Low Cost FPGA Development System For Teaching Advanced Digital Circuits

Iskandar A. Hack, P.E., Indiana-Purdue at Fort Wayne
James Haberly, BMT Microelectronics Center

Abstract

This paper covers the development of student development system to use with the Altera Max+ PLUS software for teaching Field Programmable Gate Arrays (FPGA's) and Complex Programmable Logic Devices (CPLD's). This software is available free of charge from Altera directly for students to download for use in at home or can be installed via an educational license in any university laboratory. The student version of the software includes a schematic editor and design entry, waveform editor for design entry, Altera Hardware Description Language design (AHDL) Entry, and the industry standard VHDL (VHSIC (Very High Speed Integrated Circuits) Hardware Description Language) design entry. Thus this system can be used to teach all of the major design techniques used in modern digital circuit design. The hardware portion of the development system includes an in-circuit programmable Altera CPLD on a printed circuit board (PCB) with adequate space on the breadboard area for students to development their own projects. The programming is done using a standard PC parallel port; thus there is no need for any additional programming hardware. Also mounted on the board are DB-25 and DB-9 connectors for implementing serial communication laboratories. The current system is using a standard student breadboard that is mounted onto the development board, and jumpers are used to connect the pins from the CPLD to the breadboard area or the serial connectors. There is also a laboratory manual, containing thirteen laboratory assignments and a list of final projects, that accompanies the development system designed to take a second semester Electrical Engineering Technology student from a basic introduction to Computer Aided Engineering (CAE) to a final project using the Altera Hardware Descriptive Language (AHDL), along with a short introduction to VHDL. The manual stresses basic design techniques along with simulation analysis prior to implementing the designs on the development hardware. The board has been used at Indiana Purdue University at Fort Wayne for the last three years, and the laboratory manual has just been developed.

I. Introduction

Digital Circuits II is a course that has developed over the last ten years from an elective third year course using Complex Programmable Logic Devices (CPLD) to required freshman second semester course. The original course introduced the students to the concepts of CPLD's along with the required theory to migrate the designs to custom Application Specific Integrated Circuits (ASIC). At the time during which the original course was developed the cost of CPLD design tools were extremely expensive and most companies did not have access to such tools, thus were having such work done by outside consulting firms. However, not only has the cost of the tools became much cheaper in the last ten years, the ease of using such tools has improved. The tools have also became more powerful, and the devices as well. Therefore the use of CPLD's have moved from a prototyping mechanism that was used to verify logical designs and their respective net lists prior to migrating a design to custom silicon to a complete family of devices that are used in final product designs. This technology is especially important for small production run products and initial product designs. Therefore it is more important that students are exposed to these devices early in their academic career. In the migration of the course to the second semester it was necessary to remove the portion of the course that dealt with the migration of the design from CPLD to a custom device. Thus a new course has been developed that concentrates on that technology, along with advanced VHDL design techniques.

The prototyping board we've developed can be used in a variety of courses that rely on digital logic. We are currently using the board in two courses. The first course we teach using the board is CPLD concepts along with an introduction to Computer Aided Engineering tools. The second course that we use the board for is for teaching VHDL in the third year of the program. The board would also be very useful in a microprocessor architecture course that uses VHDL as the modeling language.

II. Software used with Education Board

The boards have been designed to be used with the Altera Max+ Plus II CPLD development software package. This student edition of the software is free for downloading by students and faculty, thus the cost of the software is not an issue. The software supports almost all of the digital design entry formats and provides excellent simulation of the circuit. Because Altera developed the software it will only support Altera devices, but we did not find this to be a shortcoming in the course. The software provides schematic entry, waveform entry (combinational), AHDL (Altera Hardware Descriptive Language), VHDL, and Verilog entry with the student edition. The only design entry technique that we've found lacking in the software is State-Machine Bubble entry. Currently we are teaching schematic entry, waveform entry and AHDL in our freshman course and VHDL in our junior level course. The software also supports hierarchical design techniques we feel are very important for educational purposes. This is the same software that Altera releases for industrial use, thus the students get first hand experience using industrial grade design tools instead of a scaled back educational software package.

III. Motivation for Development Board

In the original course since the students were in their third year of study the laboratory for the course consisted of series of projects that the student was required to develop. The Altera Max+ Plus II software was taught in the lecture with the fundamentals of CPLD design techniques. The student was then provided with an 'Erasable Programmable ROM'

(EPROM) device to contain the developed circuit, and was expected to breadboard the final circuit to test the design. This approach worked very well for that level of student, and since the number of students in the class was relatively small. However as the number of students increased in the course the need for a prototyping board was evident.

When the course was moved to the second semester from the third year the need for such a board was even more clear that the students did not have the prototyping experience to test their designs. In addition they don't have the time to learn the concepts required and built prototypes. Thus the need for such a prototyping board was obvious. When we first started developing the board there were none available on the market. Altera has since developed a similar kit for classroom, but we found for several reasons that it lacked the versatility that we wanted in the laboratory. The current Altera boards that are on the market today fall in to two different categories. The boards in the first category are the boards that include everything to develop a number of laboratories. This was the approach that we took with our first development board, which will be described below. The other development boards that we find available are designed for industrial users, and have no additional components. These boards are designed to be placed into a system design for use during the development cycle. Neither type of board was what we wanted it to use, we wanted a board that allowed the students to easily add components to the board for laboratory work, thus we did not want everything to be included on the board. But the boards that did not have the components already on them did not have an easy way to add them.

IV. The Original Board

Our first board that we developed while we were still teaching the course in the third year, and included the following features:

Four Segment Displays with built in Decoder Drivers
Hexadecimal Keypad
Clock Signal
Eight Position Dip Switch
Eight LED's

All of the signals were also available to be used off the board, thus the students were not limited to using just those devices. We still used the EPROM based part, thus the student was required to remove the part and program it using an EPROM programmer with an additional Altera programming head. This board was wire wrapped and test with several classes. We discovered several problems with this board, the first of which was the number of parts that were damaged removing them from the board for programming, and that the built on devices were all the students wanted to use in their projects. Additionally the cost of such a board would be relatively expensive for the number of boards required for a large freshman required course. We needed to reduce the number of components on the board, and build it a board made instead of attempting to allow students use the wire wrap version. The wire wrap version was too easily damaged in the laboratory.

This development kit was developed in order to provide an easy method for students to test their circuits using the Altera Max+ Plus II software.

IV. The Current Board

We are on the second iteration of having the current prototyping board fabricated at one of the local board shops. The current version has been used for about two years without modification, and we've made about forty of them altogether. A number of students have purchased (at manufacturing cost only) their own boards to use with senior design projects. On this version of the board we've gone to using an Electrically Erasable Programmable ROM device instead of the EPROM device. Thus we were able to use the standard ByteBlaster® interface from Altera to program the device while it is installed on the prototyping board. However we're not using the ByteBlaster® cable, only a standard 25-pin parallel cable from the printer port on the computer. We've also installed a standard prototyping board on the board for the students to add their own their own devices. We've also included a clock, reset button, a DB9 for serial communications, a DB25 for PC parallel communications, and brought all of the undefined pins out for the students to interface with external hardware. However there are no components for laboratory use permanently installed on the board.

V. Laboratory Manual

We have written a laboratory manual that is geared for use with the board. The current manual is only for the freshman level course and consists of twelve weekly laboratories and list of suggested final projects for the course. Currently there is no textbook that supports the board at this time, but we are looking into that situation. However there are a number of books today that can be used, but need the laboratory manual to supplement their use with our board. The current freshman level course consists primarily of lectures that support the laboratory assignments with a minimal amount of theory.

VI. Conclusion and Future Improvements

The first board that we did we attempted to include every type of device that the student or instructor may want to do a laboratory assignment with. Thus most of the I/O was tied down, and it was not easy to interface any devices that were not included with the board. On the current board we've include none of the external components, only a prototyping area on the board and connectors for serial and parallel communications. We do see a need for a series of plug in components that can be added to the board for different laboratory assignments. An example of such add-on components would include the following:

Liquid Crystal Display (LCD)
A bank of seven-segment displays with built in rivers/decoders
A Hexadecimal Keypad
Motor Controller
A/D and D/A converters

We feel that the reliability of the board is adequate for student use, the only problem that we had was more the fault of the instructor not stressing the need to remove all external connections to the device prior to reprogramming the device. We use the board with an existing external DC power supply, and have had no trouble with power. At this time we're not going to be modifying the board, but will be concentrating our efforts into the add-on components as mentioned about. The course is a very popular course with the students and reviews of the laboratory have been very positive.

ISKANDAR HACK is currently an Associate Professor at Indiana-Purdue University at Fort Wayne (IPFW). He received his MSE at Purdue University at West Lafayette, Indiana, and is a registered Professional Engineer in Indiana. He has taught at IPFW since 1984. He has taught in Malaysia for about two years, as well as workshops in Abu Dhabi and Accra, Ghana. His interests are embedded microprocessor systems, field programmable gate arrays, and digital circuits.

JIM HABERLY is a senior design engineer at BMT Microelectronics center and has B.S. in Electrical Engineering Technology from IPFW. He is an associate faculty member at IPFW, and has taught the Digital Circuits II and VHDL course at IPFW for several years.