

Advanced Internet Technology in Laboratory Modules for Distance Learning

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Abstract

We describe user-friendly and efficient technologies for interactive, on-line operation of laboratory experiments over the Internet. The objectives are to utilize the most recent advances in Internet and World Wide Web, to allow communication with minimum overhead, to provide a functional client interface, to establish a variety of experiments, and to allow flexibility in configuring experiments. Our remote lab is based on a client/server architecture where students can communicate with the lab server using regular Web browsers. To fully utilize the functionalities of modern browsers and servers, the server may respond in formats such as JavaScript, HTML or XML. This is achieved by creating Web-solutions based on Internet Server Application Programming Interface (ISAPI) extensions, whereby important issues related to queuing and security are addressed. We also discuss an alternative solution based on LabVIEW 6i where the client uses LabVIEW Player. Presently, our remote lab is dedicated to semiconductor device characterization. It has been tested in distance-education courses on device technology with good results.

1. Introduction

The use of Internet and studio classrooms is an emerging trend for promoting “individual discovery” as a strategy for enhancing engineering education. Here we describe how these techniques can be combined with traditional laboratory exercises to create a suitable environment for interactive, on-line operation of lab experiments over the Internet, to be used either in the classroom, in a studio setting, or from a remote location as part of a distance learning strategy.¹

Central issues in creating a user-friendly and efficient technology for interactive, on-line operation of laboratory experiments over the Internet are to utilize recent advances in Internet and World Wide Web, to allow communication with minimum overhead, to provide a functional client interface, to establish a variety of experiments, and to allow flexibility in configuring experiments. Our remote lab is based on a client/server architecture where students communicate with the lab server using regular Web browsers. Previous versions of the lab were based on a TCP/IP (Transmission Control Protocol/Internet Protocol) solution, which used a Java Applet on the client (i.e., student) side.^{1,2} This was achieved by means of a JVM (Java Virtual Machine) in the Web browser that can download and execute Java code. The client sees a pop-up window that provides interaction and communication directly with the server. Java Applets provide good control. However, unsigned Applets make it awkward for the client to store and present the

measurement data, and to transfer them to other applications (except by "cut-and-paste") because of Java's security structure. A further problem with Java is that the functionality of an Applet may vary between different browsers. While the recently introduced Java 2 has better support for the user interface, some of the new classes included in this version are not automatically compatible with JVM, requiring an additional plug-in to be installed in the browser. For many potential users, this is a problem, partly because of skepticism towards plug-ins and partly because of local security regulations in many organizations. Besides, the future support of Java is uncertain.

For the above reasons, we felt a need to look into alternatives to the TCP/IP solution, leading us to consider the added functionalities of modern Web browsers. In this report, we describe how we can fully utilize these functionalities by enabling the server to respond to clients in rich formats such as JavaScript, HTML (HyperText Markup Language), XML (Extensible Markup Language), or even WML (Wireless Markup Language), as indicated in Fig. 1. This is achieved by creating Web-solutions based on the ISAPI (Internet Server Application Programming

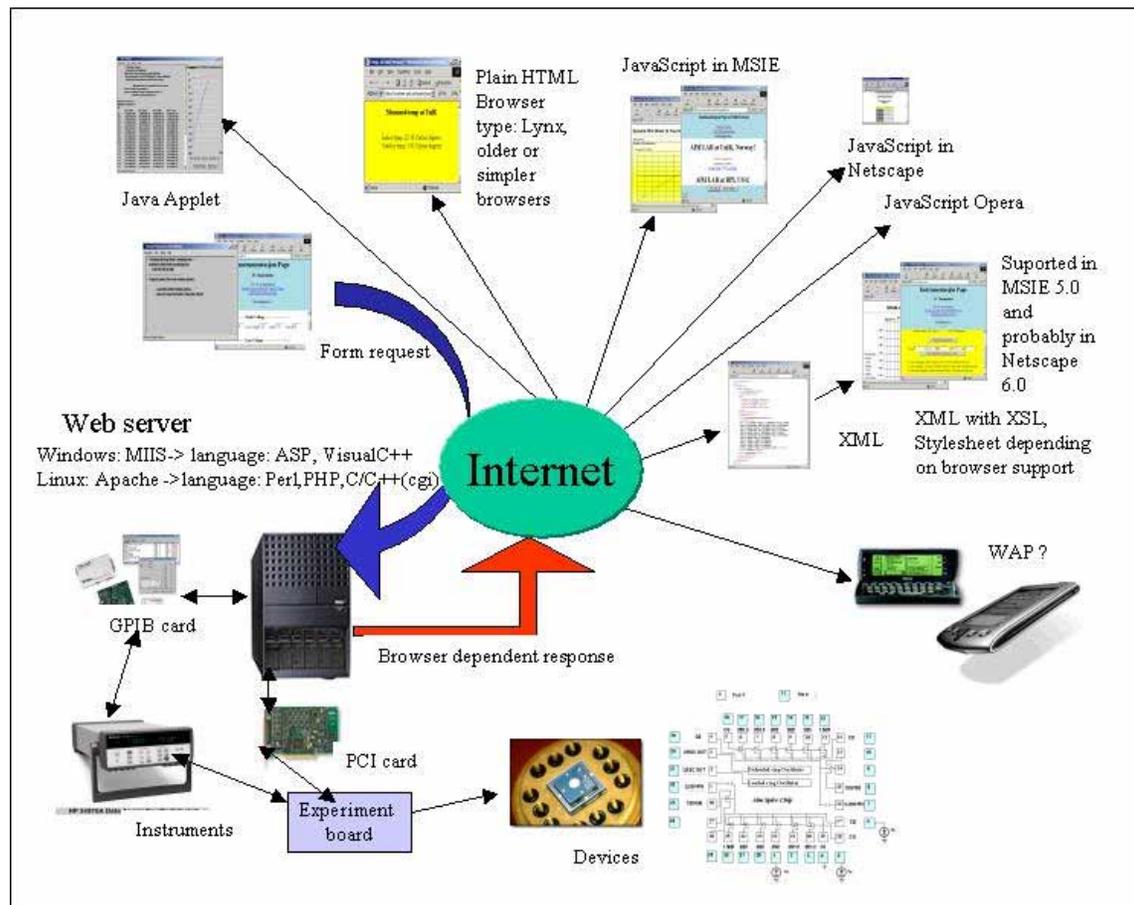


Fig. 1. System configuration of the remote lab. The server response to different client browsers are indicated on top/right.³

Interface) server extension, or COM+ (Common Object Model with recent extensions).^{3,4} This strategy also lets us address important issues related to queuing and security.

To complete the picture, we also consider solutions based on the newly released LabVIEW 6i application from National Instruments, as an interesting option for providing the desired Internet access to the remote lab.⁵ In this solution, the lab-side server runs a full version of LabVIEW 6i, which incorporate Internet communication capabilities and functionalities to access/control instruments and to acquire/output data. The client communicates with the server and the experimental setup by means of LabVIEW Player, which can be downloaded and installed for free. This unit is capable of executing secure VIs (Virtual Instruments) specifically developed for the experiment in question, providing the client with great ability to control the remote instrument and to receive and present the desired experimental data.⁶

An important server function is the physical interfacing with the experimental set-up. This is achieved either through a GPIB card and an instrument, or by means of PCI/ISA cards, which are installed directly in the expansion slots of the host PC as inexpensive alternatives to instruments.⁷

The present version of the lab is dedicated to semiconductor device characterization. It includes several experiments that are performed on a microelectronic test chip, and is used as a lab module in courses on semiconductor devices and circuits at the senior or first year graduate level at the Norwegian University of Science and Technology (NTNU) and at Rensselaer Polytechnic Institute (RPI). Both remote and local students are enrolled in these courses, and can conduct the lab exercises on an equal footing. By analyzing experimental characteristics obtained from individual devices, the students can extract SPICE parameters, which are used for simulating the behavior of circuits, for example, by means of our circuit simulator AIM-Spice.⁸ Such simulations can then be compared with experiments on simple circuits in the test chip. For the theoretical part of such a course, we use our textbook "Introduction to Device Modeling and Circuit Simulation".⁹ We have also good experience with on-line classroom lab demonstrations for more in-depth illustrations of the course material.

2. Measurement Setup

An overview of the remote lab measurement setup is shown in Fig. 2.⁴ The server is a Cinet PC PPI-600 with a 350 MHz Pentium II processor, a Windows NT Workstation operating system, and a MIIS (Microsoft Internet Information Server) version 3.0 Web server. The main instrument is an HP 4142B Modular DC Source/Monitor, a high-speed, accurate, and computer controlled DC parametric measurement instrument for characterizing semiconductor devices. It can force or measure voltages and currents within 4 ms, and store up to 1023 data samples in the internal memory. Up to eight different plug-in modules can be used with this instrument, allowing us to tailor the instrument to suit our needs. In our set-up, we installed two HP 41421B SMUs (Source Measurement Units), in addition to the built-in 0 V source GNDU (GrouND Unit). The HP 34970A Data Acquisition/Switch unit (with HP 34904A Matrix Switch plug-in modules) is used as a matrix switch in the remote lab, allowing the client to configure the experimental set-up. This is done by activating the matrix to make desired connections to terminals/devices of the test chip for a specific measurement series. Figure 2 also shows a Tektronix TDS 3052, 500 MHz

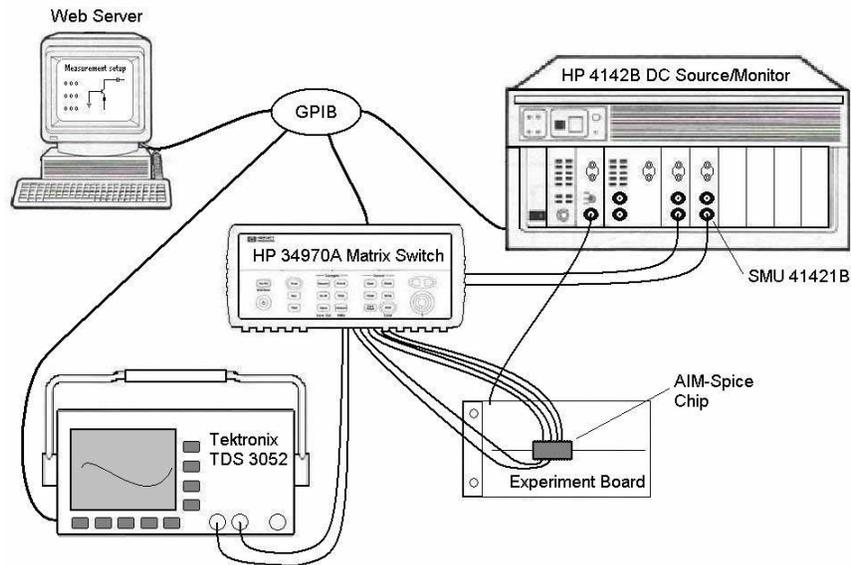


Fig. 2. Overview of the remote laboratory setup. The CMOS test chip on the experiment board includes diodes, n - and p -channel MOSFETs of different geometries, and CMOS test circuits.

oscilloscope. This instrument is used mostly for testing and servicing the setup, but it can also be used as part of the lab for measuring transient events or waveforms. As indicated in Fig. 2, the server communicates with and controls all the instruments via the GPIB bus. The layout of the CMOS test chip used is indicated in the lower right of Fig. 1.

3. ISAPI Solution

ISAPI server extensions belong to the Microsoft Active X technology, and act to extend the capabilities of the HTTP (HyperText Transport Protocol) server included in the MIIS. Such extensions are an alternative to the CGI (Common Gateway Interface) standard incorporated into HTTP, allowing browser programs to interact with scripts or separate executable programs running on the server. However, the ISAPI extensions are faster, more versatile, and have added functionality compared to CGI. For specific tasks, such as our remote lab, ISAPI extensions are programmed in Visual C++ by means of a 'Wizard' that comes with Microsoft Visual Studio.

ISAPI server extensions are implemented as a DDL (Dynamic Link Library) file on the Web server. They load when called, and act as a programming interface between the server and the server-side applications. They respond to GET and POST requests from the client and typically return information as HTML/XML code that can include JavaScripts or Applets. If a stylesheet created in the XSL (eXtensible Stylesheet Language) is applied to the XML code, the data can be directly presented as graphs or tables in the client terminal. Figure 3 shows a plot of a diode characteristic from the remote lab presented in MSIE (Microsoft Internet Explorer) as an XML document with a stylesheet.³ Different kinds of ISAPI filter functions can be implemented to perform various useful tasks for our remote lab. These include port management, authentication and access restriction, page translation, logging and traffic analysis, and encryption. Unlike the

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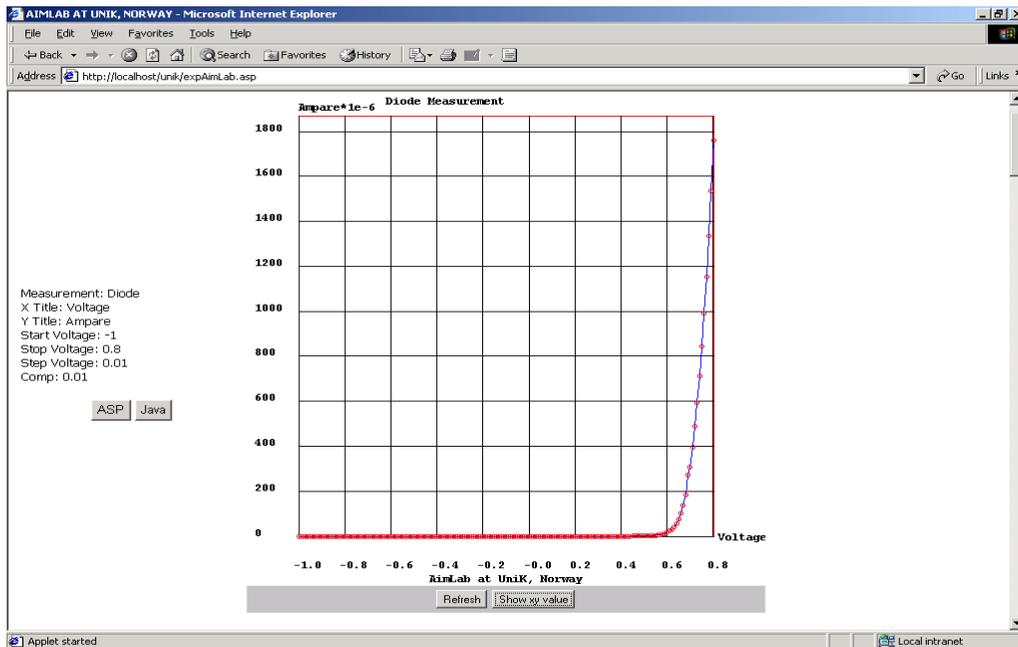


Fig. 3. Example of diode characteristic from remote lab presented as an XML document with a stylesheet using MSI.³

ISAPI extensions, the filters execute with every HTTP request. Hence, they can provide access only to, for example, clients within selected IP address domains. Port management and encryption filters contain useful security features. MIIS version 3.0 uses the SSL (Secure Socket layer) security protocol that allows data encryption and server authentication. The log filter can trap client information such as date, time and path, from which an activity log can be created. The page translation filter can be used to transform XML to, for example, HTML or WML using XSL stylesheets. For clients using up-to-date browsers, the XSL transformation can take place on the client-side, which requires that a stylesheet be transferred to the client along with the XML data. If the client browser does not support an XML parser, the filter executes the XSL stylesheet on the server, in which case the stylesheet is selected based on the browser used. In fact, an ISAPI module running on MIIS can hook onto the XML data stream going back to the client and transform the code into HTML on the fly.

In conjunction with the ISAPI extension solution, the HP VISA (Virtual Instrument Software Architecture) for Windows was used for developing I/O (input/output) applications in C++ based on the VISA I/O library. In VISA, applications can open multiple sessions to a resource simultaneously. However, when it is necessary for a session to execute without interference the lock function *viLock* can be invoked. In the implementation of our remote lab, the *Exclusive Lock* is used for granting so-called atomic access for a given thread to resources that are otherwise shared between many threads.

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4. LabVIEW Solution

LabVIEW from National Instruments is a powerful graphical programming development environment for data acquisition and control, data analysis, and data presentation. Instead of writing program code, we build Virtual Instruments (VIs) with front panel user interfaces that may contain numeric displays, meters, charts, advanced graphs, etc. Functionality is specified in block diagrams. The VI allows control of any GPIB instrument by installing appropriate instrument drivers.

LabVIEW version 6i and the new LabVIEW Player come with advanced Internet-ready capabilities and the concept of measurement intelligence, which includes automatic measurement hardware configuration for fast application development. The LabVIEW Player is a browser plug-in available free of charge from National Instruments. With this plug-in, clients can easily open and run VIs from their browsers, and obtain test results and measurement data from remote locations by means of the built-in Internet tools.

Figure 4 shows the panel of a VI created for a set of experiments on current-voltage characteristics of *p*-channel MOSFETs. Each entry in the list of experiment contains instructions for the matrix switch on how to connect the measurement instrument to the appropriate terminals of the test chip. The ranges and steps for the gate and drain voltages applied to the transistor are specified in the table. The corresponding data received by the client is shown in Fig. 5. Note that the experimental data can be forwarded to an Excel document with the push of a button, for further analysis.

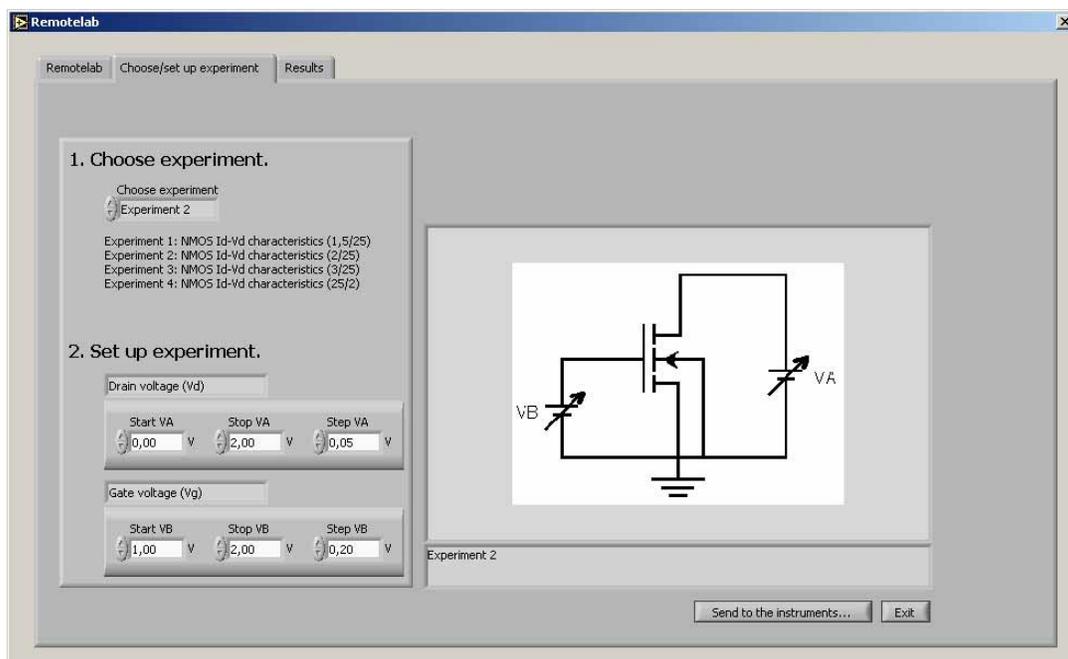


Fig. 4. Remote lab Virtual Instrument panel created in LabVIEW for selecting experiments and for specifying applied voltages.

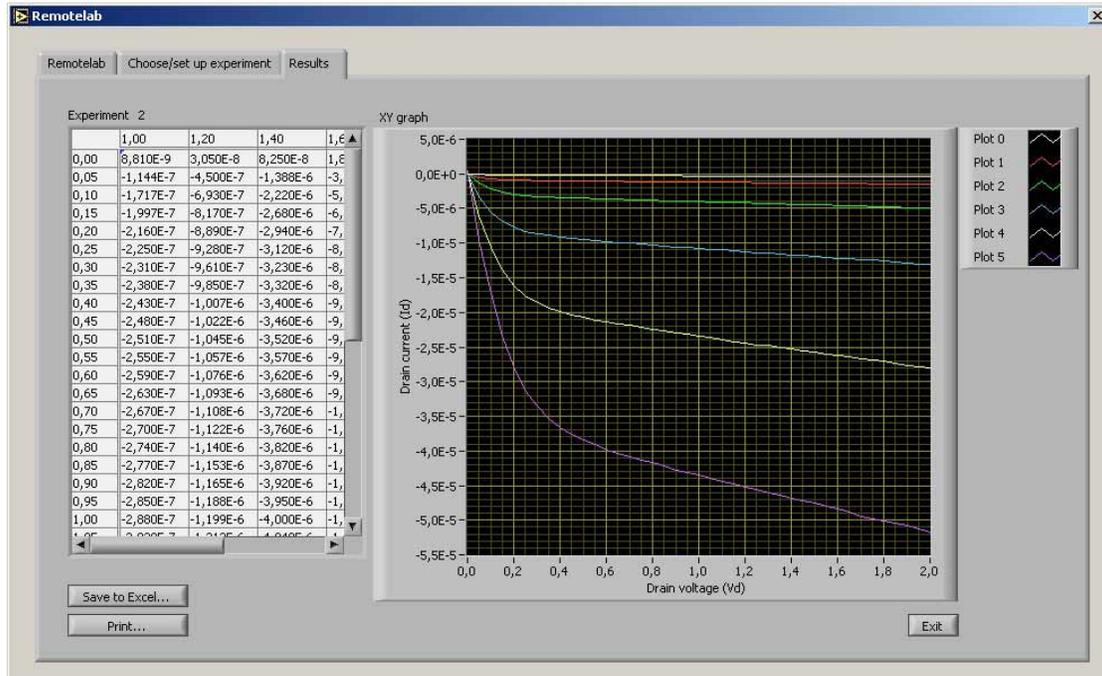


Fig. 5. Measured current-voltage characteristics corresponding to the selections made in Fig. 4, including a table and a graphical presentation.

5. Conclusion

We have investigated two possible realizations of a system for conducting interactive, on-line experiments via the Internet. Specifically, we considered a lab for characterization and analysis of microelectronic devices, which constitutes a module in courses on semiconductor technology at our institutions. In one of the solutions, based on the ISAPI server extension, we have utilized some of the advanced functionalities of modern Web browsers and servers, permitting the server to transmit data in several suitable formats for presentation and analysis at the server side. Added advantages are the ISAPI filters, which perform useful tasks related to queuing, security, logging, etc. In the second solution, we have used LabVIEW 6i with the new LabVIEW Player from National Instruments, which comes with advanced Internet capabilities. Although these solutions have many of the same functionalities, the LabVIEW solution offers a graphical programming environment that simplifies the system development, while the ISAPI solution gives more freedom in creating a tailor made system.

Acknowledgement

This work was supported by a grant from the governments in the Nordic countries through Nordunet2.

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