

Remote Operation and Control of Traditional Laboratory Equipment

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Abstract— Physical experiments are indispensable for developing skills to deal with physical processes and instrumentation. The Internet provides new possibilities for universities and other teaching organizations to share laboratories and increase the number of lab sessions without incurring any increase in cost. Blekinge Institute of Technology in Sweden has opened a traditional electronics laboratory for remote operation and control 24/7; it is the first of its kind. The laboratory is equipped with a unique virtual interface enabling students to recognize on their own computer screen the desktop instruments and the breadboard they have already used in the local laboratory. The research is focused on what is perceived to be the greatest challenge, i.e. to give the student laboratory experience that is as genuine as possible despite the lack of direct contact with the actual lab hardware at the same time as it allows the teacher to use existing equipment and teaching material. The goal is to produce an open international standard.

Index Terms—Electronics, Engineering Education, Remote labs, Online Engineering, Signal Processing, Vibration

I. INTRODUCTION

The overall goal of engineering education is to prepare students to practice engineering and, in particular, to deal with natural forces and materials. Thus, from the earliest days of engineering education, instructional laboratories have been an essential part of undergraduate programs [1]. Physical experiments allow learners to ascertain that mathematical models correspond with nature and to study the limitations of these models. Experiments and practical projects also provide the framework for students to learn to cope with real-world problems and gain hands-on experience. However, during the last decades there has been a decline in the number of instructional laboratories in engineering education. In many countries a trend may be observed towards an increased use of simulations which frequently replace physical experiments [2, 3]. Generally speaking, simulator programs are based on mathematical models and are excellent tools for analysis and design when the limits of the models embedded in the software are known and the learner can cope with the abstraction level they represent. Students must learn that these limits exist and when the models are useful, e.g. when and to what extent does a mathematical model provide an accurate and reliable description of a real-world system? What differences might be expected, and are they of importance?

When mankind penetrates deeper and deeper into the mysteries of nature the number of physical experiments in engineering education should increase and not decline. New technologies such as the Internet offer new possibilities to increase the number of experiments which can be conducted and also provide access to experimental equipment for the public with the aim of inspiring people to study science and technology. Today, many academic institutions offer web-based experimentation environments that support remotely operated experiments [4-8]. Such remote experiments entail remote operation of distant physical equipment. A preliminary assessment study comparing versions of remote labs versus hands-on labs in a junior-level course has already been presented [9]. Home experimentation is a method specially designed for distant learning students to acquire introductory hands-on experience and become familiar with electronic components and wiring etc. [10-11]. However, affordable devices such as a cheap multi-meter and/or a soundcard-based oscilloscope are only adequate for elementary experiments.

There are many different remote laboratories around the world which are used in a variety of disciplines. However, the wide range of user interfaces is a problem for students and teachers. Efforts are currently being made to handle the situation. The iLabs Project at Massachusetts Institute of Technology in the USA, for example, has developed a suite of software tools that facilitates online complex laboratory experiments, and provides the infrastructure for user management [12]. We focus on one discipline with a large number of almost identical laboratories. Traditional electronics laboratories for undergraduate education at universities around the world contain almost identical equipment although the instruments are made by different manufacturers. Most instruments already support remote control; only the breadboard or protoboard does not. Teachers and many students are already familiar with these laboratories. Would it be possible to open such a laboratory for remote operation and control? If so, teachers in different countries could use existing teaching material in their own language. Instrument manuals could be downloaded from the manufacturers' web sites.

Blekinge Institute of Technology (hereafter referred to as BTH) in Sweden has opened a local traditional electronics laboratory for remote operation and control. It is equipped with a unique virtual interface enabling the students to recognize on their own computer screen the desktop instruments and the breadboard they have already used in the local laboratory. The physical breadboard has been replaced by a circuit-wiring robot which is remotely controllable, i.e. a switching relay matrix. The laboratory

is used in regular courses for students on campus as well as for distant learning students in Sweden and abroad.

This paper is an introduction to remote operation and control of traditional laboratory equipment; the remote electronics laboratory at BTH is used as an example. The next section presents the local laboratory which serves as a model for the remotely operated one. The final section which precedes the conclusions discusses future research.

The following definitions are used later in the text. A *circuit* consists of *nodes*, connection points, and *branches* which are sources or components. It comprises at least one voltage or current source and a number of components which may be active or passive. A DMM (digital multimeter) and/or an oscilloscope are used for measurements on a circuit. A *jumper lead* is a zero ohm resistor, i.e. a component. A *remote laboratory* consists of at least one server and a number of client computers which can be scattered all over the globe. Like other authors we use the term *local laboratory* for a laboratory without a remote control option. The term “on-campus laboratory” is ambiguous because students can sit elsewhere on campus conducting experiments on a server in a room nearby.

II. TRADITIONAL LAB SESSIONS IN A LOCAL ELECTRONICS LABORATORY AT BTH

A local electronics laboratory for undergraduate education at BTH has eight identical lab stations allowing a number of students to perform experiments simultaneously. At each station there is a lab box with a white plastic breadboard and some voltage sources and instruments, as shown in Fig. 1. Many laboratories for undergraduate electrical engineering education at other universities have similar equipment. Two, or occasionally three students, work in a team and share one lab station in a local lab session at BTH. A session is supervised by one instructor who provides a set of components for each student team. During a session, the students perform a number of experiments specified in a lab instruction manual. The components in the set provided are selected

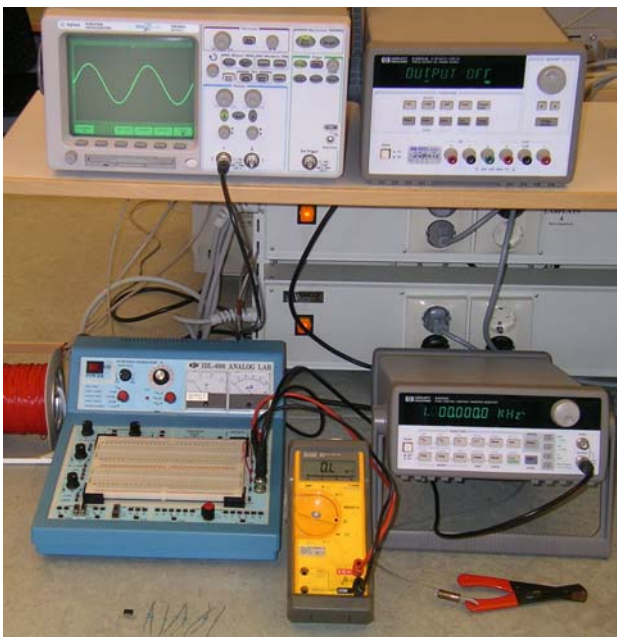


Figure 1. Lab station in a local electronics laboratory at BTH.

with respect to what is needed in the experiments in the particular session. The normal procedure for performing a single experiment is as follows:

- Every student team wires the circuit specified in the instruction manual using a voltage source, the breadboard, and some of the components provided. At least one of the instruments must be connected to test points in the circuit in order to collect experimental data.
- 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. Once 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 operations, and the students will not notice them.
- The students read the instruments and evaluate the results. If they are acceptable, the students record them in a laboratory report. Where this is not the case, troubleshooting may be necessary; this will be carried out with or without the support of the instructor.

The breadboard in Fig. 1 is large enough to accommodate circuits with many components and nodes. However, in lab sessions in undergraduate education only a small number of components are used.

III. THE REMOTELY OPERATED TRADITIONAL ELECTRONICS LABORATORY AT BTH

Lab sessions in the remotely operated laboratory at BTH are more flexible than a local laboratory in the sense that students can work alone, in a team, or together with an instructor and other teams, at any time and from any place with the aid of Microsoft's Netmeeting or some other means of communication. The instruments and the breadboard are available in all lab sessions but each session is associated with a particular set of components, and those components can only be used in that particular session. Entry to the laboratory and the lab sessions is restricted by a time reservation system. Teachers teaching courses which include supervised lab sessions in the remote laboratory make time reservations for these sessions. Only eight student teams, i.e. client computers per instructor and remote lab session are accepted in a supervised session just as in a local session. Thus a lab session comprising particular experiments must be delivered more than once. Students enrolled in such a course are then permitted to select and make reservations for the supervised lab sessions of that course. Non-scheduled time may be used by any student enrolled on a course to enter the laboratory and perform experiments using the component sets belonging to the lab sessions of the particular course. The number of client computers or student teams per instructor and remote lab session may change when the research group gains more experience from the remote lab sessions in the regular courses. Two special guest courses are open to the public when the laboratory is not being used for supervised lab sessions. Each such guest course offers one lab session.

The BTH laboratory is a client/server application; the Internet is used as the communication infrastructure, Fig. 2. The time-sharing scheme used allows simultaneous access. Only a modem and a web browser with a Flash player 7 or a later version are required to access the experimental resources. The equipment provided comprises an oscilloscope, a function generator, a DMM, a triple DC power supply, a circuit-wiring robot, and a number of component sets which are selected by the teachers who have written the lab instruction manuals for the courses supported. The laboratory staff has mounted the component sets in the circuit-wiring robot; photographs of the components are stored in a database. As in a local laboratory, a specific set of components is provided for each team and each lab session. The set is displayed in a component box on the client computer screens.

The laboratory is fitted with two equipment servers. One of these which is used in regular education and by guest users is always online. However, it is unattended and may go down at any time. Should this happen during a holiday it may take some time to bring it back online again. The other one is identical and is usually used for the research activities but also as a backup for the ordinary server. The address of the home page of the laboratory is <http://distanslabserver.its.bth.se/>.

A. Sources and instruments

The power supply, the function generator, and the oscilloscope in Fig. 1 are all manufactured by Agilent Technologies and can be remotely controlled through GPIB (General Purpose Interface Bus). However, not all of these devices are suited to this application, and the DMM from FLUKE has no remote option. To open the laboratory, the function generator, the DMM, and the oscilloscope have been replaced by computer-based instruments with an equivalent or superior performance, Table I. Such instruments are composed of a plug-in board fitted with a tiny physical panel containing connectors only as well as a software module in the host computer. This module displays a virtual front panel containing control knobs and buttons on the host computer screen; here the user can use the mouse to rotate the knobs and perform the instrument settings. In this application the virtual front panels are displayed on the screens of remote

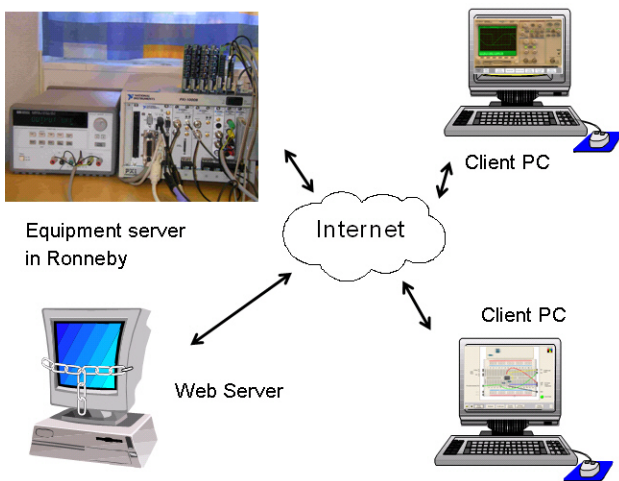


Figure 2. The remote laboratory at BTH and two client computers.

TABLE I. INSTRUMENTS

Instrument	Desktop or Hand-held	Computer-based	
		Hardware	Driver
Function generator	Agilent 33120A	NI PXI-5401	NI-FGEN
Oscilloscope	Agilent 54622A	NI PXI-5112	NI-SCOPE
DMM	FLUKE 23	NI PXI-4060	NI-DMM

client computers instead, and the panels are photographs of the front panels of the desktop instruments. As an example, the oscilloscope virtual front panel is shown in Fig. 3. The user manuals can be downloaded from the web sites of the manufacturers. The instruments and the host computer are mounted in a PXI (PCI Extensions for Instrumentation) chassis, Fig. 4. This equipment is manufactured by National Instruments.

The fact that the depicted front panels are separate from the hardware enables us to combine a front panel of an instrument from one manufacturer with the hardware from another provided that the performance of the hardware matches that of the depicted instrument. The current laboratory supports only instrument models used at BTH. Other universities have different models, and a virtual equipment shelf containing other instruments from different manufacturers can be added. The performance of the hardware provided matches most instrument models used in undergraduate education. Only those features required in undergraduate education are currently implemented in the instruments.

B. Circuit-wiring robot

It is not possible for students to manipulate the components and wire a circuit with their fingers in the remote laboratory. A type of circuit-wiring robot, e.g., a relay switching matrix must be used. The complexity of such a matrix increases with the number of circuit nodes provided. If a desired circuit has N nodes and if the user wishes to add one resistor, there are $N \cdot (N-1) / 2$ branches into which it can be introduced. There are 120 possibilities for 16 nodes. The BTH laboratory, however, is designed for undergraduate education where such flexibility is not necessary. The circuits to be formed in lab sessions contain a limited number of components and are not particularly complex, i.e. they usually have only one input and one output and a signal flow from left to right; some circuits have been excluded for safety reasons. However, the space for unexpected solutions or harmless mistakes

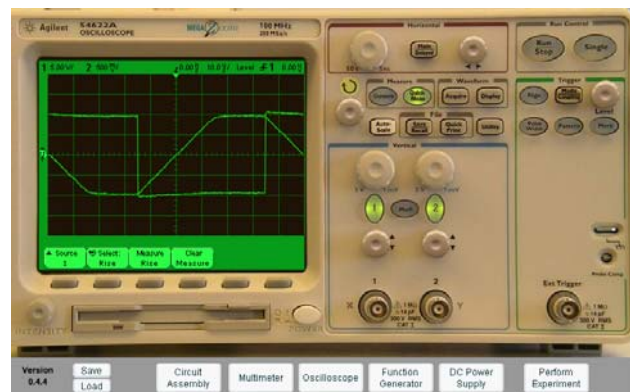


Figure 3. Oscilloscope displayed on a client computer screen.

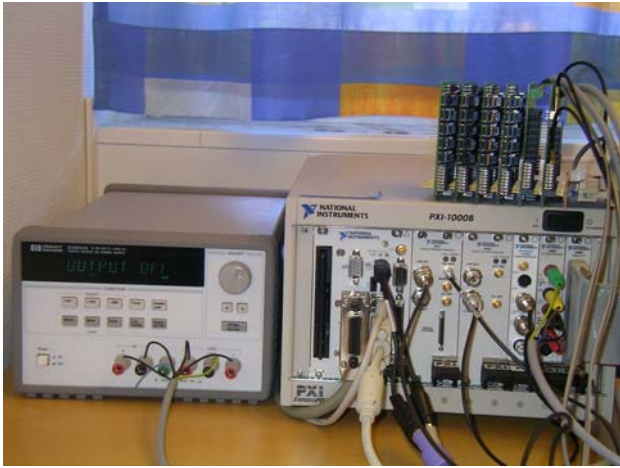


Figure 4. Equipment Server at BTH.

should be as wide as possible.

The circuit-wiring robot is the card stack on the top of the PXI chassis in Fig. 4. It is possible to wire a circuit with up to 16 nodes by engaging a number of relays in the current matrix. The card stack contains two types of board: one for components and one for connecting instruments. A component board comprises 10 sockets for components with two leads, two 20-pin IC sockets for components with more pins than two, and 10 double-pole single-throw relays. One oscilloscope and two function generators or a DMM can be connected to an instrument connection board. The nodes passing all boards can be connected to sources, instruments, and/or components mounted in the sockets via relay switches. However, the instruments can only be connected to seven of the nodes denoted A – F and 0 [13]. The ground terminals of the function generator and the oscilloscope are hardwired to node 0, which is denoted GND on the breadboard. The function generator output can be connected to node A only. There is currently only one function generator in the ordinary equipment server.

The matrix capacity in terms of the number of online components can be increased by stacking more component boards. The card stack in Fig. 4 belongs to the ordinary equipment server. It accommodates components sets required for lab sessions in two courses on circuit analysis and analog electronics respectively. The matrix is still only half filled.

If the relay switches controlling the sources and all the components in the current matrix of the ordinary equipment server were closed a large circuit would be created. The corresponding circuit diagram is shown in Fig. 5. However, the relay switches are omitted in the figure to make the diagram less complex. Instead, they are included in Fig. 6 which shows a small segment of the circuit in Fig. 5. In Fig. 6, resistors R1, R2, and R3 from the left side of Fig. 5 are shown together with their connection relays to indicate how a circuit is physically created. The signals *Connect R1 H* etc. in Fig. 6 are controlled from a digital I/O board in the PXI chassis. All circuits which can be created with the components mounted in the current matrix are sub-circuits of the circuit in Fig. 5.

Electronics laboratories for undergraduate education are designed for low-frequency experiments only. Circuits

wired using the switching matrix include longer wires than those found in circuits formed by an experienced person on a physical breadboard. The former circuits can perhaps be compared to those made by the average student. Extra wires and relays limit the bandwidth somewhat; the oscilloscope time base is currently restricted to 1 μ s/division. A square wave signal from the function generator is displayed on the oscilloscope in Fig. 7 using maximum time resolution. The quality of the displayed square wave signal is good.

C. User interface

When the client software has been automatically downloaded and the user has wired an inverting operational amplifier circuit, the virtual breadboard will be displayed as in Fig. 8 which is a photograph of a real breadboard. The component box at the top of the breadboard shows the set of components available in the selected lab session. However, two of the resistors and the amplifier (μ A741) are already inserted into the circuit. At the bottom of Fig. 8 there is a menu bar displaying a number of buttons with self-explanatory labels. As in a local laboratory it is possible to detach and save a breadboard together with a wired circuit but without the source and instrument connections. In this case it is not stored in a store room but in a file. The opposite is also possible i.e. one may load a file containing a detached breadboard. Students use the mouse to position each component to be used on the breadboard or to wire a circuit and connect sources and instruments. The two wires connecting pin 3 of the operational amplifier to GND in Fig. 8, for example, instruct the robot to insert the jumper between nodes D and 0 in Fig. 5. If the user should happen to wire the function generator output to GND by mistake, it will be connected to node A and this node will be connected to the node 0 by a jumper lead shown in Fig. 5. Such a mistake is permissible and will cause no damage because the function generator is short-circuit protected.

A consequence of the objective to make the interface as close as possible to the student's experience in a local laboratory with no computer support is that it is not possible to store measurement results even if implementation is easy. One simple method would be to store data using the floppy disk on the oscilloscope.

The earlier versions of the client software were written using the instrument graphics package Component Works from National Instruments. That package is or was based on ActiveX techniques and it is easy to use when implementing front panels. The current version of the client software is written in Macromedia Flash; this has two useful features: the flash player is supported by most systems, and it is easy to rotate the knobs in the photographs of the front panels using the mouse.

D. Virtual instructor

What happens in the remote laboratory if a user composes a circuit which is potentially destructive, e.g. could overload a resistor? It would, of course, be fatal if a resistor were to burn as the equipment server is normally left unattended. Users would in all probability observe strange results in subsequent experiments involving the destroyed component. To avoid damage to components and/or instruments the teacher specifies in advance which circuits can be wired using components from the set in the

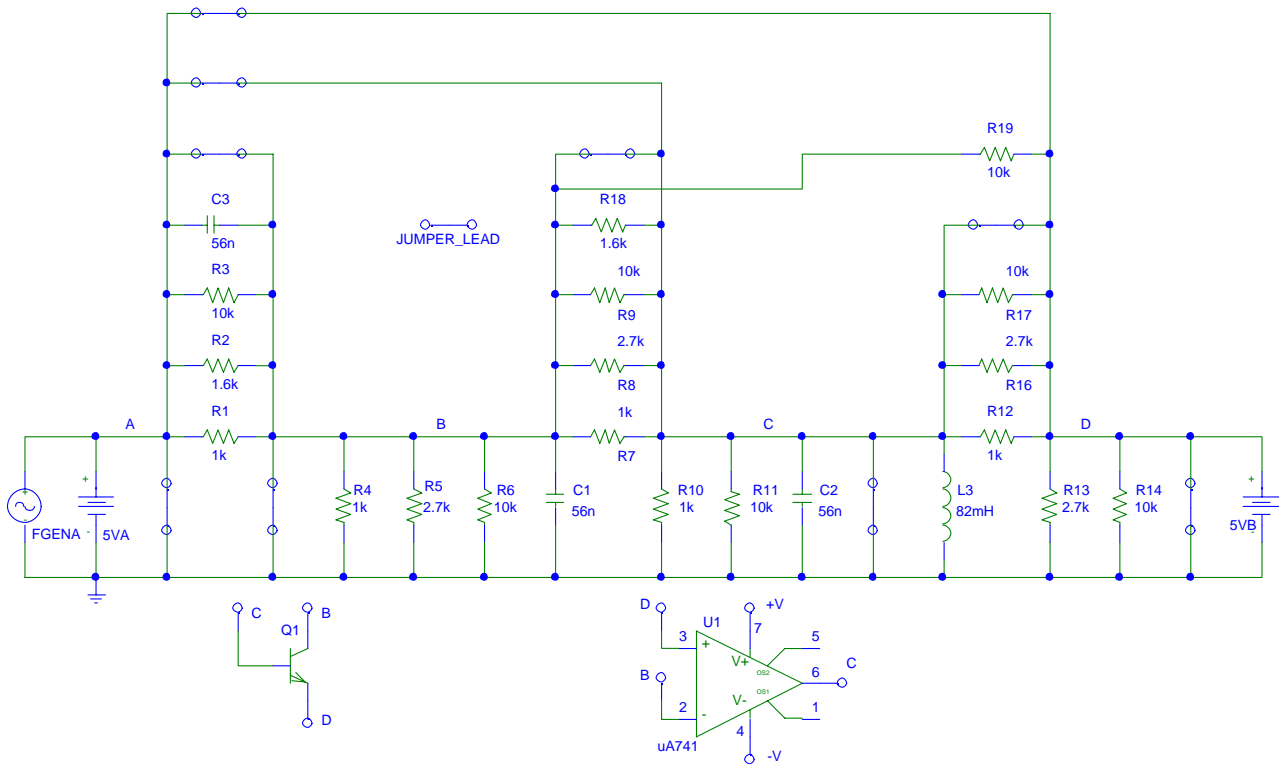


Figure 5. Circuit diagram of the current switching matrix.

box by defining so-called max. circuits which include all current loops permitted and supported by the matrix. All sub-sets of a max. circuit must also be safe circuits. A number of max. circuits are usually required to maximize the freedom of the user and allow occasional mistakes which cause no damage. The teacher also sets the max. voltage levels permitted as output from connected sources in each max. circuit. Thus, if a piece of hardware is damaged the teacher is to blame and not the student.

An example of a max. circuit for experiments on operational amplifiers is shown in Fig. 9. As in Fig. 5, the relay contacts are omitted in the diagram. The max. circuit in Fig. 9 has only five nodes. It is still possible to create both non-inverting and inverting operational amplifier circuits. The user is always free to connect high impedance instruments to any node; the multi-meter set for current measurements is, however, low impedance and it could be dangerous to connect it. As a result, the multi-meter in current mode is only allowed to replace a jumper; see, for example, Fig. 9 in which the jumper between the

output of the operational amplifier and the ground indicates that it is permitted to measure the shortcut current of the amplifier.

E. Timing

All the wiring made by a user is taken care of in the client computer, and the user can use all the time s/he requires to perform these actions. This is also true for the instrument settings. When the student presses the rightmost button *Perform Experiment* on the menu bar, a message containing the desired circuit and the instrument

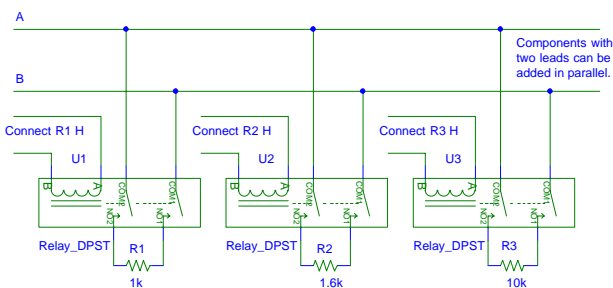


Figure 6. A part of the circuit in Fig. 5 containing the resistors R1, R2, and R3 together with their connection relays.

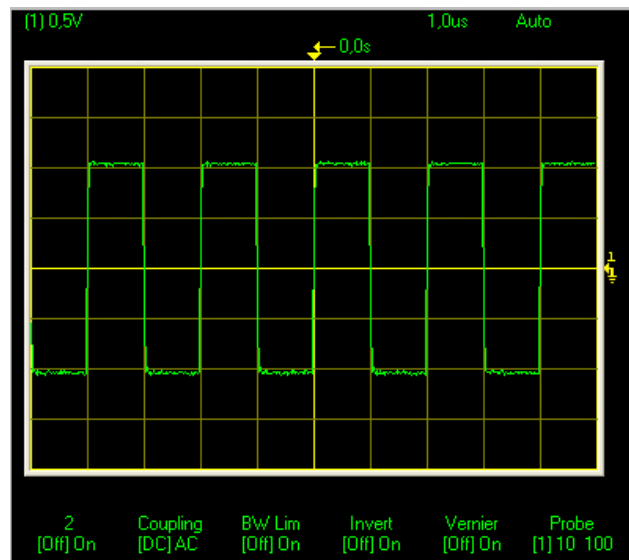


Figure 7. Square wave signal from the function generator displayed using the maximum time resolution of the oscilloscope.

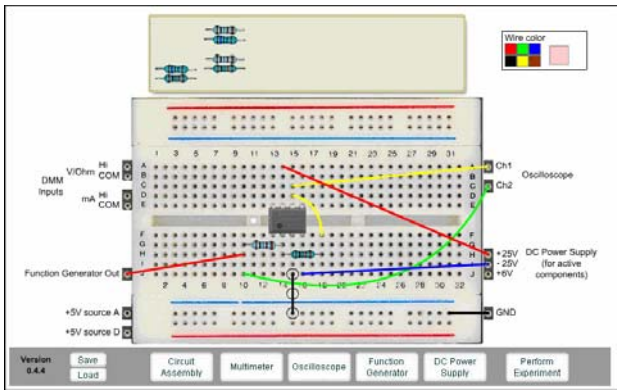


Figure 8 Virtual breadboard with a wired operational amplifier circuit.

settings are sent to the server. The message is decoded on the server side and put into a FIFO (first in first out) queue. As soon as a measurement task is finished, a user request is de-queued. The virtual instructor compares the desired circuit with the max. circuits to ascertain that the desired circuit is safe. When this is verified, the power supply is set up and activated. The circuit is then created. After a 25-ms pause to allow switch transients to disappear, the instruments are set and the test probes are connected. The DMM output is read and the oscilloscope is armed. Intentional transients, if any, are fired, and the oscilloscope traces are read. The outcome is then sent back to the client computer and is displayed on the screen. In all other cases, an error message is returned.

The time-sharing scheme which is used to allow simultaneous access to one server with an acceptable response time imposes restrictions on the time period allowed for each experiment. The time period allowed for any one measurement is currently 0.1 s. However, in electronics courses the teacher can easily choose an appropriate time scale for the experiments by selecting proper values for the components to be used by the students. Currently, the oscilloscope only allows a single sweep mode in order to avoid a heavy load on the server. However, if the number of simultaneous users is large and many press the *Perform Experiment* button frequently, the response time will increase.

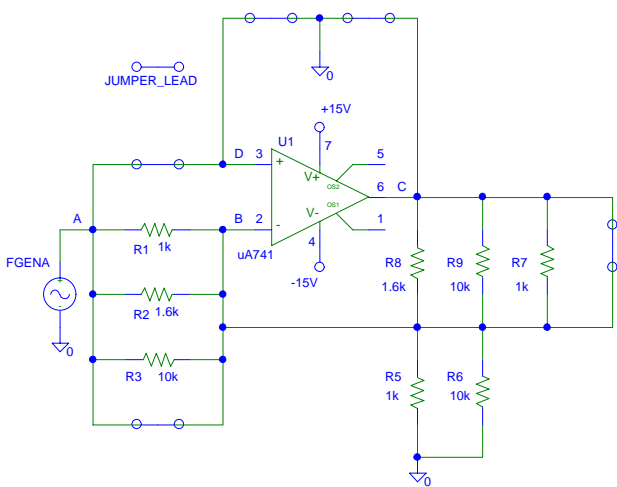


Figure 9 Max circuit for basic operational amplifier experiments.

F. Congruency

Apart from the fact that each student or team of students works remotely in a virtual environment with no face-to-face contact with an instructor or other students in the laboratory, the main difference between a lab session in the remote laboratory described here and a session in a local laboratory is that it is not possible for students to manipulate physical components and wires with their fingers in a remote laboratory. However, students can, for example, sit at home in peace and quiet and learn how to use a function generator and an oscilloscope in the same way as in a noisy local laboratory where time is limited.

If you cannot read the color code of a resistor in a local laboratory you must use the DMM to measure its resistance. When using fingers it is not so complicated to connect a resistor to the test probes of the DMM but to measure a resistor in the remote laboratory at BTH one must put it on the breadboard and connect it to the DMM using two wires. Some students find this procedure awkward and time-consuming. A solution would be to separate the two input holes of the DMM to make it possible to connect a resistor to the DMM without any wires.

In the remote laboratory the instructor must be replaced by a virtual one who supervises the circuit creation to avoid damage to the equipment. When you are anonymous it may be tempting to test the security of the laboratory. For each component set a teacher wishes to put together and insert into the matrix, s/he is obliged to instruct the virtual instructor by designing max. circuits which define all possible harmless circuits. If the teacher is lucky, some appropriate max. circuits have already been defined. By selecting as high impedance components as possible, the task becomes easier. If there is no max. circuit defined, no circuit can be activated.

In a local laboratory it is obvious that the experiments are real. How does a student in a remotely operated laboratory know that the experiments conducted are real and not simulations? A somewhat experienced user observes effects not modeled in the widely used PSPICE simulator software for analog and digital electronics. In this simulator, for example, the model for the common uA741 operational amplifier does not include some offset quantities. The output of this amplifier in PSPICE is zero if the input is zero, but this is not the case in real life. For a novice it is hard to tell if the experiments are real or not. However, remotely operated experiments will not replace local lab sessions; rather they complement and supplement them and make experimental equipment more accessible, especially for inexperienced or less confident students who require more time. It may also be possible to compensate for the reduction in the number of traditional lab sessions during the past few decades and even improve electronics courses without incurring any increase in cost.

IV. FUTURE RESEARCH

Our research is focused on what is perceived to be the greatest challenge, i.e. to give the student laboratory experience that is as genuine as possible despite the lack of direct contact with actual lab hardware. An obvious choice initially was an electronics laboratory for undergraduate education. Such laboratories are common at universities worldwide and are easy to operate and control remotely. Neither video nor sound transmission is

required in most experiments because it is not possible to see the electrical current with the naked eye or hear the electrons moving, thereby reducing the data transfer bandwidth needed. This laboratory is a new pedagogical tool available for research in the field. More effective teaching methods may emerge in the future. Experiments can, for example, easily be integrated into lectures.

A challenging task for future research is to expand into the mechanical domain where more complicated robots are required to operate mechanical structures. In the signal processing department at BTH a clear goal is to open a signal processing laboratory for experiments on mechanical structures and also to propose a standard for equipment for remote mechanical vibration experiments. Some incentives and ideas for such an expansion are listed below:

- The area of experimental vibration analysis is “vital” for society, e.g., in major industry segments such as the automobile industry, aircraft industry, manufacturing industry, etc. experimental vibration analysis has a significant impact on product design, development, productivity, production costs, etc. A large number of noise and vibration problems exist in society and they affect the development of human health, the environment, etc. In modern society humans are continuously exposed to noise and vibrations at different levels, a problem which, is not, unfortunately, expected to diminish in the future.
- Experimental vibration analysis has been identified as a key area where the development of a remotely operated laboratory is likely to have a significant impact on the educational outcome. Undergraduate students, life-long learning students, and even the general public can be invited to perform experiments in open research laboratories equipped with expensive equipment. This is also a new way to share advanced experiments and disseminate cutting-edge research.
- Results from the electronics laboratory can be directly utilized in the development of the remote laboratory for mechanical vibration experiments. The “circuit” is the mechanical structure to be studied. The function generator and the oscilloscope are replaced by a signal analyzer and an electro-dynamic shaker. The electro-dynamic shaker converts the electric signal from the signal analyzer’s source to a mechanic, one-dimensional motion which connected to a mechanical system applies a force or input signal to the mechanical structure. The test probes are, for example, accelerometers and force transducers. A virtual instructor is still required.
- The students are allowed somewhat less latitude in this laboratory. The position of the source, the input force, and the transducers cannot easily be moved remotely. However, it is possible to be generous with the number of transducers and to attach them at suitable locations for the experiments e.g. a set of transducer locations ranging from good to poor with respect to experimental vibration analysis of the structure.

The mechanical structure can be modified remotely by the students using electromagnets to add and remove structural parts.

- There is no de facto standard for laboratories for mechanical vibration experiments. However, the Agilent 35670A four-channel signal analyzer is widely used, and it is easy to control remotely.
- It can be argued that the hardware in the remote electronics laboratory could be replaced by a simulator program in undergraduate education because inexperienced students are unlikely to notice any difference. This, on the other hand, is not relevant to the vibration experiments laboratory. Here, the inexperienced student will rapidly become aware of differences. It is, for instance, simple to find mechanical structures for which there are no sufficiently accurate simulator models.

A consortium chaired by BTH will be formed to expand and disseminate our unique electronics laboratory internationally within the framework of a proposed project known as VISIR (Virtual Instrument Systems in Reality). Universities and other organizations will be invited to participate in the development and dissemination together with BTH as part of the VISIR project. Examples of potential participating organizations are schools and companies offering technical courses. Global instrument and measurement system vendors such as National Instruments, Agilent Technologies, and VXI Technology are interested in joining the VISIR project. The software produced will be released as open source ware. BTH has spent approximately 11 man-years on software development thus far.

The VISIR project also includes a second parallel activity, i.e. the opening of a signal processing laboratory for mechanical vibration experiments. The purpose is to provide equipment for experiments on dynamic systems realized by mechanical structures. Furthermore, a switch to a system supporting more than one output channel and four input channels similar to the system used in the virtual electronics lab will be carried out, i.e. to a flexible PXI system, e.g. manufactured by National Instruments. The main objective of the second VISIR activity is to design a flexible laboratory for vibration experiments including a new signal analyser with a virtual front panel. A first laboratory prototype using the Agilent 35670A signal analyzer is already being tested in a regular course at BTH [14]. It will be opened to the public during 2006. It is possible to test the prototype now but because it is used in education and research it is not always reachable online. The address is <http://distanslabserver.its.bth.se/>. Please send an email to one of the first four authors if the prototype is offline.

The goal is to provide a broad range of experimental resources accessible to learners 24/7 from home or elsewhere. However, our research has wider implications. Engineering education is not as popular today as it should be given the spread of technology in society. However, it is not as exciting to disassemble a modern digital alarm clock as grandmother’s old clock! Technical devices in our everyday life are no longer transparent. The function of a grandmother’s clock may be observed, i.e. the mechanical design with rotating toothed wheels and springs etc. are clearly visible; this is not the case with a

modern alarm clock which only contains an IC chip. It has been reported that most teachers in, for example, Swedish nursery schools have not followed any form of technical course as part of their formal training. The ultimate goal of our research at BTH is ubiquitous physical experimental resources accessible 24/7 for everyone as a means of inspiring and encouraging children, young people and others to study engineering and become good professionals or to be used as a means of life-long learning for teachers and other professionals.

V. CONCLUSIONS

It is possible and useful to open a local traditional laboratory for undergraduate education in electronics as a supplement and complement to a laboratory with face-to-face supervision. It is a way to increase opportunities for students to perform physical experiments and compensate for the reduced number of experiments during the last decades without incurring any increase in cost. It is also possible to share laboratory resources among teaching organizations. Simulations are both cheap and useful for professional designers but are not an option for people who want to test the accuracy of physical laws or cannot cope with the abstraction level the simulators represent. The open electronics laboratory at BTH is used in ordinary courses for both distant learning students and campus students. Clearly it is possible to extend the remote operation and control concept to the mechanical domain. A prototype for an open laboratory for vibration experiments has been tested in a regular signal processing course at BTH. A project, VISIR, is currently proposed to further develop such laboratories in cooperation with universities and other organizations. The goal is an international standard, enabling teams worldwide to jointly expand and develop this powerful approach by using a standardized software and equipment platform.

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