MICROCONTROLLER AND PROGRAMMABLE CIRCUIT-BASED DEVELOPMENT BOARDS USED IN DIGITAL INSTRUMENTATION LABORATORY

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Abstract - *Congested curricula results in serious need to effectively and quickly teach digital design and its application to different areas of engineering. Digital instrumentation is one of these areas which has a very rapid development as more functionality of the measuring systems is migrated from analog to digital implementation. In our faculty we have organized a laboratory for teaching digital measurements and digital instrumentation using XESS development boards which have certain advantages such as: low cost, presence on-board of both microcontroller and programmable circuit, low cost development software for students (Xilinx Student Edition), easy downloading of configuration and program files for the programmable circuit and microcontroller respectively. These features, among which one of the most important is the possibility of reconfiguring logic, allowed us to organize a large set of laboratory sessions.*

Keywords - Digital instrumentation, programmable circuits, microcontrollers, codesign.

1. INTRODUCTION

The rapid development and spread of digital technologies impose a serious need to effectively and quickly teach digital design and its application to different areas of engineering. New trends in digital instrumentation have emerged and led to new and rapid developments as more and more functionality of the measuring systems is transferred from analog to digital implementation.

In order to prepare students for these new requirements we have organized in our faculty a laboratory for teaching digital measurements and digital instrumentation using XESS development boards (XS Boards).

The XS Boards are prototyping boards that have certain advantages such as:

- low cost,
- presence on-board of both microcontroller and programmable logic allowing the development of simple to complex projects and the application of newly emerged methods such as hardware-software codesign,
- availability of two Xilinx programmable integrated circuit families, i.e. field programmable gate arrays (FPGAs) and complex programmable logic devices (CPLDs),
- low cost development software available for students (Xilinx Student Edition - includes Xilinx Foundation 1.5 design software and the Practical Xilinx Designer lab book [1]),
- easy downloading of configuration and program files to the programmable circuit and to the microcontroller external SRAM memory using XESS tools.

These features, of which one of the most important is the possibility of reconfiguring the logic, either hardware or software, allowed us to organize a large set of laboratory sessions.

2. LABORATORY HARDWARE AND SOFTWARE

The central focus of the laboratory is to teach digital measurements and measurement microsystems.

2.1 Description of the equipment

The laboratory equipment used consists of the followings:

- 4 PC Pentium computers,
- 2 XESS XS95-108 version 1.4 development boards,
- 2 XESS XS40-010XL version 1.4 development boards,
- digital multimeters, oscilloscopes, signal generators,
- power supplies.

In addition, there are available 4 other 8051 microcontroller based development systems on which students can study the 8031/51 microcontroller and its application to digital instrumentation.

The XESS XS40-010XL and XESS XS95-108 are development boards each one including:

- 8031 microcontroller,
- 32/128 Kbytes SRAM,
- 100 MHz programmable oscillator,
- parallel port, mouse/keyboard PS/2 port,
- VGA monitor port,
- 7-segment LED,
- 84-pin breadboard interface,
- serial EEPROM socket,
- 9V DC power jack and 5V / 3.3V regulators.

The two boards differ in the Xilinx programmable integrated circuit mounted in the 84-pin socket, i.e. the XC4010XL FPGA or the XC95108 CPLD respectively.

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A high-level view of the XESS development board is shown in Fig.1

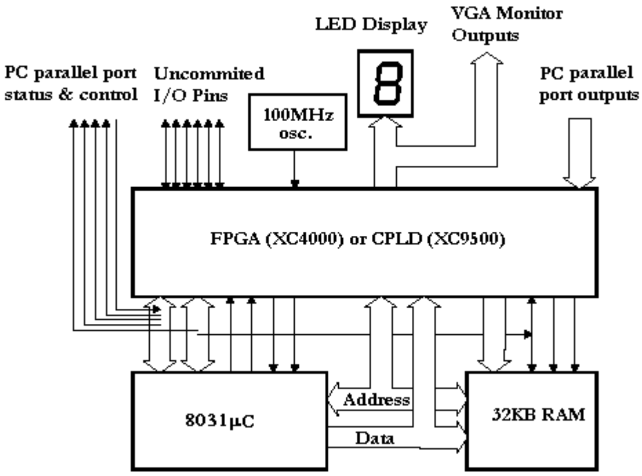


Fig.1 – A high-level view of the XESS development boards.

2.1 Software

Student laboratory works require some software tools for their successful completion. The software installed on the computers to be used with systems include:

- Xilinx Foundation Series version 1.5/2.i for designing with Xilinx FPGA/CPLD circuits
- Xilinx Core Generator for using parameterizable and optimized cores for Xilinx FPGAs
- XESS XSTools for downloading the configuration file (.bit/.svf) to the FPGA/CPLD circuits on the XESS boards and for downloading the program files (.hex) for the microcontroller to the SRAM available on the board.
- Franklin Software for programming the 8031/51 microcontroller including also a C compiler.
- XSgui – a graphical interface for the XSTools written by the authors in Tcl/Tk (www.xess.com/projects/xsgui.zip)
- a word processor (Microsoft Word) and a spread sheet (Microsoft Excel)

Xilinx Foundation Series [3] software is a complete set of user friendly tools which let you describe, simulate and compile logic designs for the full line of Xilinx FPGAs and CPLDs. The Foundation Series allows the designer to specify the design using several tools including schematic editor, hardware description language (HDL) editors for Abel, VHDL and Verilog HDLs and state machine editor. Graphical entry capabilities of these tools make them easy to use for both new and experienced designers enabling the achievement of the design goals in a simply and rapid manner. These features make the Xilinx Foundation Series Software to be easily learned and used by students.

Of great help is also the availability of the Xilinx Student Edition which contains both a lab book and XILINX Foundation 1.5 design software. “The Practical XILINX Designer Lab Book”[1] shows how to implement logic designs for XILINX XC4000 FPGAs and XC9500 CPLDs using schematics, ABEL, and VHDL. The Foundation software let the students describe, simulate, and compile logic designs for XC4010 FPGAs and below, all XC9500 CPLDs, and all Spartan FPGAs. The software included in the Xilinx Student Edition is intended for students to use at home or in their dorms in order to increase their ability to create complex Xilinx FPGA/CPLD-based design. Using the XS Board, they can also implement their design in a consistent and rapid manner.

XESS XSTools consists of additional software for downloading to the XESS boards (xsload), applying signals using the parallel port (xsport), testing if the boards are well functioning (xstest) and setting the frequency of the programmable oscillator (xssetclk).

If the Windows OS is available, students may use GXSTools which are the correspondent to the XSTools commands providing a Windows (graphical) interface. GXSTools consists of gxsload, gxstest, gxsport and gxssetclk respectively.

Students can also use the Xsgui which provides a user-friendly graphical interface to XSTools written by the authors and which has additional features compared to GXSTools. In Xsgui, both downloading and applying signals to the XS Board can be done using the same graphical interface. The students can send stimuli to the XS Board using one of the two modes: Edit mode and File mode. In the Edit mode they can modify the bits of the stimulus vector to be sent to the XS Board by means of 8 pushbuttons. When set, the stimulus vector can be sent to the XS Board. In File mode, the students can load a set of stimulus vectors from a file and send them one by one to the XS Board. At any time they can stop the sequence of stimulus vectors and return to the Edit mode or, take it from the beginning with the stimulus vectors loaded from file.

The laboratory software permits the programming of both main components of the XS Boards, the microcontroller and the programmable circuit

3. STUDENT LABORATORY WORKS

With the equipment and the software described before we have the possibility to organize laboratory works at both undergraduate and graduate level on following topics grouped in four main areas:

1. Study of combinational and sequential logic circuits:

a) study of basic combinational and sequential logic gates,

- logic signals
- logic gates
- axioms an proprieties of Boolean algebra
- functional completeness
- transition time and propagation delays
- Flip-flops (SR/JK/D/T)

b) designing and implementing combinational logic circuits,

- number systems (binary, hexadecimal)
- encoders/decoders
- multiplexer/demultiplexers

- parity and magnitude comparison.
- arithmetic operators (adders, subtractors, multipliers).

c) designing and implementing sequential logic circuits,

- latches and registers,
- shift registers,
- counters (synchronous and asynchronous),
- serial/parallel conversion,
- finite state machines,

d) design of digital circuits using programmable logic circuits

- memories,
- FPGAs,
- CPLDs,

e) testing and troubleshooting logic circuits.

For these laboratory works we use the FPGA/CPLD circuit on the XS Boards.

2. Study of microcontrollers:

a) 8031/51 microcontroller architecture,

b) 8031/51 microcontroller instruction set,

c) 8031/51 microcontroller-based development system,

d) 8031/51 microcontroller timing and communication features.

The laboratory works in this category are organized using both the dedicated 8051 microcontroller based microsystems and XS Boards.

3. Study of mixed microsystems based on FPGAs/CPLDs, microcontrollers and memories:

a) interconnecting FPGAs/CPLDs, microcontroller and SRAM memory,

b) generating microcontroller clock, reset and interrupt signals using FPGA/CPLD,

c) implementing memory controller with FPGA/CPLD for downloading and uploading data from PC into the XS Board SRAM memory,

d) using serial memory for FPGA configuration.

This laboratory works use the XS Boards, helping students to better understand how can be put to work together these different components.

4. Digital instrumentation application examples and implementation:

a) applications of 8031/51 microcontroller-based systems in instrumentation [2],

- measurement of voltage type quantities,
- measurement of frequency type quantities,
- interfacing microcontroller-based development system with input devices,
- displaying data to LCD displays from microcontroller-based system,
- data acquisition system using the 8031/51 microcontroller,
- linear and non-linear conversion,
- digital measurement of impedances using a microcontroller-based system
- digital signal processing.

b) use of FPGA/CPLD in digital instrumentation,

- implementation of successive approximation A/D converters using FPGAs/CPLDs,
- implementation of display control using FPGAs/CPLDs,
- implementation of waveform generators using FPGAs/CPLDs,
- implementation of digital signal processors

The possibility of reconfiguring the circuitry implemented in the programmable logic circuit on the XESS board gives some benefits for the laboratory works regarding the basic combinational and sequential logic experiments. One of the benefits is that the only thing we have to do between two lab sessions is to load the new configuration which implements the new circuits that have to be studied.

The second one is that on a single FPGA/CPLD we have enough resources, i.e. complex logic blocks (CLBs)/function blocks (FB) and I/O blocks [4], to implement many times the same simple logic bloc (multiplexer, counter, shift register, etc). In this way we can use a single XS Board for three or four groups of students so they can study the same logic circuit (feed inputs, measure outputs, visualize signals on oscilloscope, etc) at the same time.

We have chosen that each board should host the logic modules for 4 student working teams (Fig.2) and that each module should not use more than 14 I/O pins resulting in a total count of 56 I/O used pins. This is perfectly possible as the programmable integrated circuits on the XS Board are coming in a PC84 package in which 61 I/O pins are available for the FPGA and 69 pins for the CPLD respectively.

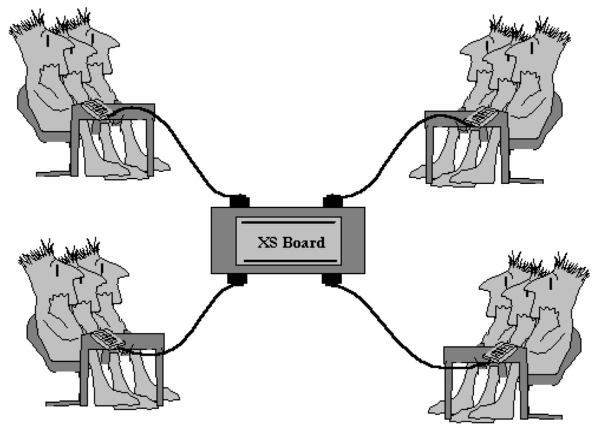


Fig.2 – One XS Board used by four groups of students.

It is difficult for the students to access the I/O pins directly on the XS Board. Therefore, the XS Board is plugged into a protoboard and each of the four group of 14 I/O pins plus the ground pin are connected to an on-board 15-pin DIN female connector. Using a 15 wire ribbon cable with 15-pin DIN male connectors, we make the connection between the protoboard and a connection board module (Fig.3). This provides an easy access to the I/O pins while the schematic of the implemented circuit is exhibited via a removable "skin" (Fig.4).

The availability of 14 I/O pins plus the ground pin gives the possibility to study the circuits in the 74 family. Part of these circuits is available in the schematic editor as design elements in the unified libraries. The other circuits in the 74 family can be implemented by the instructor using the data sheets available in the literature.

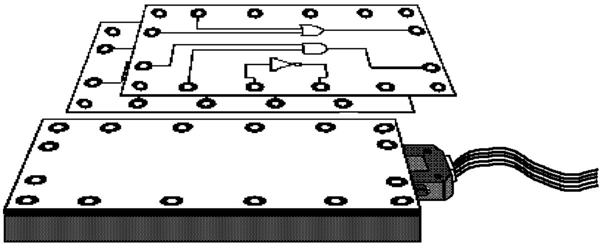
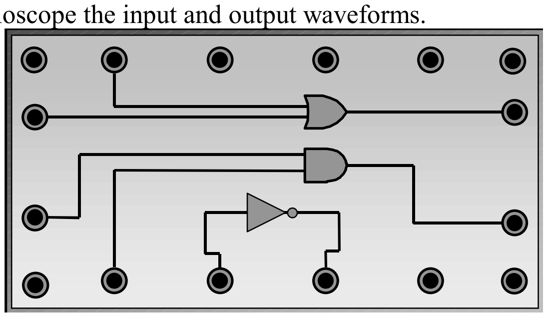
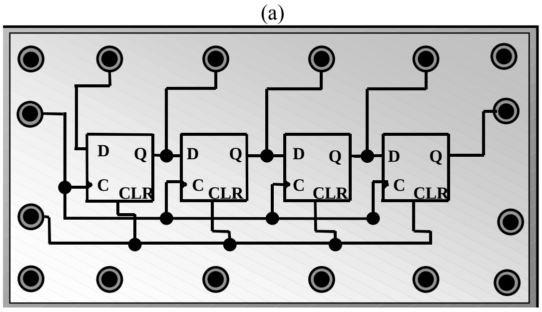


Fig.3 – Connection board with skins and 15 wire ribbon cable with 15-pin DIN connector.

This set up provides a great flexibility in organizing the laboratory works. The preparation of a lab work implies downloading the configuration to the FPGA/CPLD and installing the appropriate skins on the connection boards. The students can then analyze the schematic of the circuits they have to study, apply signals from power supplies or signal generators, measure input and output signals, visualize on the oscilloscope the input and output waveforms.



(a)



(b)

Fig.4 – Two different connection board skins serving for the study of: (a) elementary logic gates and (b) serial-in, parallel-out shift register.

Another level of flexibility is given by the fact that we can implement on an XS Board four times the same circuitry or, we can implement up to four different ones. In this way, the group of students can study the same circuit at the same time or, each group can study a different circuit.

It is up to the teacher's ability to prepare in advance a large set of configuration files in order to cover the most of the field of digital circuit design and their application to digital instrumentation system design.

Another important aspect is that, although the we can obtain the configuration files for the programmable circuit only by using Xilinx Foundation Software [6], which implies the use of a computer that has certain important resources (processor speed, large RAM, large HDD space and Windows 95 OS), once the files are generated, they can be downloaded to the circuit on the XS Board using XSTools software running on a less equipped computer. This computer needs to run MS-DOS and must include a parallel port.

4. STUDENT PROJECTS

Student projects cover a greater area of the digital instrumentation design. Students are required to know and used complex measurement schemes, know analog and digital circuits, draw schematics, write behavioral descriptions of the systems using hardware description languages, write code in assembly or in C language, modify and compare different designs and implementation solutions, analyze data with spreadsheets.

With the hardware and software in our laboratory, students have the possibility to take projects in the following areas: application of 8032/51 microcontroller-based systems in instrumentation [3], FPGA/CPLD-based digital instrumentation [5], hardware-software codesign in digital measurement applications.

The complexity of the projects implies the use of XS Board and available software tools at a higher level than in the undergraduate laboratories.

The necessary skills can be easily achieved because of the availability of Xilinx Student Edition Foundation Series Software which has a friendly interface gathering together, in a simple design flow, specification editors (schematic, hardware description languages, finite state machine), functional and time simulators, implementation and programming tools. The learning curve is accelerated by the existence of several excellent digital design educational books which are based on or use for exemplification Xilinx Student Edition Foundation Series Software [1,6-8].

Digital instrumentation projects imply supplementary hardware resources mainly consisting of A/D and D/A converters, operational amplifiers, display units, input keyboard, etc., to provide the additional amount of support circuitry to the existing XS Boards. He have realized a prototyping board in which the XS Board can easily be plugged in and which include the followings: mounting sockets for a XS40 Board or XS95 Board, prototyping area, DIP switches, push buttons, keyboard matrix, bargraph LEDs, additional seven-segment LEDs, LCD display, DAC converter, ADC converter, operational amplifier, analog multiplexer, multitour potentiometers.

In order to achieve the goals of their projects, students can use either the FPGA/CPLD integrated circuit on the XS Board working stand-alone or they can use both the FPGA/CPLD and the microcontroller working together. In the second case, students must take into account that the connections between the programmable circuit and the microcontroller are already made and that this interconnection impose a number of restrictions. Because some pins of the programmable circuit are used in conjunction with the microcontroller, they become unavailable for the use as input/output pins of the hardware logic.

The existence of both the FPGA/CPLD and the microcontroller give students the possibility to enter in the field of hardware-software codesign.

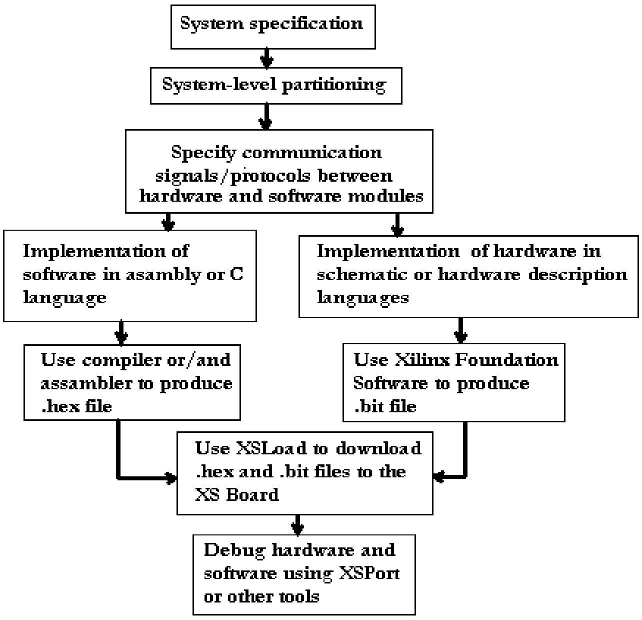


Fig.5 – Design flow of hardware-software codesign using the XSBoard.

Students working on projects that involve hardware-software codesign must learn a design methodology where a part of the functionality of the application can be implemented into the programmable logic circuits whether the other part can be implemented using the microcontroller. Generally, low-level functions of the application are implemented into the FPGA/CPLD while the high-level functions are implemented using the microcontroller. Figure 5 shows the main steps which should be followed in order to transform the initial design specification into a mixed hardware-software implementation.

For the moment, no high level/system description languages are use for the specification of the project so we use the natural language. Partitioning is a very important step that has a great impact on the shape of the final implementation. Usually based on the designer experience, this step is done manually and is accomplished by students with the help from the instructor.

Once partition done and communication signals between the two parts established, students will implement the hardware and software parts using available known tools: the compiler/assembler for the software part and the Xilinx Foundation Series Software for the hardware part.

5. CONCLUSION

It is known that universities have difficulties in providing funds for necessary hardware needed to implement all the laboratory works instructors would like to organize. A practical solution is to use a reduced amount of hardware and to use simulation. Another solution is to use programmable logic integrated circuits and microcontrollers which together, can flexibly implement a large number of laboratory works. In this case there is no need to change components (ICs), to redesign printed circuit boards or remake the interconnections between components.

The laboratory described in our paper is a flexible environment that allows students to learn the basic and advanced topics in the area of digital measurements and digital instrumentation. After finishing these laboratory works, students can come back and realize experiments for use by students following them. Using the XS Boards and the available software, students can also work for projects at both undergraduate and graduate level.

The two programmable components on the XS Boards, the programmable logic integrated circuit and the microcontroller gives us the great flexibility to cover a large area in field of digital design and digital measurements.

ACKNOWLEDGMENTS

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