EXPERIENCES FROM DESIGN AND USE OF A GENERAL PURPOSE PLATFORM FOR LOW-COST REMOTE LABORATORIES IN ELECTRONICS

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ABSTRACT
A low-cost platform for easy setup of remote laboratories has been developed, and the experiences from the implementation and use of this are reported in this paper. The remote laboratory platform is designed with focus on experiments for a module in analogue electronics on bachelor level. The platform allows a university to setup a range of experiments with relative little effort on the hardware side.

KEY WORDS
Remote laboratory, analogue electronics.

1 Introduction

A remote laboratory is a remote controlled experiment that uses real hardware on which the experiment is performed. This as opposed to virtual or simulated experiments that are run purely in software, or hand-on experiments which is the classical way of running experiments. Examples of the first type can be found in [1-4]. Common for all of these are the highly specialized hardware needed to create the physical part of the laboratory. Much resources are put into creating this hardware, making this solution less attractive for many universities. The setup described in this paper focuses on a hardware solution that makes the use of remote laboratories for engineering education, specifically in an analogue electronics module, easily available for the universities at a low cost.

The use of remote laboratories in universities has shifted from the initial phase where investigation of the technology is the focus, to remote laboratories playing a major role in the laboratory assignments students are given. This is expected as they have been found to offer benefits both to students as well as to the universities. The main motivation for universities to use remote laboratories is the reduced maintenance costs due to the fact that the equipment can be protected from destructive use and because the wear and tear of the equipment is reduced.

Using remote laboratories can to a large degree eliminate the cost of running laboratories for large groups of students, which allows the universities to spend their resources in areas where students need extra follow-up. There are drawbacks to the use of remote laboratories, such as reduced contact with the students and lack of hands-on experience. Still, remote laboratories are preferred, mainly because of the economic benefits. Students’ motivation for accepting the increased use of remote laboratories, despite the drawbacks, is elements like 24/7 access to the laboratory, at home or school at their choice. It is reasonable to assume that remote laboratories will continue to be implemented at institutions around the world for years to come.

Remote laboratory implementations can be separated into two main parts: the software frontend and the hardware backend. The software might also contain a software backend, usually database and user control, but further description of this is regarded as beyond the scope of this paper. The software tools are currently under development by large parties such as MARVEL[4], iLab[5], and Lab2Go[6], and standards for this are still under development.

The challenge for many smaller universities and schools is that the hardware backend is mostly done at the individual institutions, either by purchasing expensive equipment and modify it for their use, or making it from scratch creating the necessity for the institutions to spend a significant amount of resources on the development of the hardware backend. This is for many institutions not an option due to lack of resources or time, and the solution is often to buy off-the-shelf components that are built for other purposes than the remote laboratory. This is the case with most industrial focused systems like the National Instruments hardware/software solutions. These systems offer a low entry level to the design of control/acquisition system in general, but offer a very low degree of flexibility for institutions to develop laboratories that are tailored for the specific modules that the students follow. The authors therefore saw a need for a remote laboratory platform that
is both low-cost, easy to build and adaptable with regard to reconfiguration as the modules and hence, the design of the remote laboratory changes.

It can be argued that running physical remote laboratories is unnecessary, as these can be run as simulations instead. The focus of this remote laboratory however, is an analogue electronics module. In this setting, many of the design principles are set to deal with the non-linearities and imperfections of semi-conductor devices, which are difficult to reveal using simulation only. For instance, the actual amplification factor of a BJT or FET-transistor can vary significantly from one device to another, even in the same production batch. This leads to the need for creating a bias circuit that stabilizes the DC and AC-amplification in analogue amplifiers. Using the remote laboratory setup presented in this paper, the transistor can be selected randomly from a pool of devices, having the natural distribution of current amplification, which makes the amplifier saturate for some of the transistors, but not all, if the bias circuit does not stabilize the amplification factor or the quiescent point sufficiently. Other aspects not easily covered by simulations are the measurement noise, and temperature changes leading to non-linear parameter changes in the components, especially in the semi-conductor devices. In addition, very accurate simulations requires much processing power, leading to longer waiting times for the user, while the experiments presented in this paper takes up to a few seconds to run.

2 Design of the remote laboratory platform

2.1 Requirements

This paper is based on a previously published paper [7]. An overall design specification has been set up before the design process started, where the following requirements were defined:

- The design should be modular in the sense that it should allow for easy reconfiguration by adding or removing more or less standardized components, as required by the laboratory setup.

- The platform should have a motherboard-daughterboard design. The motherboard must be able to accommodate the circuit boards for building the circuit under test. These are from now on referred to as component boards.

- The motherboard should have connectors for 14 component boards. Connectors should be according to a defined standard.

- The motherboard should have connector for an adapter to connect to the acquisition module. A set of adapters must be designed for connecting one of the many different acquisition solutions to the motherboard. This is done in order make the platform easy adaptable to the different acquisition solution at the choice of the institutions.

- The component boards will constitute one or more of the components of the circuit to be tested in the laboratory. They should also confer to the interface description of the motherboard’s connectors given in table 1.

- The components of the test circuit that are implemented in the component boards should be configurable through the use of a simple data and control bus.

2.1.1 Motherboard setup

The motherboard design of the original paper has been further developed in order to create a board layout that will give lower production costs. The requirements are still fulfilled, but the placement of some components has been changed. The board layout is shown in figure 1, where the 14 connectors for the experiment component boards can be seen. Each component board constitutes one or more components with two or three connection points combined. Typically, a resistor will have two connection points, while a transistor or voltage divider will use three connection points. Devices with more connection points besides negative and positive power supply and ground, is not supported by this setup, meaning that operational amplifiers will be supported if their power supply pins is connected to the common positive and negative power supply or ground.

In order to configure the interconnection of the different components of the laboratory circuit, a separate configuration block is used. In figure 1 this can be seen as the connector in the center of the card. The configuration block connector is physically located underneath the card. This might be regarded as a non-optimum placement, but is done deliberately in order to allow more easy access to the pins...
Table 1. Pin allocation for configuration block

<table>
<thead>
<tr>
<th>Type</th>
<th>Purpose</th>
<th>Short name</th>
<th>Number of pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>Power supply for the lab circuit</td>
<td>V+, V-</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Ground for lab circuit</td>
<td>AGND</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Logic power supply</td>
<td>VCC</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Ground for logic</td>
<td>DGND</td>
<td>1</td>
</tr>
<tr>
<td>Analogue</td>
<td>Analogue output from the circuit</td>
<td>AOUT</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Analogue input from the circuit</td>
<td>AIN</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Connections of the circuit</td>
<td>BxCy</td>
<td>42</td>
</tr>
<tr>
<td>Digital</td>
<td>Data bus</td>
<td>DATAx</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Enable control signals</td>
<td>ENx</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Total number of pins</td>
<td></td>
<td>96</td>
</tr>
</tbody>
</table>

Table 2. Pin configuration for the component boards

<table>
<thead>
<tr>
<th>Signal</th>
<th>Pin</th>
<th>Pin</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>+15V Power supply</td>
<td>1</td>
<td>2</td>
<td>+15V Power supply</td>
</tr>
<tr>
<td>Ground</td>
<td>3</td>
<td>4</td>
<td>+5V Power supply</td>
</tr>
<tr>
<td>Data0</td>
<td>5</td>
<td>6</td>
<td>Data1</td>
</tr>
<tr>
<td>Data2</td>
<td>7</td>
<td>8</td>
<td>Data3</td>
</tr>
<tr>
<td>Data4</td>
<td>9</td>
<td>10</td>
<td>Data5</td>
</tr>
<tr>
<td>Data6</td>
<td>11</td>
<td>12</td>
<td>Data7</td>
</tr>
<tr>
<td>Analogue connect 0</td>
<td>13</td>
<td>14</td>
<td>Data Enable</td>
</tr>
<tr>
<td>Analogue connect 2</td>
<td>15</td>
<td>16</td>
<td>Analogue connect 1</td>
</tr>
</tbody>
</table>

Table 3. Component values for the component boards

<table>
<thead>
<tr>
<th>Component</th>
<th>Selectable values</th>
<th>Socket</th>
</tr>
</thead>
<tbody>
<tr>
<td>C\text{IN} and R\text{S}</td>
<td>C\text{IN}: 0.1\mu F, 0.15\mu F, 0.22\mu F, 1.0\mu F, 2.2\mu F, 4.7\mu F, 10\mu F R\text{S}: E12 series from 1.8k to 33k</td>
<td>S8</td>
</tr>
<tr>
<td>R\text{L} and R\text{C}</td>
<td>Both: E12 series from 1.8k to 33k</td>
<td>S7</td>
</tr>
<tr>
<td>C\text{OUT} and R\text{L}</td>
<td>C\text{OUT}: 0.1\mu F, 0.15\mu F, 0.22\mu F, 1.0\mu F, 2.2\mu F, 4.7\mu F, 10\mu F R\text{L}: E12 series from 1.8k to 33k</td>
<td>S9</td>
</tr>
<tr>
<td>R\text{R1}</td>
<td>E6 series from 68ohms to 3.3k</td>
<td>S11</td>
</tr>
<tr>
<td>C\text{E}</td>
<td>Open, 0\Omega, 0.1\mu F, 0.15\mu F, 0.22\mu F, 1.0\mu F, 2.2\mu F, 4.7\mu F, 10\mu F</td>
<td>S13</td>
</tr>
<tr>
<td>NPN</td>
<td>4 devices of type 2N3904 selectable</td>
<td>S12</td>
</tr>
</tbody>
</table>

2.1.2 Analogue input buffers

The connector next to the configuration block is the connector for the data acquisition module. This is designed to allow an adapter to connect the motherboard to many different acquisition solutions - from the industry standard NI-DAQ series [8] to the simple, low cost micro controller based solutions like the PIC18 series [9] from Microchip and the different variants of Arduino [10]. The type of connector selected allows also here for using straps or other temporary connections in order to facilitate the prototyping phase.

A common problem encountered when utilising low cost acquisition solutions where an analogue multiplexer is used to route analogue signals from several sources into a single analogue to digital converter (ADC). The problem is caused by the significant input capacitance of the sample-and-hold circuit placed after the analogue multiplexer in the ADC. In DC analysis, the ADC has a very high input resistance, giving an input bias DC-current in the order of a few micro- or nano amperes. In AC analysis, however, the dynamic characteristics of the analogue input are much different due to the already mentioned input capacitance. Practical analogue inputs of this type have relatively low input impedance, resulting in crosstalk between the different channels of the ADC. As a consequence of this, between each of the high impedance analogue signal sources and their respective analogue input to the ADC, input buffers in form of voltage follower coupled operational amplifiers are installed on the motherboard. In the present layout, these are not possible to bypass.
2.1.3 Power supplies

For connection of an external power supply, the small connector at the bottom of the circuit board of figure 1 has connections for 15V or 12V, in addition to ground pins. Digital VCC power supply is also included. Filter capacitors are mounted on the motherboard for reduction of EMI.

2.1.4 Component boards

The values or type of the components on the component boards are selectable by using the switching elements on the component boards. The simple scheme used is shown in the schematic of figure 2 and 3, where the connector to the motherboard is found on the left side. This strategy is previously demonstrated in [11] where a remote laboratory for a small signal amplifier using a BJT is built using remote configurable resistors and capacitors. The digital buffer circuit (‘573) is used to store the configuration data that is transferred via the data bus to all component boards. Separate enable signals for each board are used in order to avoid timing problems and glitches when using a simple bus topology. Creating a more complex bus topology is possible, but would cause tremendous obstacles when programming NI-DAQ in LabVIEW [12], when this is chosen as the programming solution.

The component realized in figure 2 is two resistors, each with 16 possible values, forming a voltage divider circuit. The configuration data is fed directly to the switching element: the analogue multiplexer u20 and U21 - DG406 [13]. This card can also be seen in figure 4 as the leftmost card. All possible resistance values are implemented as normal resistors that are switched in and out at the choice of the user. Table 2 shows the pin assignment for the component boards.

3 Implementation of the remote laboratory

The proposed system is used to set up a remote laboratory for experiments on a common emitter BJT amplifier, and the experiences of this trial are reported in this section. The general schematic for the BJT amplifier is shown in figure 5. In order to create a complete, usable circuit, the remote laboratory also includes a signal source with programmable inner resistance, and a programmable load resistor. The remote laboratory setup is now described. The laboratory setup is made for a remote lab with a standard
small signal common emitter BJT amplifier circuit. The components list is found in table 3.

In this setup 7 component boards are used for the implementation of the amplifier. The modules used, and their function is listed in table 3, where also the possible component values are shown. After the component cards are installed in their respective sockets, shown in the picture of figure 6, the configuration block is used to create the interconnect needed to form the complete circuit, as shown in the picture of figure 7. As can be seen in the picture, in this prototyping phase of the setup normal wire wraps are used for the interconnections, while temporary wires are used for measurements. Measurements are also done using the buffer circuits implemented on the circuit board.

3.1 Controlling the experiment

Two types of micro controllers are used to set up the experiment: A demo card for a Microchip micro controller, and an Arduino [10] board for an Atmel micro controller. In both cases, simple programming allows the experiment to be programmed. The experiment is first run with a standard signal source connected to the input buffer of the experiment board. Each of the micro controllers are programmed to set up the experiment with two different run. In the first case, shown in figure 10, the emitter capacitor is set to a value of $1.0 \mu F$ and in the second case, shown in figure 11 the emitter capacitor is set to a value of $10 \mu F$. In both figures, the first graph shows the input signal applied to the experiment board. The second graph shows the base
voltage of the transistor, the third graph shows the collector voltage, and the forth graph shows the emitter voltage. No alterations other than the reprogramming of the microcontroller have been done between the two runs, showing that 1. The experiment behaves as intended when subjected to an input signal, and 2. The experiment setup can be changed by the microcontrollers at will. Both of these are necessary for the experiment to function as a remote controlled laboratory.

3.2 Signal sources

Two trials have been carried out regarding signal sources. Besides using an external connected signal source, an interesting approach would be to use the microcontroller both for controlling the experiment setup and supplying the experiment with an input signal. When using simple microcontrollers there are basically two alternatives to generating an analogue signal: Pulse-width modulation (PWM), or using an external digital to analogue converter (DAC). Both of these approaches have been carried out using the microcontroller from Microchip. The reason for not using the Arduino solution is the maximum speed achievable being quite limited due to the monitoring system of the Arduino platform.

The Microchip microcontroller is programmed to first set up the experiment. Then, a 1x128 table is created for the sinusoidal signal. These values are then transmitted to the experiment. In the first case the PWM module is used to output the signal, while in the second case an external 8-bit DAC is used to output an analogue signal. Initial tests showed that the PWM signal needs heavy filtering to be usable as a signal source for the experiment. An analogue 4th order low-pass filter with critical frequency around 10kHz is set up between the microcontroller and the experiment. In figure 8 the trial with PWM output is shown, where the effect of the low-pass filter is clear. The output signal is however quite noisy, due to disturbances from the surrounding equipment. No artificial filtering in the oscilloscope is however used not to falsify the results. The next trial is shown in figure 9, where the external DAC is used. The first signal shows the original output of the DAC, while the second signal shows the filtered signal, using the same filter as in the first case.

4 Student trials and results

The authors have previously utilised various remote laboratories with students. The basis for all of these laboratory exercises is to aid the student in understanding theory, to understand when a simulation is the preferred tool, and when an experiment needs to be run on real hardware. The students are given simulation training on computers in the classroom on their ordinary computers. No specialised extra powerful or "supercomputers" are available to the stu-
students. However, the development of simulation models and the increase in processing power of computers available for the students means that the line between deciding on when to use simulations and when not to, is constantly moving. Simulation training is combined with remote laboratory exercises, meaning that the same circuit that is used in the remote laboratory is also used in the simulation training. This special combination of remote laboratory and simulation training gives the students valuable insight into how accurate simulations are able to predict how a physical system would behave in the presence of real physical noise (which is not true random), parameter uncertainty, model uncertainty, and temperature dependencies.

As part of a module in analogue electronics several remote experiments was included and all students was encouraged to utilise them, but it was not compulsory. A group of about 50 students were given access to the laboratory. The students were able to get help with the laboratory all the way through their use of it. At the end of the trial period we had a log of the number of different user that had used the remote laboratory and an informal interview was conducted with the students, as far as possible as a one on one, most students did however prefer to give a short oral feedback as a group and where not willing to spend the time a one on one interview would require.

Of the total 50 students that were given access to the laboratory about 25 tried it. The feedback from the students trying the lab was remarkable similar and even more positive than as expected. The students reported that they found the lab easy to work with, and stated that they saw a real advantage in not having to struggle with the physical connections, and avoided a lot of wasted time and frustrations. Access to the web page was for some of them hindered by the antivirus scanners installed on their private computers and let to some initial extra time spent. The authors had added a feature requiring the students to request control of the experiment every 10 minutes in order to stop a single student monopolising the use of the remote experiment. This feature however, was universally disliked and was seen by many students as a bug.

A small group of students, 5 in total, ended up using a couple of the laboratories far longer that was required to fulfil the exercise. Their use can most accurately be described as playing. Most configurations was tested multiple times and the students developed an excellent understanding of how their choices influenced the result. The possibility that one or more of the students spent enough time with any of the laboratories and actually managed to get to such a good understanding was discussed (and hoped for) by the authors before setting up the experiment. But neither expected it to happen. The fact that it did take place and happened to as many as 10% of the students are seen as very encouraging.

5 Conclusion

In this paper experiences from the implementation and use of a platform for low-cost setup of remote laboratories for an analogue electronics module has been presented. The experiences show that the platform is suited for simple setup of experiments and that low cost micro controllers can be used not only for controlling the experiment, but can also act as a programmable signal source for the experiment. The solution with an external, low-resolution DAC gives slightly better quality of the produced signal, when compared to using the PWM-output in combination with the additional analogue filter. It has also been found that the use of pre-made platforms like the Arduino platform are troublesome, in spite of their ease of setup, due to their speed limitations. Investigation of possible ways of increasing the processing speed remains.

References


