Low Cost Implementation of Remote Lab with Large Number of Configurations for a BJT Amplifier

http://dx.doi.org/10.3991/ijoe.v7iS1.1723

Dag A. H. Samuelsen and Olaf H. Graven
Department of technology, Buskerud University College, Kongsberg, Norway

Abstract—**This paper demonstrate how to construct an advanced yet low cost remote lab for experiments for an module in analogue electronics at an electrical engineering course at second year bachelor level. The remote lab is designed for running experiments on a normal BJT common emitter amplifier circuit, while maintaining the possibility for the students to use a wide range of different setups. The main reasons for using remote lab are the opportunity to give the students the chance to focus on the theory for the laboratory and not setup problems, in addition the availability of the exercise is 24/7 and not dependent on the opening hours of the physical laboratory.**

Index Terms—**Remote laboratory, BJT, amplifier, experiments**

I. INTRODUCTION

As part of a bachelor degree in electrical engineering, students have to complete several laboratory assignments. There are several different aims for these assignments, but basically the students receive training in a number of skills: setting up prototypes of circuits on a breadboard, troubleshooting circuits, identifying faulty as well as working components, reading and understanding circuit diagrams, achieving an intuitive understanding for the complex relations between currents and voltages in different circuits, among others.

Having such a high number of different aims for a single laboratory or a set of similar assignment has a negative impact on the effectiveness of the exercise, in that it is difficult to adapt the training in specific areas to the needs of each student, meaning that a student might put too little or too much effort into solving the assignments due to problems that may or may not arise during the work on the assignment. Specifically, the authors have over several years experienced the following situation in many laboratory groups: The students are given an assignment containing a description of the tasks to complete. The students then start collecting components according to the component list and set up the circuit on a breadboard. Students at this level then often do errors, both in understanding the schematic and in doing the connections on the breadboard. In addition, the components might have been broken either by the current student group, or by a previous group. When the circuit does not behave the way the students expected, they immediately suspects errors in the connections, and they start a very tedious process of going through each connection. When success fails to come, the components are suspected, and new components are brought in instead of the old ones.

It might be argued that this is good, because the students receive training in troubleshooting, but it is the authors' opinion that this is not entirely correct. One problem is that the students use a relatively large amount of time on the troubleshooting, draining the students of both available time and of cognitive resources that should have been used on circuit understanding. Moreover, for troubleshooting to be effective, a more advanced strategy than simply checking all connections must be utilized. For this to be possible, the students must gain the intuitive understanding of how circuits behave, and it becomes immediately clear that we have a sort of chicken-and-egg problem, where the students have to do experiments on a number of circuits in order to gain the understanding of the circuits, and at the same time is inhibited in this training by the quite large amount of resources, both time and cognitive, spent on doing the troubleshooting the ineffective way.

The idea now is to separate training in the different disciplines on separate assignments, so that training in circuit understanding can be done without being limited by troubleshooting, Students at the authors' university are given very simple laboratory exercises at the start of the module, in order to receive training in troubleshooting and doing connections on a breadboard, while keeping the complexity of the circuit on a simple enough level to be able to do effective troubleshooting.

For more advanced circuits, a remote laboratory is set up for the students to do the laboratory exercise. A possible alternative to a remote laboratory could be normal simulations, as is done successfully by Basher et.al. [1], Alam et. al.[2] in thermal fluid science, and by Palanki and Kolavennu [3] as control of a process, but simulation training is a separate skill students should receive training in. More important, a simulation gives a presentation of a models behaviour in the simulation program, not being able to correct represent all aspects of a circuit's behaviour, such as the effect of circuit board layout, parameter distribution between different components of the same type and brand, temperature effect on semi-conductor devices, and so on. Using very advanced models might account for one or two of these effects, but running such advanced models on student's laptop computers is not practical as the computing time will be measured in hours, not minutes.

A remote laboratory is a physical circuit with signal sources and measurement units connected, and running an experiment on a remote laboratory takes time equal to the time it takes to run the circuit in real-time. For most circuit types, this is done in a fraction of a second. This combined with the users being able to change component values by clicking buttons in a web interface, gives the students the opportunity of running the experiment several times in just minutes, allowing for very deep investigation of the effect of different component values.

Other challenges of running traditional laboratories are high demand on resources, significant maintenance costs, and that such assignments are impossible to deliver in a distance education environment. Virtual and remote laboratory experiments represent a valuable addition for educational laboratories.

II. THE REMOTE LABORATORY SETUP

A remote laboratory installation is highly complex when compared to the normal physical laboratory setup for doing an experiment. The complexity comes as a result of several factors:

- The experiment should be possible to do with a number of different components and component values. The component exchange requires some sort of switching element that can be controlled by the computer controlling the experiment, without introducing new, undesired properties of the circuit, i.e. high resistance, non-linear behavior, etc.
- The experiment needs to be accessible from a remote location, using the internet. This requires a web server and interface between the physical experiment and the web server.
- Most experiments need some sort of signal source capable of generating any desired signal as input to the circuit in the experiment, and an acquisition system for doing high quality measurements at a data rate high enough for capturing the circuits' response to the input signal.
- Measurements must be done without any more than insignificant impact on the signals in the circuit

A. *Physical installation*

The experiment presented in this paper uses a bipolar-junction transistor (BJT) in a common emitter small-signal amplifier circuit. A circuit diagram for the basic amplifier is shown in Figure 1. Many amplifier properties may be investigated using a circuit of this type. Although the students are encouraged to expand on the initial assignment, the assignment focuses on the following items:

- DC-voltage or bias point voltages.
- Attenuation of the signal from the signal source to the base point of the transistor.
- Amplification of the signal from the base point of the transistor to the output, as well as total amplification.
- Effect of adjusting the Q-point.
- Effect of changing value of the emitter capacitor.
- Effect of loading of the amplifier, also in combination with the selected value of the collector resistor.

This list of training elements sets some of the requirements for the functionality of the remote laboratory. It should be possible to log all voltages in the circuit, and present both steady state values and graphs. All resistor and capacitor values must be possible to change from one trial to the next, using the remote web interface. This requirements list is then used when deciding on the physical implementation. The remote laboratory installation should also be realized using a low cost solution, so that several installations can be made from a relatively limited budget.

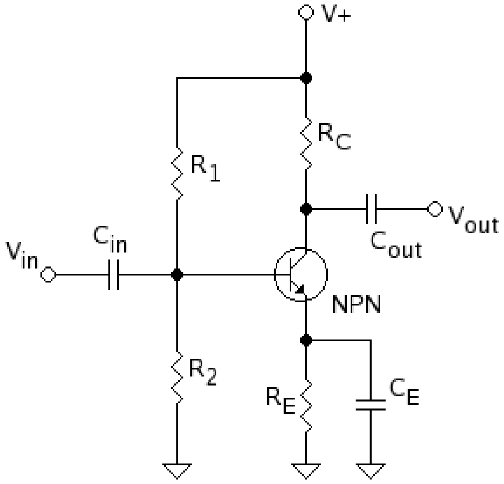

Figure 1. Schematic for basic BJT common emitter amplifier.

For changing resistor values, several solutions exist. A digitally controlled solid state potentiometer could be an alternative to set resistors R1 and R2. The main problems with this solution are high output resistance and limited possibility to conform to one of the E-series resistor values. Relays are not desirable because of high cost and large space requirement which gives large inductance due to long wires on the circuit board and large stray capacitance effect between other parts of the circuit. A third option is to use analogue solid state switches [4] or multiplexers [5], in combination with external resistors. The advantage of these elements are relatively low switch resistance (<100Ω), low internal capacitance (<200pF, combined), and good matching between components (typical 5%). It is now easy to set up the standard E12 series (or any other series) of resistor values, using 16 different values of resistors. If more than 16 different values are desired, 2-4 multiplexers can be set in parallel. Using more than 5 devices can lead to significant stray capacitance and is not recommended.

An obvious extension of this is to use analogue switches for selecting capacitor values. Here, it is chosen to use analogue switches rather than analogue multiplexers, as the commercially available switches [6] have a significant lower on-resistance than the commercially available multiplexers. This is important due to the difference in magnitude of the ac- and the dc-currents in the amplifier, especially in the emitter capacitor, where the transients in the capacitor can be more than twice the size of the current flowing through the emitter resistor. Higher currents means larger voltage drops, and in order to compensate for this extra voltage drop, switches with a lower internal resistance is selected. An obvious question then is: Why not use these switches everywhere in the circuit? The answer to this lies in the component cost. In order to keep the cost of this installation low, switching elements are selected on the basis of needed internal resistance. Multiplexers give a larger number of different values than analogue switches at the same cost.

An interesting side-effect of this switching of components is that even the topology of the circuit can changed remotely, allowing the same circuitry to be configured as different amplifier types. When the emitter capacitor is removed, the circuit actually changes type from the common emitter topology. The difference can be seen in figure 4 and 5, where in figure 4, the emitter capacitor is set to 100µF, while in figure 5 the capacitor is removed completely, where the effect of this can clearly be seen from the output signal amplitude.

For the acquisition interface between the experiment and the web server, a National Instruments PCI-6221 acquisition board is used. This card has a sufficient number of analogue input channels, fills the need for analogue outputs and digital I/O channels, and has a reasonable cost. There are however several parts of the interface between the acquisition card and the experiment where some sort of adaptation is needed. Two important adaptations are presented below:

The maximum voltage on the analogue inputs is 10V (positive or negative relative to system ground). For the circuit to be somewhat realistic, a supply voltage of 15V should be used. This means that voltage dividers made from precision resistors have to be set between the measurement point and the acquisition card. This introduces a new problem: Even though the input bias current on the analogue inputs is negligible, the acquisition card (due to the low cost) only have one analogue to digital converter (ADC), and uses a multiplexer to select one of the analogue inputs. The stray capacitance of this multiplexer cause a relatively large current to flow in or out of the analogue input in the few microseconds it takes to change the voltage between inputs, meaning the source of the measurement should have a very low output resistance, while the measurement points should have a negligible effect on the circuit's performance. The solution to this problem is to install operational amplifiers configured as voltage followers between the voltage divider and the acquisition card.

There are a limited number of digital I/O lines on the card. Each of the analogue multiplexers and switches use from 4 to 6 digital outputs each. It is not possible to connect each of these directly to the acquisition card, as the number of I/O lines required is many times the number of I/O lines available. Instead, digital buffer circuits are installed, forming a simple bus system with separate data, address and control bus. One buffer circuit is used for each switch or multiplexer, allowing for a large number of switches.

A prototype of the system is shown in figure 2, while the switching element in the form of a analogue multiplexer and external resistors is shown in figure 3. The hardware implementation described in this section represents one of two parts of the implementation. The software implementation elements in the experiment presented in the next section makes the interface between the control system and both the experiment and the web user, in addition to the actual control system.

B. *Software implementation*

The hardware used in this remote experiment is controlled by National Instruments LabVIEW [7]. In addition to that the hardware is controlled by LabVIEW the students access the laboratory via webpage with an embedded National Instrument LabVIEW remote panel application.

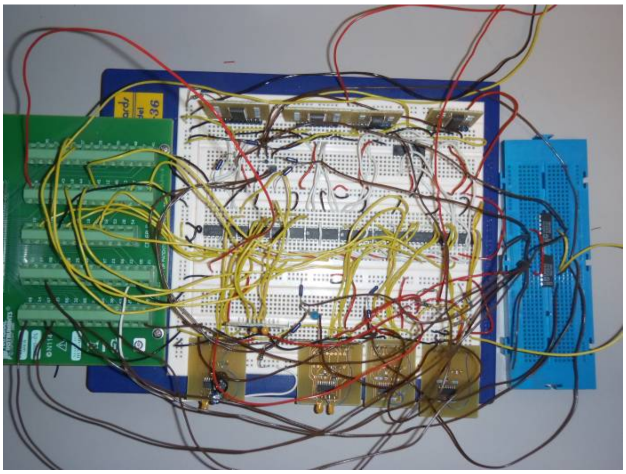

Figure 2. Prototype of the physical part of the remote laboratory installation

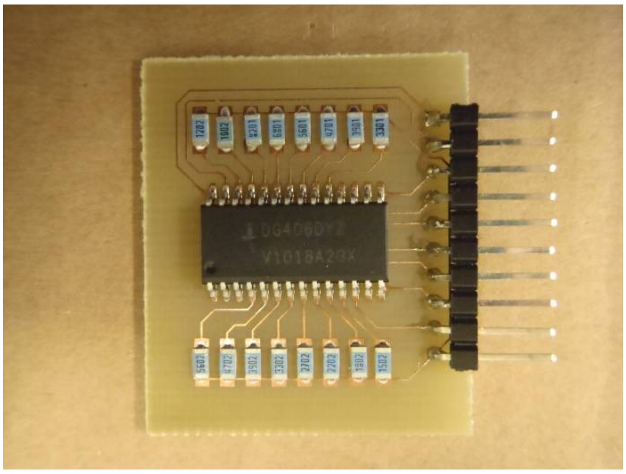

Figure 3. Analogue multiplexer with external resistors.

LabVIEW, short for Laboratory Virtual Instrument Engineering Workbench, is a graphical programming system that has been adopted as the standard for data acquisition and instrument control software. LabVIEW is a general-purpose programming system with extensive libraries of functions for data acquisition, instrument control, and data analysis.

The software implementation has two parts, one is focused on presenting a GUI (Graphical User Interface) for the students that are familiar that will aid their understanding of the theory behind the function and not be as true to real work instruments. The other part is focused on controlling the hardware, firstly setting up all the hardware and then acquiring the measurements. The graphical user interface is in use all the way through, but requires user input at the beginning, for setup, and at the end when the students are free to investigate the measurements.

Below follows a complete run thought of one cycle: setting values, acquiring measurements, and displaying the results.

To start off, the information is entered into the experiment by selection values from the drop down boxes displayed under the circuit diagram, as can be seen in figure 4. The option of allowing the users to enter the informa-

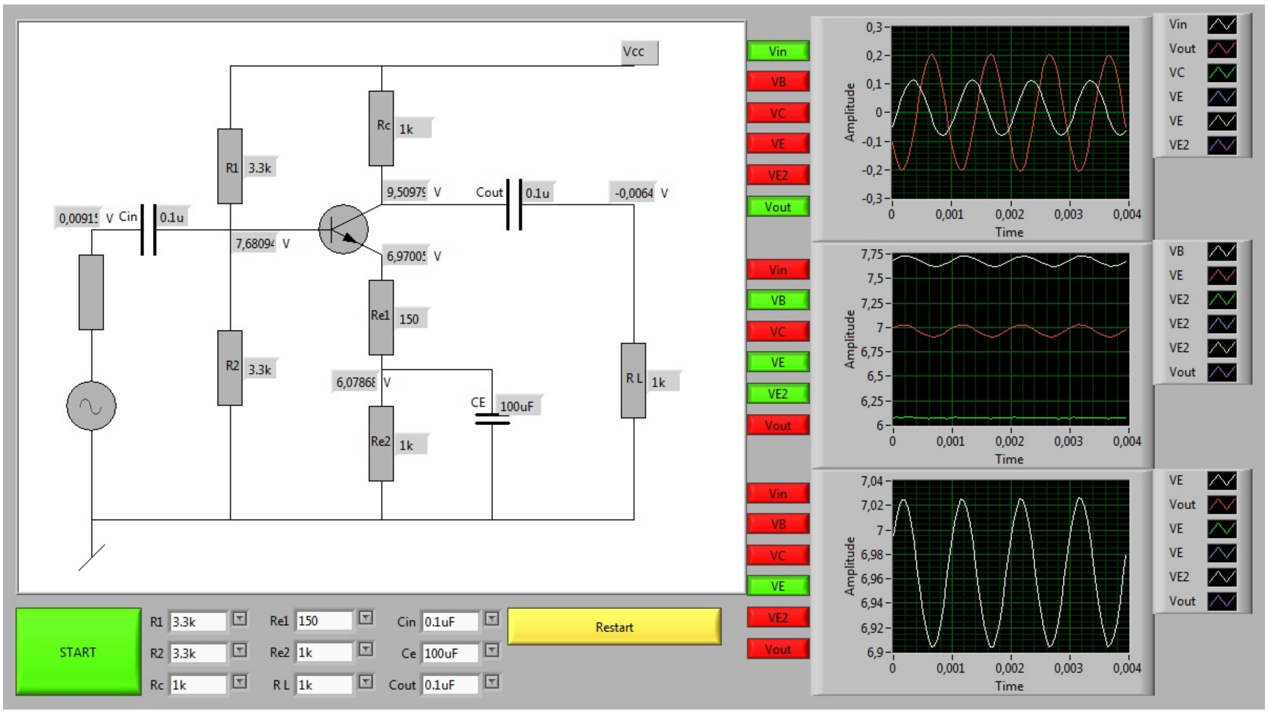
R1 3.3k
R2 3.3k
Rc 1k
Re1 150
Re2 1k
R L 1k
Cin 0.1uF
Ce 100uF
Cout 0.1uF

Figure 4. Screen capture of remote laboratory interface when selecting the 100µF emitter capacitor.

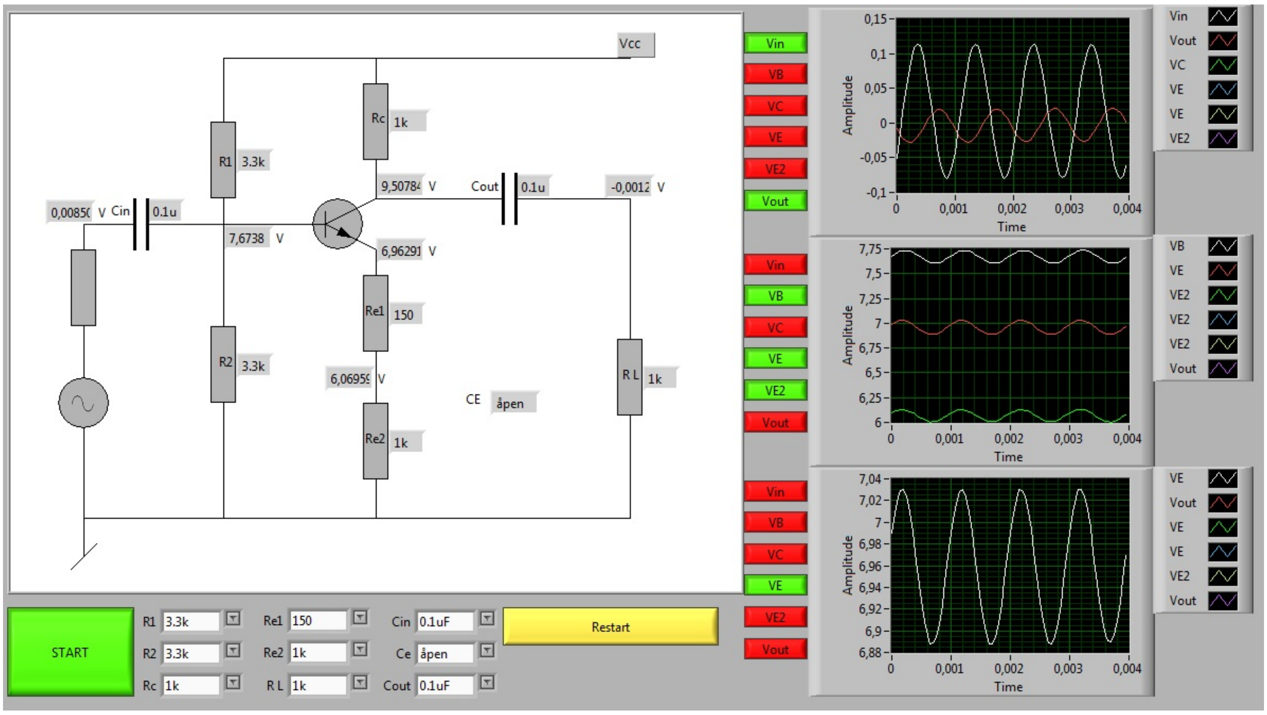
R1 3.3k
R2 3.3k
Rc 1k
Re1 150
Re2 1k
R L 1k
Cin 0.1uF
Ce åpen
Cout 0.1uF

Figure 5. Screen capture of remote laboratory interface when deselecting the emitter capacitor.

tion and then adjust it to the nearest values was considered but rejected. It was the opinion of the authors that entering a value that is then adjusted would frustrate more that it would aid.

When the student is happy with the selected values for the circuit, the student selects: start. The software then goes through all values and sets up the circuit. Due to the large amount of possible selections the circuit is designed with a data buss type setup and enables lines for all the possible selections much like an address buss. The software transfers all the setup information to the different multiplexers one by one. This setup was selected in order both to accommodate a large selection of components and to make the experiment easy to expand. After all values are set the software will set power to the circuit and wait until all values are stable. A wait time of 300 ms was selected. The Q values are then measured and displayed in the circuit diagram for the student. Once this is done the signal is applied to the input and the “real” measurement are done.

This procedure of setting up the circuit, waiting for stable values then applying the signal and performing measurements does take a bit of time. Since the current students seems to have an attention span of about 1 second the software will keep the student informed about what is going on at all time via a status field in the user interface.

After experiment is run and the application has registered all the measurements, the students are free to display which ever signals in any combination they desire. In the web interface in figure 4, there are a total of three graphs simultaneously at the students' disposal. Each of these three graphs can display any or all measurements. This selection is done via buttons that can be checked or unchecked. Thus, giving the students an opportunity to quickly combine the signals they want, it was the authors' intention when designing the user interface in such a way that the students was encouraged to "play" with the circuit. The traditional way of selecting signals before running the experiment, though encouraging the students to think through what results they want displayed and in what combination is more in line with a real laboratory, it was decided that the selected approach would offer a better opportunity for learning the theory.

The graphs used to display the results are standard graphs included with LabVIEW. These graphs offer a multitude of options for the students on zooming by selecting a range of data, thus giving them a clearer view of signals. The students can also zoom in on the level of values to gain an accurate reading.

C. *Description of the assignment*

The main objective of the assignment is to give the students a thorough understanding in how electronic circuits actually work. The ultimate goal is for the students to achieve an intuitive feel for how a certain circuit would behave when subjected to an input signal. There are several types of training used in achieving this goal, and a student should choose a strategy involving several training elements rather than focusing on one element alone. This makes it important to be able to adapt the amount of training to each student's need.

The basis for understanding is the theory, given in class and/or through the use of the textbook. But theory will only get you part of the way. Only through extensive use of practical experiments and simulations, the true complex nature of the semiconductor circuits can be revealed.

The use of the remote laboratory is only as part of a complete exercise program, intended to give the students training in a number of skills, as described in the introduction. The assignments are therefore often paired with other activities. For instance, in the case of the BJT amplifier circuit, more simple circuits, are done using physical laboratories, where parts of the circuit appears in the BJT amplifier, while the complete amplifier circuit, exactly as it appears in the remote laboratory, is also part of the simulation training, in order for the students to compare the results from the simulation training with the results from a physical experiment.

The laboratory has been run on a group of students (~45), as part of an analogue electronics module in electrical engineering education. The students were monitored when using the laboratory and their opinions after using the laboratory were orally communicated. A large group of the students found the concept of this type of remote laboratory attractive for a number of reasons, the most important being accessibility both in terms of time and location. The students did also appreciate the ability to do several trials in succession within a short time frame, allowing them to further investigate the circuit's behaviour. A large obstacle, however, was the problems related to the software needed to run the LabVIEW environment on the PCs. In order to use the LabVIEW server and hardware, a run-time version has to be installed on each computer connecting to the laboratory. This gave a large amount of problems, mostly related to the antivirus software installed on the computers.

The software installation requires administrative privileges on the computer, which many did not have for various reasons. When the software was installed, the actual connection to the remote laboratory server was inhibited by the antivirus software. Opening access to the server also required administrator privileges. This was seen as a huge obstacle when running the laboratory on very different computer environments.

The authors has identified that a main shortcoming of most of today's remote labs are a lack for support for learning. Software like the previously mentioned LabView is created to be used in an industrial environment, controlling, monitoring production equipment or similar operations. It is a convenient tool for educators to implement remote labs for two main reasons: It is often a part of the available software for a university simply due to the fact that it is part of the curricula for many engineering education degrees. It is a widely used industrial tool, which is advantageous for the students to know how to use. The other reason is that it is a simple to use and powerful tool.

The process of creating a remote lab environment with learning support is complex and requires several steps. First it is necessary to capture some information on how the users utilise the functions available to them and what strategy they employ in solving the assigned lab-work. The information that needs to be captured is who performed the experiment, how the setup looked like and what the results are. Information about what strategy individuals are using, and how different users are progressing with the experiment can then be generated for these captured data by comparing different experimental runs by a single user over time. A user may attempt multiple different setups in quick succession indicating that a trial and error approach is being used. Similarly multiple attempts at longer time intervals may indicate a struggling user, attempting to calculate or use other sources to arrive at a more correct setup.

It is important that a set of rules are developed that can be formulated into rules and included in the remote lab environment. These rules will then give the environment the ability to detect these predetermined behaviours and notify the instructor. The information captures about the users will form the basis for the identification of more behaviour and the development of a more complete and complex rule-set.

It is also necessary to ensure that captured information about the users is not made available to the wrong persons. The information captured will not be of a highly sensitive nature, but any information relating to individual students must be kept secure and only be made available to the identified persons, like a lecturer/instructor in a module.

III. CONCLUSIONS

A setup of a remote laboratory installation has been described, where users can set up a large number of different configurations, and quickly observe the circuits' response to different component values. The process of connecting components, measurement units and signal sources, as well as troubleshooting and faulty components is removed from the exercise so that the students can focus on one training element at a time, giving them full attention to the understanding of how the circuit actually works, and allows the supervisors to adapt the training program to each student's need for training and practice, reducing the amount of training as he or she fulfils the desired skill level.

As the remote lab is done on real, physical components, the results given are realistic, and the difference between a simulation and a real experiment can be identified. If more complete models are used, simulation time when run on normal computers takes a stupendous amount of time, while the running of the remote laboratory setup is done within milliseconds, each time.

The remote laboratory has been implemented using relatively low cost components, and the development time is limited, allowing the laboratory to be constructed within a reasonable time frame. The laboratory is fully automated, and is run on a 24/7 basis. This gives the students the opportunity of doing the assignments at the time and place of their choice, which is useful when students have competing activities, besides the study.

The laboratory has been successfully tested on a group of students, and the feedback is clear that it was useful to separate out the "side activities". This type of setup allowed them to give full attention to the problem of understanding. We have thus showed that this is both a viable and even preferred way to present some of the laboratory exercises in a module.

A. *Further work*

The current setups uses as previously mentioned LabView, a tool that is created to be used in an industrial environment, controlling, monitoring production equipment or similar operations. The authors would like to see special remote laboratory software developed that are as easy to use for implementation of new remote laboratories as LabView but that also offers extended support for pedagogical issues.

The current setup has the option for the user to select the topology of the circuit, class B or class AB, in addition also a set of different transistors setups within each topology. It is desired that instructors should have the possibility to setup a random choice of transistors for each series of experiment the students runs.

The authors also plan to create a new implantation of the prototype implementation shown in this paper, and offer this to groups of students in the summing semester.

REFERENCES

[1] H. A. Basher, S. A. Isa, and M. A. Henini, "Virtual laboratory for electrical circuit course," in Proc. IEEE SoutheastCon, 2004, pp. 330–334.

[2] F. Alam, H. Tang, and T. J., "The development of an integrated experimental and computational teaching and learning tool for thermal fluid science," World Transactions on Engineering and Technology Education, vol. 3, pp. 249–252, 2004.

[3] S. Palanki and S. Kolavennu, "Simulation of control of a cstr process," International Journal of Engineering Education, vol. 19, pp. 398–402, 2003.

[4] Maxim IC, Maxim IC, Application note 638: "Selecting the right CMOS analog switch", retrieved from: http://pdfserv.maxim-ic.com/en/an/AN638.pdf, 01.08.2010.

[5] Intersil, Intersil, Datasheet FN3116.9: "DG406, DG407", retrieved from http://www.intersil.com/data/fn/fn3116.pdf, 01.08.2010.

[6] Maxim IC, Maxim IC, Datasheet 19-2184: "10Ω, Quad, SPST, +3V Logic-Compatible Analog Switches", retrieved from: http://datasheets.maxim-ic.com/en/ds/MAX312-MAX314.pdf, 01.08.2010

[7] National Instruments, National Instruments, LabVIEW, retrieved from: http://www.ni.com/labview/

AUTHORS

D. A. H. Samuelsen is with Buskerud University College, Department for Technology, Kongsberg, Norway (e-mail: dag.samuelsen@hibu.no).

O. H. Graven is with Buskerud University College, Department for Technology, Kongsberg, Norway (e-mail: olaf.hallan.graven@hibu.no).

This article is an extended version of a paper presented at the International Conference EDUCON2011, held in April 2011 at PSUT, in Amman, Jordan. Received June 25th, 2011. Published as resubmitted by the authors August 2nd, 2011.