AC 2011-895: DIGITAL LOGIC DESIGN: MEETING INDUSTRY'S NEEDS THROUGH UNIVERSITY & COMMUNITY COLLEGE COLLABORATION

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Digital Logic Design: Meeting industry's needs through university & community college collaboration

Abstract

Hardware Description Language and Field Programmable Gate Array (FPGA) have revolutionized the way Digital Logic Design is taught and implemented. Traditional ways of teaching logic design using discrete components (TTL: Transistor-Transistor Logic and CMOS: Complementary Metal Oxide Semiconductors) have been replaced by Programmable Logic Devices (CPLD: Complex Programmable Logic Devices and FPGA). Today, a more standard development process is widely used in industry. The process uses Hardware Description Languages as a design entry to describe the digital systems. The two most widely used Hardware Description Languages in industry are VHDL (Very High Speed Integrated Circuit Hardware Description Language) and Verilog (Verifying Logic). Although most traditional electrical and computer engineering programs have updated their curriculum to include topics in hardware description language and programmable logic design (FPGA/CPLD), two-year and four-year electrical engineering technology programs have fallen behind and are moving slowly in updating their curriculum. To effectively meet the next generation's workforce needs, the electrical and computer engineering technology curriculum must be current, relevant, and teach technology that is widely used in industry. To meet this goal, this paper propose a curriculum development project designed to meet the needs of both community college and university-based two- and four-year technology programs that will develop new courses in logic design and hardware modeling using VHDL and Field Programmable Gate Array (FPGA) Logic Design to teach students marketable logic design skills. Curriculum development will include the development of hands-on re-configurable computing labs both at the university and the community college, we will be able to provide students at universities and community colleges with state-of-the-art training tools that match the expectations of industry. Through this enhanced partnerships with community colleges, which will involve faculty development, sharing of curriculum resources, and undergraduate research exchanges, we aim to increase the transition of students from two-year to four-year programs. Our aim is not to take away from students attending or planning to attend community college but rather to improve curriculum for students in both two- and four-year programs and to make pathways clear and easy for those who do wish to continue their technology education past their two-year degree.

I. Introduction

Although most traditional electrical and computer engineering programs have updated their curriculum to include topics in hardware description language and programmable logic design (FPGA/CPLD), only 19.5 % of 4-year and 16.5 % of 2-year electrical and computer engineering technology programs at US academic institutions currently have a curriculum component in hardware description language and programmable logic design [3]. To effectively meet the next generation's workforce needs, the electrical and computer engineering technology curriculum must be current, relevant, and teach technology that is widely used in industry. To meet this goal, we propose a curriculum development project for university- and community college-based programs that will develop new courses in logic design and hardware modeling using VHDL and

Field Programmable Gate Array (FPGA) Logic Design to teach students current marketable logic design skills.

One key factor of the proposed new and updated courses will be to update the curriculum to meet the expectations of industry by supplying qualified technicians and technologists who have extensive hands-on experience with current design tools. By developing a re-configurable computing lab, we will be able to provide students at universities and community colleges with state-of-the-art training tools that match the expectations of industry. Likewise, by strengthening partnerships with diverse community colleges through this curriculum development project, we aim to increase the transition of students from two-year to four-year programs through aligned curriculum planning. Our aim is not to take away from students attending or planning to attend community college but rather to improve curriculum for students in both two- and four-year programs and to make pathways clear and easy for those who do wish to continue on past their two-year degree.

II. Research Background

Historically, electrical engineering technology Associate and Baccalaureate programs have included a traditional logic design course that covers topics in combinational logic and sequential logic circuits. The course is usually based on discrete components (such as TTL and CMOS) and although these topics represent fundamental concepts in logic design and optimization theory, they are far from most current industry practice in logic design. Topics that are traditionally taught in logic design courses are less important to current employers. The time spent teaching Boolean algebra and how to minimize Boolean expressions using Boolean algebra or Karranugh Map (K-Map) can be better spent teaching current and industry-relevant practice in logic design. This line of thought applies to design of combinational circuits and also to the design of sequential circuits [3]. For the curriculum to adequately meet the current needs, EET two-year and four-year programs must teach digital logic using VHDL and FPGA [3] and students must be equipped with design skills that are current, relevant, and widely used in industry.

Recent research also suggests that the proposed courses are industry-relevant. Furtner and Widmer conducted an employer survey to rank currently taught logic design concepts at Purdue University. The survey included questions about many topics that are heavily explained in logic design courses such as Boolean algebra, design simplifications using K-Map or Quine Mclusky, and design implementation using discrete gates. Each was given a low priority from the employer perspective. On the other hand, topics that cover designing with hardware description language (such as VHDL or Verilog) received high-priority rankings from employers [3].

Unfortunately, the curriculum has not yet “caught up” to industry needs. A survey of digital design textbooks users by Pearson’s Press shows that only 19.5% of the total of 52 four-year electrical engineering technology programs and 16.5% of the total 107 two-year programs who responded to the survey cover topics in logic design using hardware description languages, and only 40% of the four-year and 30% of the two-year programs are planning to introduce hardware description languages in the near future [3].

Clearly, electrical engineering technology programs are far behind in teaching the skills that represent current and future industry needs. As a result, the School of Technology at Michigan Technological University in partnership with College of Lake County in Illinois are stepping up to this challenge by developing and introducing curriculum in hardware description languages and programmable logic design. The major objectives of this curriculum shift are to give the students in the Electrical Engineering Technology program at both Michigan Technological University and College of Lake County the opportunity to learn and experience logic design using FPGA that is in line with industry expectations. This will create a pool of informed electrical engineering technicians and technologists from which industry can draw upon. This pool of students will also be given the opportunity to conduct undergraduate research in hardware modeling and Field Programmable Logic (FPGA) design.

III. Why FPGA

Programmable Logic Devices in general and FPGA-based re-programmable logic design became more attractive as a design medium during the last decade, and as a result, industrial use of FPGA in digital logic design is increasing rapidly. As would be expected following technology change in industry, the need for highly qualified logic designers with FPGA expertise is increasing at a fast rate. According to the United States Department of Labor, the job outlook is on the rise and will continue to expand for at least the short- to medium-term future [6]. To respond to the industry needs for FPGA design skills, universities are updating their curriculum with courses in hardware description languages and programmable logic design. Although most traditional electrical and computer engineering programs have updated their curriculum to include topics in hardware description language and programmable logic design, to date, **only 19.5%** [3] of electrical and computer engineering *technology* 4-year programs among US academic institutions have a curriculum component in hardware description language and programmable logic design. Similarly, only **16.5**% [3] of electrical and computer engineering technology 2-year programs have a curriculum component in hardware modeling and programmable logic design.

The applications utilizing FPGA as a design medium are predominant [1]. FPGAs have been used extensively not only in logic emulation but also in custom-computing machines. The re-programmable nature of Static Random Access Memory (SRAM) -FPGA makes it the workhorse of many new applications that require re-programmability. SRAM-FPGA's are the most popular and are becoming the tools of choice in many re-programmable applications. SRAM - FPGAs' re-programmability features make them more attractive because they can be completely changed by the same electrical process. A microprocessor can be configured to run different applications and the configuration of SRAM-FPGA can be changed for bug fixes or upgrades, making them an ideal prototyping medium. FPGAs have evolved from only a glue logic device to a platform-based design medium. According to International Technology Roadmap on Semiconductors (ITRS), we are approaching a four-billion-transistor chip by the end of this decade [5]. This will allow building of very complex, high performance systems using FPGA [5].

Platform FPGAs will dominate the embedded system design in the near future [5], and the capability to use a single programmable device that includes a processor, interfaces, and programmable logic makes them the design of choice as the price of FPGAs comes down, the development cycle shortens, and the time-to-market (TTM) pressure is reduced. As FPGAs become more widely used, the need for highly qualified logic designers with FPGA expertise will continue to increase, perhaps at an even more rapid pace.

IV. Curriculum Revision

University Curriculum Content

Figure 1 shows the current and proposed digital design logic sequence which incorporates the addition of two new courses that will be added to the current course (Digital Electronics). The EET program will introduce two new courses (Digital Design Using VHDL and Topics in Programmable Logic). Each of these courses is three credit hours (2 class, 3 lab). The descriptions of the two new courses are provided below. We were able to add the two new courses without impacting the overall degree plan. The current EET program has a shortage of courses in digital logic design; only one course (Digital Electronics) is currently offered. The EET program will still be structured as a 127 credit hour program with sixty-eight (68) credits of technical courses in Electrical Engineering Technology. This is in line with ABET requirements [7]. ABET Criterion **5. Curriculum: "**Baccalaureate programs must consist of a minimum of 124 semester hours … and the technical content is limited to no more than 2/3 the total credit hours for the program" [7].

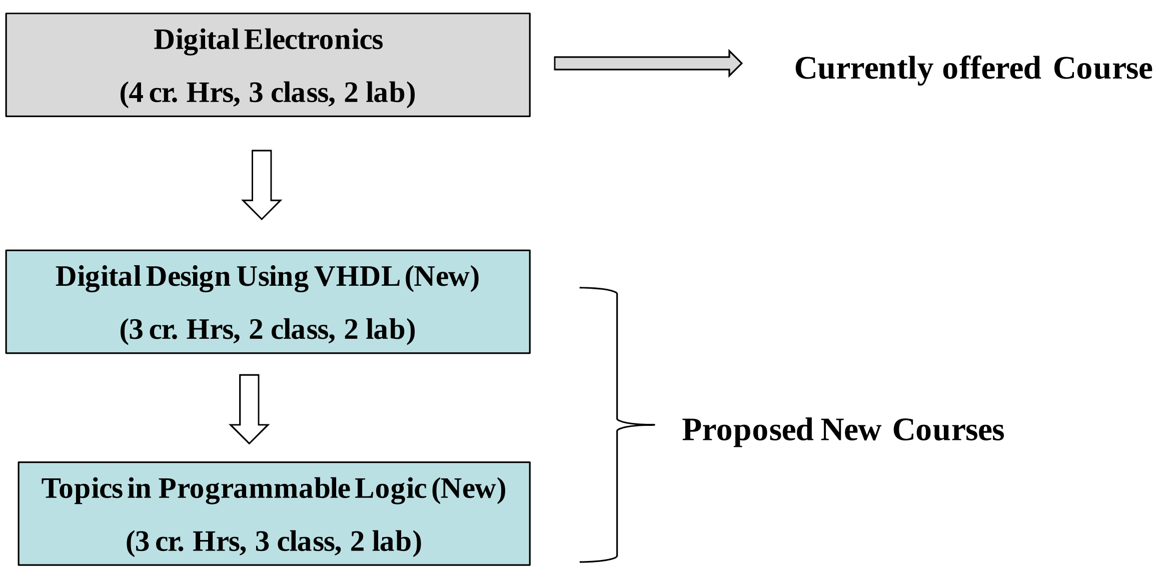

Figure 1: Proposed Digital Logic Design Courses Sequence

<u>New Course 1: Digital Design Using VHDL</u> (3 Cr hrs, Class 2 hrs, Lab 3 hrs)

Course Objectives

The course places an emphasis on the language concepts of digital systems design using Hardware Description Language (VHDL). The course will focus on good digital design practices and writing testbenches for design verification. Low-level gate modeling techniques with varying timing details will be presented, as well as structural level of abstraction for wiring predefined gates and other predefined components. The information gained can be applied to any digital design by using a top-down design approach. Students will gain valuable hands-on experience in writing efficient hardware designs using VHDL and performing high-level HDL simulations.

The academic objectives of the “Digital Design using VHDL” course are to provide students with skills and experience that will help them to be attractive in the job market and as employees with high-value skills in the workplace. The students will learn the design of major components of digital systems, such as arithmetic logic units (ALUs), floating points, memory, and controller using hardware description language (VHDL). In addition, the students will learn FPGA design flow starting from HDL design entry and circuit simulation to verify the correctness of the intended design, writing testbenches. To accomplish this in a one-semester course, the intent of lectures and labs is to have the students:

1. Gain the knowledge on programmable logic devices (PLD) and their design methodologies
2. Learn fundamental concepts of hardware description language
3. Learn how to use HDL for modeling basic building blocks of digital system
4. Learn about different design entry methods
5. Learn how to model digital circuits in hardware description languages
6. Learn how to use VHDL editors, debug designs and perform logic simulation
7. Learn how to use Altera’s Quartus® II development software
8. Learn how to perform timing analysis and verification

Course Structure

The course “Digital Design using VHDL” is three credit hours with two hours per week of recitation and three hours per week in the lab. The course will be open for sophomore or higher students and the pre-requisite is “Circuits I” and “Programming Languages”. The course will integrate Altera’s Quartus® II development software, and the lab will use Altera’s DE2 FPGA evaluation board.

<u>New Course 2: Topics in Programmable Logic Design</u> (3 Cr hrs, Class 2 hrs, Lab 3 hrs)

Course Objectives

Due to industry’s increased demand for FPGA designers, the intention of this course is to give students real-world experience in FPGA logic design and give them the necessary training with design tools widely used in industry. Tools used will include Altera’s Quartus® II development software and FPGA design implementation on Altera’s DE2 FPGA evaluation board. The long-term objective of this course is to provide a learning opportunity that will result in research activities focused on FPGA design. This research will provide more in-depth training for senior students and engage undergraduate students in applied research opportunities.

The academic objectives of the FPGA logic design course are to provide students with skills and experience in the FPGA design process. The students will learn the FPGA design flow using Quartus® II [2] development software to develop an FPGA, starting from HDL design entry, circuit simulation followed by FPGA Synthesis for Altera FPGA devices, Place and Route and timing analysis. To accomplish this in a one-semester course, the intent of lectures and labs is to have the students:

1. Learn how to use HDL for modeling basic building blocks of digital system
2. Learn FPGA technology and the impact of using FPGA in logic design
3. Learn FPGA design flow using Altera’s Quartus® II development software

4. Gain FPGA design experience by synthesizing, mapping, and placing and routing a given design on Altera's DE2 FPGA evaluation board
5. Work in groups of two or three and thereby learn how to cooperate in teams
6. Learn to document their results

The designs are carried out using modern computer-aided design (CAD) tools, and the Altera's Quartus® II development software [2]. The final systems will be implemented with state of the art devices such as the Altera FPGA device family and micro-controllers. Altera's DE2 evaluation boards will be used as the target platforms.

Course Structure

The course "Topics in Programmable Logic" is three credit hours with two hours per week of recitation and three hours of lab. The course will be open to senior students and the pre-requisite is "Digital Design using VHDL". The course will integrate Altera's Quartus® II development software. The lab will use Altera's DE2 FPGA evaluation board, the FPGA boards will be used as target platforms for lab experiments. Students will learn how to implement a complete system on the FPGA evaluation boards.

Altera Corporation represents a market leader and holds a large market share in programmable logic. Each FPGA vendor development software is device dependent, for example, Altera's Quartus® II development software only targets Altera's device family. Learning Altera's Quartus® II development software will give students the opportunity to learn FPGA design flow using the most widely used tools for FPGA design. At the same time, these skills are largely transferable to other design tools, so students will learn valuable skills useful across industrial platforms.

Community College Curriculum Content

The current Associate degree electrical engineering technology program curriculum includes one 4-credit course (EET 213: Introduction to Digital Electronics) that teaches students traditional logic design principles based on discrete components (such as TTL and CMOS). The contents of this existing course will be updated to include topics in logic design using VHDL. In addition to exploration of traditional logic design principles, enhancements will allow students to learn a set of skills that covers VHDL as a new and industry-respected logic design tool. Students who choose to enter the job market after they earn their associate degree will be equipped with skills needed by employers. Students who choose to transfer to Michigan Technological University (or any four-year program) to continue for their Bachelor of Science in Electrical Engineering Technology degree will also be better prepared for these further studies. Students who transfer to Michigan Tech as part of the articulation agreement will enroll in Michigan Tech's new two-course digital logic sequence.

The updated EET 213 course at the community college will teach students fundamental concepts of hardware description language. Students will learn how to model digital circuits in hardware description languages, how to use VHDL editors, debug designs and perform logic simulation, and how to use Altera's Quartus® II development software.

V. Undergraduate Research Opportunities: System-on-FPGA (SoFPGA) Research Project

New System-on-Chip (SoC) design techniques are necessary to address the communication requirements for future SoC. The currently used Bus-Centered approach has become an inappropriate choice because of its limitation as a shared medium that restricts the scalability of the communication architecture. Also, long bus wires result in performance degradation due to the increased capacitive load. The long wires also consume more power to drive all of Intellectual Property Cores (IP Cores) on the bus. A research project examining new communication architecture, the NoFPGA (Network-on-FPGA), for future SoFPGA (System-on-FPGA) [4] is currently under investigation by the primary author. The long-term objective of this project is to provide a learning opportunity at the School of Technology which will result in research activities focused on SoFPGA and hardware design modeling. This research experiences will provide more in-depth training for undergraduate senior students.

VI. Facilities: Re-Configurable Computing Lab

The 4-year Electrical Engineering Technology Program has identified current needs for a new Re-Configurable Computing Lab, that will support the two new courses in VHDL design and FPGA design and provide students with a state-of-the-art, hands-on training experience. A similar re-configurable computing lab will be established at the partner community college. This will ensure the continuity needed for an effective articulation program.

The re-configurable computing lab will consist of twelve workstations and support a class size of 24 students. High-end computers, FPGA development boards, and development software represent the basic set of tools that are necessary to teach both courses. Additional test and measurement equipment such as power supplies, function generators, digital multimeters, and oscilloscopes are currently available at both partner institutions.

There are many options for FPGA development boards. Most FPGA manufacturers such as Altera and Xilinx have a university program that provides low-cost or free FPGA development boards. A decision has been made to use Altera for the following reasons:

- Altera offers the Development and Education (DE2) development board for academia at a minimal cost of $269.
- Altera has a strong University Program complete with web resources that allow college faculty to stay current with technology and incorporate web resources into course delivery.
- Learning Altera's Design tools develops skills that are transferable if students need to learn design tools made by other vendors.
- Altera provides Quartus® II development software for free, no licensing required.
- Altera provides college faculty training at a minimal cost.

The Altera® Development and Education (DE2) board provides an ideal vehicle for learning about digital logic, computer organization, and FPGAs. Featuring an Altera Cyclone® II FPGA, the DE2 board offers state-of-the-art technology suitable for our laboratory use [2]. Altera also provides the Quartus® II development software free to universities. The current need is to equip the Lab with high-end computers capable of running the system.

VII.Conclusion

With the demand of skilled FPGA designers on the rise, the objectives of this paper was to present the curriculum development in Hardware Description Language and FPGA designed to meet the needs of both community college and university-based two- and four-year technology programs. The goals of this new curriculum revision are to give students a real-world experience on FPGA logic design and give them the necessary training with industry widely used design tools. Students of the electrical engineering technology two- and four-year programs will not only gain skills and knowledge that are highly marketable, but also will work with faculty advisors on applied research projects in hardware modeling and programmable logic design.

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