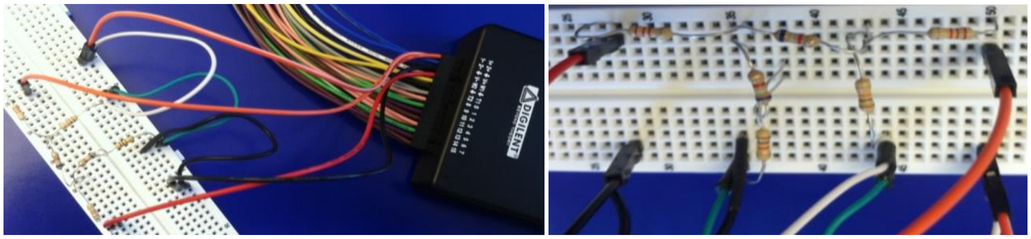


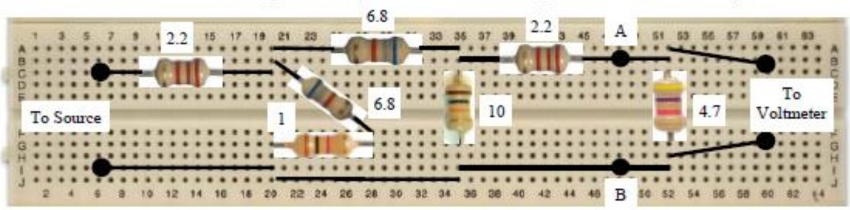
Figure 1. Sample of a setup to measure Thevenin's equivalent for an electric circuit.

ENL 220 CIRCUITS LAB

Analog Discovery and Waveforms

24. Breadboard the circuit in Fig. 1.

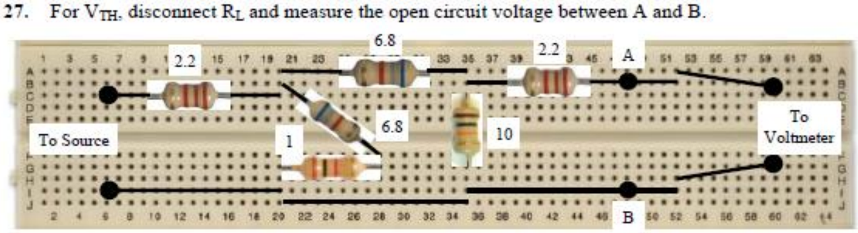
25. Use the voltmeter of Analog Discovery to measure the voltage across R_L in the complete circuit.



V_{RL} (Comlete Circuit) = ____________________

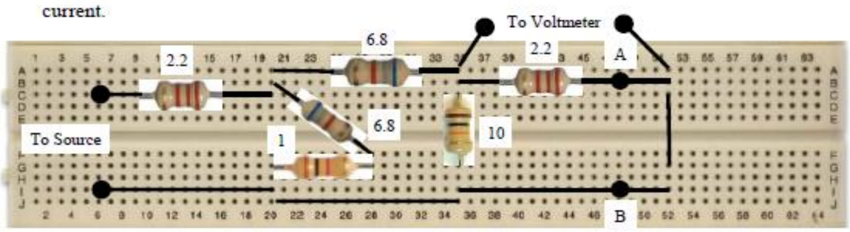
26. Find Thevenin's and Norton circuits between A and B.

27. For V_{TH}, disconnect R_L and measure the open circuit voltage between A and B.



V_{TH} = __________________

28. For I_N, replace R_L by short circuit, then I_N is the current in the short circuit from A to B. Since Analog Discovery measures voltage only, and the short circuit current is the same as the 2.2k current (the right one), measure the voltage across this 2.2k, and use Ohm's law to calculate its current.



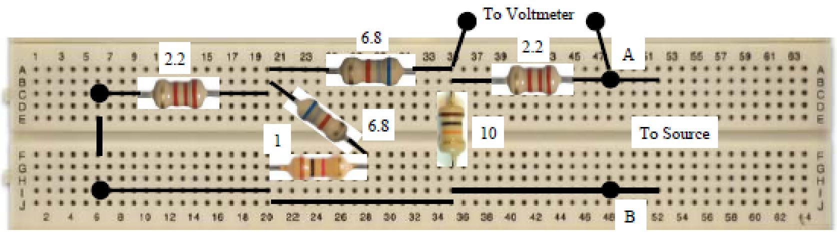
I_N = __________________

Lab 8, page 6-9

Fig. 2. Circuit building and measuring – Part 1.

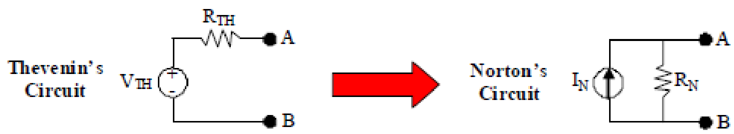
ENL 220 CIRCUITS LAB

29. For R_{TH}, replace the voltage source by short circuit, then connect the voltage source between A and B, and calculate the input current from A to B (from the - to + in the source). This current is the same in the 2.2k (the right one), but in the opposite direction of the one in Step 28. Measure the voltage across this resistor and calculate the current using Ohm's law. Finally, the thevenin's resistance equals the voltage of the source divided by that current. $R_{TH} = V_1 / I_{-to+}$.



R_{TH} = ____________________

30. The Thevenin's and Norton Circuits will be as those shown below.



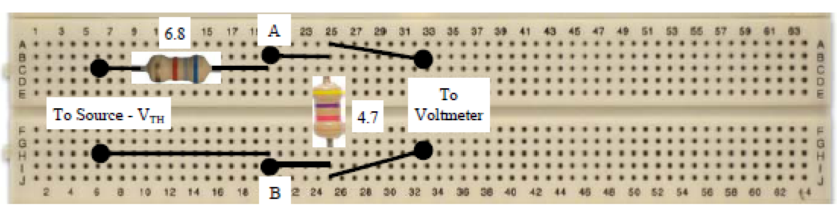
31. Norton's Circuit is a source transformation for Thevenin's one. According to source transformation R_N is equal to R_{TH}, and $V_{TH} = I_N \times R_{TH}$, then R_{TH} should be calculated as follow:

$R_{TH} = R_N = V_{TH} / I_N$.

Calculate R_{TH} again using this method. R_{TH} = __________________

Compare the two results obtained for R_{TH} in steps 29 and 31. The results must be the same, and this verifies source transformation. However, small differences may result because the multimeter rounds the results.

32. Connect R_L (4.7k) to the Thevenin's Equivalent Circuit, and re-measure the voltage.



Lab 8, page 7-9

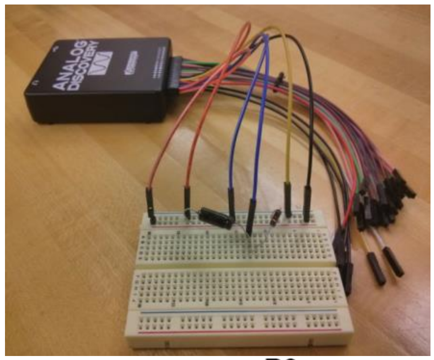
Fig. 2. Circuit building and measuring – Part 2.

APPENDIX D
North Carolina A&T State University

Example #1: KVL and KCL Circuit Analysis

Build the circuit in figure 1 on the breadboard and use the ADB with 4 volts dc signal. Use the following resistor values to measure the voltage and currents in each resistor and compare the measured results with the calculated results and record them in the table below.

R1 = 220 Ω, R2 = 10KΩ, R3 =1KΩ, R4 =100KΩ.



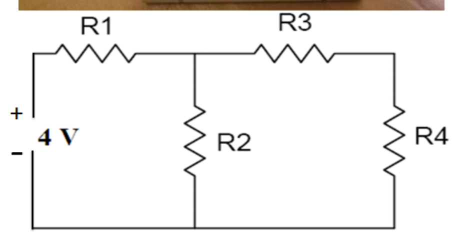


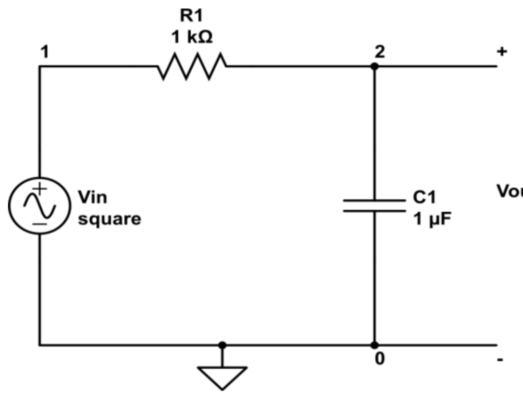
FIGURE 1

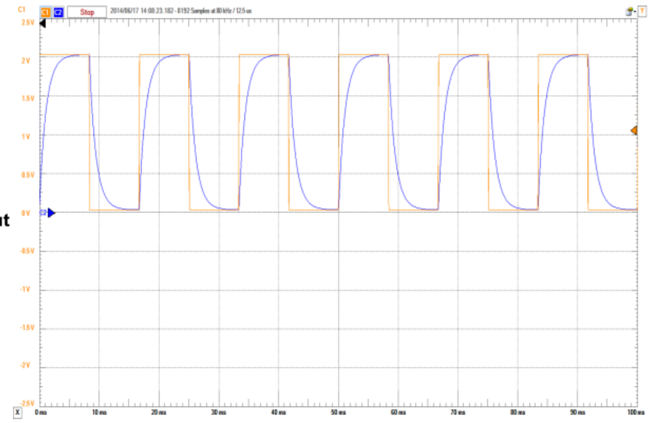
V_S =4 VDC	I_S	I_1	I_2	V_{R1}	V_{R2}	V_{R3}	V_{R4}	I_S
THEORETICAL								
MEASURED								
ERROR %								

Example #2: Transient Analysis of First Order RC circuit

Build the series RC circuit on the breadboard and make the following connections between the ADB pins and the nodes on the breadboard, them measure the voltages V_c and V_R and the time constant (T) of the circuit.

- 1 – WaveGen1, W1 (Solid Yellow Line)
- 1 – Scope Channel, 1+ (Solid Orange)
- 2 – Scope Channel, 2+ (Solid Blue)
- 0 – Ground (Black)
- 0 – Scope Channel, 1- (Striped Orange)
- 0 – Scope Channel, 2- (Striped Blue)

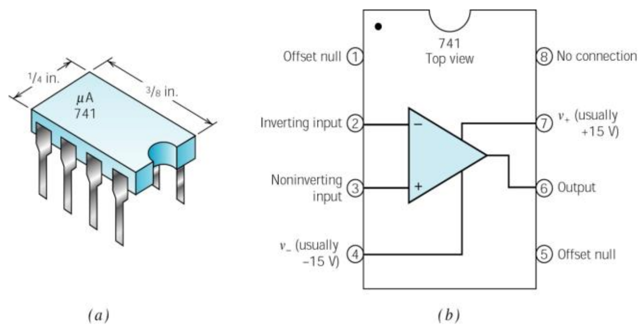




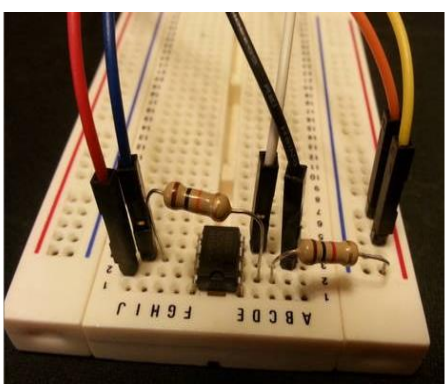
Example #3: Op-Amp Circuit Analysis
Students were asked to build inverting and non-inverting op-amp circuits and <u>measure the gain</u> of the op-amp and compare their experimental results with the theoretical results.

OP-AMP 741 PIN Configurations

- **# 2-** Inverting input
- **# 3-** Non-inverting input
- **# 4-** (V-) negative bias voltage
- **# 7-** (V+) Positive bias voltage
- **# 6-** Output



Pins 4 and 7 are the DC voltages which define the peak-peak value of the output signals.
These values could be set from the pairs of (-4 & 4) up to (-15 & 15) volts.
We will use (-5v and +5v) as they are made available to us in ADB toolbox.



Students had the freedom of taking the ADB kit with them home and work on the experiments at their free time. Later they had to schedule an appointment with the instructor to show their work, discuss any problems and submit a formal report that has all the results.

APPENDIX E
Norfolk State University

Second Order Transient Circuits

A second order transient circuit has in general three passive components: resistor capacitor and inductor. After being charged and then isolated, the two storage components oscillate the stored energy back and forth to one another. The frequency at which this oscillation occurs and how long it lasts is dependent upon the values of the components. The frequency response is said to be either over, critically or under damped. The purpose of this lab was to become familiar with how the values of the components in a second order transient circuit affect the circuit's behavior.

The circuit shown in Figure 1 is a series second order transient circuit. This circuit was designed for use in all instances of the experiment. The values of the components were adjusted to alter the damping factor of the circuit from one damping fashion to another.

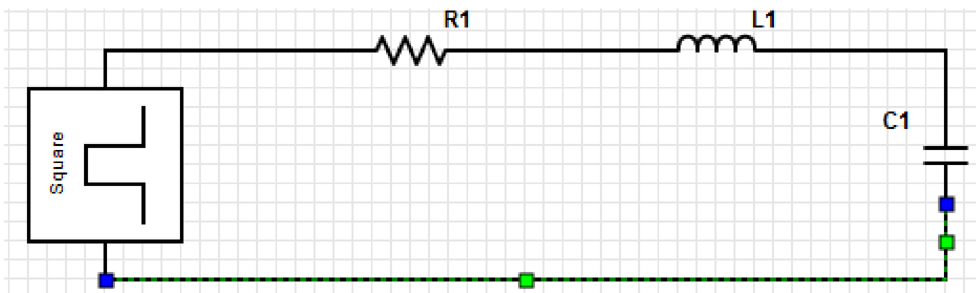


Fig. 1. A series RLC circuit used along with the ADB kit.

The homogeneous equation for the circuit is given as

$$L\frac{d^2i}{dt^2}+R\frac{di}{dt}+\frac{i}{C}=0$$

We can designate the natural frequency and damping ratio as shown below:

$$\omega_n=\frac{1}{\sqrt{LC}};\ 2\varsigma\omega_n=\frac{R}{L}\Rightarrow\varsigma=\frac{R}{2}\sqrt{\frac{C}{L}}$$

When $\varsigma>1$, the homogeneous equation has real and distinct root resulting in over-damped output response. For $\varsigma=1$, critically damped response is obtained with real and equal roots whereas for $\varsigma<1$, complex conjugate roots provide under-damped response. One could vary the component values to find appropriate damping ratio.

First, the circuit was constructed using component values for an under damped circuit. The circuit had a resistor value of 10Ω, an inductor of 1mH and a capacitor with a value of 0.1μF. This means that the damping ratio had a value of $\varsigma<1$, in fact it was 0.05 and the following response is obtained. Figure 2 shows the input voltage in blue and the voltage across the capacitor in yellow. The input was a 2V square wave at 500Hz.

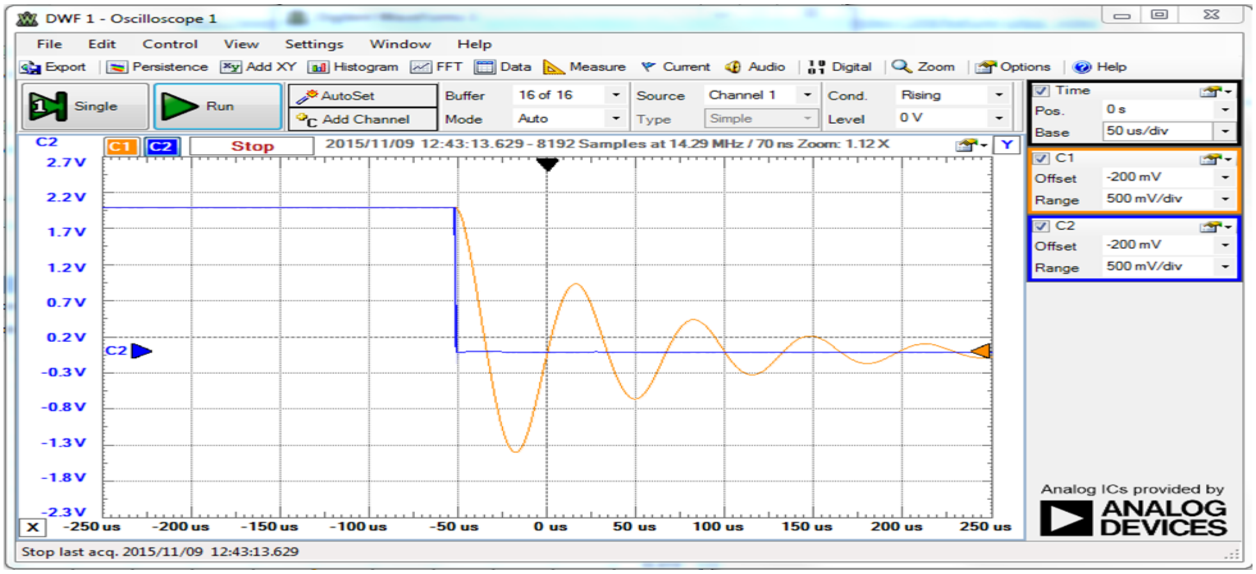


Fig. 2. An under-damped response. The input voltage in blue color is 2V square wave at 500Hz. The voltage across the capacitor is in yellow that shows decreasing amplitude with time.

One could change any of the components to achieve $\varsigma=1$. In our case, the inductor was changed to 2.5µH leading to a damping ratio of 1 which made the circuit critically damped. The values of the other components and the input were kept the same. The results are shown in Figure 3.

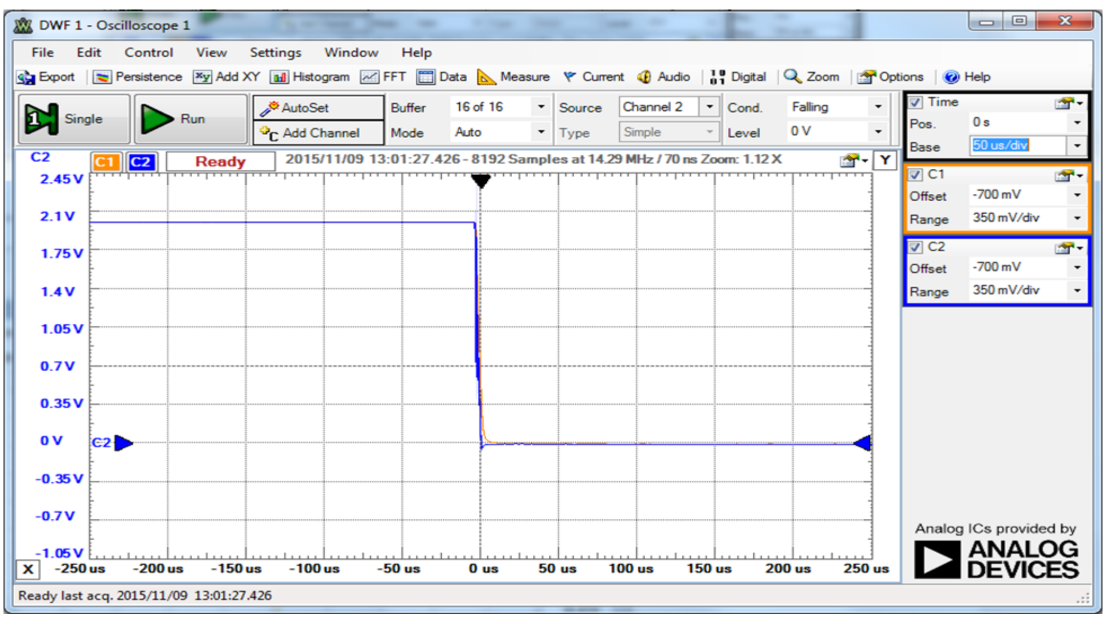
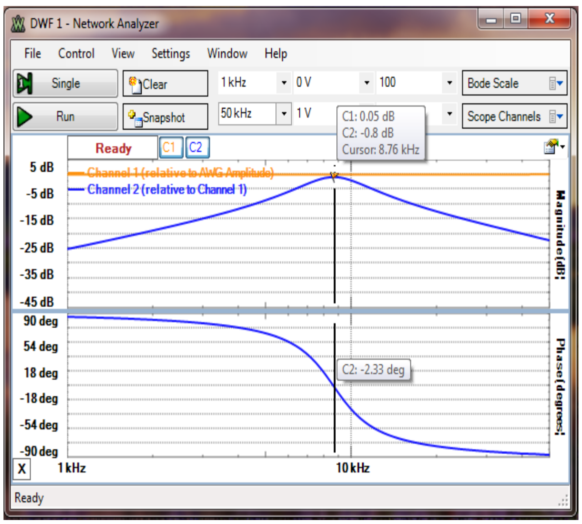


Fig. 3. Response of a critically damped circuit.

APPENDIX F
Prairie View A&M University

ADB Usage in Circuit Analysis II

At Prairie View A&M University, the students performed two projects with the ADB in the Circuit Theory II class (ELEG 3013). The first project involves obtaining the frequency response of a resonant RLC circuit, and the second project the determination of the frequency content of periodic signals. For the RLC resonant circuit, the students designed bandpass or band-reject filters that met some specifications. The frequency responses of the RLC circuits were obtained by using the Network Analyzer of the ADB. Figure 1 shows the Bode plot of a bandpass filter designed by a group of students. The Frequency Analyzer of the ADB was used to obtain the frequency content of the both a square and triangular waveforms. The spectral contents of the periodic signals obtained through the Frequency Analyzer were compared with the theoretically calculated values. Figure 2 shows the frequency content of a square wave obtained by using the ADB.



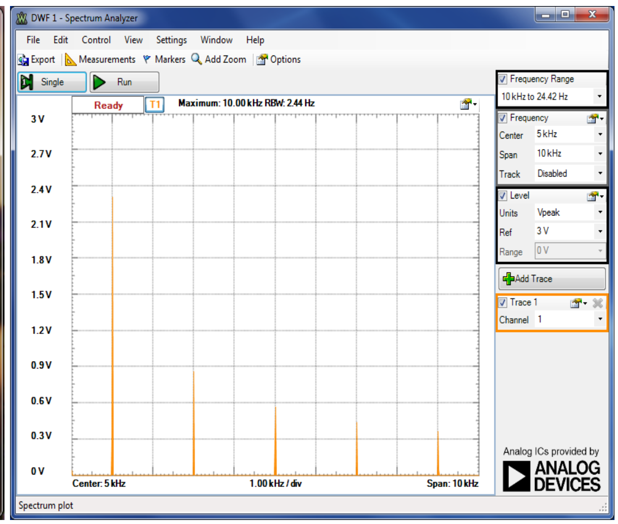
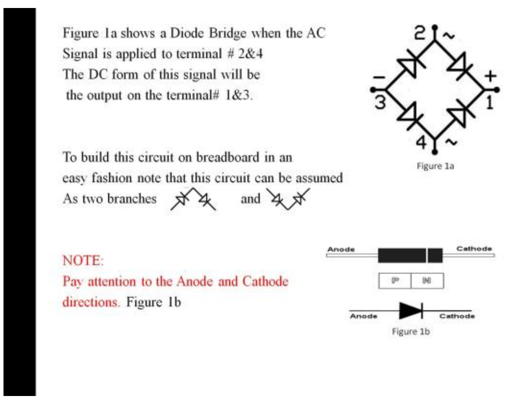


Fig. 1: Bode plot of a resonant RLC circuit. Fig.2: Spectral components of 1kHz square wave.

APPENDIX G
Morgan State University

ADB Usage in Electric Circuits / Electric Circuits Lab Online Hybrid courses

Students at Morgan State University used the ADB to complete their laboratory experiments and projects in a hybrid face-to-face (F2F) and online Circuits and Circuits Lab courses during the summers of 2014 and 2015. Both courses are offered over a combined two summer sessions (14 weeks total) and the students have to option to complete their project and laboratory demonstrations using the ADB online or F2F. They are required to complete 8 laboratory experiments that cover concepts starting from Voltage Division up to RLC circuits and Operational Amplifiers. The students have access to all the lecture notes, and demonstration videos online using our Blackboard learning management system (LMS). We also assigned at least one teaching assistant (TA) per course to support both the F2F and online students. A sample laboratory experiment is shown below.



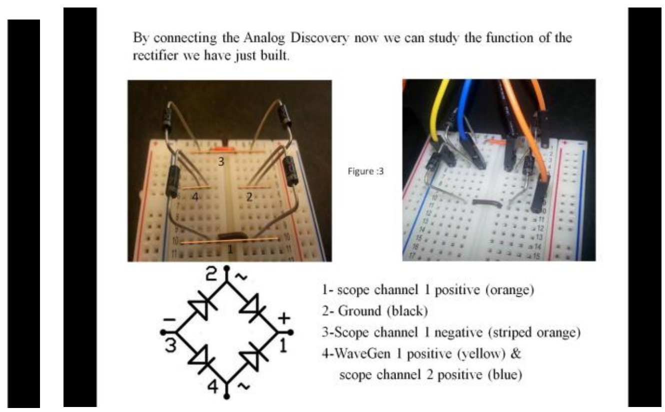
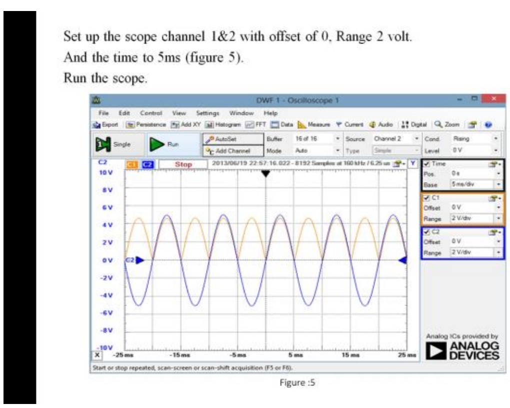


Fig. 1: Instructions given to student. Fig.2: Sample breadboard connection shown to students



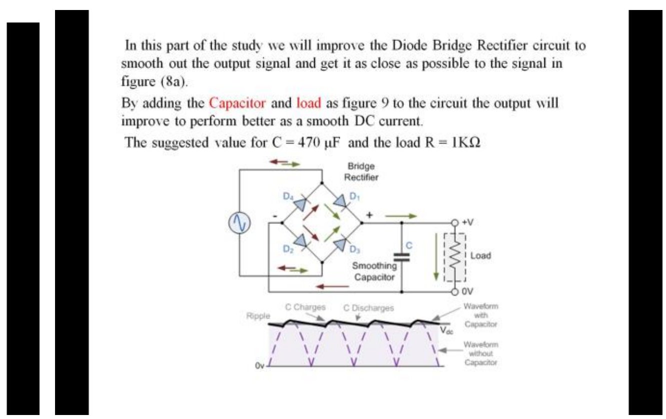


Fig. 3: Sample output given to student. Fig.4: Suggested improvement to rectifier circuit