

An integrated framework to support remote IEEE 1149.1 / 1149.4 design for test experiments

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Abstract — Remote experiments for academic purposes can only achieve their educational goals if an appropriate framework is able to provide a basic set of features, namely remote laboratory management, collaborative learning tools and content management and delivery. This paper presents a framework developed to support remote experiments in a design for test class offered to final year students at the Electrical and Computer Engineering degree at the University of Porto. The proposed solution combines a test language command interpreter and various virtual instruments (VIs), with a demonstration board that comprises a boundary-scan IEEE 1149.1 / 1149.4 test infrastructure. The experiments are presented as embedded learning objects, with no distinction from other e-learning contents (e.g. lessons, lecture notes, etc.).

Index Terms — Remote / Online labs, LabView, electronics, digital / mixed-signal testing, parametric and interconnect testing.

I. INTRODUCTION

E-learning platforms are now widely used in many academic domains, providing a relevant added value in terms of pedagogical effectiveness. However, e-learning platforms traditionally fall behind teachers' expectations, when it comes to support access to laboratory experiments. This situation is not serious when simulation packages are an alternative to achieve the same educational goals, but such a replacement is not always possible. Particularly in the case of multidisciplinary experiments using easily available devices, it may be simpler and cheaper to set up a remote experimentation workbench [1,2].

Even in the case of non-multidisciplinary areas that use easily available devices, there are pedagogic arguments for preferring remote experiments to simulation packages, since the awareness of reality increases motivation. Whatever the case, it is important to embed the remote experiments into the e-learning platform, instead of isolating them from the accompanying e-learning materials.

Pedagogic issues related to remote experimentation (or indeed experimentation in general) are not however restricted to their integration into the e-learning platform [3,4]. Laboratory experiments are traditionally carried out in the form of group work, and as such any remote experimentation setup must provide adequate tools to enable synchronous communication among the students (that may participate in the experiment from various locations).

The learning effectiveness of remote experimentation is compromised if one or more of these features is not present. It is worth looking into the general requirements that must be taken into consideration when preparing a remote experiment, and to proceed from there to more domain-specific requirements for a given experiment. This paper starts by presenting the selected experimentation domain and then relates it to the corresponding experiment / workbench requirements. The specific experiments that are currently proposed to the design for test students at FEUP are then described. The research topics that are currently under consideration are presented, and a concluding section closes the paper.

II. IEEE 1149.1 / 1149.4 EXPERIMENTS

The experiments that are presented ahead address the test of *mixed-signal* circuits that are compliant with the IEEE 1149.4 standard [5]. Any integrated circuits that are compliant with this test standard have a dedicated test cell associated to every functional pin, which connects the pin to the core when the circuit is in *mission mode* (normal circuit operation), or isolates the pin from the core when in *test mode*. IEEE 1149.4 is an extension of IEEE 1149.1 [6], which defines a similar test architecture that is nowadays present in most *digital* VLSI circuits. The test cells present at digital pins are known as *digital boundary modules* (DBM), and those present at analog pins are known as *analog boundary modules* (ABM). DBMs and ABMs are serially connected to form the *boundary-scan register* (BSR), as illustrated in Fig. 1.

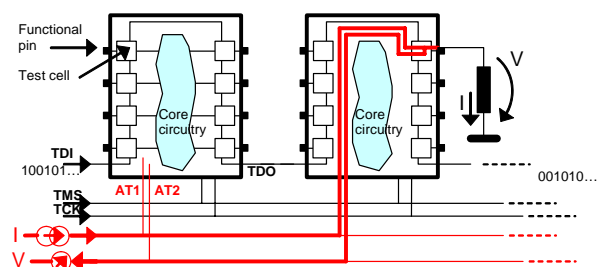


Figure 1. The IEEE 1149.1 / 1149.4 test infrastructure.

The overall on-chip test architecture comprises the BSR and various other data and control registers that are required to support interconnect and parametric test operations. Interface to this on-chip test architecture is done via a digital 4-pin *test access port* (TAP): TDI (test

data in), TDO (test data out), TMS (test mode select) and TCK (test clock). A 2-pin *analog test access port* (ATAP) is present in all IEEE 1149.4-compliant circuits to handle analog signals. One of the ATAP pins (AT1) is used to drive an analog test stimulus and the other one (AT2) is used to observe the corresponding analog test response. The operating mode of DBMs and ABMs is defined by a sequence of control and data bit streams that are shifted into the TDI-TDO path. These bit streams are at the heart of the IEEE 1149.X test protocol and their specification is made in the form of a *test program* specified in SVF [7], which is the outcome of the experiments proposed to the students.

IEEE 1149.X embedded test architectures have a cost (they degrade performance, increase pin count and silicon area), but their availability greatly simplifies production test. The expression *design for test* indicates that the embedded test circuitry is brought into the design at a very early stage in the development process, with the main objective of facilitating all subsequent test operations.

III. EXPERIMENT / WORKBENCH REQUIREMENTS

Design for test courses that include 1149.4 mixed-signal test experiments require a workbench comprising at least an oscilloscope, a waveform generator, and a multimeter (current and voltage measurement). These instruments will suffice to handle the necessary analog test signals. Moreover, since it is the digital 4-pin TAP in each circuit that defines the operating mode of the embedded test architecture, some form of digital test controller is also necessary. Finally, any real experiment will need a demonstration board where one or more IEEE 1149.X circuits are present.

Additional requirements will have to be considered if all or part of the students are able to carry out their experiments from a remote location (instead of being all present in the lab). A synchronous communication tool is required to enable on-line discussions as the experiment progresses. Video-conferencing is of course the preferred solution, since the information transfer rate of text-based chat is not satisfactory in this context.

Finally, remote experimentation in an academic context hardly makes any sense when the accompanying learning contents and materials are not provided electronically. Any remote experimentation setup must therefore envisage its integration into an e-learning platform that will be used to deliver lecture notes, presentations, assessment exercises, etc. The requirements identified to setup an IEEE 1149.X design for test remote experimentation workbench may therefore be summarised as shown in Table I.

In the case of remote experiments, all test and measurement equipment will of course possess an appropriate web interface, usually known as a *Virtual Instrument* (VI). For most cases this is not a problem, since various instrument manufacturers also provide software packages to enable web observation and control. LabView is a good example of a technology that supports local or remote interface panels for a wide range of

instruments. In the case of experiment-specific resources, however, extra development work may be necessary to provide an appropriate user interface. That is the case with the 1149.1 dedicated test controller (from Göpel Electronic GmbH), since its user interface must enable the specification and execution of the required test programs. A dedicated LabView interface was therefore developed for this purpose.

TABLE I.
RESOURCES REQUIRED TO SET UP AN IEEE 1149.X
REMOTE EXPERIMENTATION WORKBENCH.

Test and measurement equipment	
Test controller	To interface the IEEE 1149.1 test access port
Oscilloscope	To observe analog test stimulae / responses
Waveform generator	To provide analog test stimulae
Multimeter	To observe current / voltage levels
Demonstration board	To host the experiments
Communication resources	
Video-conferencing	To support collaborative tasks
Content management and delivery	
E-learning platform	To deliver lecture notes, presentations, etc.

IV. APPLICATION EXAMPLES

The demonstration board that was developed to support remote IEEE 1149.1 / 1149.4 experiments may be represented as shown in Fig. 2 (the DBMs / ABMs associated with digital and analog I/O pins are not represented for the sake of simplicity).

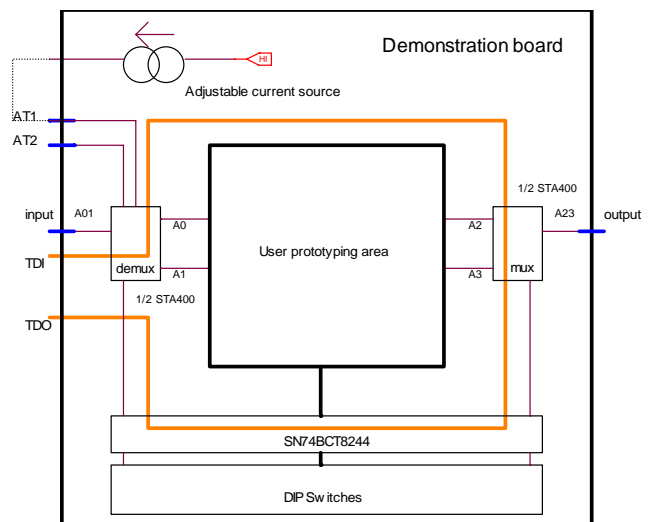


Figure 2. Demonstration board used to support remote IEEE 1149.4 mixed-signal test experiments.

The STA400 circuit comprises two 2:1 bidirectional mux/demux blocks which are used to route the analog signals between the input and output of the board. In addition to this IEEE 1149.4-compatible circuit, the board comprises an IEEE 1149.1 octal buffer, which together with the STA400 defines the board test infrastructure (the

control and data bit streams traverses the board-level TDI-TDO path). A built-in adjustable current source provides an analog test stimulus that may be used to drive AT1 when performing parametric tests (e.g. when measuring the value of one resistor placed in the user prototyping area).

A. Experiment description: Observability

This experiment is proposed with the objective of demonstrating that the IEEE 1149.4 test architecture supports a non-intrusive operating mode to enable the observation of the analog signal at any pin that has an ABM (using the 1149.4 PROBE instruction). The switching structures in the 1149.4 test architecture route the selected (input or output) pin to AT2, without disturbing the operation of the circuit. An oscilloscope connected to AT2 displays the waveform present at the selected pin.

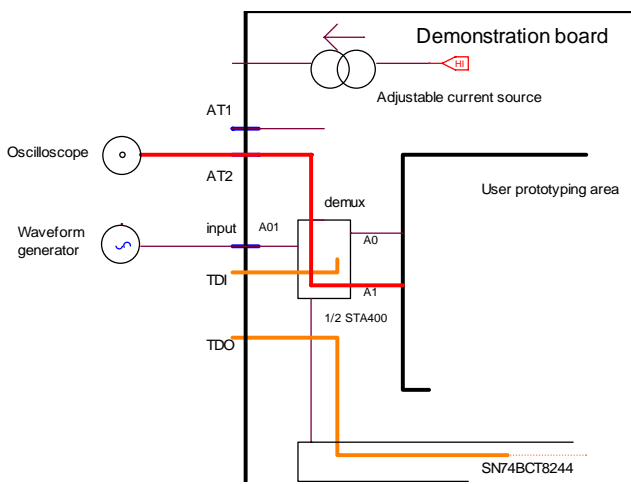


Figure 3. Test setup for the observability experiment (non-intrusive).

In one specific experiment proposed to the students, a waveform generator drives the STA400 A01 pin, which may be connected to A0 or to A1, depending on the control input of this demux block. As represented in Fig. 3, the objective of this experiment consists of connecting A1 to AT2, and then verifying that the control input of the multiplexer is able to divert the input waveform from A0 to A1 and vice-versa.

The work proposed to the students consists of writing the test program that will set up the appropriate operating mode in the IEEE 1149.X test architecture of both chips (the STA400 and the SN74BCT8244). In this experiment the analog chip will be in mission mode (operating normally), while the octal buffer will be placed in “external test” (EXTEST) mode. Since the outputs of the second chip are now controlled via its IEEE 1149.1 boundary-scan test cells, it is possible to control the STA400 multiplexer via the TDI-TDO test data path. Besides writing the test program, the students need to adjust the waveform generator and the oscilloscope, and to register all observations that may be included in the experiment report. Their tasks are as follows:

1. Define a test strategy (i.e. what specific test actions will enable them to achieve the experiment objectives)
2. Find out the TDI-TDO bit streams that set up the appropriate operating mode for the IEEE 1149.X test architecture present in the STA400 and BCT8244 chips
3. Write the corresponding test program, execute it and observe the test results

Notice that communication is important for all the tasks referred above. The test program will be written by one of the students, who will be in control of the experiment interface (the student that requested and was granted control of all VIs). The remaining students are able to observe what is going on, since all VIs are seen simultaneously by all participants.

Access to the remote workbench must be reserved beforehand. A *booking* tool was therefore developed as an extension of Moodle, the open-source e-learning platform that was selected to support this framework [8]. This tool may indeed be used to share any scarce resources in a co-ordinated manner (e.g. to share a general purpose video-conferencing room), and has the additional advantage of helping the students to organise their activities (otherwise they wouldn't be able to predict when the remote workbench was available). The link to the *STA400 r-workbench* – which is actually the link to the booking tool – is illustrated in Fig. 4 and is seen by the students just as any other activities created by the teachers.

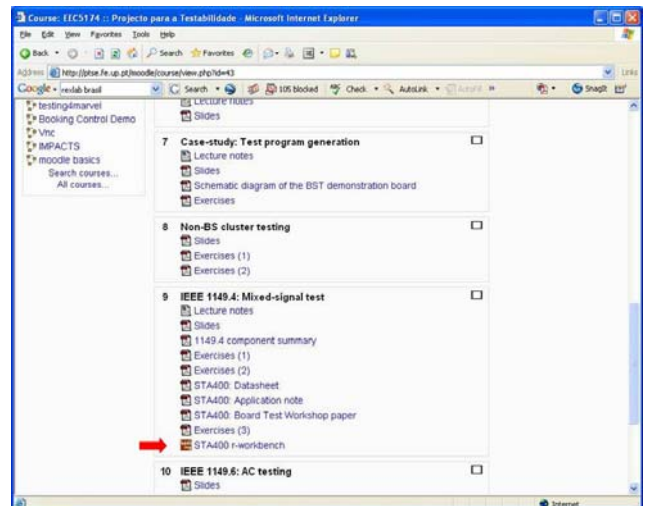


Figure 4. Link to the experiment in the Moodle contents.

Clicking to book access time will open a weekly agenda, where the students may select one or more one-hour slots, as illustrated in Fig. 5. Since the current time when capturing the screenshot shown in Fig. 5 was already within a reserved time-slot, a red arrow link had automatically been created by the booking tool and was available to launch the experiment interface panels. The following features are also supported by this tool:

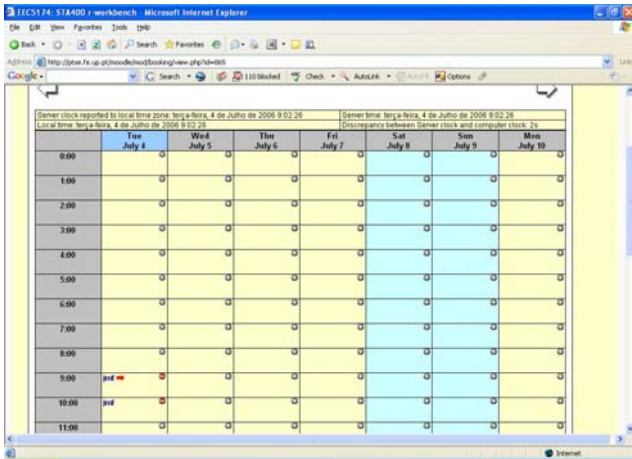


Figure 5. The booking tool weekly agenda.

- The URL of the experiment interface panels includes a random 32-digit access key that is dynamically generated at launch time, ensuring that each session corresponds to a unique address (it is not possible to run an experiment with the URL of a previous session)
- When experiment mirrors exist, the booking tool will allocate experiment servers to each request, until no more servers are available in the mirror queue (i.e. a given time-slot will only be full when the number of reservation requests for that slot equals the number of experiment mirrors)
- Student group information is automatically extracted from the Moodle database, so that a reservation made by one student will grant access permissions to his / her colleagues in the same group
- The booking tool recognises the time difference between the client computer and the experiment server (a reservation made for 11 pm client time will display at 11 pm in the client computer booking agenda, but will indeed correspond to 9 pm – and be seen at this time – in the experiment server, if it is located in a -2 hours time zone)
- To prevent misuse of the experiment resources, the teachers may impose an upper limit to the time that each student / group is able to reserve (per day, per week, per month, etc.)
- The reserved time-slot may be released if the students that made the reservation do not initiate the experiment within a predefined time delay (defined by the teacher when creating each experiment)

The experiment interface is divided across two browser windows that are launched sequentially when the experiment starts, as presented in Table II.

Test program specification and execution, and test result analysis, are the tasks where discussion is more important. As such, the test controller interface panel was merged with the video-conferencing channels in a single browser window, shown in Fig. 6.

The test program shown for this specific example comprises five SVF commands that carry out the following operations:

- 1- Reset the test logic infrastructure (the TAP controller is sent to the Reset state);
- 2- Shift-in the control information that prepares the test logic to receive the configuration data (SAMPLE / PRELOAD to the STA400 and BYPASS to the SN74BCT8244);
- 3- Shift-in the bit stream that corresponds to the configuration shown in Fig. 3;
- 4- Shift-in the control information that imposes the new configuration (PROBE to the STA400 and BYPASS to the SN74BCT8244);
- 5- Return the TAP controller to the Run Test / Idle state, where it will remain when the test program completes execution.

TABLE II.
EXPERIMENT INTERFACE ELEMENTS.

Window # 1	
Test controller	To interface the IEEE 1149.1 test access port
Video-conferencing	To support collaborative tasks
Window # 2	
Oscilloscope	To observe analog test stimulae / responses
Waveform generator	To provide analog test stimulae
Multimeter	To observe current / voltage levels
Live images from lab	To reinforce awareness of reality

Recall that only one student will be able to write the test program, but all the remaining students are able to see it in real time and to contribute as needed. Once the test program is written, execution will follow. The log area below the test program specification window provides runtime information as each test command is executed. This information will indicate if any errors were found when comparing the bit streams shifted out against their expected values. The students conclude the experiment by recording all relevant data and submitting a report for assessment.

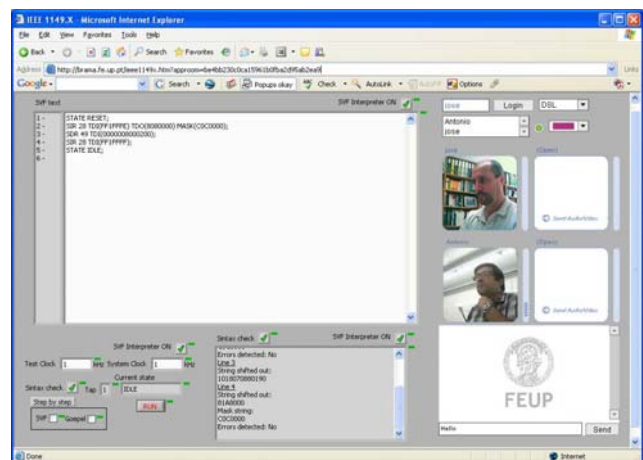


Figure 6. Experiment interface window #1 (test controller and video-conferencing channels).

All test and measurement VIs, as well as live images from the lab, are present in the second browser window, shown in Fig. 7. The multimeter is not necessary for this experiment and the corresponding VI might have been removed when the teacher created the experiment. However, their presence ensures that the students will become acquainted with a standard experimentation environment and as such there are no reasons to remove it (it would not necessarily be removed from a standard workbench set up in a real lab, just because it was not going to be used in a given experiment).

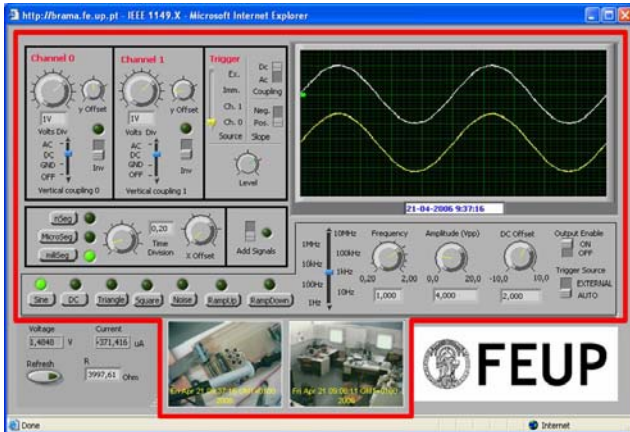


Figure 7. Experiment interface window #2: Oscilloscope, waveform generator, multimeter, live images from the remote lab. Notice that the multimeter is not used in this case and that the live images from the remote lab reinforce the perception of a real experiment.

B. Experiment description: Controllability

This experiment is represented in Fig. 8 and illustrates the intrusive EXTEST mode (normal circuit operation will be suspended while in this mode). When the IEEE 1149.X test architecture is configured to operate in EXTEST, all core circuitry is isolated from the pins.

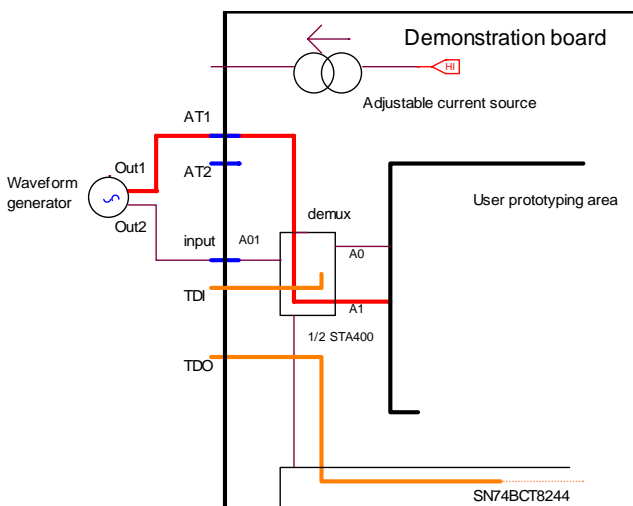


Figure 8. Test set up for the controllability experiment (intrusive).

Interconnect and parametric test operations may be carried out while in EXTEST mode. Interconnect tests will drive the PCB interconnects to HIGH or LOW

voltage levels, with the objective of detecting open or short-circuits. It is also possible to use the ATAP pins to route an analog stimulus to any analog pin for parametric test purposes.

The objective of the experiment proposed to the students consists of controlling the A1 output of the STA400 demux block. An external test signal present at AT1 (driven by a waveform generator) will be routed to A1, as shown in Fig. 8. Since A1 is now controlled from AT1, regardless of the operating mode of the internal demux block, this experiment requires the core circuitry to be isolated from the pins. The experiment interface windows are again as represented in Fig. 6 and 7 (notice that the multimeter is once again not necessary).

C. Experiment description: Parametric testing

In this experiment the students are asked to determine the value of one resistor placed between an STA400 pin and ground. The test setup is represented in Fig. 9 and shows that the resistor is placed between pin A0 and GND.

The switching structures in the 1149.4 test architecture will i) disconnect A0 from the core circuitry (all other pins will also be disconnected from the core circuitry, since this is an intrusive operation); ii) connect A0 to both pins in the ATAP (AT1 and AT2). The current driven through AT1 will flow out of A0 and via the unknown resistor R to ground. The value of the current driven into AT1 is measured in the external ammeter. Since AT2 is also connected to A0, the voltage drop across R will be measured in the external voltmeter. The value of the unknown resistor may then be calculated as $R = V / I$, provided that certain conditions are met (error considerations are omitted from this description for reasons of simplicity, but the students are required to analyse the measurement setup and to determine the conditions that make the obtained result acceptable).

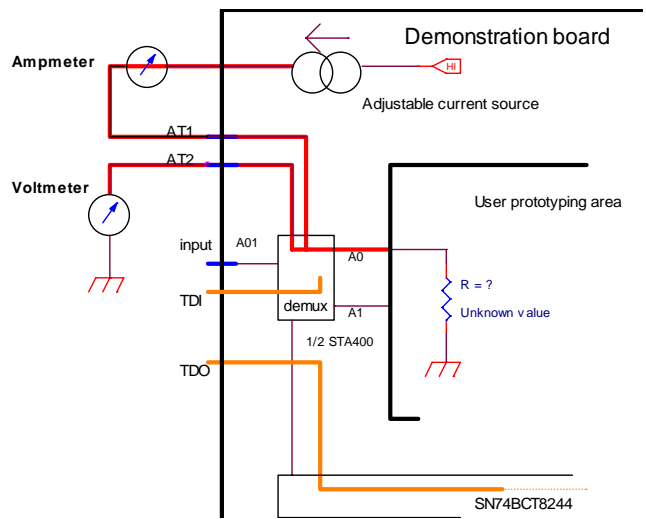


Figure 9. Test setup for a parametric testing experiment (intrusive).

The required configuration of the 1149.4 switching structures will determine the necessary TDI-TDO bit streams and therefore the new test program. If runtime errors are not detected (syntax errors or errors found in

the bit streams shifted out), the students will conclude the experiment by reading the resistor value (the ammeter and voltmeter readings are available, but the multimeter VI also provides the result of the calculation). The experiment interface elements in the second browser window are shown in Fig. 10 and are the same as before, but the multimeter is the only test and measurement equipment needed.

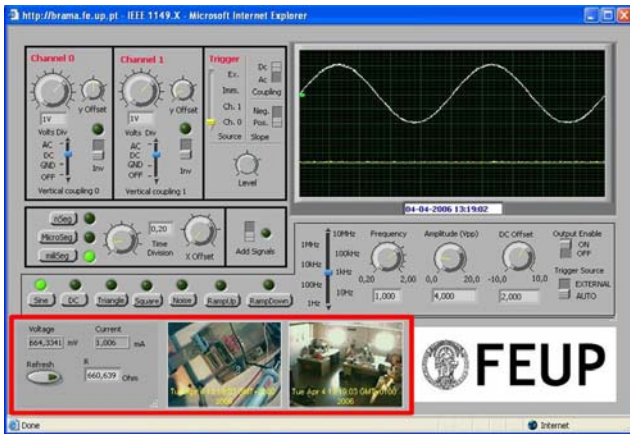


Figure 10. Experiment interface window #2 for parametric testing: Oscilloscope, waveform generator, multimeter, live images from the remote lab. Notice that the oscilloscope and the waveform generator are not used in this experiment.

V. FUTURE RESEARCH

Various remote experiments in similar areas were previously setup and made available to students before the 1149.1 / 1149.4 design for test framework herein described. Seen from the students' point of view, all remote experimentation requirements have been met, and virtual / mixed-mode / remote experiments may now be integrated into most e-learning platforms. However, when seen from the teachers' point of view, the situation is less satisfactory. There are at least two areas where further research and development is still required:

- Internet programming skills should not be required to set up web-based experiments, since the teachers' expertise will only occasionally reside in this area. The *automatic generation of experiment interfaces*, built from a library comprising various interface elements (e.g. oscilloscope, waveform generator, video-conferencing channels, live images from the lab, etc.), is therefore important to support teachers who might otherwise never come to use this technology [9].
- Formative assessment is usually done by the teacher when he accompanies the work done by his/her students in a real lab. In that context the teacher will circulate among the students and note down positive or negative impressions that result from the actions observed in each student group. This information is of course important and appropriate means should be made available to capture and store it when the experiment is carried out via the web. The interface elements referred in the previous paragraph should therefore include *embedded assessment features*, able

to detect when the students exhibit higher or lower than average skills in each context (e.g. if the student needs to adjust the time base, but repeatedly modifies the V/div control instead of the time/div control, such action should be registered and made available to the student and to the teacher at the end of the session).

Teacher support is therefore an area where further investment is still needed in order to promote the acceptance and pedagogic effectiveness of web-based experiments.

VI. CONCLUSION

The integrated framework described in this paper addresses design for test of mixed-signal circuits and brings together several modules that were developed in previous projects. The general resources provided comprise synchronous communication by video-conferencing (to support collaborative tasks), a booking tool (to enable co-ordinated resource sharing in the remote workbench and to facilitate the organisation of student activities), and a panoply of standard workbench instruments, e.g. oscilloscope, waveform generator and ammeter / voltmeter functions. Experiment-specific resources comprise a dedicated experiment board that is based on the first commercial chip supporting the IEEE 1149.4 embedded test standard (the STA400 IC from National Semiconductor), and an SVF test command interpreter that interfaces an IEEE 1149.1 TAP controller board from Göpel Electronic GmbH. Since this SVF interpreter was written in LabView, it offers the same "look-and-feel" of the remaining VIs that are present in this remote workbench.

The booking tool provides a bridge to the e-learning platform used to deliver the course contents, and was developed in the form of a PHP extension to Moodle. This tool enables the teachers to include access to the experiment as a standard activity when building the course contents, and enables the remote experiments to be perceived by the students in just the same way as any other embedded learning object. The current setup is being used in a design for test course that is lectured to final year students in the Electrical and Computer Engineering degree at the University of Porto (FEUP).

For usability reasons, the experiment interface uses two browser windows. A two-window interface requires frequent swap operations, but we concluded that swapping is less disturbing than regular up/down scrolling.

The readers (and everyone interested in web-based experimentation) should be aware that such tools are not to be offered as a replacement to real laboratories, but rather as a complement to real lab sessions. Virtual / mixed-mode / remote experimentation extends e-learning to the lab, but does not eliminate the importance of the student-teacher interaction, and student access to real labs. Moreover, in the near future we will see enhanced web-based experimentation interfaces that generate client profiles and formative assessment information. The interface to an oscilloscope may continue to look like the

“real thing”, but there is no reason to prevent it from being able to provide a much richer learning experience (in the same way that e-books may go far beyond the reading experience of printed books).

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