# ENHANCING ELECTRICAL ENGINEERING EDUCATION USING ONSITE, VIRTUAL AND REMOTE LABORATORIES

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## Abstract

Limited financial resources for the acquisition of new laboratory hardware continue to marginalize the quality of electrical engineering education. However, the complementary use of onsite, remote, and virtual laboratories can be used to help overcome this trend. There is a variety of ways to integrate these three types of lab experiences into the curriculum. For fulltime, on-campus students, remote and virtual labs can be used as supplemental work to the onsite labs. Virtual and remote labs are especially useful for "predict and measure" experiments that focus on analytical learning. Onsite labs can continue to dwell on design and troubleshooting-oriented exercises. Remote labs can also be used to increase access to one-of-a-kind equipment among a group of students. This is especially true in upper-term courses where the quantity of advanced test equipment restricts availability. There are also opportunities to form collaborative arrangements with other institutions in which remote labs can be shared.


## Introduction

The use of software-based test and measurement tools in engineering education has increased substantially, in part due to the rapid development of low-cost, high-speed computers. The acquisition and ongoing costs of modeling and simulation tools is much less than that of hardware and yet can provide a valuable learning experience. Consequently, universities with science and engineering programs are incorporating more software-based tools in both teaching and research laboratories. Science and engineering courses typically involve students performing practical experiments and assignments in laboratories as part of their knowledge and skills development. This is essential in reinforcing the theories learned in lectures and in providing a means to foster independent thinking. Knowledge and skills development also bring the course theory alive so students can see how unexpected events and natural phenomena affect real-world measurements and control algorithms.

Equipping a traditional electrical engineering laboratory is a major expense, and maintenance (both break-fix and calibration) is an ongoing expense. Qualified instructors are needed to manage the laboratory, oversee students, and grade their work. The laboratories are available only when equipment and instructors are both available. These resource limitations are an impediment to achieving more efficient use of the space and equipment. Limited financial resources to support traditional hardware-oriented laboratories continue to marginalize the quality of engineering education. in this paper, the authors discuss the use of onsite, remote, and virtual laboratories as complementary tools to reduce cost, increase access, and, thereby, promote learning.

Combining the onsite laboratory experience with remote and virtual work allows educators to enhance the quality of engineering education. The approach is not to replace the onsite laboratory experience, but rather to supplement it with a system that provides greater access to many of the same experiments. The focus should be on integrating a constellation of onsite, remote, and virtual laboratory resources so that students receive good, hands-on experience. The National Instruments (NI) ELVIS (Electronics Laboratory Virtual Instrumentation Suite) platform, along with its various plug-in modules, can support experimentation across a wide variety of science and engineering topics. The authors have successfully implemented this approach for a combination of all three types of labs [1].

## Onsite Lab Experience

The NI-ELVIS platform provides an economical solution to equip electronic laboratories for onsite courses. It allows users to run experiments nearly identical to the ones that they now perform with hardware-based equipment. It is less expensive to outfit multiple lab stations with this platform than with traditional dedicated test and measurement equipment. Such tools as variable DC power supplies, digital multimeters, oscilloscopes, and waveform generators appear as virtual instruments displayed on a computer screen with knobs, readouts, and controls similar to their hardware counterparts. Each lab station then consists of a personal computer, an NI-ELVIS base unit and at least one plug-in board to support a specific set of experiments. The most often-used NI-ELVIS built-in instruments are: function generator, digital multimeter (DMM), oscilloscope, and variable DC power supply. The NI ELVIS platform is flexible enough to teach analog and digital circuit fundamentals, instrumentation, control systems, and wired/wireless communications techniques.

The authors have evolved the electrical laboratory to be a blend of traditional measurement equipment and virtual instruments. Dedicated test and measurement equipment are primarily used in the 1st and 2nd year of the four-year program; however, in the 3rd and 4th years, several courses in communications and instrumentation now employ the virtual instruments within the NI-ELVIS platform. After several semesters, the authors' experience with integrating NI-ELVIS into their lab sections has been positive. Students are first introduced to the platform with two introductory experiments that give them exposure to the virtual instrument panel. Initially, the oscilloscope and waveform generator configurations are employed to make measurements on hardware devices under test (DUT). Later, other virtual instruments are introduced so that students get experience on them as well. Placing jumpers and cables on the plug-in board is a convenient and easy way to set up a DUT. Each experiment contains a connection diagram that illustrates how this should be done. Data is collected from the virtual readouts in much the same way as with traditional instruments.

The student experience with the NI ELVIS setup was measured using a survey in a third-year RF communications class [2]. The results showed that students were highly supportive and described it as a positive process. A number of elements contributed to the positive, hands-on experience of our students. For example, they were able to quickly create a wide range of test configurations with minimal time required to wire and troubleshoot the DUT. The Help resource for the virtual instruments is well-written and enables students to understand how to modify settings and obtain accurate data. Furthermore, the detachable breadboard allows project work to be carried out independent of the base unit itself. NI-ELVIS, coupled with other tools such as Multisim and LabVIEW™, provides an inexpensive yet powerful teaching platform.

# Virtual Lab Experience

NI's Multisim circuit simulation environment shown in Figure 1 can also be used as a virtual lab to supplement its onsite counterpart. Multisim offers a user-friendly experience, especially for students who are new to circuit simulation software. New users do not need to work with SPICE (Simulation Program with Integrated Circuit Emphasis) syntax and commands, while advanced users have access to all SPICE details. Multisim has a wide range of components and models to teach analog, digital, and microcontroller concepts. It also provides special components known as interactive parts, which can be modified while a simulation is running. Interactive parts such as switches and potentiometers will immediately and accurately affect the results of the simulation. This is useful to explore 'what-if' scenarios and to observe how a change in a circuit can affect its behavior.

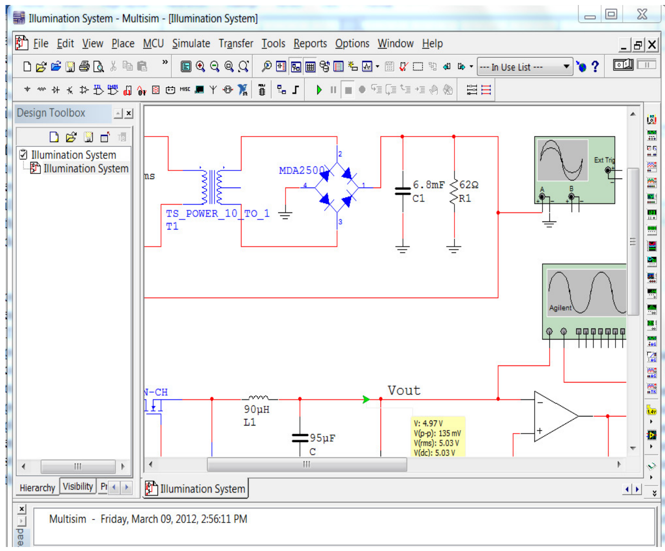


**Figure 1. Multisim Circuit Environment**

When the need arises for more advanced analysis, Multisim delivers over fifteen sophisticated analyses. Some examples include sinusoidal steady-state, transient, and frequency spectrum analyses. In addition to traditional SPICE analyses, Multisim allows users to intuitively connect virtual instruments to schematics. These virtual measurement instruments can be used to interactively measure the response of circuits that behave like their real-world equivalents as the user sets, changes, and reads the outputs.

Virtual instrumentation can be used to help institutions overcome the resource limitations of onsite laboratory space and hardware. One of the approaches in this study was to allow students to connect to onsite equipment and pre-staged experiments remotely over the Internet. In cases where space and facilities are limited, access was expanded.

# Remote Lab Experience

Remote laboratories are a way to allow laboratory equipment to be accessed by students from a distance using the Internet. Some exciting applications can be easily done using NI-ELVIS. Experiments can be made available 24 hours a day, 7 days a week, and students can perform experiments from their campus residence or home. This approach also enables research teams to make expensive equipment available to others, enabling institutions to get more use from its current equipment base and to meet demand without necessarily purchasing more.

A significant hurdle lies in providing a requisite substitute for the traditional onsite experience. Early work on remote delivery of experiments appeared in 1998 with Esche & Chassapis [3]. It was followed in 2000 with a report by Gurocak [4]. A distance platform that supplements the hands-on experience was developed and pilot tested at the University of Hartford in 2004 [5], [6]. The system allows users to control test and measurement equipment remotely and, thereby, run the same experiments normally performed by coming to the lab.

Sharing a remote laboratory platform between students in different courses, sections, and perhaps across institutions, requires detailed planning across several fronts. Two types of management approaches are possible; however, both require a high degree of pre-planning with minimal change during the semester. As shown in Table 1, the first approach is called ‘synchronous’ in which all students perform the same set of experiments on the same weekly schedule. The advantage is that the set-up and take-down for each experiment need only be done once. The main issue is ensuring sufficient access for a given population of users and time period to get the work done. The second approach, called ‘asynchronous’, is the most flexible; however, it requires weekly coordination to ensure that the relevant experiments are made ready. This approach works only if an onsite technician with sufficient time to focus on DUT set-up and take-down is available.

**Table 1. Approaches to Course Collaboration**

| Approach | Advantage | Disadvantage |
|---|---|---|
| Synchronous | Minimal setup and take down required | Experiments and timing must overlap |
| Asynchronous | Experiments and timing are flexible | Help needed for frequent DUT change |

For a truly effective remote lab, there is no commercially available solution that offers a comprehensive suite of management and learning tools, e.g., video conferencing/ chatting, remote hardware configuration, simulation software, and downloadable lecture/lab materials. There is a need to develop a more complete and fully integrated distance learning environment that offers sharing and collaboration options between and among institutions [7]. An Integrated Virtual Learning Platform (IVLP) was developed and reported in 2010 to address this need [8]. An interesting advantage of IVLP is that it employs a simple architecture based solely on LabVIEW™.

LabVIEW™ can be used to programmatically control hardware in the base unit, enabling, for instance, automated signal acquisition and generation. NI-ELVIS instruments can be opened inside the Multisim environment to analyze both simulated and real signals. Students can compare expected results using simulations with actual values from physical devices promoting an understanding of the difference between theory and practice.

The NI-ELVIS workstation can be reconfigured for various electronic laboratories by choosing different plug-in modules. Plug-in modules are available for controls, communications, electronics, fiber optics, digital logic, and other topics. The eTCB (electronics Training Circuit Board) is one example from Delmar Cengage Learning. This unit supports DC and AC circuit analysis for design and analysis topics. For advanced courses, Emona Instruments has developed the DATEx and FOTEx boards as plug-ins. Figure 2 is a picture of the Emona DATEx-ELVIS setup used in radio frequency (RF) and data communications. Figure 3 shows the Emona FOTEx-ELVIS used for fiber-optic communications.


**Figure 2. DATEx-ELVIS Setup**

## Remote Lab Experiment

This experiment demonstrates the use of the Emona FOTEx board to transmit two discrete message signals along an optical fiber in the same direction using WDM. At the receiver end there is filtering in order to recover just one of the messages. Figure 4 presents a block diagram for the

WDM experiment, while figure 5 presents the actual connections on the FOTEx board [9].

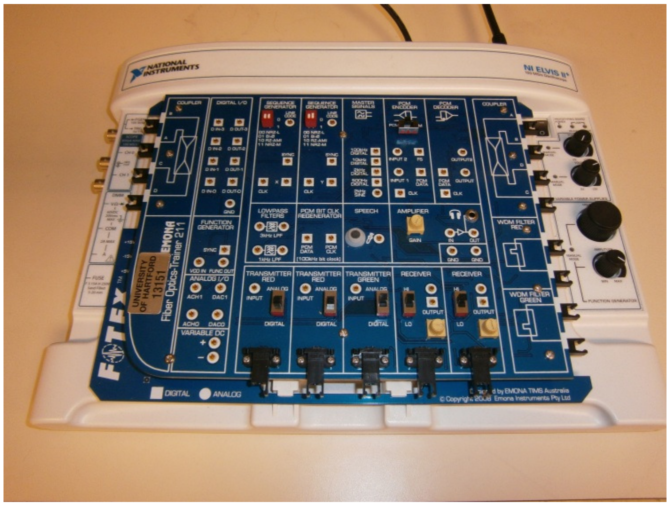

**Figure 3. FOTEx-ELVIS Setup**

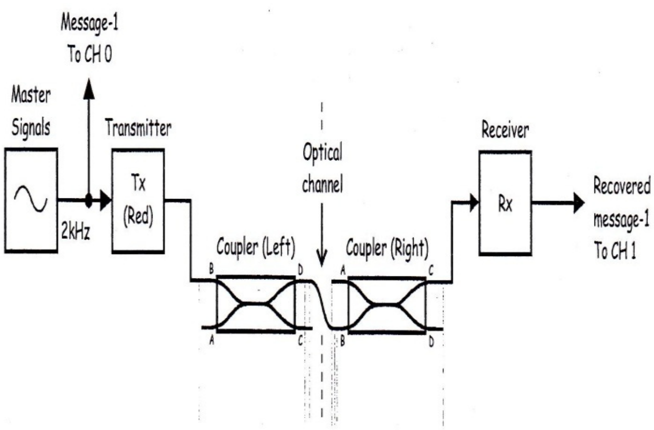


**Figure 4. WDM Experiment Block Diagram**

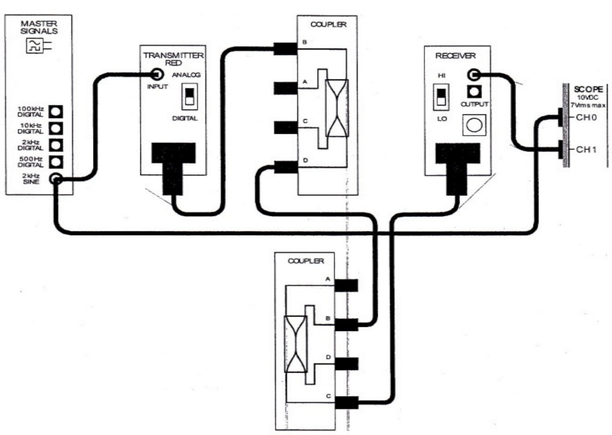


**Figure 5. WDM Experiment Setup**

The setup is a single-channel transmission system. The master signal module's 2kHz sine output is used to model an analog message. Coupler modules are used to facilitate the remainder of the experiment remotely. Then set the NI ELVIS II oscilloscope VI as follow:

- Timebase control is 100us/div.
- Channel 1 is activated. Recovered message observed is given in Figure 6.

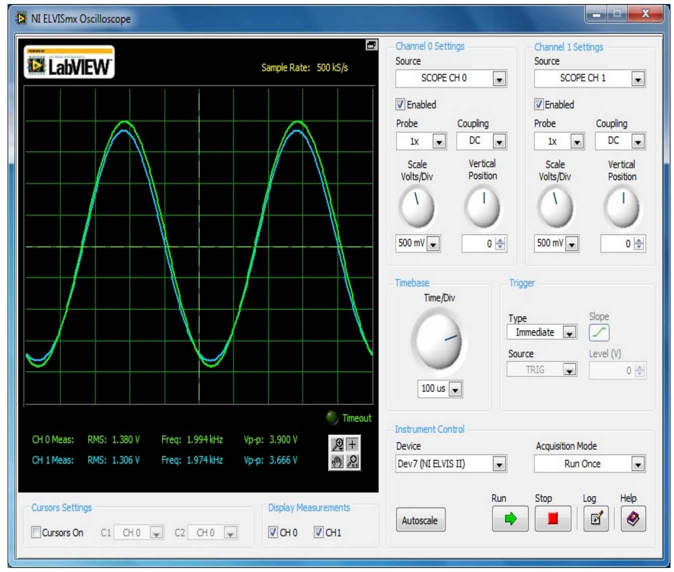


**Figure 6. WDM Experiment Set-up**

Then, send the two signals over the channel – an analog and a digital message (modeled by the master signal module's 10kHz Digital Output). The result of the WDM operation can be observed on the oscilloscope virtual instrument, as given in Figure 7. The set-up used for this experiment enabled students to use LABVIEW capabilities for data calculations.

# Students Experience Using Remotely Controlled Test Environment

Two surveys were conducted to get student feedback about the use of the FOTEx communication trainer set-ups in the lab. The following questions about their experience in using the FOTEx-ELVIS II setup in a Fiber-Optic Communications course were used for the survey:

1- Do you feel comfortable using this setup?
2- Were the setup experiments clearly written?
3- Were the experimental procedures easy to follow?
4- Did the use of the setup increase your interest in the labs?

5- Did you have difficulties in configuring the FOTEx -ELVIS setup software?
6- Did you have difficulties in configuring the FOTEx -ELVIS setup hardware?
7- Did you experience difficulties in performing any Fiber -Optic Communications experiment?
8- Was the lab setup very valuable in terms of learning?
9- Overall, do you support the use of the FOTEx -ELVIS setup in this course?

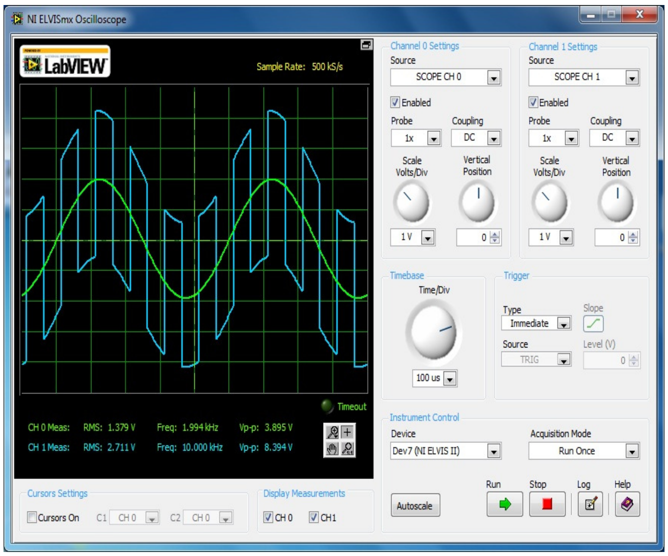


**Figure 7. WDM Output**

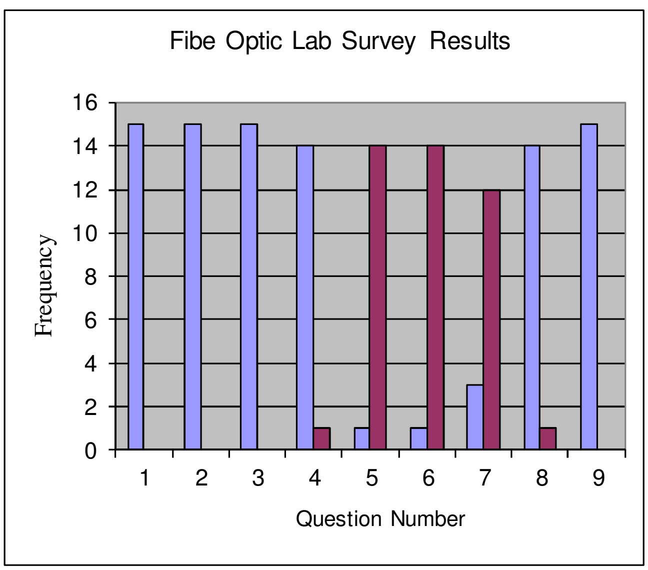


**Figure 8. Fiber Optic Communications Survey Results**

The survey included 15 students enrolled in a graduate fiber-optic communications engineering course, and the results of the survey are illustrated in Figure 8, where the blue (light) bar represents a YES answer and the red (dark) bar represent a NO answer. The X-axis represents the question number, and the Y-axis represents the frequency of each answer. As given in the graph, there is a total agreement among all students that they feel comfortable using the FOTEx-ELVIS setup and that FOTEx -ELVIS setup experiments were clearly written. Also, all students surveyed support the use of the FOTEx -ELVIS setup. The results of this survey also show that this setup is user friendly and has a fast learning curve. The next step is to implement the use of this set-up with an optical switch matrix and use the set-up in a collaborative distance learning environment.

## Conclusion

Institutions that offer science and engineering programs continue to be under pressure to do more with less. Limited resources for equipment and instructors make a blended architecture of virtual and remote labs an attractive way of supplementing onsite labs. Remote access to experimental setups expands the window of equipment availability and opens the possibility of collaboration across other campuses and schools. To date, there is no commercially available management system that meets the needs for remote lab operation. A course management system integrated with LabVIEW™ would appear to be the most effective. Otherwise, institutions will continue to rely on proprietary or other work-around solutions.

On the positive side, the combination of LabVIEW™, Multisim, and NI-ELVIS is a useful way to mesh theory and practice. Students develop a firm grasp of the principles of electronic devices, circuits, and systems using a blend of onsite, virtual, and remote labs.

## References


[1] Abu-aisheh, A., & Eppes, T. (2010). Remote and Virtual Instrumentation Platform for distance Learning. *International Journal of On-line Engineering*, *6* (2), pp. 4-7.

[2] Abu-aisheh, A., Eppes, T., & Al-Zoubi, A. (2010). Implementations of a Virtual RF and Digital Communications Laboratory for E-Learning. *IEEE Educational Conference (EDUCON2010).* Madrid, Spain.

[3] Esche, S. K., & Chassapis, C. (1998). An Internet-Based Remote Access Approach to Undergraduate Laboratory Education. *Proceedings of the 1998 Fall Regional Conference of the Middle Atlantic Section of ASEE.*

[4] Gurocak, H. (2000). Initial Steps Towards Distance Delivery of a Manufacturing Automation Laboratory Course by Combining the Internet and an Interactive TV System. *Proceedings of the ASEE National Conference & Exposition*, Session 2663.

[5] Eppes, T., & Schuyler, P. (2005). Pilot Test Results of a New Distance Laboratory Platform. *Proceedings of the ASEE National Conference & Exposition*, Session 2550.

[6] Eppes, T., & Schuyler, P. (2004). A Robust and Scalable Distance Laboratory Platform. *Proceedings of the ASEE National Conference & Exposition*, Session 2426.

[7] Abu-aisheh, A., Eppes, T., Hasan, O., & Al-Zoubi, A. (2011). Remote Laboratory Collaboration Plan in Communications Engineering. *IEEE Educational Conference (EDUCON2011)*. Amman, Jordan.

[8] Abu-aisheh A., & Farahmand, F., (2010). LabVIEW™-based Integrated Virtual Learning Platform. *10th IEEE International Conference on Advanced Learning Technologies*, Sousse, Tunisia.

[9] Laboratory manual for the Multi-experiment Single Board Fiber Optics Trainer for NI ELVIS™. Retrieved on April 20, 2012, from http://www.tims.com.au/emona-fiber-optics-trainer-ett-211 extracted April 2,

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