LAB-on-WEB – A COMPREHENSIVE ELECTRONIC DEVICE LABORATORY ON A CHIP ACCESSIBLE VIA INTERNET

Tor A. Fjeldly[1], Jan Olav Strandman[2] and Raymond Berntzen[3]

Abstract *— We discuss the implementation of a comprehensive electronic device laboratory on a chip that significantly enhances the learning experience of our remote laboratory, LAB-on-WEB. This chip contains several device and circuit test structures, all fabricated in CMOS technology. Besides providing a valuable familiarity with the behavior of the building block of modern integrated circuits, the lab is also designed for the extraction of device and processing parameters needed for circuit design. The extracted parameters are suitable for use with circuit simulators such as SPICE, to predict the behavior of more complicated circuits. This experience, provided either as homework or as classroom or studio demonstrations in conjunction with, for example, more theoretical courses on circuit design, is of great value for conveying deeper insight into the practical aspects of electronic circuit engineering.*

Index Terms — Remote laboratory, CMOS, device characterization, Internet, World Wide Web.

INTRODUCTION

We have previously reported on the development of our remote lab system, LAB-on-WEB, where the clients (students) communicate with the server and the experimental setup utilizing the functionalities of modern Web browsers. The most recent versions of this system are based on the Internet communication capabilities of LabVIEW 6i or COM+ (Component Object Model with extensions) with ASP (Active Server Pagers) [1]-[4]. The system was successfully tested in a senior/graduate level course on electronic device technology.

Laboratory courses are an integral part of engineering education, so the purpose of remote laboratory installations have so far been aimed at filling a gap in the remote engineering education curriculum and saving the students travel expenses for visiting the physical location of the laboratory units. Another objective has been to share lab resources among institutions, whereby also a wider variety of experiments can be made available to the students.

However, as the remote laboratories have become operational, novel pedagogical uses have emerged, including experimental demonstrations to enhance traditional classroom lectures, adding laboratory modules as homework exercises in regular courses, establishing studio classrooms where students do supervised laboratory exercises on individual terminals, and encouraging individual discovery activities among students.

In this report, we describe a comprehensive electronic device laboratory on a chip that significantly enhances the learning experience of our remote lab. This so-called Alfa chip contains diodes, capacitors, transistors, inverters, and other test structures, all fabricated in CMOS technology. Besides providing a valuable familiarity with the static and dynamic behavior of the building block of modern integrated circuits, the lab is also designed for the extraction of device and processing parameters needed for circuit design. The extracted parameters are suitable for use with the circuit simulators such as AIM-Spice [5], [6], to predict the behavior of more complicated circuits, such as the ring oscillator also included on the chip.

This experience is gained through homework or classroom and studio demonstrations, and should be backed up by more theoretical courses on device modeling and circuit design. The objective is to convey a deeper insight into the practical aspects of modern circuit engineering.

The laboratory instrumentation includes a switch matrix system that allows many of the device and circuit structures on the chip to be accessed at will by the students.

ALFA CHIP

Emphasizing the use of our remote lab system for the characterization of electronic devices, we have incorporated a comprehensive electronic device laboratory on a chip. This chip, called Alfa, was developed as part of a project under the European Commission within the ALFA exchange program between universities in the European Union and Latin America [7], [8]. The integrated circuit was designed by the ALFA partners using the Microwind tool developed by INSA, Toulouse [9]. The Alfa chip was fabricated at ATMEL Rousset in France, using a 2-metal 0.7 μm CMOS process.

The Alfa chip layout is shown in Figure 1, where the relevant devices used by LAB-on-WEB are highlighted. The chip is packaged in a PGA 144 chip carrier and the various contact pads (40x40 μm^2) are bonded to the carrier pins. Here follows a brief discussion of some of the important test structures on the chip.

Figure 2 shows a more detailed view of an array of NMOS transistors located in the upper right corner of the Alfa chip. It contains five *n*-channel MOSFETs with a gate

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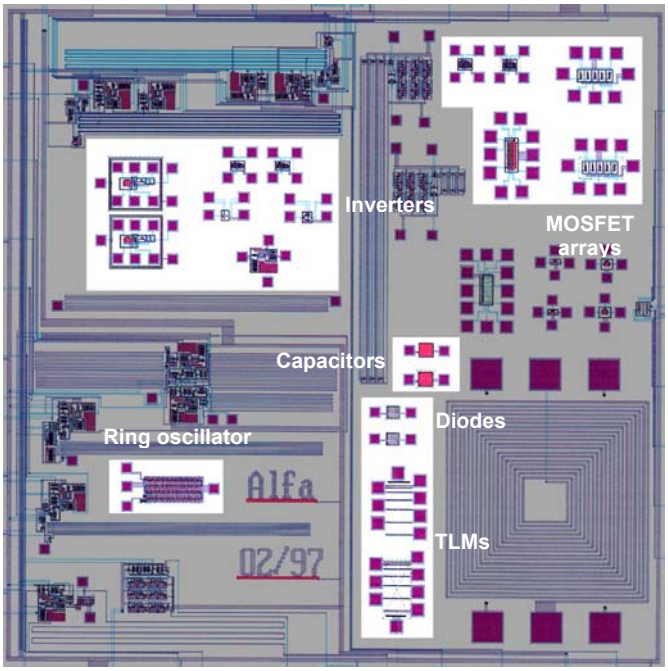

FIGURE 1
ALFA CHIP LAYOUT. THE DEVICES USED IN LAB-ON-WEB ARE LOCATED WITHIN THE HIGHLIGHTED AREAS.

width W = 25 μm and gate lengths L varying from 0.8 to 2.5 μm. The MOSFETs have separate drain contacts while all the gate electrodes are interconnected, and so are the source contacts. The Alfa chip also contains a PMOS array with the same geometries. These arrays are suitable for characterization of individual MOSFETs, for extracting their model parameters, and for studying the effects of geometrical scaling of these devices.

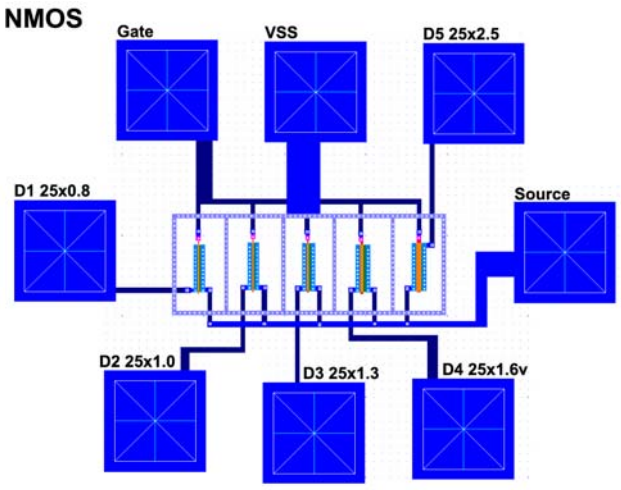

FIGURE 2
LAYOUT OF NMOS ARRAY. THE INDIVIDUAL DRAIN PADS INDICATE THE GEOMETRY OF THE CORRESPONDING GATE ELECTRODES. THE ALFA CHIP ALSO INCLUDES A SIMILAR PMOS ARRAY.

The Alfa chip includes two separate CMOS inverters with different geometries (upper left area of Figure 1). The one shown in Figure 3 has W = 25 μm and L = 0.8 μm for both the NMOS and the PMOS transistor. The second inverter has the same gate length, but a gate width of 1.2 μm. Note that inverters with other geometries can also be formed by making suitable external connections between devices in the two MOSFET arrays discussed above.

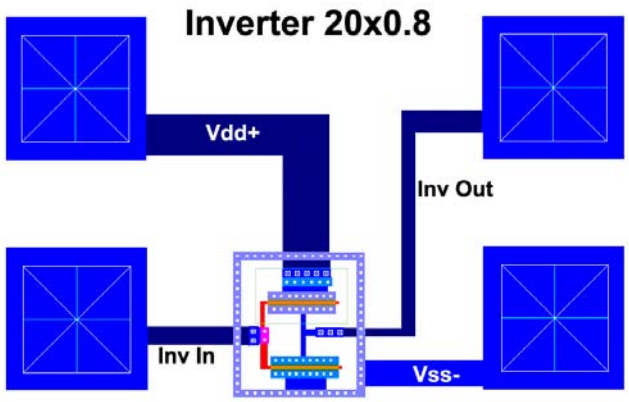

FIGURE 3
LAYOUT OF CMOS INVERTER WITH AN NMOS (LOWER) AND A PMOS (UPPER) DEVICE. THE GATE GEOMETRY FOR BOTH TRANSISTORS (IN MICROMETERS) IS INDICATED IN THE FIGURE. THE ALFA CHIP ALSO CONTAINS A CMOS INVERTER WITH A SHOTER WIDTH (1.2 MICROMETER).

A ring oscillator consists of a series connection of an odd number of inverters, where the signal from the last inverter is fed back into the first one. The individual elements are visible in Figure 4. The oscillation is triggered by an external signal input at the enable pad, and is sensed at the output pad. The oscillation frequency is the inverse of the sum of the signal delays experienced by each inverter. The NMOS gate geometry is W = 1.6 μm and L = 0.8 μm, and the PMOS gate geometry is W = 2.4 μm and L = 0.8 μm. The difference in gate widths between the NMOS and PMOS serves to compensate for differences in electrical properties of the two types of devices.

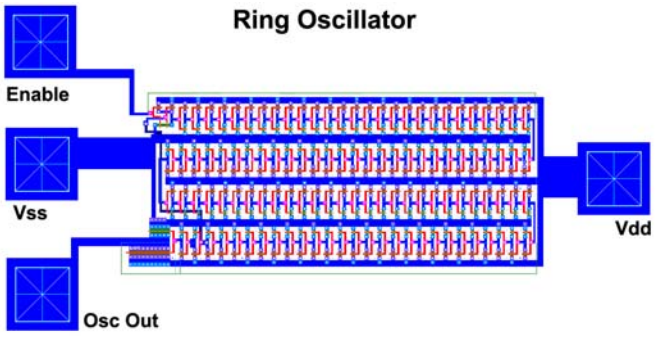

FIGURE 4
LAYOUT OF RING OSCILLATOR SHOWING THE INDIVIDUAL IVERTER EMENTS. THE OSCILLATOR COMPRISES 110 INVERTERS AND ONE NAND GATE.

Hence, from a measurement of the oscillation frequency and using the number of inverters in the device, the single-stage delay can be extracted. This is a very important parameter that expresses the speed of digital signal transmission between the elements.

The structure shown in Figure 5 consists of a series of unevenly spaced electrodes across a region of doped material, typically of the same kind as that used in the ohmic source and drain regions of the MOSFETs. This structure is called a transmission line model (TLM) [10]. By measuring the total resistances between the adjacent contacts and plotting these versus their contact separations, the contact resistance can be determined by extrapolating the resulting straight line to zero separation. From the slope of this plot, the sheet resistance of the doped semiconductor region is found. The TLM regions are 120 μm wide and the distances between the contacts are 5, 15, 25, 35, 45 and 45 μm.

In addition, the Alfa chip contains a pair of capacitors and a pair of diodes, which are very useful for the extraction of important parameters such as gate oxide thickness, parasitic capacitances associated with source and drain, flat-band voltage, substrate doping etc.

Note that not all the devices described above will be made available simultaneously at LAB-on-WEB at any given time. At times, LAB-on-WEB also will include separate experiments on other semiconductor devices and structures, including bipolar devices such as diodes and junction transistors.

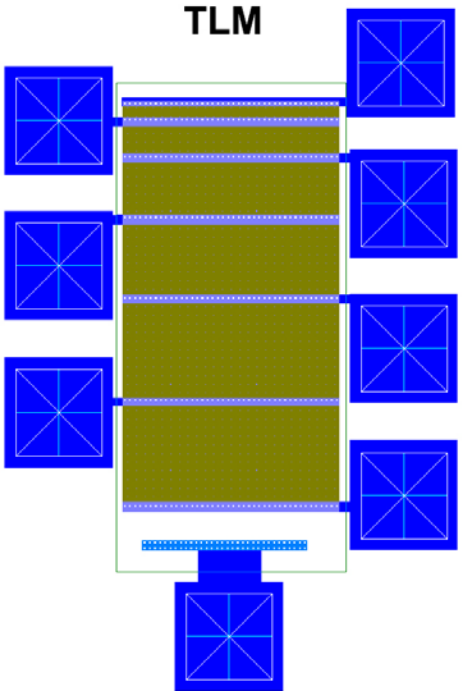

FIGURE 5
TLM PATTERN FOR DETERMINING CONTACT AND SHEET RESISTANCES OF THE OHMIC CONTACT REGIONS.

INSTRUMENTATION

The present experimental setup of the LAB-on-WEB server/laboratory unit is shown in Figure 6. The Web server is a Dell Power Edge 4300 computer with a 500 MHz Pentium III processor, a Windows 2000 Server operating system, and an MIIS (Microsoft Internet Information Server) version 5.0.

The main instrument is an HP 4142B Modular DC Source/Monitor shown in the middle right of Figure 6. This is a high-speed, accurate, and computer controlled DC parametric measurement instrument for characterizing semiconductor devices. Voltages and currents can be applied or measured within 4 milliseconds, and up to 1023 data samples can be stored 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 setup, three HP 41421B SMUs are installed, in addition to the built-in 0 V source GNDU (GrouND Unit).

In some cases, the client is afforded the possibility to remotely reconfigure the pre-selected experiments by rearranging the connections between the HP 4142B and the CMOS test chip. For this purpose, we installed an HP E5250A Low Leakage Switch unit. LAB-on-WEB also includes a Tektronix TDS 3052, 500 MHz digital oscilloscope and an HP 4284A Precision LCR Meter. The oscilloscope is used both for testing and servicing the system, and for measuring transients or waveforms in the

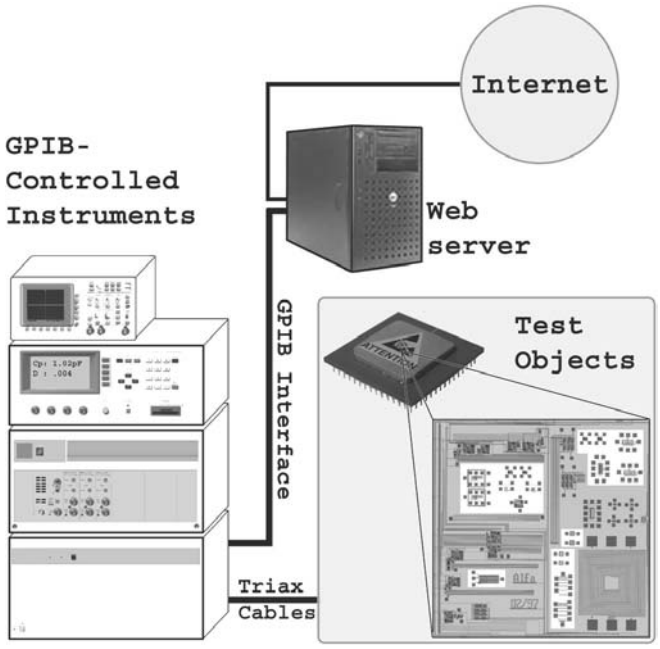

FIGURE 6
LAB-ON-WEB SETUP. THE INSTRUMENTS TO THE LEFT ARE FROM BELOW: HP E5250A LOW LEAKAGE SWITCH UNIT, HP 4142B MODULAR DC SOURCE/MONITOR WITH HP 41421B SMUS, HP 4284A PRECISION LCR METER, AND TEKTRONIX TDS 3052, 500 MHZ DIGITAL OSCILLOSCOPE.

CMOS inverters and the ring oscillator. The LCR meter is used for measuring the capacitance voltage (*C-V*) characteristics of the Alfa capacitances.

The server and the instruments are connected via a GPIB bus, using an HPIB instrument driver installed in the web server.

ARCHITECTURE

The LAB-on-WEB is based on flexible solutions that utilize the rich functionalities of modern Web browsers, allowing the server system to respond in many different formats, such as JavaScript, HTML (HyperText Markup Language), XML (eXtensible Markup Language) and SVG (Scalable Vector Graphics), which give the client great flexibility in storing, processing and presenting the data received. The server-side Web-solutions presently installed in LAB-on-WEB are based on either COM+ (Component Object Model with extensions) or the LabVIEW 6i software from National Instruments [11].

COM+ is the second generation of COM (Component Object Model), which is a set of services that allows us to create object-oriented, customizable and upgradeable, component-based and distributed applications. One of the primary goals of COM is to ease the creation of multi-tier applications that can be reused from any programming language. COM+ includes added features that make COM easier to use and simplifies the development. Some of these features are: component load-balancing, just-in-time activation, asynchronous method invocation, in-memory database, queued components, improved administrative services.

The COM+ component developed for the remote laboratory is a library application, which is compiled to a DLL (Dynamic Link Library), and is loaded into the process of the client. As indicated in Figure 7, the component is called from an HTML-form in the active client page, via an ASP (Active Server Page). Subsequently, this ASP receives the measurement results from the component and relays them to the client, for example, in the form of SVG (Scalable Vector Graphics) presentations. The layout of the client interactive page and a diagram with measurement results are indicated in the upper part of Figure 7.

In the LabVIEW solution, the server runs a full version of LabVIEW 6i, which incorporates Internet communication capabilities and functionalities to access and control instruments and to obtain and return data. The client can communicate with the server and the experimental setup in two ways: either by means of a Web browser, which runs a dedicated CGI (Common Gateway Interface) script in the server, or using the LabVIEW Player which is a client excecutable free of charge from National instruments. However, the Player has a considerable size, about 17.2 MB, which makes it inconvenient to download and install for many students.

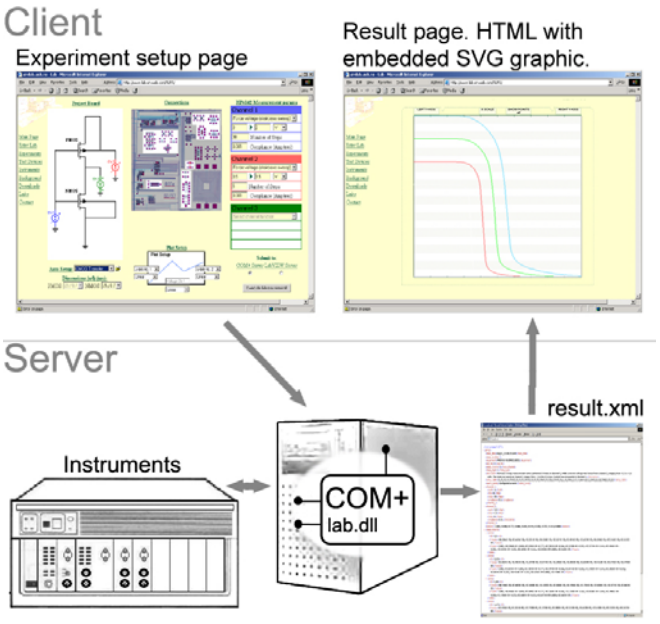

FIGURE 7
LAB-ON-WEB ARCHITECTURE BASED ON A COM+ SOLUTION. FROM THE HTML WEB BROWSER PAGE (UPPER LEFT), THE CLIENT CALLS THE COM+ COMPONENT VIA AN ACTIVE SERVER PAGE. MEASUREMENT DATA ARE RETURNED IN XML FORMAT.

An alternative to the above network and instrument control systems is to use Microsofts newly released .NET platform for XML-based WEB services. .NET seeks to integrate Internet, Web services building block services, and numerous tools for developers, providing an excellent environment for further improvements of remote lab systems. An example is the Next Generation Lab (NGL) developed at the Norwegian University of Science and Technology [12].

CONCLUSION

We have reported on the implementation the Alfa chip, an electronic device test laboratory on a chip, in our on-line laboratory facility, LAB-on-WEB. The Alfa chip contains diodes, capacitors, transistors, inverters, a ring oscillator and and other test structures, all fabricated in submicrometer CMOS technology. This facility serves to provide electrical engineering students with a valuable familiarity with the behavior of the building block of modern integrated circuits. In addition, it also designed for the extraction of device and processing parameters needed for circuit design.

Our system, LAB-on-WEB, is based on modern Web and instrument control technology, including COM+, ASP, ISAPI and LabVIEW 6i. Advanced functionalities of modern Web browsers are utilized, allowing the system to communicate in terms of formats such as XML and SVG. The COM+ and ISAPI solutions are based on the ActiveX technology. COM+ offers the most flexible solution since it utilizes a well-structured development environment that has

been widely adopted by the Web community. It also offers several useful tasks related to security, queuing, logging, etc.

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