A Distance Measurement Platform Dedicated to Electrical Engineering

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Abstract—This paper presents the remote laboratory **eLab**, dedicated to electrical engineering education. **eLab** is a flexible measurement platform that permits to run more than 130 experiments in the fields of electronics and microelectronics. The instructor can choose or create different types of pedagogical scenarios, covering teaching requirements from undergraduate to graduate levels. Furthermore, **eLab** implementation and use do not require any commercial software. Its reliability has been proven during many practical classes in France and other countries. **eLab** is now a key component of the Bordeaux University e-Learning material in electrical engineering. In the field of analog integrated circuits design, **eLab** offers a unique measurement solution, which can be combined to traditional circuit simulation sessions.

Index Terms—e-Learning tools, remote laboratories, electrical engineering, integrated circuits, analog design and test.

◆

1 INTRODUCTION

NET-BASED techniques begin to be widely used in education. In sciences education, the experimental method is an essential point of the pedagogy and students must face it during practical sessions. Moreover, it is an opportunity to develop the students understanding, autonomy, and finally, increase their interest in the topic. In the electrical engineering (EE) curriculum, an important part is devoted to the implementation of electrical functions involved in signal processing. The physical realization of the function leads to nonidealities that must be quantified by electrical measurements. A net-based laboratory for characterizing electronic circuits has many advantages: It allows sharing high-quality instruments and full-custom circuits, which could not be duplicated in several stations, for cost reasons; the net-based access allows the users to launch experiments and analyze the results anywhere, as often as they want.

The **eLab** platform is dedicated to the characterization of electrical components and circuits of analog signal processing. In that domain, there is an important evolution between the undergraduate level and the graduate level, which finally follows the thematic progression from electronics to microelectronics. First, the student must face with measurement techniques and deduce some basic parameters or properties; low-cost equipment can be sufficient for that preliminary teaching. In graduate-level curriculum, the context becomes microelectronics and the future Electrical Engineer must get knowledge and practice on Integrated Circuit (IC) design and test. In digital design, programmable devices like FPGA offer many possibilities to develop consistent and reusable practical experiments. In analog design, the practical experiments are often reduced in software simulation sessions.

eLab is a flexible measurement platform which gives access to a huge number of electronics and microelectronics devices or building blocks, with different types of pedagogical scenarios, covering teaching requirements from undergraduate to graduate levels. **eLab** implementation and use do not require any commercial software. Its reliability has been proven during many practical classes, and **eLab** is now a key component of Bordeaux University pedagogical material in EE. It offers especially a unique alternative to software simulations in analog IC design and test, due to the so-called *Cyberchips*.

The paper is organized as follows: Section 2 summarizes the requirements of a remote lab, taking examples in a review of existing solutions; Section 3 gives a brief history of the previous projects that made the **eLab** concept emerge. The rest of the paper shows how **eLab** implementation choices fill the previously listed requirements: Section 4 describes the **eLab** hardware/software architecture; Section 5 develops **eLab** pedagogical organization and pertinence; and Section 6 proposes three examples of **eLab** practical use, at different levels of the curriculum. Finally, a conclusion is proposed in Section 7.

2 STATE OF THE ART AND REMOTE LAB REQUIREMENTS

A literature review of remote laboratories is provided in [1]. All platforms implement the same software/hardware architecture paradigm: a device under test is connected to a local computer which communicates with a remote computer (the user) through a certain middleware. The

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different solutions may be classified per scientific domain and per software implementation choices.

In electronics domain, several platforms exist for the characterization of components or functional blocks [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13]. Generally, a set of typical components is connected to instruments through a specific test fixture and the user is invited to make some measurement choices (input waveform, amplitude, frequency range, power supply, etc.), then he launches the experiment and can display or record the results. Each remote lab is often focused on one main topic which can be: circuit theory and Kirchhoff laws [2], [4], [8], design and test of oscillators or filtering functions [2], [6], [8], [9], [11], [12], characterization of microelectronics components [3] (diodes), [5], [6] (transistors), [7] (CMOS operational amplifiers), or characterization of HF devices [10], [13].

In remote labs, software applications are needed: 1) for the link between the device and local computer (instruments drivers), 2) for the link between the local and remote computers (middleware), and 3) for the link between the remote computer and its user (human computer interface). Two strategies mainly arise: the use of proprietary languages like Labview and Matlab-Simulink [3], [4], [6], [9], [12] and the use of standard programming languages (Java, PHP, etc.) [2], [5], [8], [10], [13].

The important features of a remote lab are: availability, security, flexibility, portability, and implementation cost.

Availability is related to free user access and management of multiuser requests. When many users want to access the same instrument, the first in first out (FIFO) sequencing method seems to be the most efficient, because it avoids booking procedures [2], [5], [11], [12]. However, for [10], this simple sharing access does not permit to implement a collaborative learning strategy. Availability is also enhanced when the user's computer interface does not need any commercial software.

Security is related to both remote hardware and data transfer on the middleware. The first point can be solved by implementing a software validation of the user's inputs, in order to protect the instruments and devices, and the second point requires at least a user authentication protocol.

Flexibility is related to the number of available experimental units and the possibility to use them in different pedagogical scenarios, at different levels in the curriculum. It is also related to the facility to add or change an experiment in the platform. Among the reviewed remote labs, many offer only one or a few number of specific devices under test. The use of a programmable device [12] or a switching matrix between instruments and test boards [5], [6], [7], [13] can improve the platform flexibility. Another important point is software solutions reusability [10], [13].

Portability is an important feature for the future system development and possible migrations. In that respect, the platform-independent languages and open-source components should be used as much as possible; furthermore, that choice limits the **implementation cost**.

3 ELAB BRIEF HISTORY

eLab was developed in the framework of several European initiatives.

Remote on-distance measurements have been performed for more than 10 years at Bordeaux 1 University, France. During this period, different approaches have been developed. The first approach has been carried out via the European project called "RETWINE," which stands for Remote Worldwide Instrumentation Network. The basic idea was to share powerful lab instruments via the WWW [14]. Starting from this experience, we wanted to address others remote lab issues: how to design an adequate experiment and how to introduce it in course packages. This approach has been developed in the framework of European Community SOCRATES-MINERVA project called "eMerge" [15]. This project was dedicated to the development of an innovative and advanced educational network structure to disseminate online laboratory experiments to support engineering and sciences education. We have examined acceptance, usability, learning effect, and usefulness. The learning effect was also measured by knowledge tests [16]. The next step was to address pedagogical aspects in the microelectronics engineering domain. Practical learning of analog integrated circuit design is often based on circuit simulations and not on real testing. We decided to overcome this weakness by including a complete set of analog building blocks in our remote platform. The basic building blocks have been implemented on two chips, the *Cyberchips*, which were manufactured within a Multiwafer Project [17], [18]. Thus, a variety of typical building blocks for analog IC design have been made available for measurement and characterization via the **eLab** platform [18]. This work has been carried out in the context of the UNIT project and is part of its platform [19].

Today, **eLab** is used in the curriculum of EE, in high schools or universities, for undergraduate and graduate students, in an open international network. Our current main partners are: Sfax Superior Institute of Electronics and Communications (Tunisia), Dublin Institute of Technology (Ireland), Tampere Polytechnical University of Applied Sciences (Finland), and Catholic Polytechnical University of Bruges-Ostend (Belgium).

4 ELAB ARCHITECTURE

eLab is a Web-based platform which allows users to perform real electronic measurements on a wide variety of experiments in EE.

Availability was the main objective during the design phase: it is possible to run many sessions simultaneously, on the same topic, without any booking, as the system manages concurrent access to the hardware (instruments and circuits) transparently. Moreover, only standard open Web technologies (HTML, Java, and Javascript) are involved and no specific software has to be installed on the user side. So, **eLab** is available for students to work anytime from everywhere.

Users of **eLab** are given access to so-called *textbooks.* A *textbook* is a group of PDF, HTML, etc., documents containing course material, documentation, and a set of proposed measurements about one topic. The experimental data they collect are stored in a personal *notebook.*

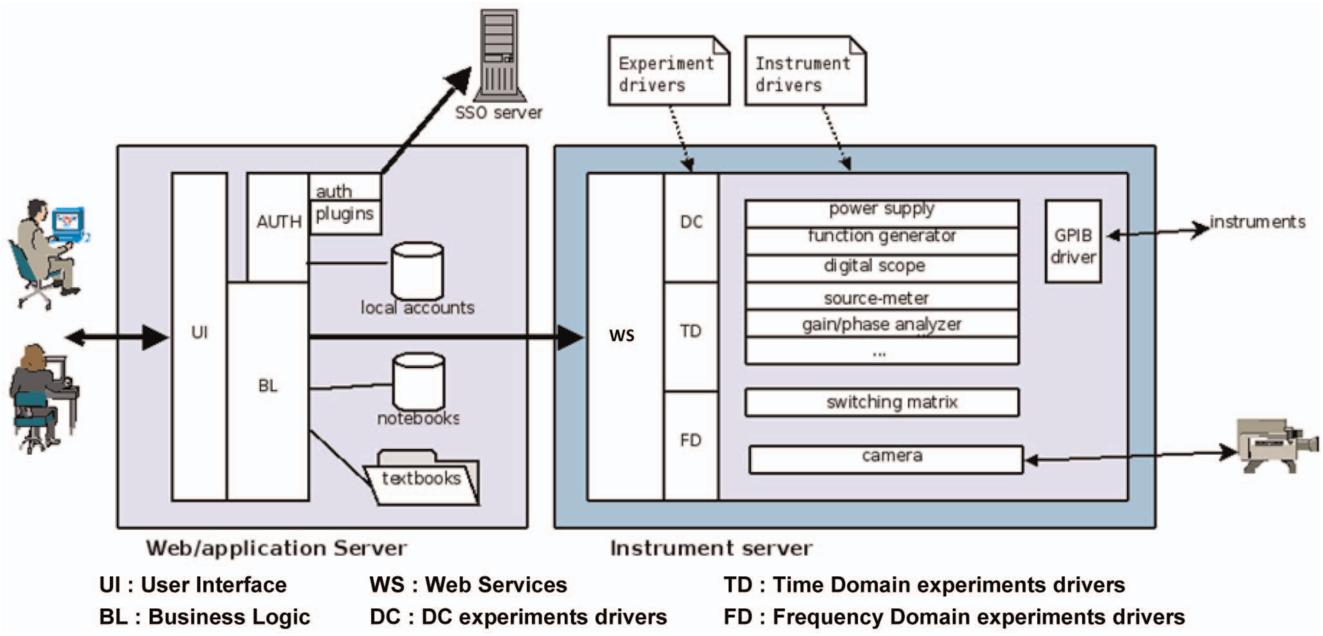


Fig. 1. Architecture of **eLab** platform.

A local database of accounts was first used for the authentication of a small number of local users. Over the time, several Single sign-on (SSO) *plugins* have been added when it became necessary to integrate **eLab** to the Ulysse [20] pedagogical platform of Bordeaux 1 University, then to the eMerge portal [21], and finally, to the University top-level portal [22].

Measurements are performed through a simple form-based interface; according to the *textbook*, users have to answer questions about the experimental results, which are stored in a *notebook* to be reviewed later by the teachers.

Experimental results can be seen as arrays of numbers, curves (generated by GNUplot), and also through an interactive Java applet which provides easy calculation of slopes near interesting points.

The measurement time is relatively short (typically, 20 to 40 s). Besides, students don't start measurements too frequently because they also have to understand the course material and the experimental data they collected. Consequently, the system load is rather low. Practically, we seldom observe more than two or three measurements in the queue, even with 20 users working simultaneously on **eLab**. Most of the time, users don't have to wait at all.

However, in order to attenuate the likely unpleasant experience of waiting, a feedback is provided to the user through a real-time view of the on-going measurements (a motorized camera automatically zooms on the different active instruments), together with the list of the pending jobs.

The user interface follows an object-oriented design: each type of experiment is managed by a separate object created from a dynamically loaded class. This object is responsible for

- HTML presentation, code generation for forms, and results displaying,
- user's input data validation (including checking hardware limitations),
- requesting the instrument server to start a measurement through an SOAP call,
- storing/retrieving the results in the user's *notebook*.

Since June 2009, there are approximately 150 experiments managed by three main classes *Freqdomain*, *Timedomain*, and *DC*. The latter is by and large the most complex with 29 subclasses to manage all the hardware configurations of 80 separate types of experiments.

Fig. 1 gives an overview of **eLab** architecture.

The instrument server has three layers: at the bottom level, each type of instrument is driven by a specific class: for example, a *PowerSupply* has methods to set its output voltage and get the current level. At the middle level, a PHP script coordinates the work of instruments, power supplies, and switching matrix, in order to perform a type of measurement. The top level presents these measurements as SOAP Web Services.

The current implementation of **eLab** runs on two low-end computers, with the classical Linux Apache MySQL PHP (LAMP) setup.

The front-end computer runs the Web server with the **eLab** application; it also hosts the database with accounts, *notebooks,* and results.

The instrument server is hosted on a local network; it drives the instruments and the two switching matrices (through parallel and serial ports) that can operate simultaneously, with separate queues. A specific extension of PHP has been written in order to drive the GPIB-IEEE-488 interface card directly from PHP scripts; it is now available as part of the open-source PHP5-GPIB package of Linux/Debian [23].

The switching matrix for time- and frequency-domain measurements connects one device/circuit under test (75 among a maximum of 128) to an AC Gain-Phase Analyzer (HP 4194) for frequency-domain measurements, or a function generator (Agilent 33220A) coupled to a digital oscilloscope (Agilent 54621A) for time-domain

TABLE 1
Elab Available Resources

	title	number of test units	summary	language	level
1	Hands on Real-Lab	4	Frequency and time domain measurements on a RC-circuit	English / French	Undergraduate (1-2)
2	Passives circuits in harmonic regime	5	Measurement and use of complex impedance	French	Undergraduate (1-2)
3	Op-Amp (1)	9	Characterization in open or closed-loop	French	Undergraduate (1-2)
4	Op-Amp (2)	7	Application of voltage follower – Slew-rate measurement	French	Undergraduate (1-2)
5	Differential amplifier: Emitter coupled pair	14	Measurement and comparison of performances for three different circuits	English	Undergraduate (3) - Graduate (1)
6	Effect of negative feedback on a voltage amplifier	10	Investigation of feed-back effects on the amplifier performances	English	Undergraduate (3) - Graduate (1)
7	The MOS transistor	2	Measurement, modelling, and parameter extraction	English	Undergraduate (3) Graduate (1)
8	Analog building blocks for integrated circuit design	69	An exhaustive characterization platform of typical analogue integrated cells	English	Undergraduate (3) - Graduate (1)
9	Electronics of devices and circuits	14	About 20 different circuits are dedicated to this course of fundamental electronics (Diodes and transistors)	English/ French	Undergraduate (1-2)
10	e-Lab versus Spice	2	Frequency and time domain measurements on a RC-circuit	French	Undergraduate (1-2)

measurements. The device under test is also connected to power supply (Agilent 3649A).

The switching matrix for DC measurements connects 25 building blocks from the so-called *Cyberchips* to three DC source meters (Keithley 2400) and a power supply (Agilent 3649A).

5 eLAB PEDAGOGICAL ORGANIZATION AND PERTINENCE

In this section, we will see how the previously described material can be organized in e-Learning pedagogical resources.

The current version of **eLab** results from a 10-year-old history, and we now clearly see the interest of this tool for EE education.

A set of pedagogical resources is available on **eLab** site, which can be used at different levels of the Bachelor or Master curricula. They are listed in Table 1.

Each pedagogical resource is associated to a *textbook,* which contains a summary of the objectives, a short description of the circuits under test, and several preformatted measurement sessions. One specific experiment can be run by the teacher, as an illustration of a theoretical course, in a multimedia equipped amphitheatre. More frequently, a subset of these pedagogical resources is used during practical courses by a class of students. Students are expected to study the characteristics of circuits, make calculations and practical measurements, and answer questions. Results and answers are stored in the student's *notebooks*, so they can be retrieved, analyzed, and printed later.

For resources 1-7, the circuits are implemented with discrete components on Printed Circuit Boards (PCBs); for resource 8, Specific Integrated Circuits (*Cyberschips*) are connected to DC instruments. These *Cyberchips* [17] have been designed in 2003, with a $0.8\mu\mathrm{m}$ BiCMOS technology; they integrate all typical building blocks used in analog IC [24].

5.1 The Instructor Point of View

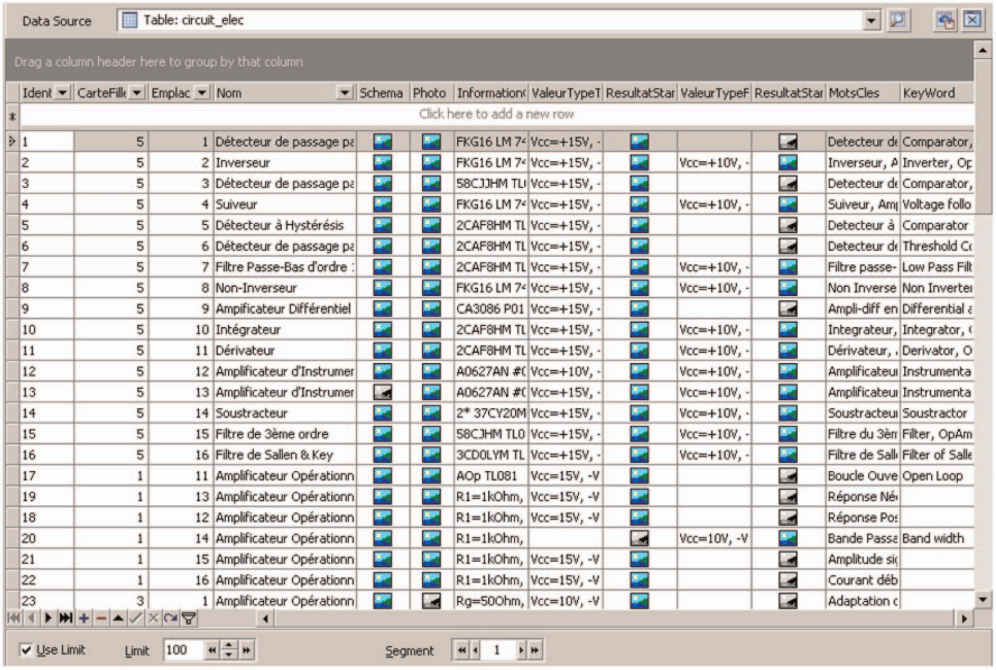
The resources that are listed in Table 1 have been designed by teachers of Bordeaux 1 University, in order to be included in specific teaching modules. The task of designing a new resource is quite easy. The final document must be in HTML format, but instructors often use their usual text editor with an automatic format translator. The *textbook* document contains links to the specific measurements. Teachers have access to a list of available measurements (individual test units, formatted for DC, AC, or time-domain measurement), stored in the database, with information and description data for all test units (site identifier, schematic, photography of the PCB, components values, power supply, circuit function, and key words). Fig. 2 shows a partial view of this list.

From our experience, we know that during the first semester, students must be closely guided in their experimental approach, while it is important to stimulate autonomy and evaluate the experimental approach of graduate-level students. Consequently, the *textbooks* of resources 1-7 are step-by-step descriptions of the practical course. Resource 8 has been implemented differently: it is composed of many independent *textbooks*, one *textbook* for each test configuration and each component. The way to combine these test units is up to the user and gives the opportunity to emphasize the experimental approach and the meaning of the measured results (Which measurement? Why? How to exploit it?).

At the end of a practical session, the instructors can get the *notebooks* which result from the answers of the students with related curves. These e-reports are automatically edited (for example, in PDF format) and can be used by the instructors for the students' evaluation.

5.2 The Student Point of View

Students are quickly comfortable with the process of launching and retrieving measurements. The distant access to **eLab** allows them to finish a part of the work at home or to efficiently prepare one practical session.



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Ident	CarteFill	Emplac	Nom	Schema	Photo	Informatio	ValeurTypeT	ResultatSta	ValeurTypeF	ResultatSta	MotsCles	KeyWord
1	5	1	Détecteur de passage p	🖼	🖼	FKG16 LM 7	Vcc=+15V, -	🖼		▨	Detecteur d	Comparator,
2	5	2	Inverseur	🖼	🖼	FKG16 LM 7	Vcc=+15V, -	🖼	Vcc=+10V, -	🖼	Inverseur,	Inverter, O
3	5	3	Détecteur de passage p	🖼	🖼	58CJJHM TL	Vcc=+15V, -	🖼		▨	Detecteur d	Comparator,
4	5	4	Suiveur	🖼	🖼	FKG16 LM 7	Vcc=+15V, -	🖼	Vcc=+10V, -	🖼	Suiveur, Am	Voltage follo
5	5	5	Détecteur à Hystérésis	🖼	🖼	2CAF8HM TL	Vcc=+15V, -	🖼		▨	Detecteur à	Comparator
6	5	6	Détecteur de passage p	🖼	🖼	2CAF8HM TL	Vcc=+15V, -	🖼		▨	Detecteur d	Threshold C
7	5	7	Filtre Passe-Bas d'ordre	🖼	🖼	2CAF8HM TL	Vcc=+15V, -	🖼	Vcc=+10V, -	🖼	Filtre passe-	Low Pass Fil
8	5	8	Non-Inverseur	🖼	🖼	FKG16 LM 7	Vcc=+15V, -	🖼	Vcc=+10V, -	🖼	Non Inverse	Non Inverte
9	5	9	Ampificateur Différentiel	🖼	🖼	CA3086 P01	Vcc=+15V, -	🖼		▨	Ampli-diff en	Differential
10	5	10	Intégrateur	🖼	🖼	2CAF8HM TL	Vcc=+15V, -	🖼	Vcc=+10V, -	🖼	Integrateur,	Integrator,
11	5	11	Dérivateur	🖼	🖼	2CAF8HM TL	Vcc=+15V, -	🖼	Vcc=+10V, -	🖼	Dérivateur,	Derivator, O
12	5	12	Amplificateur d'Instrume	🖼	🖼	A0627AN #	Vcc=+10V, -	🖼	Vcc=+10V, -	🖼	Amplificateu	Instrumenta
13	5	13	Amplificateur d'Instrume	▨	🖼	A0627AN #	Vcc=+15V, -	🖼	Vcc=+10V, -	🖼	Amplificateu	Instrumenta
14	5	14	Soustracteur	🖼	🖼	2* 37CY20M	Vcc=+15V, -	🖼	Vcc=+10V, -	🖼	Soustracteu	Soustractor
15	5	15	Filtre de 3ème ordre	🖼	🖼	58CJHM TL0	Vcc=+15V, -	🖼	Vcc=+10V, -	🖼	Filtre du 3è	Filter, OpAm
16	5	16	Filtre de Sallen & Key	🖼	🖼	3CD0LYM TL	Vcc=+15V, -	🖼	Vcc=+10V, -	🖼	Filtre de Sall	Filter of Sall
17	1	11	Amplificateur Opérationn	🖼	🖼	AOp TL081	Vcc=15V, -V	🖼		▨	Boucle Ouve	Open Loop
19	1	13	Amplificateur Opérationn	🖼	🖼	R1=1kOhm,	Vcc=15V, -V	🖼		▨	Réponse Né	
18	1	12	Amplificateur Opérationn	🖼	🖼	R1=1kOhm,	Vcc=15V, -V	🖼		▨	Réponse Po	
20	1	14	Amplificateur Opérationn	🖼	🖼	R1=1kOhm,		▨	Vcc=10V, -V	🖼	Bande Pass	Band width
21	1	15	Amplificateur Opérationn	🖼	🖼	R1=1kOhm,	Vcc=15V, -V	🖼		▨	Amplitude si	
22	1	16	Amplificateur Opérationn	🖼	🖼	R1=1kOhm,	Vcc=15V, -V	🖼		▨	Courant déb	
23	3	1	Amplificateur Opérationn	🖼	▨	Rg=50Ohm,	Vcc=10V, -V	🖼		▨	Adaptation	

☑ Use Limit Limit 100 Segment 1

Fig. 2. Part of the **eLab** test units' database.

Questionnaires were used to obtain the students' views as to acceptance, usability, learning effect, and usefulness in studying and vocational terms [16].

The students' answers are summarized in Table 2.

The acceptance scale scores an average result ($\mathrm{M} = 3.62$), as does the usefulness scale ($\mathrm{M} = 3.36$). However, the usability of the Internet experiments does much better ($\mathrm{M} = 4.14$).

Looking at the acceptance scale, it is interesting to note that students enjoyed working with the experiments ($\mathrm{M} = 3.97$). The fact that the experiments were not carried out in a physical lab did not disturb them ($\mathrm{M} = 4.29$), but they would prefer to see them in reality ($\mathrm{M} = 2.07$).

6 EXAMPLES OF ELAB PRACTICAL COURSES

In Bordeaux 1 University, in the curricula of Bachelor of Electrical Engineering or Master of Microelectronics, students have practical teaching modules that follow the dual-approach circuit simulation/circuit measurement, for each electronic function. The measurement session is usually performed on customized boards with discrete components, but this situation has many drawbacks, as detailed hereafter.

TABLE 2
Parameters of the Questionnaire Scales

scale	items	N	alpha	M [a]	SD
Acceptance	9	28	.87	3.62	0.84
English language skills	4	30	.70	4.16	0.78
Usability	6	30	.85	4.14	0.86
Usefulness	5	28	.81	3.36	0.89
Self-assessed learning effect	3	29	.88	64.08 [b]	16.59

[a] Response scale from 1 = "I totally refuse" to 6 = "I completely agree"

[b] Response scale from 0% to 100%

The following examples are taken among typical building blocks in analog circuits design, and illustrate the most significant advantages of using a remote platform like **eLab**.

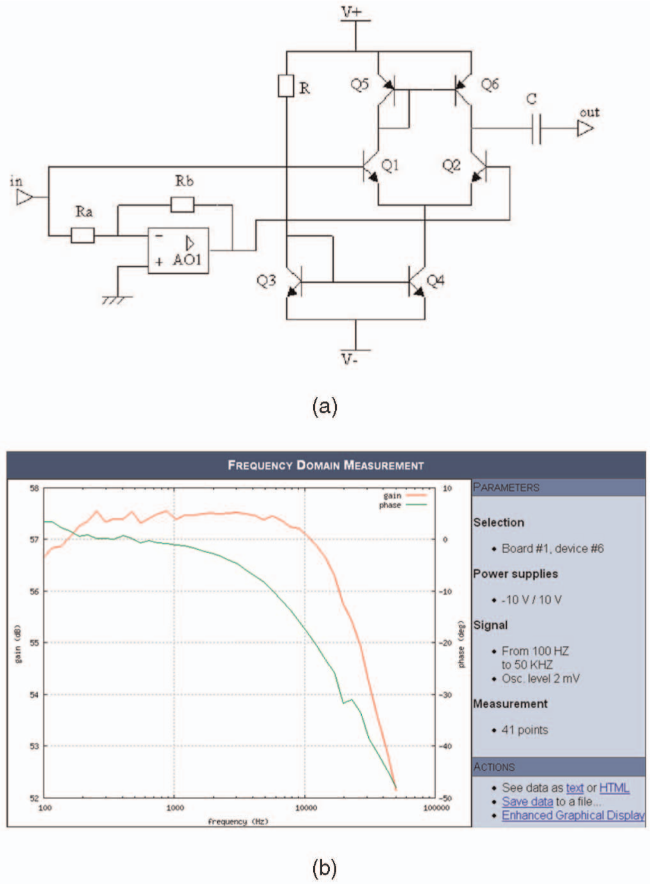
6.1 Differential Amplifier

This building block is found at the input stage of all operational or transconductance amplifiers; its investigation by the electrical engineer students is of the highest importance. Different topologies exist for this function, with different performances. When using discrete components on a test board, the main difficulty comes from instabilities due to the density of wire connections and the generally high voltage gain. Even with the simpler topology (differential amplifier with long-tail resistance and resistive load), the test configurations (specific to differential or common modes) introduce other external components making the overall circuit quite complex.

The solution is to use a standard integrated circuit (CA3046), instead of discrete components, and realize a specific PCB for each test configuration, which considerably minimizes the connections. It is finally possible to characterize the most complex version of the differential amplifier in differential mode, with current mirrors as active load and active biasing circuits, as it is shown in Fig. 3.

6.2 MOS Wilson Current Mirror

The current mirror is another widely used function in analog IC. The theoretical development generally describes a perfectly balanced structure and its performance (ability to duplicate a current) depends crucially on the transistors matching. This matching property is once again not realizable with discrete components. The solution is to use a specific IC (part of the previously mentioned *Cyberchips*) which implements a set of current mirror topologies. Furthermore, by embedding this specific IC in **eLab** remote platform, we avoid the delicate problem of chip manipulation: the circuit under test remains at a permanent place,



(a)

(b)

PARAMETERS

Selection

- Board #1, device #6

Power supplies

- -10 V / 10 V

Signal

- From 100 HZ to 50 KHZ
- Osc. level 2 mV

Measurement

- 41 points

ACTIONS

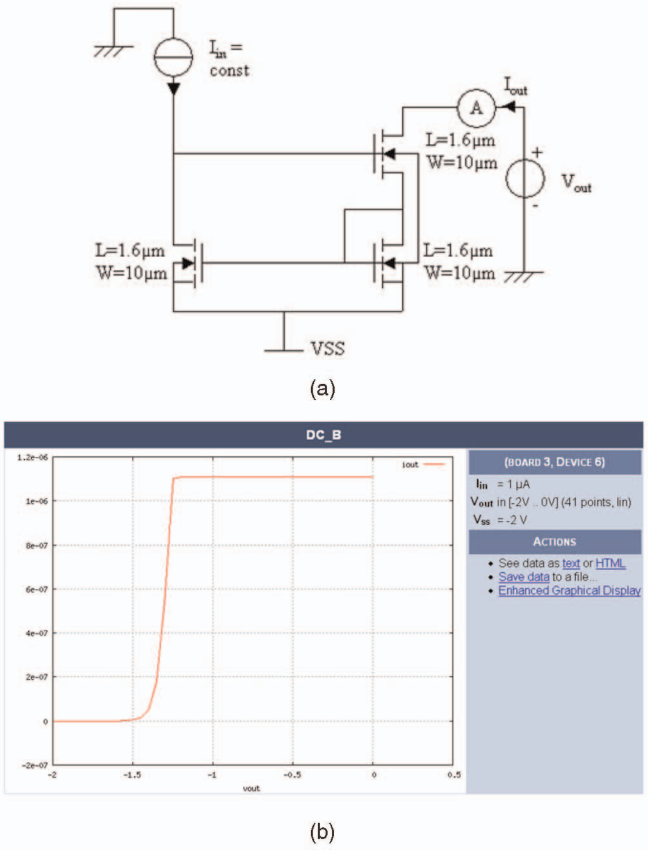
- See data as text or HTML
- Save data to a file...
- Enhanced Graphical Display

Fig. 3. Differential amplifier frequency characterization: (a) test circuit and (b) **eLab** measurement results.

while the switching matrix permits to configure different test circuits. In **eLab**, four different types of current mirror are available and the result of MOS Wilson mirror static characterization is shown in Fig. 4.

6.3 Transistor Gummel Characterization

As the last example, we consider the transistor, which is the fundamental device in microelectronics. Students in an EE curriculum have generally teaching modules on Physics of Semi-conductor Devices, which permit to understand the transistor electrical characteristics. **eLab** platform gives access to a Semiconductor Parameter Analyzer (HP4145), which is an accurate research lab instrument. Furthermore, alone transistors (MOS or Bipolar) are available on the *Cyberchips*. For example, Fig. 5 shows the typical Gummel plot for a PNP transistor that student can perform with **eLab**. It is obvious that such costly equipment couldn't be duplicated in several stations.



(a)

(b)

(BOARD 3, DEVICE 6)

I_{in} = 1 µA

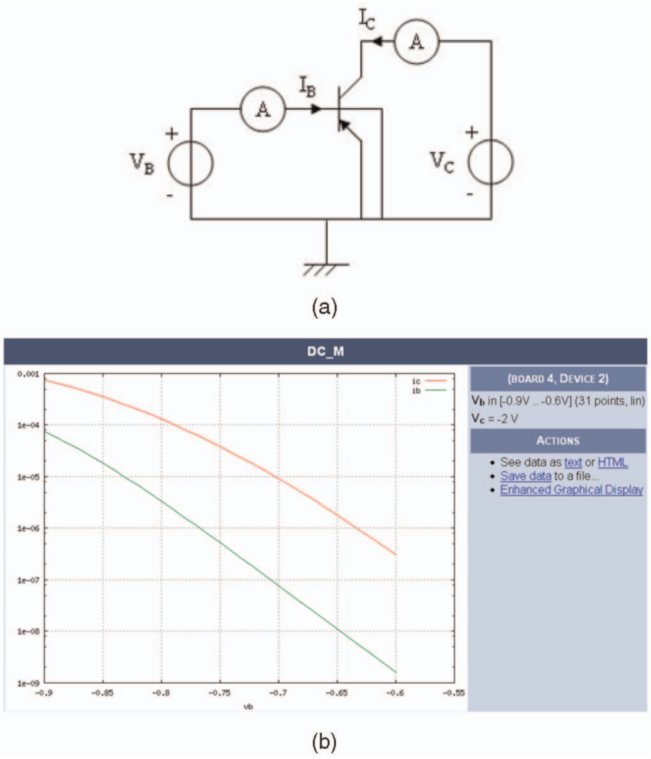
V_{out} in [-2V .. 0V] (41 points, lin)

V_{ss} = -2 V

ACTIONS

- See data as text or HTML
- Save data to a file...
- Enhanced Graphical Display

Fig. 4. MOS Wilson current mirror output characterization: (a) test circuit and (b) **eLab** measurement results.



(a)

(b)

(BOARD 4, DEVICE 2)

V_b in [-0.9V .. -0.6V] (31 points, lin)

V_c = -2 V

ACTIONS

- See data as text or HTML
- Save data to a file...
- Enhanced Graphical Display

Fig. 5. Gummel plot for a PNP transistor: (a) test circuit and (b) **eLab** measurement results.

7 CONCLUSION

Practical experiments have a great importance in electrical engineering, not only to compare theory and practice, but also to learn how to employ research and industrial instruments. This paper has presented the **eLab** remote platform, in terms of history, architecture, use, and pedagogical interest. **eLab** is an Internet-based platform which relates the user to a set of electrical circuits and instruments. A huge number of real experiments can be performed through the Web, with a wide range of typical circuits in electrical engineering. Examples have been presented to show that **eLab** can solve several obstacles that usually disturb students' practical measurements. The **eLab** architecture offers a rapid access to the instruments and devices, without any booking procedure, and does not require any commercial software. After identification, the user is given access to a personal desk gathering his *textbooks*, *notebooks*, and previous measurements. The instructor can easily edit a *textbook*, using the test units' database, to create a personalized **eLab** session. In conclusion, **eLab** fits the main requirements of remote labs: availability, security, flexibility, portability, and limitation of implementation cost.

Today, **eLab**-based practical modules are concretely integrated in the curriculum of Bachelor of Electrical Engineering or Master of Microelectronics at Bordeaux 1 University. A recent cooperation with Sfax Superior Institute of Electronics and Communications (ISECS) has been leading to introduce an **eLab** module in the program of the ISECS institute since 2007 [25]. It has provided a significant impact on users' learning motivation. Future plans address the integration of the **eLab** platform into complete learning units that are accredited by European Credits Transfer System (ECTS), within a Learning Management Systems.

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