

An Online Microelectronics Device Characterization Laboratory with a Circuit-like User Interface

Jesús A. del Alamo, Massachusetts Institute of Technology, Cambridge, MA, alamo@mit.edu
Victor Chang, Massachusetts Institute of Technology, Cambridge, MA, vchang@alum.mit.edu
James Hardison, Massachusetts Institute of Technology, Cambridge, MA, hardison@alum.mit.edu
David Zych, Massachusetts Institute of Technology, Cambridge, MA, dzych@mit.edu
Lisa Hui, Massachusetts Institute of Technology, Cambridge, MA, elyssah@mit.edu

Abstract — *We have developed and deployed a new graphical user interface for an online microelectronics characterization laboratory that we call the MIT Microelectronics WebLab (or "WebLab" for short). WebLab allows the characterization of transistors and other microelectronic devices in real time through the Internet. The new graphical interface consists of a Java applet that uses the circuit language of electrical engineering to specify the experiment to be performed. The latest release of WebLab features a new remote management system designed to allow the efficient deployment of the system in multiple subjects with large numbers of students. Since its release in mid 2002, this version of WebLab has been used by nearly 700 students to complete assignments for credit in six different subjects.*

Index Terms — *Internet, microelectronics, online laboratories, WebLab*

1. INTRODUCTION

In the teaching of microelectronic device physics, hands-on characterization of transistors and other devices substantially enhances the educational experience. However, for a variety of logistical and economic reasons, conventional microelectronics courses are rarely able to include a laboratory component. A remote laboratory that allows the characterization of microelectronic devices without the need for the user to be in front of the experimental setup solves many of these logistical concerns while largely preserving the educational experience. The use of web technology allows the creation of such a laboratory while imposing minimal requirements on the remote user. Many institutions in different fields have explored this concept of an online laboratory [1-7].

Over the last few years, we have been experimenting at MIT with a system called the MIT Microelectronics WebLab, or WebLab for short. This system allows microelectronics device characterization through the web [8,9]. There are similar efforts throughout the world [10-12]. Through WebLab, students can take current-voltage measurements on transistors and other microelectronics devices in real time from anywhere and at any time. WebLab was first deployed in 1998, and since then it has been used for graded course assignments in several graduate and undergraduate subjects at several different universities. The basic architecture of the system and its use in a variety of educational settings was reported in [7]. A prototype collaboration system for WebLab was described in [13].

In this work, we describe WebLab 5.0, released in mid 2002 and used in several educational settings during the academic year 2002-2003. WebLab 5.0 features two key improvements over previous versions of the system. First, it employs a graphical user interface that uses the circuit language of electrical engineering to specify the experiment to be performed. This is much more intuitive than the textual, form-based user interface that was utilized in previous versions of WebLab. The text-based approach, though very similar in nature to the instrument's own interface, was found to be intimidating and to represent a significant barrier to first-time users. The new graphical interface improves usability by reducing clutter and hiding unnecessary details from the user.

The second major improvement in this latest release of WebLab is a new remote management system that has been designed to allow the efficient deployment of WebLab in multiple subjects with large numbers of students. Through this system, the WebLab administrator can manage user accounts, user groups, device specifications, and device access permissions, as well as examine a variety of system usage records. These are all important tasks that can become a significant administrative burden as the number of courses and the number of students that use the lab increase.

WebLab 5.0 was deployed mid 2002 and extensively utilized during the academic year 2002-2003. This paper describes the key improvements in WebLab 5.0 and summarizes the educational experiments that have been performed. It is organized as follows. Section 2 provides some technical background on WebLab. Section 3 describes the new graphical user interface. Section 4 presents the new remote management system. Section 5 summarizes the most significant educational experiments performed with WebLab 5.0.

2. BACKGROUND

At the heart of WebLab is an Agilent 4155B Semiconductor Parameter Analyzer, a state-of-the-art instrument for measuring the current-voltage characteristics of microelectronics devices and small circuits with up to eight terminals. The analyzer is connected to an Agilent E5250A Switching Matrix, a multiplexer which, in its current configuration, allows up to eight different devices to be connected to the system at any given time. Both the analyzer and the switching matrix are controlled by a GPIB (IEEE 488) interface card on the WebLab server computer, which is currently a Dell PowerEdge 4600 running the Windows 2000 Server operating system. The devices under test are mounted in a packaged form onto standard test fixtures that are connected to the switching matrix.

The user interface for WebLab is a Java applet which duplicates the essential functionality of the analyzer's console, allowing the user to set up a measurement for one of the devices that is currently connected to the system (the necessary information about these devices is provided by the server when the applet loads). When the user is ready to execute a measurement, the applet sends the measurement specifications to the server. The server then sets the switching matrix to the appropriate device, instructs the analyzer to run the measurement, obtains the results from the analyzer, and finally transmits the data back to the applet, where they can be graphed and otherwise analyzed by the user. More details of the system's operation are given in [8,9].

Since its original release in 1988, WebLab versions 1.0 through 4.x have provided a textual, form-based user interface (now referred to as the "Classical" Interface) that closely mimics the front panel of the analyzer itself. This approach was based on our judgment that the designers of the instrument would have already put a great deal of thought into creating an optimal user interface for performing device characterization measurements. The Classical Interface consists of three frames. The *device configuration frame* (shown in Fig. 1) illustrates the connections between the ports of the analyzer and the terminals of the microelectronics device under test. The *measurement specification frame* (shown in Fig. 2) allows the user to specify the voltages or currents to be applied to each terminal, and optionally to specify simple algebraic functions on the data which will be computed by the analyzer as the experiment is being performed. The *measurement results frame* (shown in Fig. 3) displays a customizable graph of the data returned by the analyzer, and also allows the user to download a copy of this data for offline processing using an external spreadsheet or mathematics software application.

The advantage of the Classical Interface is that it is extremely simple, and consequently runs very reliably on any standard Java-enabled web browser. Also, the Classical version of the applet downloads quickly because the code archive is very small (about 58 KB). We have therefore continued to maintain the Classical applet in WebLab 5.0 to accommodate those users for whom compatibility issues and/or network bandwidth constraints make it difficult or impossible to use the new Graphical applet.

However, the Classical Interface has two major problems. First, the text-based measurement specification frame is highly intimidating and not particularly intuitive, and this has always represented a significant psychological barrier for first-time users of the system. Note that this effect is not limited to first-time users who are students; it also applies to teachers of microelectronics who are evaluating WebLab for possible adoption into their courses.

The second problem with the Classical Interface is the clutter created by the use of multiple frames. This becomes especially troublesome when considering the collaborative use of WebLab. A prototype collaboration system for WebLab was presented in [13]. The key concept behind this system is the "dual-domain interface", in which each user is given essentially two copies of a standard WebLab interface: an individual domain which belongs to that user alone, and a group domain that is controlled by only one member of the group at a time but seen by all members of the group. In this way, individual and group work can proceed simultaneously but separately. However, a dual-domain interface based on the Classical applet requires a large number of frames: two measurement specification frames (one for each domain), two measurement results frames, and at least one additional frame for listing the composition of the group and transferring control of the group domain between members. Chatting among group members (either as part of the WebLab client, or using a different third-party messaging application) requires yet another frame. At best, having all of these frames open at once results in a great deal of clutter and confusion; at worst, they may not fit onto the user's display at all.

3. A GRAPHICAL USER INTERFACE FOR WEBLAB 5.0

The new Graphical Interface featured in WebLab 5.0 (shown in Fig. 4) was designed to address the deficiencies of the Classical Interface. It uses the standard circuit language of electrical engineering to represent the experiment setup, making the user experience much more intuitive. It also reduces desktop clutter by combining the measurement specification panel and the measurement results panel into a single window. This unified interface greatly simplifies the look and feel of the dual-domain collaboration system [14].

The measurement specification panel of WebLab 5.0 (on the left in Fig. 4) displays a circuit schematic which illustrates the connections between the device under test and the various ports of the analyzer. As each analyzer port is configured, its icon in the schematic changes to reflect the port's new function and behavior. For example, Fig. 4 shows an experiment setup for a bipolar transistor. The port connected to the emitter is programmed to be a direct ground connection, the port connected to the base is a variable current source, and the port connected to the collector is a variable voltage source. The WebLab server provides a bitmap image for each device attached to the system and specifies the pixel coordinates of the terminals; the remaining pieces of the schematic diagram (the terminal labels, port icons, and connecting wires) are assembled dynamically by the interface.

To make the user experience less intimidating, many features of the interface have been moved out of the main window and into dialog boxes and menu items. The analyzer ports are configured through dialogs like the one shown in Fig. 5, which the user opens by clicking on a port icon in the schematic diagram. Similar dialog boxes are used to configure each axis of the measurement results graph. Several other features, such as user-defined functions, viewing data, and downloading data, are now accessed through the applet's menu bar. The net effect of all of these changes is that the main window of the interface is much less cluttered than before; instead of being confronted simultaneously with every available piece of detailed information (as was the case in the Classical Interface), the user is initially presented with an intuitive visual representation of the measurement. All of the details are still present in the interface, but the user can examine them a few at a time by opening and closing the various dialog boxes.

The Graphical Interface does have a few disadvantages. The applet code for the Graphical Interface makes substantial use of the Swing toolkit, a sophisticated library of GUI components for Java that is much more versatile and powerful than the older Abstract Window Toolkit (AWT). However, because the Swing toolkit is more recent, it is not directly supported by the Java virtual machines in standard Java-enabled web browsers. WebLab users must therefore download and install the Java Plug-in from Sun in order to use the Graphical applet. Unfortunately, the Java Plug-in itself is not yet free of bugs, and certain operations in the Graphical applet that run flawlessly on one client machine may cause the applet to behave erratically or even crash when run on a second client machine that uses a different version of the Java Plug-in (or even the same version of the Java Plug-in but for a different operating system). Debugging the Graphical applet has therefore been a complicated, ongoing process. While the majority of our students are able to use the system without ever encountering technical problems, each new WebLab assignment usually results in at least one bug report that we are eventually able to trace back to an obscure inconsistency in the behavior of the Java Plug-in. Additionally, there are some platforms (Windows 95 and 98, and Mac OS 8.x and 9.x) on which we have never been able to successfully run the Graphical applet at all due to inadequate Java support. Finally, because the Graphical Interface is substantially more complicated than the Classical Interface (the code archive is about 261 KB), the applet takes longer to download and longer to initialize. However, for users with compatible system configurations and enough network bandwidth to support the longer load time, the intuitive feel of the new Graphical Interface has dramatically improved the overall quality of the user experience.

4. A REMOTE MANAGEMENT SYSTEM FOR WEBLAB 5.0

The second significant improvement in WebLab 5.0 is the introduction of a remote management system. Prior to the v. 5.0 release, most of the administrative tasks had to be performed while at the lab. This meant that a common task, such as adding a user account, could only be performed by a lab manager who was physically present in the lab. As the number of WebLab users and the overall demand on the system increased, the need for a more efficient method of system administration also grew. By taking advantage of Microsoft Active Server Pages (ASP) technology and a dedicated SQL database, lab managers using WebLab 5.0 are able to perform the bulk of their tasks over the Internet.

Technologically speaking, ASP is an established way of incorporating functional logic into online forms or documents. In particular, ASP allows for this functional logic to utilize server components such as a database. In this way, information can be programmatically stored and retrieved by the functions written into a set of online forms. The technology involved is rather simple, but the value added is significant. In the case of WebLab, it allows administrative tasks that were previously time-consuming and inconvenient to become efficient, highly available and, in some cases, automatic.

For instance, the new management system streamlines common user management tasks. In the current implementation, users are responsible for registering their own accounts. These registrations are then either approved or rejected by a lab manager at the WebLab site. Realizing that the lab manager and user may not be logged onto the site at the same time, email alerts are sent to the appropriate groups at each step.

From this same web interface, a lab manager may add a new user to a custom user group and grant the user access to resources on the system, such as physical devices or software functions. Again, all of this functionality is available to a lab manager at any Internet-enabled workstation regardless of time or location. The end result of this is that students are able to

log onto the system and perform experiments within hours or even minutes of requesting their accounts where, prior to version 5.0, it could take days.

From the WebLab site, lab managers may also edit the resources available on the system as well as the permissions associated with those resources. Of particular import is that the representations of the physical devices connected to the lab can be edited through this interface. In fact, the only portion of the lab device setup process that cannot be performed via the Internet is physically connecting the device to the system. This means that there is minimal lab setup work necessary to accommodate a new class or even multiple classes simultaneously.

Finally, a searchable records system allows lab managers to track user logons and job executions. This, coupled with new bug reporting and system notice interfaces, allows problem tracking and resolution to occur much faster than before. By adding an easy means of communication between lab users and managers, students who are having problems may report those problems to a manager, who then can view system logs and correspond with the user in order to isolate and solve the problem. Also, the resolution can then be quickly posted to the site, making the information available to all users of the system.

The end result of the new functionality is that the system experiences less downtime because the resistance to addressing potential issues is lowered. This means that the technology involved in the lab becomes more transparent to the student and they are able to focus their experience more on the educational aspect of the system.

5. EDUCATIONAL EXPERIMENTS USING WEBLAB 5.0

Since its deployment in mid 2002, WebLab 5.0 has been used in several subjects for credit-bearing assignments. In the Fall of 2002, WebLab was used in three courses: 6.012 “*Microelectronic Devices and Circuits*”, a junior-level course at MIT with about 120 students, 6.720 “*Integrated Microelectronics Devices*”, a graduate-level subject at MIT with about 50 students, and SMA5104 “*Fundamentals of Semiconductor Device Physics*”, a graduate-level subject in the Singapore-MIT Alliance with about 20 students.

In the Spring of 2003, WebLab was used again in another edition of 6.012 at MIT (with about 120 undergraduate students) and also in FFY171/ET1145 “*Semiconductor Devices*,” a sophomore level subject at Chalmers University in Sweden, with 350 students. This was the largest ever deployment of WebLab to date. All together, nearly 700 students have used WebLab 5.0 for lab projects for credit since its deployment.

Since the architecture of WebLab 5.0 is the same as that of earlier versions, the scaling behavior of WebLab should be unaffected. The Chalmers University experiment allowed us to explore the capabilities of the system beyond our previous peak [9]. On Feb 25, 2003, between noon and 1 PM EST, there were 134 characterization experiments executed in a single hour (on average, that means a job every 27 seconds). This represents a 35% increase over our previous record.

The user feedback we have received suggests that the new Graphical Interface indeed provides for a pleasant and intuitive working environment. Here is the opinion of a 6.012 student in the Spring of 2003: “The WebLab interface worked flawlessly for me. The applet was very intuitive to use and I was able to complete the data collection portion of the assignment easily.” Here is another: “I found WebLab to be very user friendly and a great tool. It beats walking all the way to the lab to perform these measurements.”

CONCLUSIONS

In conclusion, we have developed a new Graphical User Interface for an online microelectronics device characterization laboratory. The new interface uses the circuit language of electrical engineering to specify an experiment. Students report that the new interface is intuitive and feels familiar. On the down side, the graphical nature of the interface requires a Java Plug-in which makes debugging more complicated. We have also introduced a new management system that allows remote user management and system management through the web. This has allowed us to support courses with as many as 350 students. WebLab 5.0 has now been used by nearly 700 students in different subjects from academic institutions on three continents.

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FIGURES AND TABLES

FIGURE. 1

WEBLAB 4.2 CLASSICAL INTERFACE: DEVICE CONFIGURATION FRAME

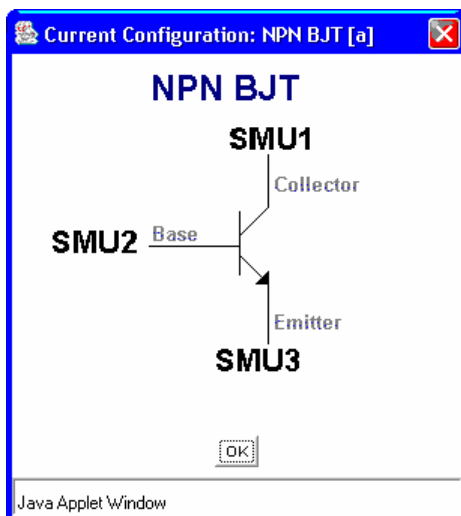


FIGURE. 2
 WEBLAB 4.2 CLASSICAL INTERFACE: MEASUREMENT SPECIFICATION FRAME

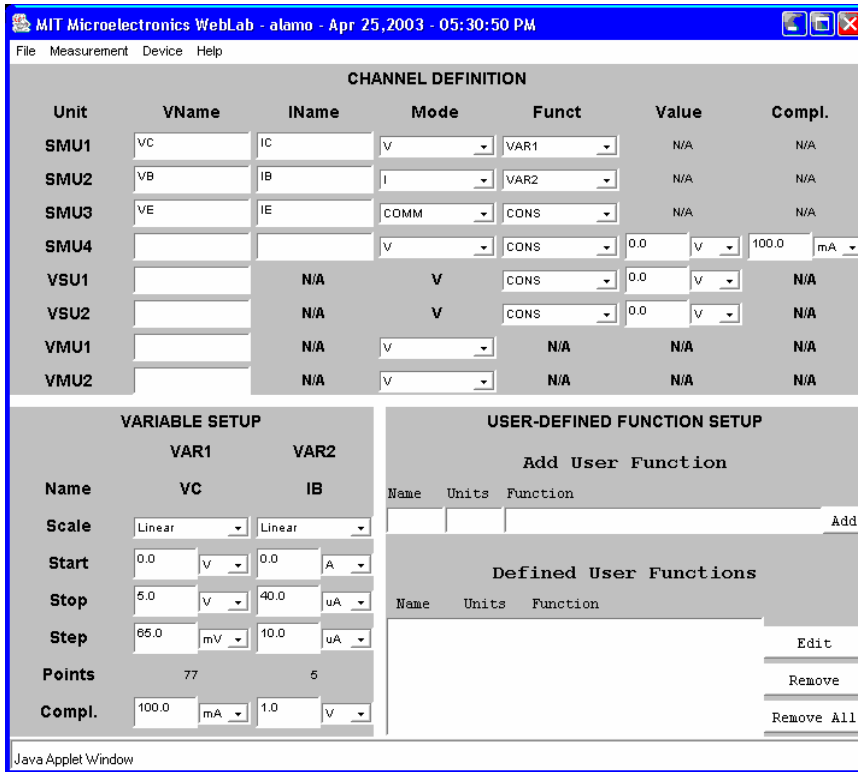


FIGURE. 3
 WEBLAB 4.2 CLASSICAL INTERFACE: MEASUREMENT RESULTS FRAME

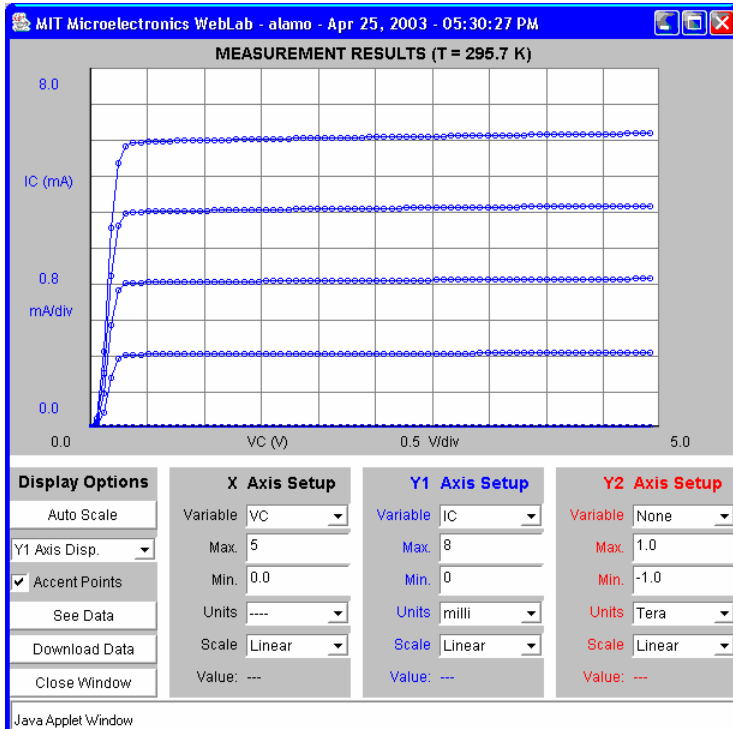


FIGURE. 4
 WEBLAB 5.0 GRAPHICAL INTERFACE: MAIN WINDOW

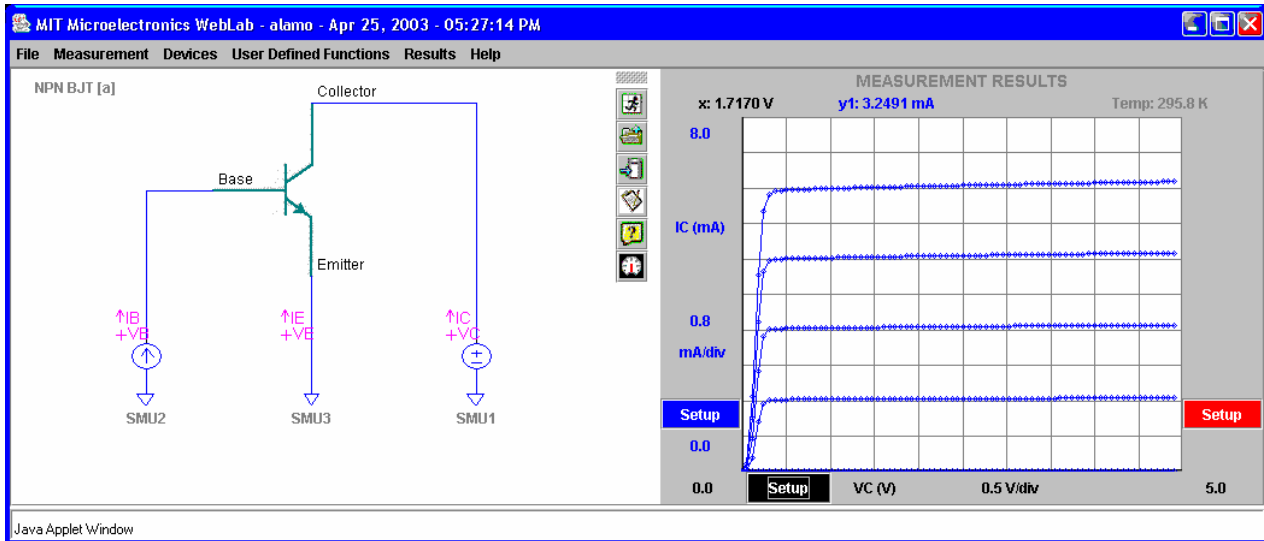


FIGURE. 5
 WEBLAB 5.0 GRAPHICAL INTERFACE: PORT CONFIGURATION DIALOG

