

# Traditional Laboratory Exercises and Remote Experiments in Electrical Engineering Education

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**Abstract**—*Laboratory work is recognized as an efficient method for students to assimilate knowledge and to develop skills for solving real world problems. The Internet provides new opportunities for remote experimentation. Laboratory exercises in electrical engineering courses such as circuit theory and basic electronics can be performed remotely using real equipment. What equipment is required for remote experiments? Is it possible to design and implement a traditional laboratory with Internet access only? A traditional undergraduate electronics laboratory at Blekinge Institute of Technology (BTH), Sweden, makes eight identical lab stations available. Each station is equipped with a breadboard, some desk top instruments and a power supply. Experiments on electrical circuits have been conducted over the Internet using experimental hardware located in a small closed room at BTH. This tiny laboratory provides one lab station equipped with computer-based instruments and a remotely controlled switch matrix to replace the traditional breadboard. The matrix makes it possible to make all the necessary connections needed to form a circuit and to connect test probes in a fraction of a second. Is it possible to use time sharing to enable students to perform experiments simultaneously at eight different locations? How can I argue that a remote experiment is not a simulation? This paper addresses these and other similar questions and discusses some implementation issues. The address of the laboratory home page is <http://www.its.bth.se/distancelab/english/>.*

**Index Terms**—*Circuit, distance learning, laboratory, on-line, remote lab.*

## INTRODUCTION

During the last decades there has been a trend towards increased use of simulation in engineering education. One reason is that physical experiments are expensive both to implement and maintain. Another obvious reason is the belief that simulators can replace physical experiments [1]. The Greek philosopher Aristotle (ca. 340 B.C.) asserted that after a brief period, during which its speed increases, a body falls at a constant speed which is proportional to its weight. Thus, a body which is twice the weight of another would take half as long to fall from a given height. For Aristotle no experiment was necessary. Almost two thousand years later, in 1586, the Dutch mathematician Simon Stevin performed an experiment to test the ancient “natural law”. He dropped two lead balls, one ten times the weight of the other and noted that their impacts on a board on the ground produced “a single sensation of sound” [2]. Experiments are indispensable for students if they are to trust to physical laws and test their limitations. Practical projects and experiments also provide the framework for students to learn to cope with real world problems. Many physical laws and other mathematical models are complicated and difficult to understand. Simulations are a useful tool to demonstrate how they work.

The traditional way of conducting experiments is to go to a university laboratory where students work in teams and receive tutorial help from teachers. There is no doubt that nothing can replace synchronous learning through face-to-face interaction, but it is not always feasible for students to attend conventional classes. Models for using information technology to enhance the learning experience for students who are asynchronous in time or/and space and which are also suitable for on-campus students have been presented earlier [3]. A number of so-called remote laboratories have been set up by a number of universities around the world. These offer remote access to laboratory equipment and experimental setups [4]. Conventional laboratory exercises have for many decades been used with success to teach science and engineering. To design a remote laboratory where students can perform traditional laboratory exercises from home or elsewhere seems to be a good starting point from which new teaching methods may emerge.

A lab station with Internet access is setup in a small closed room at Blekinge Institute of Technology (BTH) in Sweden [5]. The desk top instruments are replaced by computer-based ones with virtual front panels and the breadboard is replaced by a switch matrix which can be controlled remotely. A number of people located in different places around the globe can perform experiments simultaneously using client PCs connected to the BTH laboratory server via the Internet. They download client software from the laboratory web site. This is one way to use equipment and premises efficiently. The cost of the equipment and its maintenance can be reduced if the number of lab stations is reduced and/or the laboratory is used outside ordinary working hours. Would it be possible using time sharing and the single lab station in the closed room to imitate a whole traditional laboratory equipped with 8 lab stations? These and other questions will be addressed in this paper. Exercises in a traditional laboratory will be described in the section that follows.

## EXERCISES IN A TRADITIONAL LABORATORY

Students perform traditional laboratory exercises in a laboratory supervised by instructors. The laboratories are open only during organized laboratory sessions for three main reasons:

- A laboratory with electrical experiment is a hazardous place due to high voltage. At BTH, students must pass a test before they are allowed to enter the laboratories.
- Some instruments are very expensive and could be damaged by improper use.
- Laboratory equipment could be stolen.

A traditional laboratory session in undergraduate education requires a laboratory where there are several identical lab stations allowing a number of students to perform experiments simultaneously. Two to three students work in a team and share the same lab station.

Most laboratory sessions at BTH are four hours and each session is supervised by one instructor only. In a traditional undergraduate electronics laboratory there are eight identical lab stations. At each station there is a lab box with a white plastic breadboard and some voltage sources and instruments as shown in Figure 1. The instructor provides the components necessary for each laboratory session. The engineer who earlier was responsible for maintaining the laboratory equipment has become an instructor due to budget cuts. Nowadays some students may use a significant part of the time available to troubleshoot connecting failures or other faults due to lack of maintenance. All experiments are described in an instruction manual. The normal procedure for performing a single experiment is as follows:

- Every student team forms the circuit specified in the laboratory instruction manual using a voltage source, the breadboard, and some of the components provided. A circuit is a collection of electrical elements interconnected in some way. Examples of elements used are resistors, inductors, capacitors and sources [6]. At least one of the instruments is connected to test points in the circuit.
- The instructor checks each circuit formed to avoid possible damage. If the circuit is safe the student team is allowed to continue by activating the source. When the source is activated transients will appear in the circuit. The duration of these transients is usually short in comparison with the time required for manual operation of the instruments and the students will not notice them.
- The students read the instruments and evaluate the results. If they are acceptable they record them in a laboratory report. Where this is not the case, some troubleshooting must be carried out if necessary, with the support of the instructor.

The breadboard is large enough to accommodate circuits with many components and nodes. However, courses in circuit theory and basic electronics use only small circuits with a few nodes. It is also possible to assemble compact circuits providing relatively high bandwidth though only low frequency phenomena are studied. General purpose oscilloscopes are used to display the signals.

Even if it is impossible to see the electrical current with the naked eye it is easy for a student to see that the electrical experiment is genuine when desk top instruments are used. This is somewhat more difficult to see when computer-based instruments are used because a computer is involved. Is it possible, for example, that a result displayed on a virtual front panel on the computer screen originates from a simulator program running in the computer? No, such a program needs a complete description of the circuit, and only a limited amount of data concerning the circuit and the electrical phenomena occurring in it can be input to the computer via the instruments. It is always easy to modify the circuit, for example, to remove a critical wire from the circuit and notice that the output from the instruments will change. A circuit simulation does not depend on something in the physical world.

## A REMOTE LABORATORY FOR TRADITIONAL ELECTRICAL AND ELECTRONICS EXPERIMENTS

The lab server in the closed room at BTH is shown in Figure 2. To the left there is a PXI (PCI Extensions for Instrumentation) chassis containing a controller and four plug-in boards from National Instruments. The controller comprises a PC connected to the Internet which hosts the plug-in boards in the form of two function generators, an oscilloscope and a digital I/O board. The instrument settings are controlled from the host computer, and there are no buttons or control knobs on the generators or the oscilloscope, only connectors. Next to the PXI chassis is a Data Acquisition/Switch Unit which functions as a multi-meter; this is connected to the controller via the GPIB (General Purpose Instrument Bus). To the right is a power supply. The traditional breadboard is replaced by a remotely controlled switch matrix large enough to accommodate most of the circuits used in electrical and basic electronic experiments in undergraduate education. The matrix used in the remote laboratory at BTH has five main nodes and ten main branches. The main nodes are denoted A, B, C, D and GND. The ground terminals of the function generators and the oscilloscope are connected to GND. Each main branch can be composed of a jumper lead or up to four components with two leads mounted in parallel in holders on the printed circuit boards shown in Figure 2. In this way a total of 40 different components can be connected [7].

The window appearing on the client PC screen when a user starts an exercise is shown in Figure 3. The circuit to be formed is defined using the PSpice-compatible net list shown. In PSpice the ground terminal, GND, is denoted "0". The net list is sent to the server in the closed room to set the switches in the matrix. Virtual front panels are used to set and connect the instruments. The oscilloscope panel is shown in Figure 4. The server software is written in LabVIEW 6.1 (Laboratory Virtual Instrument Engineering Workbench) and the client software is written in Visual Basic 6 [8].

## REMOTE EXPERIMENTS

The normal procedure for performing a single experiment in the remote laboratory is as follows:

- The student starts the client and selects the desired exercise. The experiment options panel will be displayed on the screen. S/he can choose an experiment and, for example, use a default net list representing the circuit in the instruction manual. The student can delete components or sources in the list. S/he connects one or more instruments to desired test points. Finally, the student presses the "Single" button to send the list, the instrument settings, and the test probe connections to the server.
- When the user request is dequeued on the server side, a virtual instructor compares the list received with a max list belonging to the experiment selected in order to ascertain that the desired circuit is safe. Where this is the case, the circuit will be formed, the instruments set, the test probes connected and the voltage applied. The outcome will then be sent to the client computer. In all other cases an error message will be returned.
- If there is no error message, the student reads the result on the virtual front panels of the instruments and evaluates it. If the result is acceptable, s/he will record it in the laboratory report. Where the result is not acceptable, troubleshooting must be carried out - if necessary, with the support of a real human instructor when available.

The reason why the list, all the instrument settings, and the test probe connections are sent to the server in one message only when the user presses the "Single" button is to ensure that the hardware is engaged for only a short time. In this way a number of student teams can share the same server. The main parts of the server response time are divided up as follows:

- The server decodes the message received.
- The virtual instructor checks the desired circuit.
- Some switches are opened, others are closed to turn the last circuit into the desired circuit.
- The sources in the desired circuit are activated. Transients will now appear. A delay is entered here to let these disappear before the oscilloscope is armed or the multi-meter is read. The delay is currently fixed at 5 ms.
- If the oscilloscope is used the time needed to sample a signal depends on the time/division setting.
- When data from the instruments are available the outcome is converted into a message to be returned to the client PC.

An example of a desired circuit drawn using PSpice symbols is shown in Figure 5. One well-known circuit of this kind where you make use of energy stored in an inductor after the power source has been disconnected is the classic breaker-point ignition system for an automobile. Students are expected to test what happens when a DC current through the inductor is broken. First the server forms the circuit and activates the power source to generate the current to be broken. When this has taken place it is necessary to wait at least five time constants, i.e. 40  $\mu$ s in this case, for the current to increase. However, the oscilloscope is armed only when the fixed delay (5 ms) expires and the switch is later opened. The outcome of the experiment is shown in Figure 4. The time setting of the oscilloscope is 100  $\mu$ s/division. It is possible to achieve a server response time below 1 s with eight simultaneous users.

Circuits assembled using the switch matrix need more cabling than that required by an experienced person using a conventional breadboard. The former circuits can perhaps be compared to those made by the average student. The extra wires and the relays limit the bandwidth somewhat; the oscilloscope time base is currently restricted to 1  $\mu$ s/division. The teacher can choose an appropriate time scale for the experiments by selecting proper values for the components to be used by the students. Time settings on the oscilloscope in circuit theory and electronics experiments normally range between 1  $\mu$ s/division and 10 ms/division. Thus, a single shot is usually 10  $\mu$ s to 100 ms because the time axis is 10 divisions on most oscilloscopes. A square wave signal from the function generator is shown in maximum time resolution in Figure 6.

How can I maintain that a remote experiment is not a simulation? It is possible to replace the computer-based instruments and the other hardware by a simulator program in the lab server. All data required for a simulation is sent from the client PC or is already available on the server. If people are present in the closed laboratory when a remote client is using the lab server the only thing they will notice is the clattering of the relays. Should a microphone be put in the vicinity of the server so that the clatter can be transmitted to the client PCs? Perhaps, but it is also possible to simulate the sound of the relays. You might say that the user interface for a simulator looks different. It would probably be hard to sell a simulator program with an oscilloscope type display as the only output.

## CONCLUSIONS

Students can conduct physical experiments from the comfort of their own home. It is possible to imitate traditional laboratory exercises. The only difference is that students will not handle components and test probes with their fingers. At BTH the students use PSpice compatible net lists to control a switch matrix which emulates the breadboard and the mouse pointer turns the instrument knobs on virtual front panels on the client PC screen. The teacher will in advance mount the components to be used in the matrix. It is possible to use time sharing to let students from more than one client PC perform experiments simultaneously. Eight teams of campus students, based in a computer hall supervised by one instructor, have been conducting remote laboratory exercises simultaneously using the single lab station at BTH. The teacher is expected to select suitable component values to ensure that the time constants involved in the phenomena to be studied are not too long to avoid an irritating slow lab server response time.

One can anticipate that computer-based instruments with virtual front panels will gradually replace desktop ones. It thus makes no difference if you handle instruments in local labs or by remote control. Nevertheless, students need a great deal of hands-on practice. At BTH students gain this experience in practical projects, which provide the right methodology to cope with real-world problems such as EMC issues, finding bad connections etc.

One issue remains: how can we convince a student who will never see the hardware s/he will use that remote experiments are not simulations? It should be easy for electrical or computer engineering students to understand a description of the laboratory and how it works. Would Aristotle want to use the remote laboratory if he were alive today? The laboratory can be used by anyone with an Internet connection whenever it is not being used in ordinary education. The address of the laboratory home page is: <http://www.its.bth.se/distancelab/english/Kretsteorilabbar/intro.html>.

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## FIGURES AND TABLES

FIGURE. 1

A TRADITIONAL LAB STATION IN A LABORATORY FOR UNDERGRADUATE EDUCATION IN ELECTRICAL ENGINEERING AT BTH.

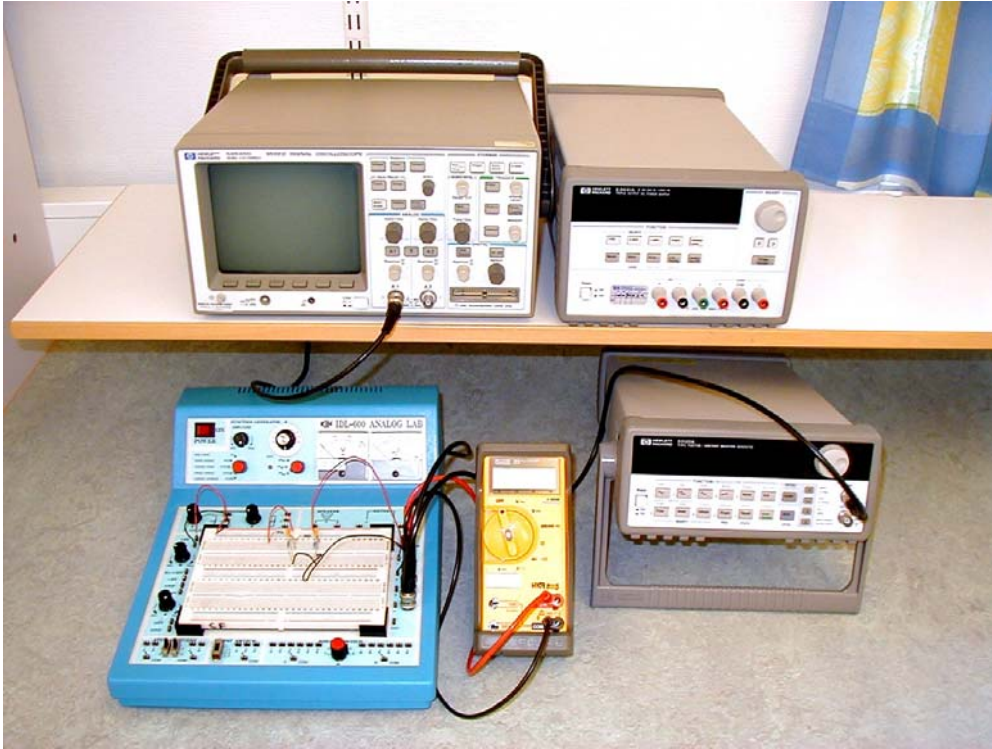


FIGURE. 2  
A LABORATORY SERVER FOR EXPERIMENTS IN CIRCUIT THEORY AND BASIC ELECTRONICS.

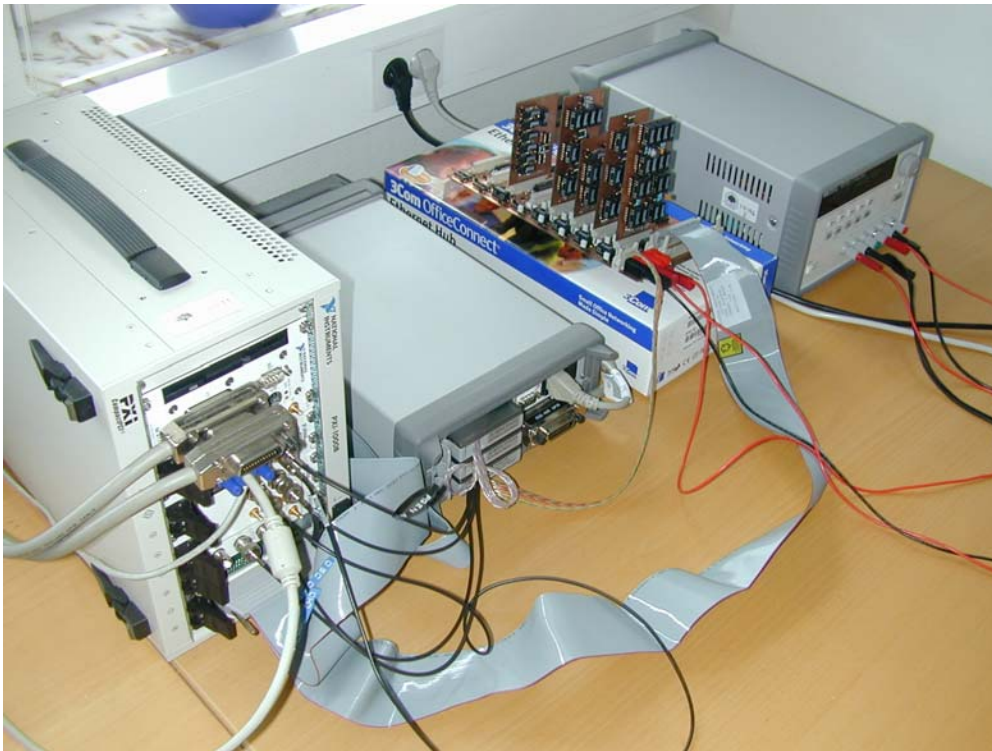


FIGURE. 3  
THE EXPERIMENT OPTIONS PANEL.

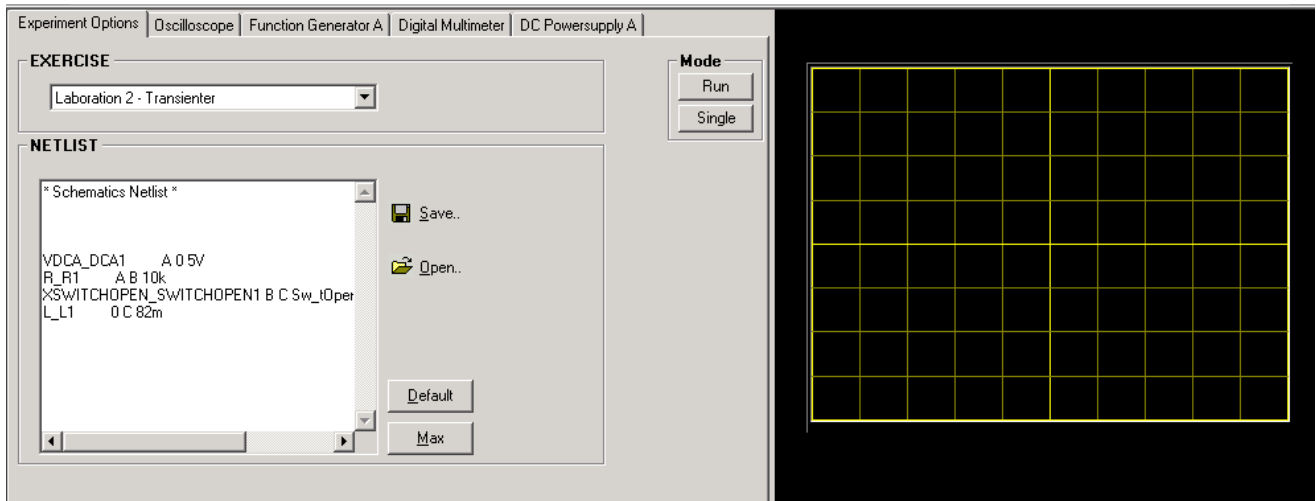


FIGURE. 4  
THE VIRTUAL FRONT PANEL OF THE OSCILLOSCOPE.

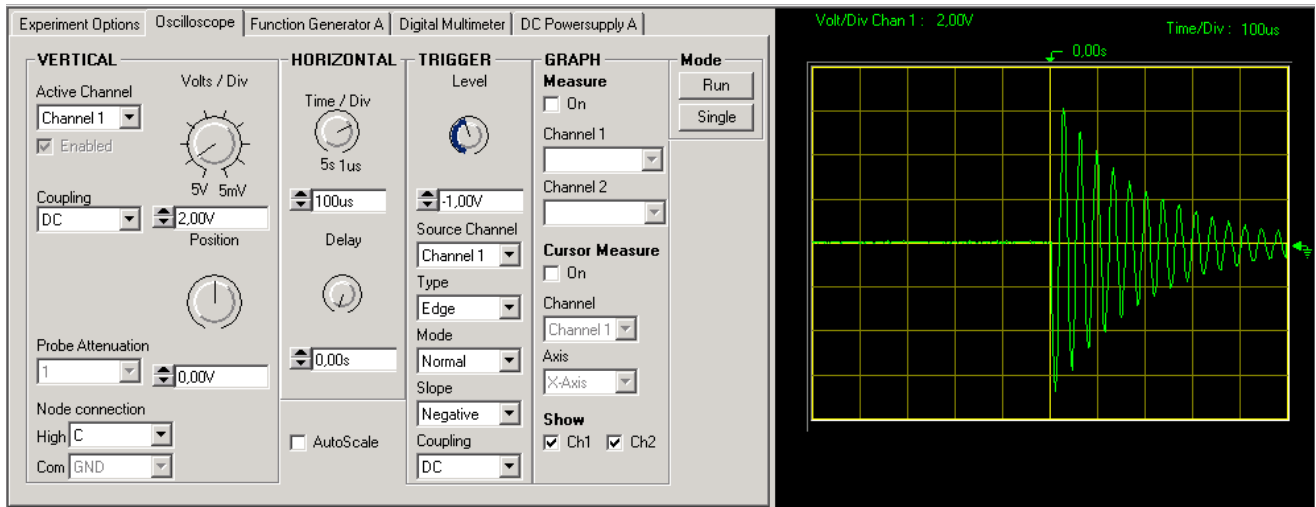


FIGURE. 5  
A TRANSIENT EXPERIMENT.

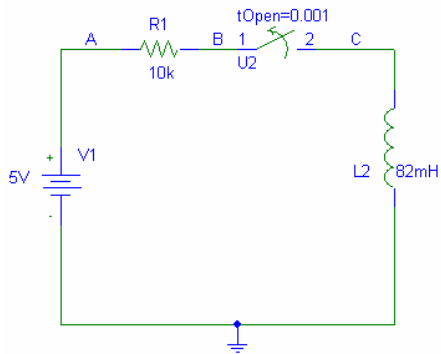


FIGURE. 6  
A SQUARE WAVE SIGNAL FROM THE FUNCTION GENERATOR DISPLAYED IN MAXIMUM TIME RESOLUTION ON THE OSCILLOSCOPE.

