
AC 2012-4732: ONLINE DELIVERY OF ELECTRICAL ENGINEERING LABORATORY COURSES

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Electric Circuits Online – Online Delivery of Electrical Engineering Laboratory Courses

Abstract

This paper presents our experiences and results in developing and delivering new laboratory experiments for the sophomore level Electric Circuits Lab, and Introduction to Digital Logic design courses completely online. The paper will clearly outline how we utilized a new pedagogy to re-write our laboratory experiments so that they can be completed by face-to-face and/or online students using new portable laboratory instrumentation devices, such as the Mobile Studio™ board. We also present detailed descriptions on how we used the Adobe Connect™ software to allow the students to demonstrate their design and laboratory experiment circuits to the course instructor from a remote location.

We have successfully developed and delivered over 10 laboratory experiments completely online for the two sophomore level courses during the Spring 2011 semester. The laboratory experiments have been updated in the Fall 2011 semester with the addition of new Agilent X-Series Oscilloscopes with integrated Function Generators. The new oscilloscopes have optional LAN connection modules that allow students to control every feature of the oscilloscopes remotely using a web browser on their personal computer (PC) through a virtual front panel that looks and operates the same way as the real front panel of the scopes with the same associated keys and knobs. This implies that students who are conducting ECE laboratory experiments online will have access to the same type of equipment that is used by the students enrolled in the face-to-face (F2F) laboratory courses.

The results have shown that the students were able to conduct most of the design and laboratory experiments required in the online lab courses without the need to be on campus. This new approach represents a major paradigm shift in the way higher education institutions should think when delivering Electrical Engineering education.

Introduction

Trends in higher education for the past 10 years have shown that enrollments in online courses or online degree programs have been growing substantially faster than overall higher education enrollment. A survey of online learning conducted in 2009 by the Sloan Consortium indicated that enrollment in one or more online courses reached 4.6 million students in 2008 [1]. The 17 percent growth rate for online enrollments is significantly higher than the 1.2 percent growth rate of the overall higher education student population during the same time period [2]. A follow-up report published in 2011 [3], and other papers [4], [5], [6] seek to address and provide answers to some of the fundamental questions related to the nature and extent of online education. Some of the questions addressed in the report are, whether retention of students is harder in online courses, if the learning outcomes in online courses are comparable to face-to-face (F2F) courses, whether faculty acceptance of online education has increased, or the impact of the current economic conditions on online education. The results of the surveys conducted in [3] based on the responses from 2,500 colleges and universities are summarized in Table I. The

authors of the survey conclude their report by stating that “online enrollments in U.S. higher education show no signs of slowing.”

One discipline that has lagged behind all others in the development and delivery of online education is engineering. While close to 320 engineering schools in the USA have received accreditation from ABET, formerly known as the Accreditation Board for Engineering and Technology (ABET) for their undergraduate programs, only a handful of those offer engineering programs that are completely online at the graduate and/or undergraduate level. The trend has started to change lately, and each year more engineering programs add an online component to their regular curriculum. The main obstacle impeding adoption is that most engineering curriculums require intensive hands-on laboratory components that can be challenging to implement and deliver completely online due to cost and inability of students to manipulate equipment remotely.

Table I: Results from Online Education Survey [3]

Survey Question	Survey Results
Is Online Learning strategic ?	65% of all reporting institutions said that online education is a critical part of their long term strategy.
Are learning outcomes in online courses comparable to face-to-face ?	67% of academic leaders rated their learning outcomes in online education to be the same to those in F2F. This number was 57% in 2003.
Has faculty acceptance of online learning increased ?	Less than one-third of chief academic officers (VPs or Provosts) believe that their faculty accept the value and legitimacy of online education. This number has not changed since 2003.
What training do faculty receive for teaching online ?	72% of institutions conduct internally run training courses, and 58% provide informal mentoring.
What is the future of online education enrollment growth ?	There is growth in fully online programs by disciplines in public institutions. However, private and for-profit institutions that currently have the largest enrollment are showing a slight decline.

Most online engineering programs currently available are at the Master of Science (MS) level, and are targeted at engineers in professional practice, most of whom have received their undergraduate degrees from a campus based program. A summary of the list of engineering programs that offer an online Master of Science (MS) degree is published by the Sloan Consortium [2]. The list in [2] indicates that the Master of Science in Bioinformatics from Johns Hopkins University (JHU) is the only program that is accredited by ABET. An even smaller number of institutions offer an online Bachelor of Science (BS) engineering degree program. They are listed in Table II. Universities also utilize various types of technologies to increase and enhance the learning experience of their online students [9][10][11]. Some universities use web-conferencing and synchronous streaming technology provide a high degree of interactivity to the online students. Another approach is to use technology that allows online students to attend live lectures delivered on campus to the regular students. The goal is to allow online students to have a very flexible academic schedule, while providing them with a learning experience that closely mirrors that of on-campus students.

Table II.
Online B.S. Engineering Programs [3]

University	B.S. Degree Program offered online
University of North Dakota	Chemical,Civil, Electrical, and Mechanical Engineering
The State University of New York (SUNY): Binghamton, Buffalo, and Stony Brooke campuses	Electrical Engineering

The electrical and computer engineering (ECE) courses offered to online students at our institution will utilize various technologies and tools that are commercially available and used by many other engineering schools with online programs. However, our approach is slightly different from the other two universities that offer a BS degree in Electrical engineering because we are able to utilize a new technology, the “Mobile Studio IOBoardTM,” developed at Rensselaer Polytechnic Institute (RPI), and the Agilent X-Series Oscilloscopes with integrated Function Generators to implement the laboratory and design components of our undergraduate courses. We also supplement our online courses with captured lectures of our face-to-face, on campus courses using the Panopto FocusTM software. All online courses developed at our institution have to undergo a thorough evaluation process to assure that they conform to “The 2008 – 2010 Quality MattersTM (QM) Rubric” [12]. This rubric outlines many of the practices that are generally accepted for teaching engineering courses and includes some items that are critical for an online student’s success [13]. Finally, we use the Adobe ConnectTM software to allow online students to demonstrate their projects and laboratory assignments to their instructors from another location. The results of our implementation of 10 laboratory experiments in two sophomore level ECE courses completely online are discussed in the rest of the paper.

Online Course development

The development of the two online ECE courses discussed in this paper started about 10 years ago with the addition of web-based course supplements for the regular courses. The web-based course supplements consisted of additional course materials such as PowerPoint slides, animations, short video, and other website links that were there to help the regular students understand the course material better. Regardless of the amount of supplementary course materials available to the students, the one thing that was always required by all students is fact that they had to come to the ECE laboratory rooms and use the laboratory equipment to design, build, test and demonstrate their projects and laboratory experiments to the course instructor. This changed three years ago, when our university joined the Mobile Studio project that was funded by a five year NSF grant at RPI. The addition of the Mobile Studio IOBoardTM allowed us to redesign our regular and laboratory ECE courses in such a way that the students can now conduct the majority of their design and laboratory experiments outside of the ECE laboratories.

In the first phase of our implementation, regular students were allowed to use the Mobile Studio boards to complete their laboratory and design projects in their dorms or the library. However, they were still required to see the course instructor in his/her office or in the ECE laboratory to conduct a live demonstration of their final projects. The faculty at our institution

worked with peers at other institutions involved in the Mobile Studio project to redesign various laboratory and design experiments so that they can be completed by the students using the Mobile Studio IOBoard™. The key issue that we had to address was the fact that the Mobile Studio IOBoard™ is limited to very low voltages (plus or minus 4 Volts) because it draws its power from the USB port of the laptop it is connected to. This implied that laboratory experiments that required a “Power Supply” or “Function Generator” with more than 5 volts had to be redesigned in such a way that the overall concept of the experiments could still be understood by the students. The instructors involved in the Mobile Studio project at the various institutions worked together very closely so that they all followed a very sound pedagogy to deliver the educational content using the Mobile Studio IOBoard™ technology. Various papers on the use of the Mobile Studio IOBoard™ technology and pedagogy have been published by the other members of the Mobile Studio project at several conferences [JOEE paper #5].

Phase I- Pedagogy and Implementation of Online Courses

The circuits laboratory (known as “Introduction to Electrical Lab”) course is a one credit course that meets once a week for three hours. The circuits and circuits laboratory courses are prerequisites for the digital logic course. The digital logic course is a three-credit course that meets for three fifty-minute periods each week. Both courses enroll about 70 students during the academic year. Most of the class time in both lecture courses is spent lecturing the students. The circuits laboratory course meets in the electronics laboratory, to allow students complete assignments in groups, under the guidance of the instructor. Some of the digital logic course periods are for laboratory assignments and are held in computer engineering laboratories. During these sessions, students demonstrate, to the instructor, laboratory exercises and projects that they have built on a prototyping board and tested using the Mobile Studio IOBoard™ or the regular laboratory equipment. These laboratory exercises are completed outside of the classroom, in groups of two or three. The laboratory exercises and projects allow students to apply the topics covered in the course and are used to reinforce the material in the course.

The F2F courses were converted to asynchronous online courses over a four to six month period from January to July 2010. The “Intro to Electrical Lab” online course was completed by June 2010 and was offered completely online in July 2010 as pilot course along with the “Electric Circuits” online course. The digital logic course was converted to an online course by July 2010. It was then offered to a few students as an online course in the Fall 2010 semester. All online courses were designed so that students would be able to access course resources at their own time. Our university requires all online course builders to attend an “Online Course Design Workshop” that is offered on campus. This course is delivered online, via Blackboard Learn™. The course topics include the online teaching environment, creating modules, the role of discussion, technology integration and assessment. The main goal of the “Online Course Design Workshop” is to teach instructors interested in developing and teaching online courses how to divide the course into modules that last approximately one to two weeks. These modules have to further be divided into sub-modules with topics that students can work through in about an hour.

All courses were required to conform to “The 2008 – 2010 Quality Matters™ (QM) Rubric” [12]. This rubric outlines many of the practices that are generally accepted for teaching engineering courses and includes some items that are critical for an online student’s

success[7],[8]. The rubric assigns points to several aspects of an online course to ensure a student's success. Any MSU course that is converted to an online course cannot be offered to students until it meets and passes the grading scale set by the instructor of the "Online Course Design Workshop" course. This is done to ensure that all online courses meet the minimum course development standard to assure the success of the students who will be enrolled in it. Samples of the different components of the rubric used to evaluate all online courses at XXX are shown in Table V [12].

Phase II- Pedagogy and Implementation of New Online Laboratory Experiments

Students enrolled in the online ECE courses have to first complete introductory training laboratory experiments that familiarize them with the various features of the Mobile Studio IOBoard™ technology. They are then allowed to conduct additional laboratory experiments that utilize new features of the Mobile Studio IOBoard™. Detailed discussions on how our university developed various design projects and laboratory experiments using the Mobile Studio IOBoard™ technology has been discussed in detail in our previous papers [list asee 2011 and joe papers]. One question that has constantly been raised with the exclusive use of the Mobile Studio IOBoard™ to conduct laboratory experiments online is whether students have acquired enough laboratory skills to easily transition and start using regular function generators and oscilloscopes found in most ECE laboratories. The focus of this paper is to show how we utilized the new Agilent X-Series Oscilloscopes with integrated Function Generators, that have the optional local area network (LAN) connection modules, to allow students to control every feature of the oscilloscopes remotely using a web browser on their personal computer (PC). Agilent X-Series Oscilloscopes provide the user a virtual front panel that looks and operates the same way as the real front panel of the scopes with the same associated keys and knobs. This implies that students who are conducting ECE laboratory experiments online will have access to the same type of equipment that is used by the students enrolled in the face-to-face (F2F) laboratory courses. We proceeded to develop laboratory experiments that can be conducted completely online using the Agilent X-Series Oscilloscopes. We tested the new laboratory experiments using an undergraduate student who conducted the experiments completely online.

The following section shows the pedagogy we used to convert a RC filter laboratory experiment that is designed for a F2F laboratory to one that can be conducted completely online using the same equipment. **Fig. 1** shows a section of the RC filter lab experiment where students enrolled in the F2F laboratory course are given the instructions on how to build and test RC High Pass and Low Pass filter circuits with a certain cut-off frequency. The approach we took in converting the F2F laboratory experiments into online laboratory experiments is to make sure that the outcomes of both types of laboratory experiment were the same. We also wanted to find out whether students who completed the online laboratory experiments had the same confidence level in using the laboratory equipment as those who participated in the F2F laboratory courses. Until now, we had no means of directly evaluating whether students who conduct laboratory experiments online using the Mobile Studio IOBoard™ can transition smoothly and be able to use comfortably the regular Oscilloscopes and Function Generators found in the F2F laboratory. By using the Agilent X-Series Oscilloscopes with integrated Function Generators for both the online and F2F laboratory experiments, we were able to evaluate and compare the performance of the students enrolled in both types of courses.

Lab 7 – Low Pass and High Pass Filter Circuit Design

The characteristics of the low pass and high pass filter circuits were discussed in the classroom. Please refer to your class notes for more information related to filter circuits. This laboratory experiment will be conducted in the regular laboratory room using the **Agilent X-Series Oscilloscopes** with integrated Function Generators.

Part I- Low Pass Filter: Design, build and test the low pass filter circuit shown in Figure#1a such that the cutoff frequency is about 5 KHz. Build the circuit and use the Agilent X-Series Oscilloscopes with integrated Function Generators to test the response of your circuit. Assume that V_{in} is a 1 Volt peak to peak sine wave.

You need to be able to answer the following questions after completing the experiment:

- What do you expect the output voltage V_{out} to be when you reach the cut-off frequency ? Why ?
- What happens to V_{out} after you pass the cut-off frequency ? Why ?
- Plot your data on Microsoft Excel using V_{out} versus frequency and (V_{out}/V_{in}) versus frequency and prove that the cut-off frequency that you have designed matches the one that is obtained after you build the circuit.

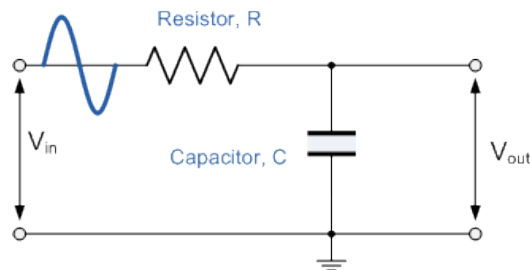


Figure 1a: **Low Pass Filter**

Part II- High Pass Filter: Design, build and test the high pass filter circuit shown in Figure#1b such that the cutoff frequency is about 5 KHz. Build the circuit and use the Agilent X-Series Oscilloscopes with integrated Function Generators to test the response of your circuit. Assume that V_{in} is a 1 Volt peak to peak sine wave.

You need to be able to answer the following questions after completing the experiment:

- What do you expect the output voltage V_{out} to be when you reach the cut-off frequency ? Why ?
- What happens to V_{out} after you pass the cut-off frequency ? Why ?
- Plot your data on Microsoft Excel using V_{out} versus frequency and (V_{out}/V_{in}) versus frequency and prove that the cut-off frequency that you have designed matches the one that is obtained after you build the circuit.

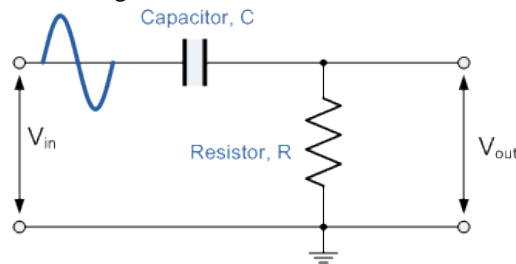


Figure 1b: **High Pass Filter**

Figure 1: RC lab given to the students enrolled in the **F2F** laboratory course

The online students were initially given a laboratory experiment that introduced them to the features of the Agilent X-Series Oscilloscopes when it is used remotely. After the online students complete Lab#0, they are ready to complete the remaining laboratory experiments online. They have access to additional training and user manuals in case they need extra support to use the equipment and complete their laboratory experiments. Fig. 2 shows the original RC filter lab experiment (shown in Fig. 1) after it is converted to the online version.

Lab 7-WEB – Low Pass and High Pass filter circuit design

The characteristics of the low pass and high pass filter circuits were discussed in the classroom. Please refer to your class notes for more information related to filter circuits. This laboratory experiment will be **conducted completely online** using the internet to connect to the **Agilent X-Series Oscilloscopes** with integrated Function Generators **remotely**. The **goal** of this **experiment** is to **determine the type of filter** that is attached to the instrumentation board **after taking measurements** and **analyzing the data** that is collected.

Part I- Determine the type of filter circuit connected to the laboratory equipment

The **Agilent X-Series Oscilloscopes** with integrated Function Generators located in the laboratory is connected to an **unknown RC filter** circuit as shown in Figure 2a. Assume that V_{in} is a 1 Volt peak to peak sine wave. Connect to the oscilloscope remotely and **take measurements of V_{out} versus frequency** by varying the frequency from 100Hz up to 10KHz.

You need to be able to answer the following questions after completing the experiment:

- What type of filter circuit do you think the circuit in the Black Box represent ?
- Is it a High Pass or Low Pass filter ? Why ?
- What is your estimate for the cut-off frequency ? Why ?
- Plot your data on Microsoft Excel using V_{out} versus frequency and (V_{out}/V_{in}) versus frequency and prove that response of the filter circuit behaves as expected.

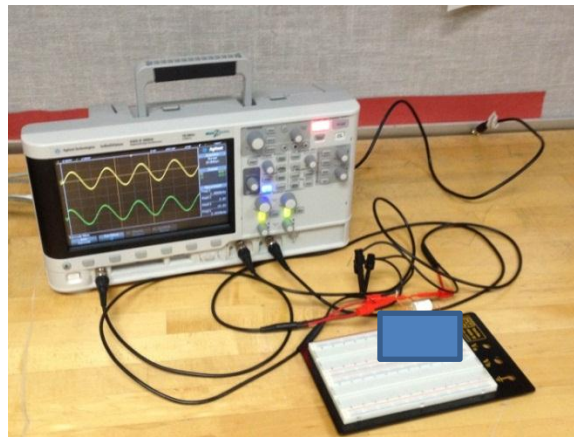


Figure 2a: **Unknown Filter circuit connected to Agilent Equipment**

Part II- Design, build and test a **new filter circuit** that has the **same cutoff frequency** as the circuit tested in Part I. Use your **Mobile Studio IOBoard™**, to test your filter circuit. Assume that V_{in} is a 1 Volt peak to peak sine wave. **Choose** the appropriate values for **R and C** such that the **cut-off frequency** is **as close as possible** to the estimated value obtained from part I of the laboratory experiment.

You need to be able to answer the following questions after completing the experiment:

- What do you expect the output voltage V_{out} to be when you reach the cut-off frequency ? Why ? Plot your data on Microsoft Excel using V_{out} versus frequency, and (V_{out}/V_{in}) versus frequency.
- How does the response of the new filter circuit compare to that of the original circuit given in Part I ?
- Please discuss your results in detail by comparing the cut-off frequencies of the two filter circuits given in Part I and Part II.

Part III- Repeat the experiments in Part I and Part II after the circuit connected to the Agilent X-Series Oscilloscopes **has been changed by the instructor**.

Figure 2: RC lab given to the students enrolled in the **F2F** laboratory course

Phase III- Integrating the Technology for Online Delivery of Laboratory Experiments

In the third stage of the implementation of our online courses, we started evaluating various hardware and software technologies that would make the course experience of online students as close as possible to the F2F students. We had to carefully evaluate the advantages and disadvantages of synchronous and asynchronous modes of content delivery for our online students. Since our goal was to offer the online ECE courses to students from within the United States or abroad, we decided to use a tool that can offer both synchronous and asynchronous course contents to the online student.

The course instructors enhanced the PowerPoint based lesson files by recording lectures for each sub-module using the Panopto Focus™ lecture capture software. Some instructors used the lecture capture software to record “live”, the daily course lectures of their regular ECE courses, while others recorded separate lectures for each PowerPoint lesson file outside of the regular classroom. The online lectures can be watched over the internet using streaming technology, or can be downloaded as podcasts. A screen capture of a digital logic lecture recording is shown in Fig. 3. The different time stamps on the left indicate that the students can access any part of the lecture recording by forwarding and rewinding the lesson. This allows the students to focus on a specific section of the lecture without the need to go through the whole recording. The picture on the right shows the monthly statistics on the usage of the various lecture recordings.

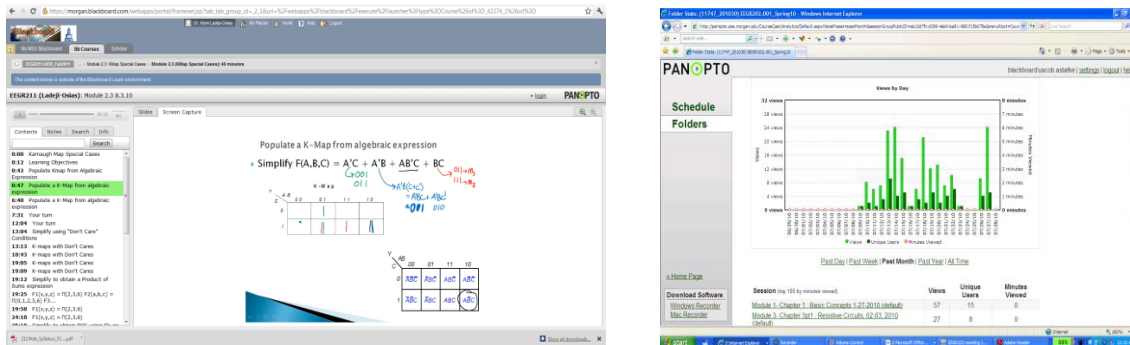


Figure 3 : Panopto Focus™ lecture recording for digital logic course (left). Panopto Focus™ lecture recording monthly usage in circuits lab course (right).

The last phase of our project was to determine how to allow students to demonstrate their project and laboratory experiments to their instructors without being present on our campus. Although our on-campus students used the Mobile Studio IOBoard™ to complete their project and laboratory experiments outside of the laboratory classrooms, they were still required to come to our campus in order to demonstrate their final work in front of the course instructor. Since we wanted our online students to be able to complete all of their course requirements without being physically being present on our campus, we started evaluating various video conferencing software packages. After careful evaluation, we chose the Adobe Connect™ software because it was available on our campus. The Adobe Connect™ software is commonly used by other institutions and corporations to conduct face-to-face video conferencing in real time. It provides instructors with a virtual classroom environment for sharing their presentations, and desktop applications with remote participants such as online students anytime, anywhere. The main

advantage of the software is that it works via a web browser, and does not require users to download any special software to join a meeting. It also allows instructors to go beyond simple PowerPoint and screen sharing by providing with additional options such as interactive chat, quizzes/polls, and breakout rooms for individual interactions.

The most difficult aspect of the online course delivery process was the implementation of the project and laboratory demonstrations online using the Adobe Connect™ software. First, we noticed that the video conferencing software requires users at both ends to have a good quality audio/video or web-cam in order to successfully conduct the meetings. This created a problem with one of the students enrolled in the online course because he had a very low quality web-cam on his laptop that prevented him from using all the features of the video conferencing software. Once the technical difficulties were taken care of, the students were able successfully demonstrate the results of their laboratory experiments to the course instructor completely online from three different locations. The course instructor was attending a conference in Troy, New York. Therefore, he conducted the project and laboratory experiments demonstrations from his hotel room. Two students were located in their dorms on the campus of our university. Two students were located in their apartment bedrooms in Baltimore, Maryland and one student was in his apartment in New York City, NY. Although the instructor could have conducted the online laboratory demonstrations from his office, he chose to do it while he was on travel to test the capability of the software to work from any location at any time. The screen captures shown in Fig. 4 show how the instructor and the students were able to conduct the complete laboratory demonstration online. Note that in Fig.4 (right side), other students can follow the demonstrations of their classmates while they wait for their turns. Additional information related to the implementation of the Panopto Focus™ and the Adobe Connect™ software in our online courses can be found in [18], and [19].

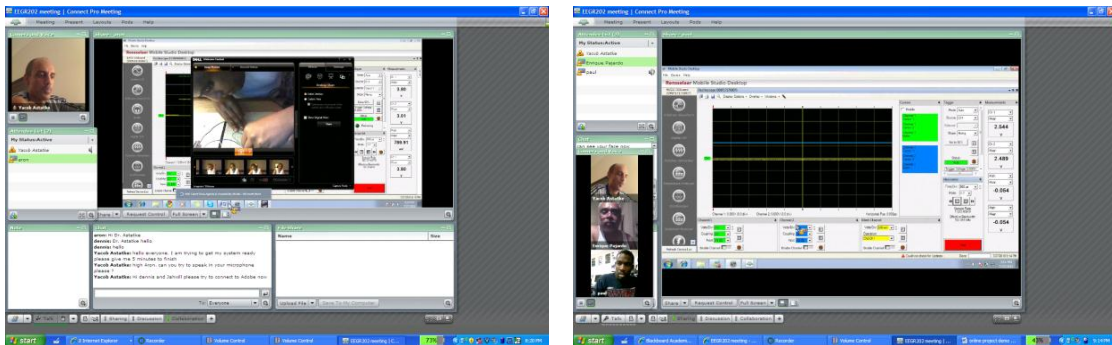


Figure #4: Student conducting laboratory demonstration completely online

Results from the Online laboratory Experiments

The discussion of the results for the online laboratory experiments that were conducted using the Mobile Studio IOBoard™ were discussed in great detail in [18][19]. Therefore, we will focus in this paper on the results obtained after conducting online laboratory experiments using the Agilent X-Series Oscilloscopes with integrated Function Generators. This is because the purpose of our research was to evaluate whether we can give the online students access to the same type of equipment that is used by the F2F students. The final goal will be to determine whether students who have access to the virtual version of a test instrument can actually transition and be

able to use it without major difficulty in the F2F scenario. A typical introductory laboratory experiment (Lab#0) for online students is shown in Fig. 5.

Lab 0-WEB – Instructions on how to use the Agilent X-Series Oscilloscopes remotely

Step 1: Download Java Runtime Environment 6 update 29

- Click on the following link: <http://www.oracle.com/technetwork/java/javase/downloads/jre-6u29-download-513650.html>
- Accept the License agreement and then click on the JRE download that is described below:

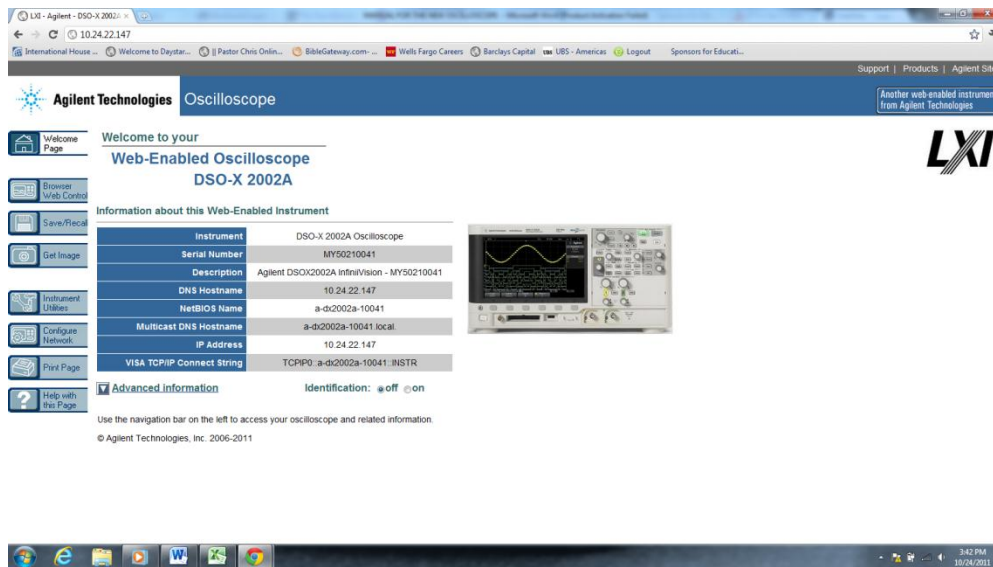
Windows x86 Offline 16.12 MB [jre-6u29-windows-i586.exe](#)

- Save the file, open its folder location and then follow the installation instructions.

Step 2: After the Installation, check to see if Java has been enabled in your browser. Click on the link below to follow the procedure on how to enable java on your respective browsers (Internet Explorer, Firefox, Google Chrome and AOL): http://www.java.com/en/download/help/enable_browser.xml

Step 3: Now, you are ready to operate the DSO-X 2002A oscilloscope on your PC!

- Open your web browser
- Copy and paste the IP address of the Oscilloscope – “<http://10.24.22.147/>” to your web browser and then press ‘Enter’. The screen below should be displayed on your web browser:



- If the screen above is displayed, then you are sure to be connected to the scope’s network environment.

Figure 5: Lab 0 given to online students

Fig. 6 shows the interface of the virtual instrumentation as seen by the online student. It should be noted that each icon on the virtual instrument represents an actual button in the real instrument. Therefore, an online student that understands the functionality of an icon on the virtual instrument should be able to utilize the same button on the real instrument. The captions in the orange boxes on the right are added inside the laboratory instructions to make it easier for the online students to understand the functionality of each icon.

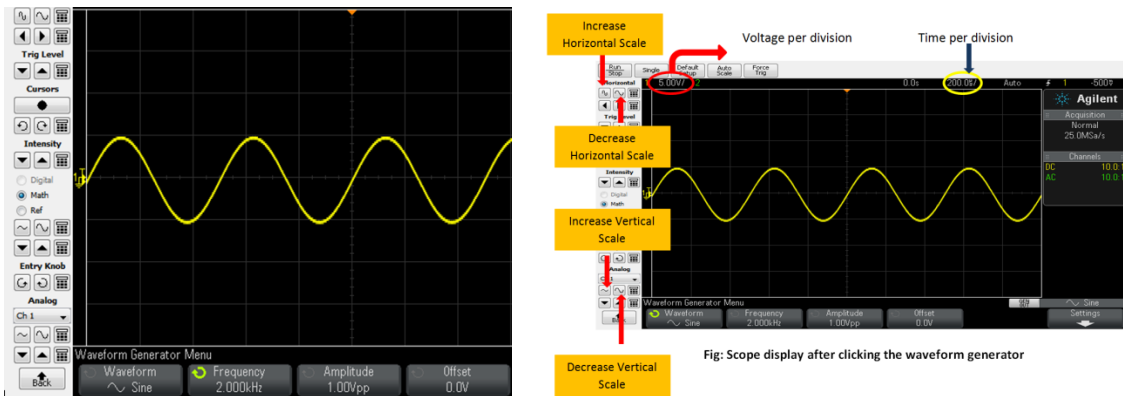


Figure 6: Virtual instrumentation interface seen by online students

Figure 7 shows the view on the screen of a computer that is remotely connected to the real instrument using Wi-Fi. Notice that the waveforms on the screen of the laptop are exactly the same as those seen on the real instrument. The picture on the right illustrates one of the results of the RC laboratory experiment (shown in Fig. 2) conducted by an online student. After the student completed Part I of the laboratory experiment, he was then able to build his own filter circuit in Part II of the lab. Note that the 3dB point (4.8KHz) of the low pass filter circuit that he designed and built is near the theoretical 5KHz value of the original circuit shown in Fig. 1 (F2F lab). This implies that the online student was able to understand the purpose of the online laboratory experiment and used it to design a new experiment that replicated the results of the original experiment. Finally, we connected two laptop computers remotely using to the same oscilloscope and conducted some tests by changing the values of the input signals using one of the laptops. We were pleasantly surprised when we realized that any change we made on the oscilloscope using one laptop was also visible on the second laptop. This implied that we can now create a scenario where two or more students can collaborate and conduct laboratory experiments remotely using the same oscilloscope.

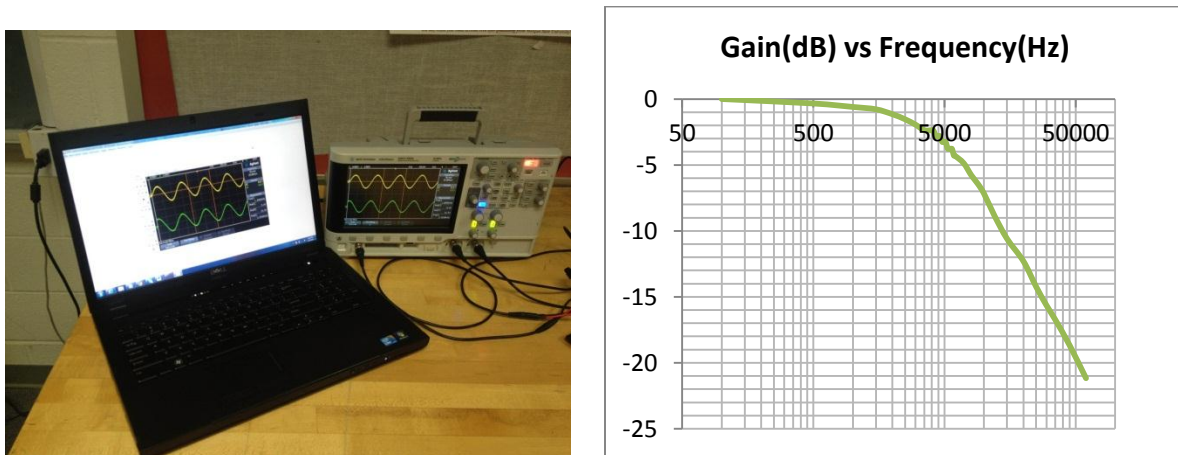


Figure 7- View from laptop of online student (left). Results of RC lab experiment from online student (right).

Comparison of Portable ECE Laboratory Kits

Although the focus of this paper was on the implementation and results obtained after we conducted ECE laboratory experiments using the Agilent X-Series Oscilloscopes and the Mobile Studio IOBoards™, similar results can be obtained by conducting the same experiments using other portable ECE laboratory kits such as, the Digilent “Electronics Explorer™” and National Instrument (NI) myDAQ™ boards . Each ECE laboratory measurement instrument has its advantages and disadvantages based on the method of use and the type of experiments that need to be conducted. Table III shows the basic description of each type of device, its features and price. Fig 8 shows the pictures of each ECE laboratory equipment next to each other.

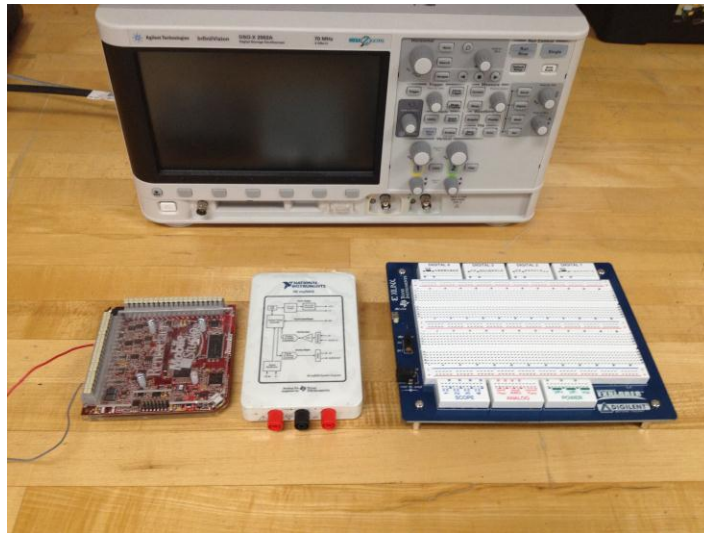


Figure 8: Mobile Studio IOBoard™, myDAQ™ board, Digilent Electronics Explorer™, and Agilent X-Series Oscilloscope

The cheapest instrument by far is the Mobile Studio IOBoard™ developed by RPI [20]. This implies that ECE departments can easily adopt it and make it part of the lab kit for their students because the cost is less than the typical engineering textbook. One of its main advantages is that it is very small (4in x 4in), and does not require an external power supply because it draws all of its power from the USB port of the computer or laptop that it is connected to. The Mobile Studio Software is free and very easy to run on any type of laptop or tablet PC. It comes pre-loaded with at least 6 instruments, including an arbitrary waveform generator and a spectrum analyzer. It has an audio I/O port that can be used to import any sound signal for processing and export it for listening using speakers or headphones. The Mobile Studio IOBoard™ also has a 16 port digital I/O port. Here are some of the disadvantages of the Mobile Studio IOBoard™ : it is limited by a voltage source that cannot exceed +4V or -4V, its voltmeters cannot be used to measure current or resistance, and it has a limited frequency range (less than 100Khz). The constraints on the voltage sources imply that the laboratory experiments that we design have to be formatted to meet the low voltage and low frequency requirements. The mobile studio project website [20] provides its users with a set of laboratory experiments on circuits, electronics, and optical communication that have been designed by faculty members from RPI, Howard University, Rose-Hulman Institute of Technology, and Analog Devices. Fig. 9 shows the Mobile Studio IOBoard™ set-up with the laptop and bread-board with the circuit

being evaluated. Fig 10 shows the student conducting an experiment using the Mobile Studio IOBoards™. Note the comparison in size with his set-up, and the rack behind him that is currently used by the face to face students to conduct their laboratory experiments.

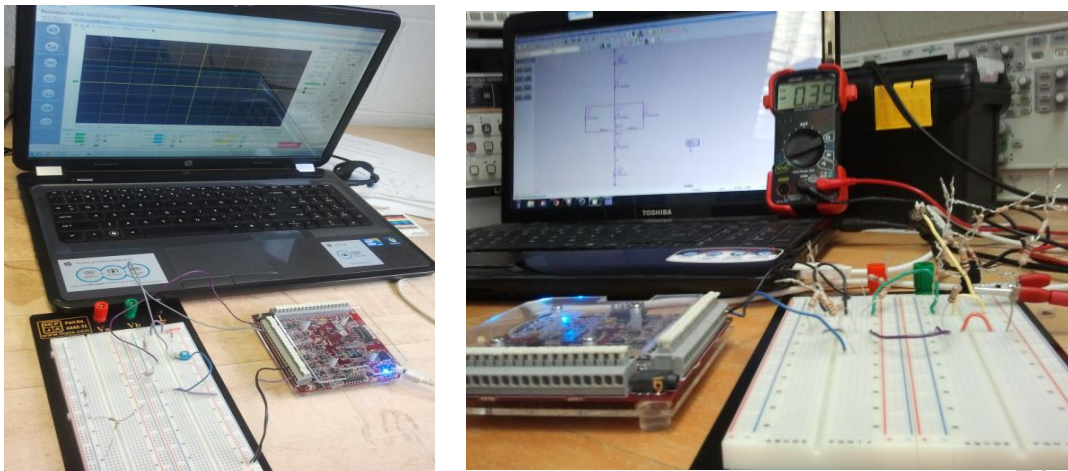


Figure 9: Typical laboratory set-up using the Mobile Studio IOBoard™



Figure 10: ECE Student using the Mobile Studio IOBoard™

The second portable ECE laboratory instrument is the National Instrument (NI) myDAQ™ board [21]. The board provides more features than the Mobile Studio IOBoard™. It requires an external power supply and the user also has to purchase a pre-packaged proto-board in order to easily access the different input/output ports of the board. The fact that the myDAQ™ board is based on the Labview™ software can be seen as both an advantage and disadvantage. It is an advantage for universities that have already adopted the Labview™ software and make it available to their students. It is however a disadvantage if the students have to purchase the Labview™ software on their own. It adds to the cost of the board and forces the students to use a software package that is not free of charge. Unlike the Mobile Studio Desktop™ software, the Labview™ software requires a more powerful memory and processing power to run on a PC or laptop. The myDAQ™ board website [21] provides its users with a curriculum resource section where they can download course materials and laboratory experiments in circuits, signals and systems, and mechanical areas.

Digilent's Electronics Explorer™ laboratory kit is the latest product on the market [22]. Although the price is twice as the myDAQ™ board, and the Mobile Studio IOBoard™, it provides users with additional functionalities and features that are not available in both boards. The high price (\$300 to \$500), and the large size (8in x 7in) take the Electronics Explorer™ out of the range of being a portable student lab kit. It however can serve as an excellent small size and cost effective laboratory equipment that can be used to teach various types of analog and digital ECE laboratory experiments. It will be a very attractive ECE laboratory equipment for US and international engineering schools that want to provide their students with cost effective laboratory teaching equipment. The Digilent Electronics Explorer™ website provides its users with a comprehensive set of educational materials and videos called "Real Analog" that can be used in introductory analog electrical circuit classes. The educational materials are divided into 11 modules. Each module includes written and videotaped lectures, solved problems, homework assignments, and one laboratory assignment. Figure

The Mobile Studio IOBoard™, the myDAQ™ board, and Electronics Explorer™ laboratory kit, are all portable devices that allow students to design, build, and test analog and digital laboratory experiments anytime, anywhere outside of the typical ECE laboratory. Agilent's X-Series Oscilloscope, on the other hand, is an instrument that serves a different purpose. It cannot be used as a portable laboratory kit, although it is very light (around 11 lbs), that all students will purchase and use anytime and anywhere. However, it is by far the most cost effective and efficient analog instrumentation device currently available on the market for any ECE or other department that is looking to replace or upgrade its aging laboratory equipment. It shows that Agilent has pushed the envelope in analog/digital instrumentation when you consider that you can get three instruments in one: a 70Mhz oscilloscope, with a built-in logic analyzer, and 20 Mhz function generator for less than \$1,000. Other attractive features of the X-Series Oscilloscopes are that the bandwidth, digital channels, and waveform generators can be upgraded at a later time by simply downloading software keys.

One additional feature of the X-Series Oscilloscopes that attracted us is the availability of the LAN modules that allow students to access the instruments remotely from any location that has access to the internet. This opens up the door for ECE departments and other technical schools that want to teach and train their students from a remote location. Although students that conduct ECE laboratory experiments from a remote location using the X-Series Oscilloscopes do not get the chance to physically touch the equipment, they get the benefit of utilizing and learning the different features of the equipment remotely. We ran some test experiments where two students enrolled in the online version of the Electric Circuits and Electric Circuits laboratory courses were asked to conduct two experiments remotely using the X-Series Oscilloscopes. The students were then asked to come to the face-to-face class room and conduct new experiments using the same X-Series Oscilloscopes. The students were able to quickly figure out the different features of the laboratory instrument based on their experience from the use of the same equipment from a remote location. We plan to conduct additional experiments with more students to make sure that our approach can easily be scaled up to more users. We also intend to design laboratory experiments that can be remotely conducted by multiple students in different locations using the same oscilloscope. This implies that online students will be able to work in "virtual teams" and collaborate on the same laboratory experiments the same way face to face students currently do in their laboratory courses.

Table III.
Comparison of ECE Laboratory Measurement Instruments [20][21][22]

ECE Laboratory Instrument	Main Features	Price
Mobile Studio IOBoards™ by RPI	<ul style="list-style-type: none"> • 32bit, 200MHz Blackfin processor with 128K of memory • 2-channel, 1.5 MSPS per channel, 12-bit ADC (Scope/Spectrum Analyzer) • 2 14-bit, 1.4 MSPS per channel DACs (Function Generation/Arbitrary Wave Generation) • USB 2.0 High-Speed (480Mbps) • 16-channels of digital (3.3V) I/O • 2 dedicated Pulse-Width Modulation (PWM) channels • Expanded input voltage range • 250kSPS Impedance Analyzer • 2.5GHz, 1Mbps Wireless Transceiver 	\$150
MyDAQ™ by National Instrument (NI)	<ul style="list-style-type: none"> • Two Differential Analog Input and Analog Output Channels (200 ks/s, 16 bit, +/- 10 Volts) • +5 , +15, and -15 Volt Power Supply Outputs (up to 500m Watts of Power) • Eight Digital Input and Digital Output Lines (3.3 Volt TTL-Compatible) • 60 Volt Digital Multimeter (DMM) for Measuring Voltage, Current, and Resistance • Reusable Storage Box with Storage Tray, DMM Probes, and Audio Cable 	\$199- \$300
“Electronics Explorer™” by Digilent	<ul style="list-style-type: none"> • 4-channel, 40MSa Oscilloscope • 4-channel voltmeter • 2 programmable reference voltages • 2-channel Arbitrary Waveform Generator • Triple-Output Power Supply (two programmable) • 32-Channel Logic Analyzer • 32-Channel Pattern Generator • Discrete digital I/O’s (buttons, switches, LEDs, etc) 	\$300- \$400
70 Mhz X-Series Oscilloscopes by Agilent	<ul style="list-style-type: none"> • Screen: 8.5-inch WVGA display • Update rate of 50,000 waveforms per second • Memory: 100 kpts • Integrated logic analyzer (MSO, Optional and upgradable with DSOX2MSO) • 20-MHz function generator (WaveGen) • Upgradability: add bandwidth, digital channels, or WaveGen after purchase • Segmented memory • Mask Testing 	\$750- \$1K

Summary and Conclusion

We have learned from the experiences of our online courses that have been piloted during the Spring 2011 and Fall 2011 semesters. We have also taken additional steps to improve current and future online ECE courses offered at our institution by developing several additional training and teaching materials that clearly explain how to use the Mobile Studio IOBoards™ and the Agilent X-Series Oscilloscopes to future online students. All the laboratory experiments that were given to the students enrolled in the pilot online courses have been updated and improved during the Spring 2011 and Fall 2011 semesters. Although we conducted the online laboratory experiments using the Agilent instrumentation using only two students in the Fall 2011 semester, we plan to offer the new labs to additional online students during the Spring 2012 semester. One of the key research questions that we plan to answer during the Spring 2012 and Fall 2012 semesters is to evaluate whether students will be able to transition smoothly from using the Agilent X-Series Oscilloscopes remotely to using them in the F2F classroom based only on their experience and the instructions given in the online course. We also plan to design laboratory experiments that can remotely be conducted by multiple students from multiple locations using the same oscilloscope. We plan to use video conferencing software such as Adobe Connect to facilitate the collaboration between the students. If this is successful, it implies that we will be able to replicate the discussion and collaboration that occurs when two or more students complete a laboratory experiment in the F2F course. Note that although we conducted all of our experiments using the Agilent X-Series Oscilloscopes, we are sure that the same experiments can be conducted with other types of oscilloscopes as long as they have the remote LAN access built in. We also plan to evaluate other portable ECE laboratory kits such as the Digilent “Electronics Explorer™,” and National Instrument (NI) myDAQ™ boards to evaluate their performances and compare them to the Mobile Studio IOBoards™.

Although both the Mobile Studio IOBoards™, the Agilent X-Series Oscilloscopes technology, and the Adobe Connect™ software have previously been used separately by other institutions for similar applications, to the best of our knowledge no other higher education institution in the United States has combined the three technologies to offer ECE undergraduate courses completely online. This new approach represents a major paradigm shift in the way higher education institutions should think when delivering Electrical Engineering education. We hope that it will open the door to many students who are candidates for joining the science, technology, engineering and mathematics workforce such as, current and new personnel relocating to new military bases, mid-career employees, and ex-military personnel because they typically require the opportunity to continue to earn a living while pursuing their education and are most often unable to relocate to college campuses for the two to three years required to complete the requisite courses for a Bachelor’s degree. Online education is here to stay, therefore we hope that engineering schools nationwide can follow the path set by the other disciplines [6].

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