Web-Based Real Electronics Laboratories

Yolanda Guran-Postlethwaite, David N. Pocock, and David Dutton

Electronics Engineering Technology
Oregon Institute of Technology

I. Introduction and Background

In recent years, numerous institutions of higher education in the United States and abroad have started to offer Web-based courses and complete degree programs on the Internet. In this context, the Internet continues to demonstrate its versatility and effectiveness as a tool for curriculum delivery. As stated by Plaisent, institutions of higher education will increasingly rely on various forms of web-based delivery in order to survive in the 21st century. This is due, in part, to the fact that there has been substantial research dealing with distance education, and the findings prove conclusively that distance learning is as good as traditional education. Numerous published assessment studies comparing web-based vs. classroom-based instruction have concluded that e-learning courses compare favorably with classroom-based instruction and enjoy high student satisfaction [1].

Despite the widespread use of the Internet as a conduit for content-based curriculum delivery, the availability of engineering laboratory courses remains moderate, and effective distance delivery of engineering laboratory courses remains a challenging problem to be solved [2]. Currently, there are very few engineering laboratory courses being offered online [2-12].

In the specific discipline of electrical and electronics engineering, one approach for delivering electronics laboratories on the Internet has been to use simulation software with virtual instruments such as MultiSim to conduct the experiments. Hall conducted several assessment studies comparing students who performed the labs using Electronics Workbench vs. students who completed the lab course in the hardware lab and found that there were no statistical or practical differences between the two groups [2]. Campbell conducted a similar study [3]. The results of his study showed that students who completed the courses using labs based on simulation software performed as well as those who completed the physical labs on a final test conducted on the physical lab. Specifically, he found no statistical significant difference between the groups in the time required to complete a physical lab at the conclusion of the course. The simulation software approach is especially well suited for working professionals such as engineering technicians who are completing an engineering degree. These professionals are often already well trained using electronics test equipment such as oscilloscopes, function generators, power supplies and digital multimeters, and don't need further instruction using these devices.

Another approach has been to develop courses that combine the use of simulation software and a personal lab kit to conduct the experiments. A personal lab kit that includes all the required lab functions necessary to perform electronics circuit design and test (i.e. DC supplies, signal generators, oscilloscope) may be built on a board to plug directly into the PC at a relatively low-cost (less than $200). This solution may be more adequate for students without prior lab experience (e.g. freshman students taking DC and AC circuit analysis courses).

A third possible solution is to develop web-based labs using virtual instruments connected to real test equipment and real devices. In this scenario, the instructor, lab technician, or on-campus lab partner must set-up the circuit or device under test on-campus and connect it to the test equipment. The remote student can then use the web interface to take all the required measurements and perform the lab online. This solution can be used in combination with any of the previously described approaches. For instance, a student can use the online virtual instruments to characterize a specific electronic device (e.g. op-amp, diode, FET, MOSFET, and BJT), model the real device based on the characterization, perform simulations using the modeled device, and complete the experiment using their personal lab kit.

At Oregon Institute of Technology (OIT) we have been developing a web-based laboratory sequence in the Electronics Engineering Technology (EET) Department. The EET Department at OIT is taking steps to increase access to engineering education for working professionals interested in completing their B.S. degree in EET. In this paper we present our approach for distance delivery of an introductory electronics lab course on amplifiers and semiconductor devices.

In our sophomore-level analog electronics classes at Oregon Institute of Technology, every lecture class has a required commensurate laboratory class. Students are required to do hand calculations, computer simulations, and experimental measurements on a variety of electronic circuits involving semiconductor components, and compare results. Each student has a lab kit consisting of a variety of electronic components and a proto-board, and they are required to assemble and interconnect the components on their proto-boards to perform some specified electronic function. They are then requested to make a variety of experimental measurements on the circuit that they have built. While in the electronics laboratories, students have access to such instruments as DC power supplies, function generators, digital multi-meters (DMM's) dual-channel oscilloscopes, and curve tracers. We tried to design the web-based laboratory experiments as close as possible to the in-class experience.

II. System Description

II.A Hardware Description

Five hardware systems were purchased and installed, four on the main campus in Klamath Falls and one at the OIT satellite campus in Portland.

The following criteria were used in the design of the web-based laboratories:

1. The circuits must use the same real devices as in the classroom laboratories.
2. Students are required to select and interconnect components to form a correctly wired electronic circuit.
3. Virtual instruments corresponding with those used in the classroom laboratories are used (e.g. virtual function generator, oscilloscope, DMM, and curve tracers).
4. All DC power supplies are hard-wired and not under the control of the students.
5. Any student regardless of location has access to any one of the five systems.

We decided to not allow the student to wire the DC power supplies over the web directly, mainly because of the potential to impact the system. Since real devices-under-test (DUT's) are used, there exists some possibility of students incorrectly wiring the DC power supplies. Reversal of polarities, for example, could cause the DUT to fail and become unusable for other students.

Because of its extensive use in industry, we decided to use National Instruments hardware for the web-based labs. The major components of one such system are listed in Table 1, and a photograph of one set of the hardware is shown in Figure 1.The total cost of the National Instruments hardware for the five systems was a little over $47,000.00, which was paid for by a grant from Intel Corporation.

Table 1. Web-Based Lab Hardware Per Station

QUANTITY	NI PART #	FUNCTION	COMMENTS
2	SCXI-1130	High-density multi-configuration switch matrix	256 micro-switches each configurable in a row x column matrix.
2	SCXI-1378	Terminal block to configure switch matrix as a 4 x 64	Provides for a total of 512 micro-switches configured in an 8 row x 64-column matrix.
1	PCI-4070E	Digital multimeter, isolated digitizer, and matrix controller	Used to control switches in switch matrix. Plugs into PCI slot on PC.
1	PCI-6070	Data Acquisition (DAQ) card	Used to generate the function generator, oscilloscope, and curve-tracer virtual instruments. Plugs into PCI slot on PC.
1	BNC-2120	Input/Output connector block	Used to patch inputs and outputs between the DAQ card and the DUT via BNC cables.
1	SCXI-1000	4-slot chassis	Used to house, power, and control the switch matrixes and terminal blocks.
1		Dedicated PC with keyboard and monitor.	Contains LabVIEW software to control hardware.
1		DUT experiment printed	Custom PCB used to mount DUT

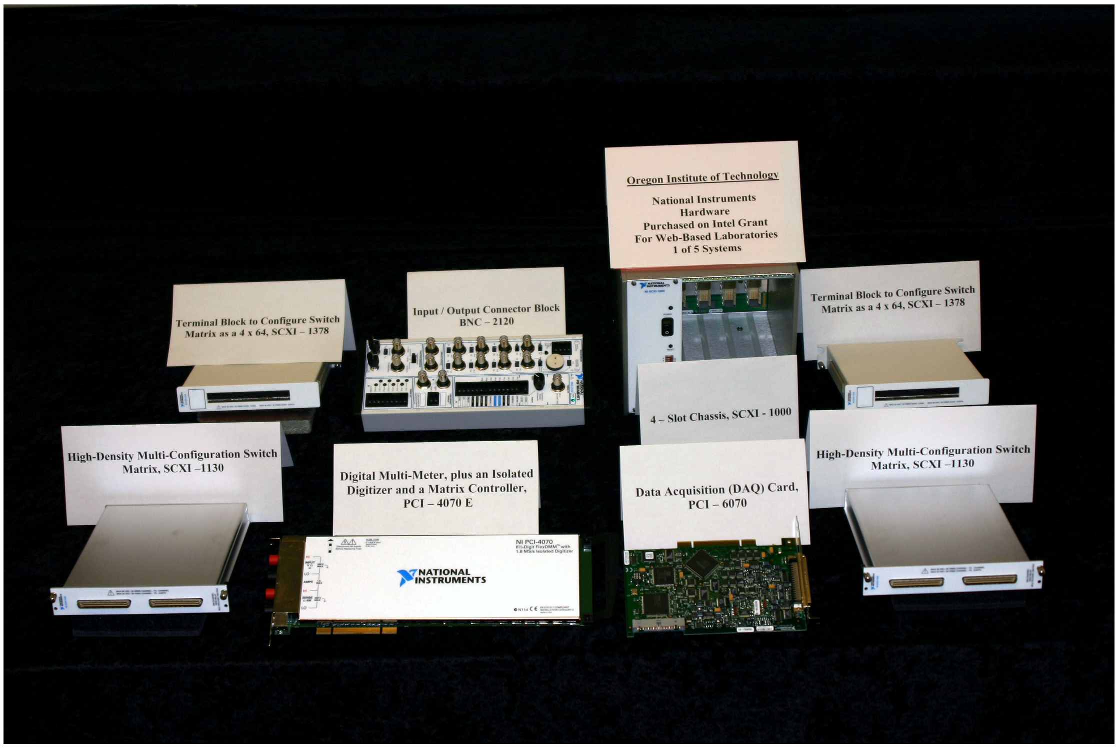


Figure 1. Hardware Components for Web-Based Labs. (Desktop Pc and DUT printed circuit board not shown.)

The core of each system is the switch matrix and the terminal block that configures the 512 micro-switches into an 8 row by 64-column format. The opening and closing of these switches is triggered by the matrix controller, which is controlled by the LabVIEW software running on the dedicated personal computer. All 64 columns of the switch matrix are connected through ribbon cables to a custom PCB containing the DUT and electronic components such as resistors and capacitors required for a particular experiment. It is convenient to conceptually think of the "columns" as connections to the individual leads of a particular electronic component, and the "rows" as circuit nodes where two or more components are electrically connected. For instance, consider the schematic diagram shown in Figure 2. Resistor R_S is hard-wired to columns 4 and 5, resistor R_F to columns 6 and 7, the op-amp to columns 8, 9 and 10, etc. Referring to Figure 2, the student wires the circuit by closing the following matrix switches under computer control:

Node 1:	(R1, C1),	(R1, C2),	(R1, C9)
Node 2:	(R2, C3).	(R2, C4),	
Node 3:	(R3, C5),	(R3, C6),	(R3, C8)
Node 4:	(R4, C7),	(R4, C10)	

Note that this simple circuit (Figure2) requires four of the available eight rows and 10 of the available 64 columns. Furthermore, two more columns are required to connect the dual-channel virtual oscilloscope to monitor the input and output voltage waveforms.

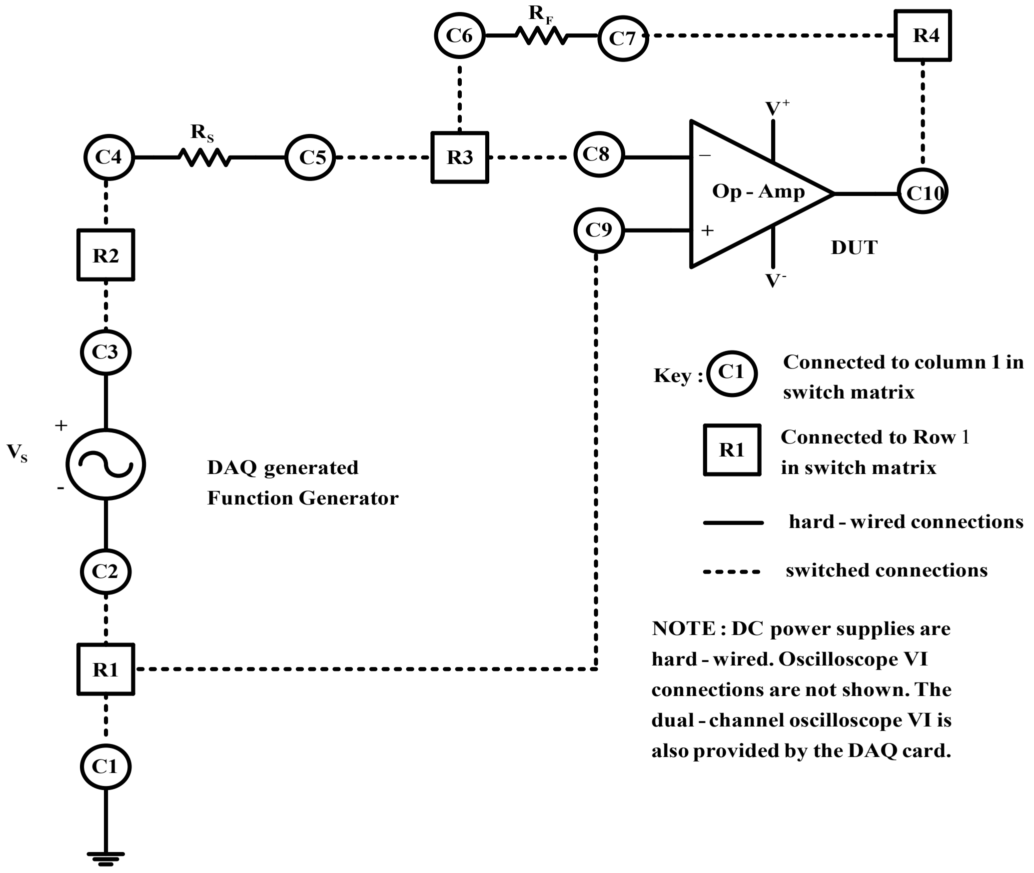


Figure 2. Row / Column Interconnect Scheme for Wiring a Circuit

II.B Software Development

We found that LabVIEW, as a graphical development software tool, is ideal for this project. Specifically, LabVIEW enables efficient development of interfaces for student control of virtual instruments because of the built-in web-publishing capabilities.

Throughout this paper, several references will be made to the two applications already developed and functional, "Operational Amplifier Lab" and "MOSFET Lab". These two applications vary in complexity. The safety precautions are also different. The Op-Amp lab is more complex than the MOSFET lab. Thus, it takes longer for the student to download the lab.

The Op-Amp lab has a feature allowing the user to see a schematic when the correct circuit is configured, enabling the student to visualize the circuit wired as a conventional schematic diagram. This capability is helpful for troubleshooting the wiring. Another important feature is to provide circuit protection at the software level. This involves analyzing the wiring connections made and checking for predetermined configurations that cause problems. This protection allows the Op-Amp to survive wiring errors throughout the learning process. These are useful features, but increase the time necessary to download the experiment over web. The MOSFET lab does not incorporate these features. As a consequence, the user can damage the device under test. In some cases this may require the device to be replaced. However, the download time for this lab is significantly shorter.

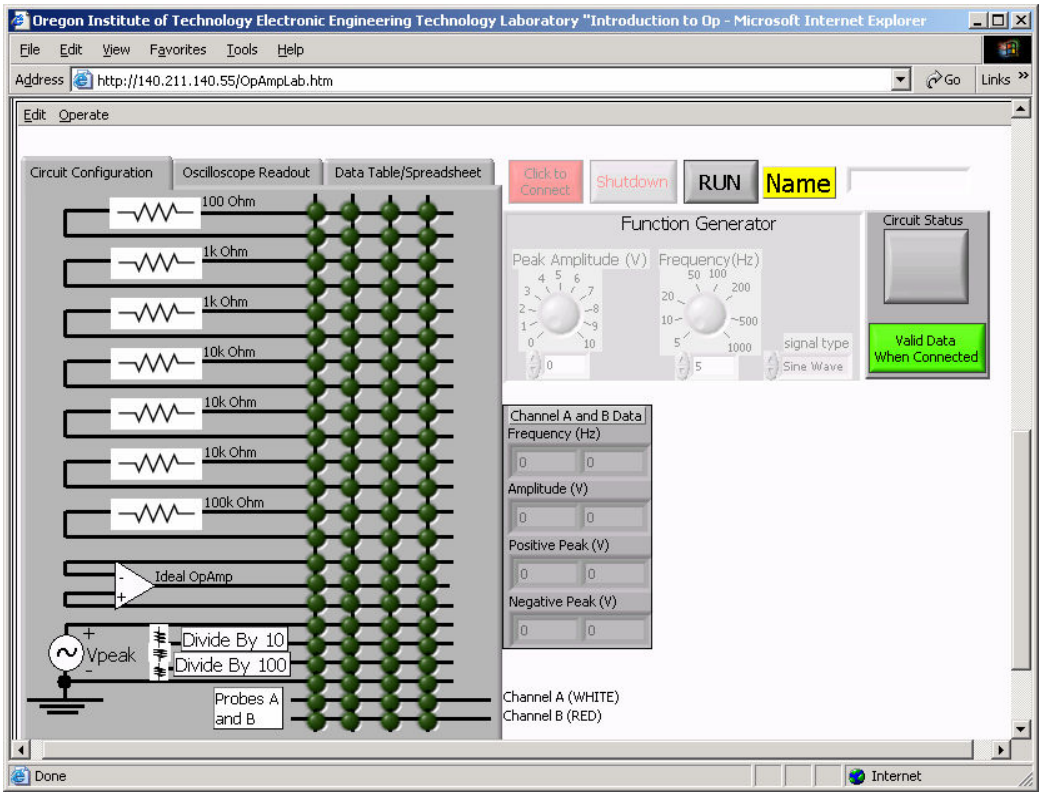
III. Web-Based Labs

Currently, two sophomore-level laboratory experiments are available to OIT electronics majors to be run remotely over the web - an operational amplifier (op-amp) lab, and a MOSFET lab.

The op-amp lab is an introductory experiment, treating an integrated circuit operational amplifier as an "ideal" op-amp. The student is expected to choose appropriate resistor values and wire the circuit to provide inverting and non-inverting voltage amplifiers with a wide range of voltage gains. The resultant closed-loop gains and input impedances are predicted using hand calculations, measured using the web-based lab, and computer simulated using PSPICE.

The MOSFET lab is an introductory experiment where the student is expected to measure the common-source output characteristics (drain current, $I_{D,}$ versus drain-to-source voltage, V_{DS}) as a function of the input voltage, V_{GS}, with the body-to-source equal to zero. The DUT is a CD4007 CMOS transistor array that contains three n-channel and three p-channel devices. In this lab the students are required to determine values for PSPICE parameters VTO (threshold voltage), KP (transconductance parameter) and LAMBDA (channel shortening parameter) from the real device. To implement this "curve tracer" function, the custom PCB for this experiment contains two DUT and a "virtual ground" using a transresistance amplifier with a gain of 1 volt/mA to convert the drain current of the MOSFET into a voltage that is then input to the DAQ card for the vertical axis (i.e. I_D) of the virtual curve tracer. This transresistance amplifier is transparent to the student.

The actual front-panel interfaces between the student and the web-based labs are shown in Figures 3 through 7. By selecting (i.e. "clicking on") the "LEDS" at the row/column intersections, the student can close or open that particular switch in the switch matrix, thereby configuring the desired circuit. Only one student can have control of the experiment at a time, but the results can be viewed by all students that are logged on to that web page at the time.



Address: http://140.211.140.55/OpAmpLab.htm

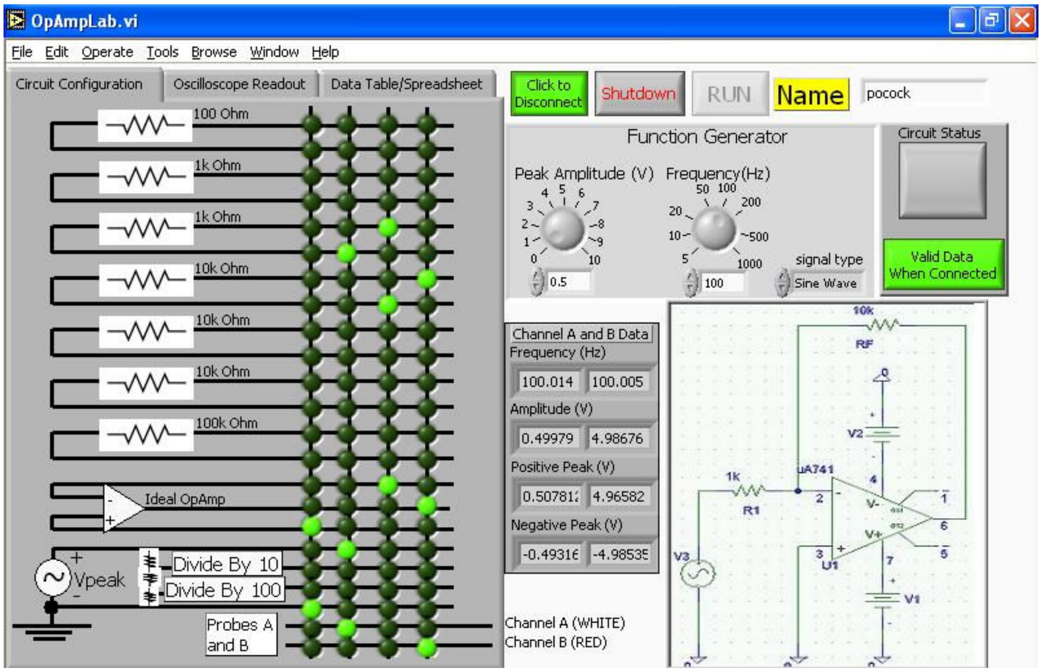
Peak Amplitude (V): 0

Frequency(Hz): 5

signal type: Sine Wave

Channel A and B Data		
Frequency (Hz)	0	0
Amplitude (V)	0	0
Positive Peak (V)	0	0
Negative Peak (V)	0	0

Figure 3. Front panel display for the operational amplifier lab as initially seen by student.



Name: pocock

Peak Amplitude (V): 0.5

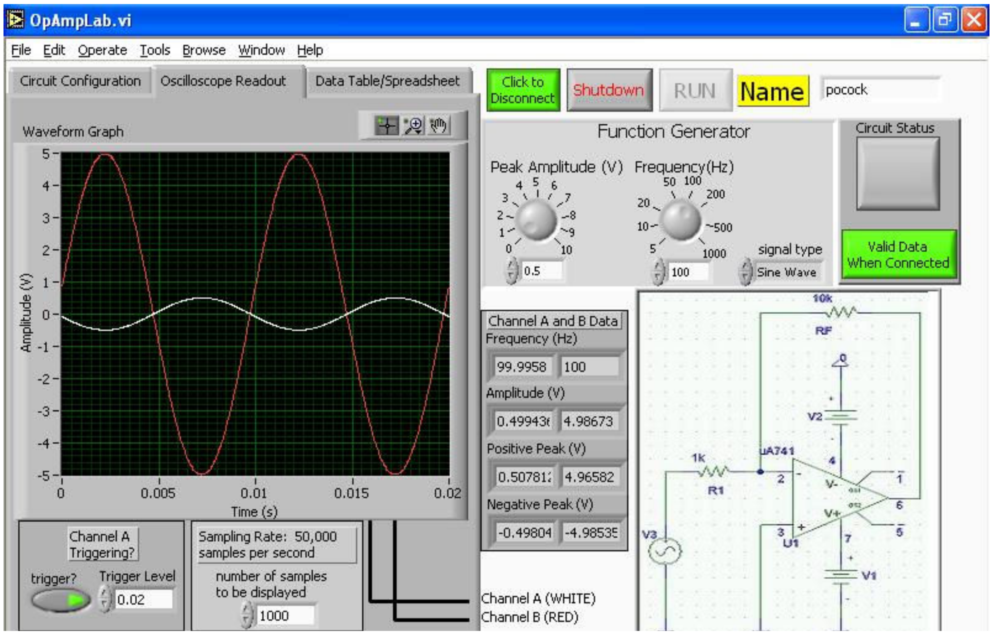
Frequency(Hz): 100

signal type: Sine Wave

Channel A and B Data		
Frequency (Hz)	100.014	100.005
Amplitude (V)	0.49979	4.98676
Positive Peak (V)	0.50781:	4.96582
Negative Peak (V)	-0.4931ε	-4.98535

Figure 4. Front panel showing correctly wired circuit. Highlighted "LED's" indicate student-selected closed switches.

"Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition Copyright © 2005, American Society for Engineering Education"



Name: pocock

Peak Amplitude (V): 0.5

Frequency(Hz): 100

signal type: Sine Wave

Channel A Triggering?

trigger?

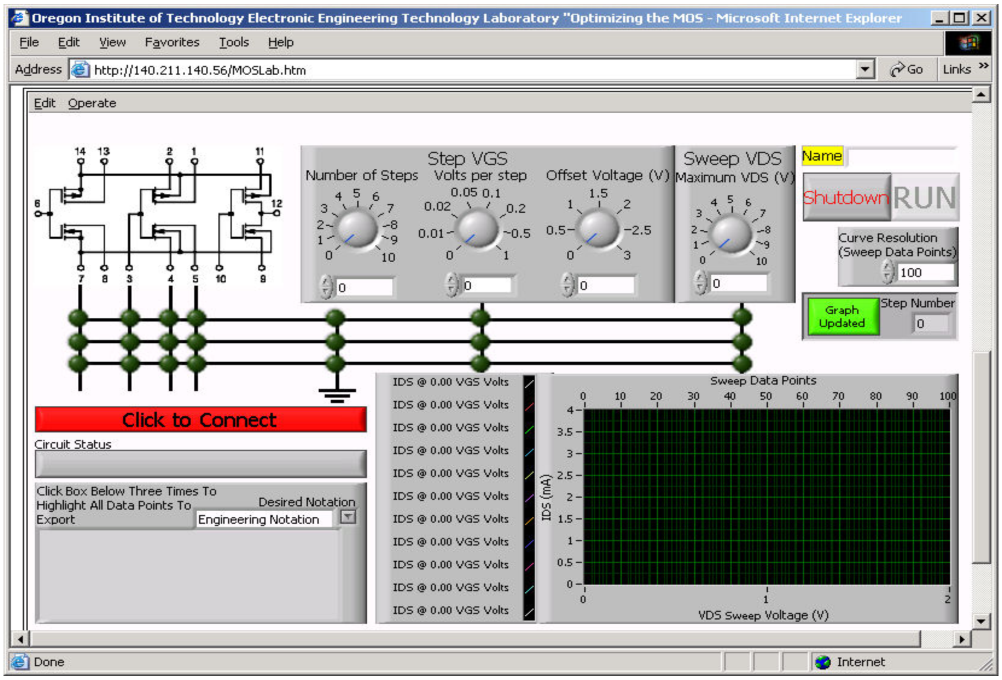
Trigger Level: 0.02

Sampling Rate: 50,000 samples per second

number of samples to be displayed: 1000

Channel A and B Data		
Frequency (Hz)	99.9958	100
Amplitude (V)	0.49943	4.98673
Positive Peak (V)	0.50781	4.96582
Negative Peak (V)	-0.49804	-4.98535

Figure 5. Front panel showing virtual oscilloscope waveforms of actual input and output voltages.



Address: http://140.211.140.56/MOSLab.htm

Name:

Number of Steps: 0

Volts per step: 0

Offset Voltage (V): 0

Maximum VDS (V): 0

Curve Resolution (Sweep Data Points): 100

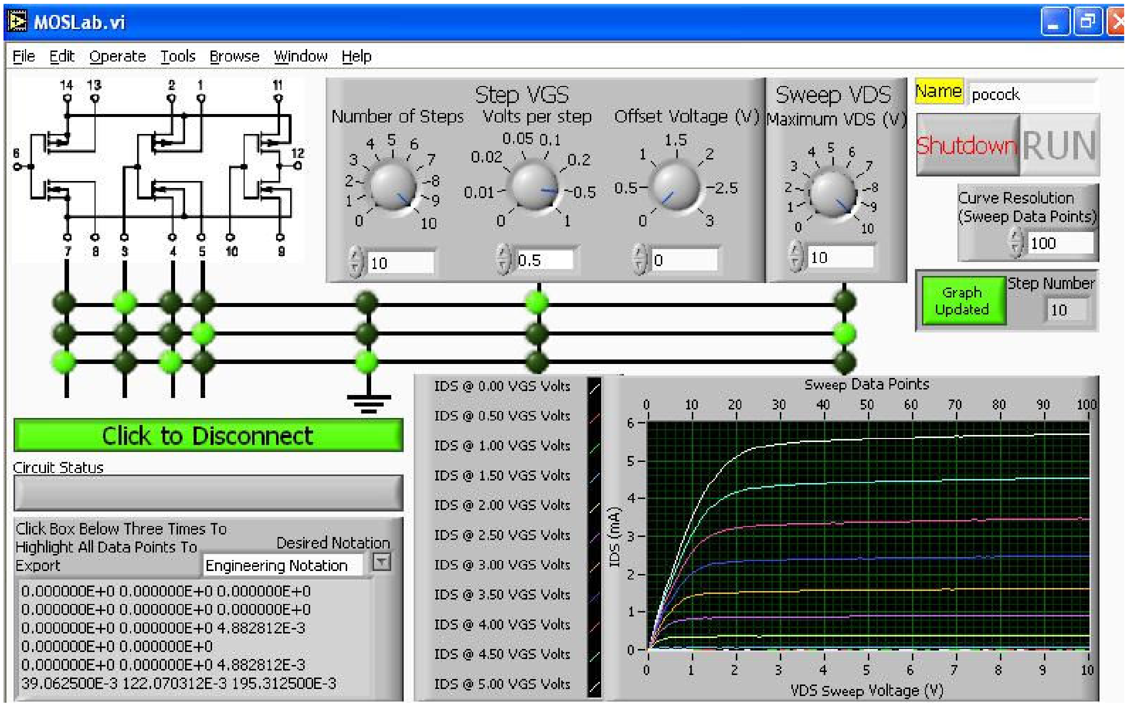
Step Number: 0

Click Box Below Three Times To Highlight All Data Points To Export

Desired Notation: Engineering Notation

IDS @ 0.00 VGS Volts
IDS @ 0.00 VGS Volts
IDS @ 0.00 VGS Volts
IDS @ 0.00 VGS Volts
IDS @ 0.00 VGS Volts
IDS @ 0.00 VGS Volts
IDS @ 0.00 VGS Volts
IDS @ 0.00 VGS Volts
IDS @ 0.00 VGS Volts
IDS @ 0.00 VGS Volts
IDS @ 0.00 VGS Volts

Figure 6. MOSFET Web-Based Lab front panel



Name: pocock

Number of Steps: 10

Volts per step: 0.5

Offset Voltage (V): 0

Maximum VDS (V): 10

Curve Resolution (Sweep Data Points): 100

Step Number: 10

Circuit Status

Click Box Below Three Times To Highlight All Data Points To Export

Desired Notation: Engineering Notation

```
0.000000E+0 0.000000E+0 0.000000E+0
0.000000E+0 0.000000E+0 0.000000E+0
0.000000E+0 0.000000E+0 4.882812E-3
0.000000E+0 0.000000E+0
0.000000E+0 0.000000E+0 4.882812E-3
39.062500E-3 122.070312E-3 195.312500E-3
```

Figure 7. Front panel showing correctly wired MOSFET and virtual curve-tracer actual I-V curves.

IV. Results

The results of the project to date have been very encouraging, with the following major accomplishments:

1. Five dedicated and identical laboratory workstations were designed, purchased, assembled and installed — one in Portland and four in Klamath Falls. All five are fully operational.

2. Two laboratory experiments were designed and implemented in LabVIEW to test the feasibility of the project.

3. These two experiments were run by students taking a sophomore-level class titled “Introduction to Amplifiers and Semiconductor Devices”. The students were located in Portland and Klamath Falls, and ran both experiments both “in-the-lab” and “over-the-web” with similar success.

4. Students completed a survey, and the results are summarized in Table II below.

5. An additional $30,000.00 was recently awarded by Intel for the continuation of this project.

Table 2. Summary of results from student survey

	Op-Amp Lab		MOSFET Lab	
	Number of Students	Percent	Number of Students	Percent
1. Taking survey	20		15	
2. Considered web-based lab at least as good a learning experience.	9	45%	4	27%
3. Considered web-based lab at least as pleasurable to run.	12	60%	9	60%
4. Preferred web-based lab.	8	40%	8	53%
5. Considered web-based lab an acceptable alternative if they lived a long way from campus.	17	85%	13	87%

V. Future Work

The project is a success for distance education efforts at OIT. This is in spite of all the challenges related to new hardware and software, networking problems, and the new concept of taking measurements from home. The EET department's future plans include the following:

1. The development of complete laboratory courses available over the web.

We will begin to develop the sophomore level analog electronics laboratories: "Introduction to Amplifiers and Semiconductors", "Transistor Amplifiers", and "Frequency Response of Amplifiers." These web laboratories will be available to students in addition to the classroom labs conducted at OIT.

In parallel with designing the laboratory projects, we will start an effort to develop the lecture courses associated with these projects as web courses. In this way, a full lecture-laboratory package will be available for part-time students who need to travel for their work and for students whose work schedule makes attendance of face-to-face classes impossible. This latter occurrence is very frequent in Portland where students are employed in industry and work modified shifts. These efforts would eventually lead to a completely distance-delivered program in the future.

2. Development of the scheduling program

With the growth of the number of students and classes using the equipment, time conflicts will be hard to avoid, especially with the hardware shared by two remote campuses. We plan to implement a scheduling program to avoid the various types of possible conflicts. Students will be able to sign-up for different time slots on the available hardware systems. Analogously, the instructor will be able to see who is using the systems at any given time.

As the web delivery of laboratory courses will extend to other courses in the program, such as the digital courses, OIT is expected to develop more experiment boards and acquire more hardware systems. Continued funding for the project is being sought.

Acknowledgments

The authors acknowledge the help of two companies who were key in the implementation of the project — Intel Corporation for granting the funds to purchase the hardware, and National Instruments for technical support and cost reductions.

The authors acknowledge the funding received from various OIT offices including: Distance Education (Beth Murphy), Assistant Provost (Gary Naseth) and the EET Department Chair (Andrew Sedlock) for development of the two "proof of concept" labs.

The authors extend their gratitude to the following individuals who helped with the success of the project: Steve Pawlowski from Intel Co. for being the industry sponsor, Steve Summers and Tricia Lee from National Instruments for invaluable technical support, Dave Cowan (Intel), Joe Engert (Maxim Co.) and the entire EET advisory board, Prof. Dr. Hakan Gurocak from Washington State University for inspiration and collegial help and Prof. Mateo Aboy from Oregon Institute of Technology for his help with the introduction section of this paper.

References

1. Phippd, R., Merisotis, J. "What is the difference? A review of contemporary research on the effectiveness of distance learning in higher education." Report. The Institute for Higher Education Policy, 1999.

2. Gurocak, H. "e-Lab: An electronic classroom for real-time distance delivery of a laboratory course." Journal of Engineering Education, v 90, n 4, October, 2001, p 695-705, 734-735

3. Campbell, J., Mosterman, J.P., Rassai, R. "Cost-effective distributed learning with electronics labs." JALN, v 8, n 3, 2004, p 5-10.

4. Ngo, C.C. "A web-based measurement lab for thermal sciences." ASEE Annual Conference Proceedings, 2002, p 4893-4900.

5. Henry, J. “24×7: Lab experiments access on the web all the time.” ASEE Annual Conference Proceedings, p 43-50.

6. Wiebe, E.N. “Supporting lab report writing in an introductory materials engineering lab.” ASEE Annual Conference Proceedings, 2001, p 9237-9247.

7. Hu, J. “Tele-lab IT security: A means to build security laboratories on the web.” Proceedings - 18th International conference on Advanced Information Networking and Applications, AINA 2004 v 2, 2004, p 285-288.

8. Lin, P.I., Broberg, H., Mon, A. “A web-based lab for distance learning.” ASEE Annual Conference Proceedings, 2002, p 10161-10172.

9. Scott, T.C. “Versatile, low cost electronics lab protoboard” ASEE Annual Conference Proceedings, 2004, p 15243-15250.

10. Naghedolfeizi, M.; Arora, S.; Garcia, S. “Survey of Lab VIEW technologies for building Web/Internet-enabled experimental setups.” ASEE Annual Conference Proceedings, p 7897-7906.

11. Grinberg, I, Matusiak, R.C. “Experiments with electrical motors in distance learning environment: Operating lab-volt electro-mechanical system using web-based tools from national instruments” ASEE Annual Conference Proceedings, p 5599-5608.

12. Goolsby, L.K. “Converting a traditional lecture/lab programming course to an online course “ASEE Annual Conference Proceedings, 2003, p 5371-5392.

Biographies

YOLANDA GURAN-POSTLETHWAITE is a Professor Emeritus of Electronics at Oregon Institute of Technology. She is the program director of the Electronics Engineering Technology program for OIT campus in Portland, Oregon. Professional interests focus on analog integrated circuit design and engineering education improvement techniques. She is registered as a professional engineer in the state of Oregon.

DAVID N. POCOCK is an Associate Professor and head of the Analog Block of the Electronics Engineering Technology department at Oregon Institute of Technology in Klamath Falls, OR. His main research interests are semiconductor device modeling, infrared focal plane arrays and nuclear radiation effects.

DAVID DUTTON is a recent graduate of the EET program at Oregon Institute of Technology, and is presently attending graduate school at Oregon State University.