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TEACHING OF FPGA APPLICATIONS IN INSTRUMENTATION

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Abstract – Programmable logic seems to be a future of the digital design. To acquaint students with this technology, a new subject was prepared to fill the blank space in their knowledge. The laboratory practice is primarily focused on applications in instrumentation and is supported by newly designed development boards, which contain most of the components necessary for student's designs. This paper briefly describes approaches and teaching methods and demonstrates them on selected laboratory projects.

Keywords: FPGA, teaching, digital design.

1. INTRODUCTION

Today digital design trends lead to a wide usage of programmable logic. Especially the FPGA circuits replace standard LSI and VLSI logic. Thanks to their features, especially the flexibility and in-system reconfigurability, they also can be used in a wide number of digital designs, typical for the data acquisition and measurement instruments. Their use in education brings another important positive attribute – the wide range of different circuits can easily be implemented and tested in the same hardware. It simplifies the laboratory work and allows students to focus on the problem itself and not on the secondary issues. Of course, it also saves the total cost of the laboratory equipment, as the same boards are used for all designs.

2. SUBJECT MOTIVATION

We have quite interesting precedent in teaching specialised subject focused on using microprocessors in the instrumentation [1]. It simply combines the teaching of microprocessor technology focused on the embedded systems with its applications in instrumentation. Students have to realise several microprocessor based instruments, starting with resistance meter, dual-slope integration voltmeter, and finally the transient recorder or oscilloscope. They use the breadboards with a famous Atmel 89C52 microprocessor and serial debugger for the software development, the instrumentation part they build up on the contact array. This subject is very popular and most of students sign it in, although it is not easy to pass. Knowledge the students get here is required and used in the proposed subject, as the processor part of the below described development board uses the same microprocessor. Microprocessor technology is very popular among students and this subject helps us to increase number of students focused on instrumentation. We hope that this new subject will meet with the same success and bring other students to study measurement and instrumentation.

3. SUBJECT BACKGROUND

As the subject belongs to the group of optional subjects offered for all students at the faculty, the students that sign in have different level of knowledge (they are from different study programs, from different semesters). In order to allow students with lower level of required education easily and quickly amend their knowledge, the set of study materials is being prepared. Materials are available at the WWW site and acquaint students with the basic groups of programmable circuits, their structure, features, advantages and disadvantages. The list of literature concerning this field is also available, most of them can be borrowed in faculty library. Also the wide list of on-line WWW resources is available. We also expect the presentation of smart or subtle solution on the web site.

4. SUBJECT CONTENT

The subject is focused on practical education. There are no lectures allocated for and all the time (3 hours per week) is spent by the work on laboratory projects. Students are mostly working individually and teacher has time enough to help to those having weaker background. Nevertheless the first lesson is devoted to the subject introduction (form of a lecture), which provides a very basic information about the programmable devices, programming languages and development tools (both software and hardware). The programming languages for the hardware development like VHDL, Verilog and AHDL are mentioned with the focus on the last one. The main reason why the AHDL (Altera Hardware Description Language) was selected as a primer language is its relative simplicity and especially the support we have directly from Altera. Nevertheless, other languages are allowed as well if students already know them or prefer them.

A number of the laboratory tasks is proposed from the simplest to rather complex. Students that already have some experience in the FPGA design can skip the simple tasks.

The simple tasks are intended for the basic familiarisation with the FPGA technology, programming language and especially the software development tools.

They include:

- multiplexed LED display control
  There are 4 7-segment LED displays on the breadboard; the aim is to design simple "video card" with video memory (character + attribute for each position). Attributes may not be implemented at all or than can influence character blinking and its period or character brightness.
- simple counter/timer
  Using the display driver the counter/timer is built to measure frequency or time intervals. Wide range of inputs and their relations can be measured with simple design changes.
- pushbutton check
  Pushbuttons can be used to control the counter/timer functionality. The aim of this sub-design is to serve the pushbutton contact bounce in hardware (the same task was solved in software in above-mentioned subject focused on microprocessors in instrumentation).
- PWM modulator
  With a small change in the design the PWM modulator can be built, which uses the previously designed parts.

Students are not forced to build all these designs, on the other hand good student should spent not more than three laboratory classes to pass all.

The complex tasks represent (nearly) full implementation of a selected instrument or its part. Students that already attended the subject focused on microprocessor in instrumentation have an advantage – they already built similar instrument using the microprocessor and quite large number of other circuits. This approach uses just the FPGA and A/D converter (all the data acquisition or generation is controlled by hardware, on-board microprocessor is used just for the data transfer to or from the PC). All the designs make use of relatively large and fast internal memory, which is implemented in FPGA circuits used on breadboards.

The designs include:

- arbitrary waveform generator
  This design uses the analogue output available on the breadboard. It is equipped with an analogue filter and 1-bit D/A converter. Design can use either the internal FPGA memory or external RAM or FLASH, if the generated signal is more complex. On board microprocessor is used to download required data from PC. Software for PC that allows easy waveform design and download is available and students focus just on the generator design. The degree of the design complexity varies from the simplest designs to those that allow more than one waveform (switched by an on-board pushbutton and indicated on display), synchronisation on external signal and other features.
- digital pattern generator with sequencing
  This design is focused on the digital patterns (8 bits wide) generating. The basic task solution is very simple but memory consuming. The advanced design focuses on saving the fast memory in FPGA by a suitable "data compression". Another important part of the design is the sequencing support and conditional sequence branching defined by external signal. The pattern data are again downloaded from the PC; an appropriate software is available.
- simple logic analyser
  This is the first design that some students could already make in the microprocessor in instrumentation focused subject. Thanks to the FPGA logic capacity the features of this instrument can be larger and parameters better. The transitional timing data acquisition mode can be implemented. The glitch detection and a wide range of trigger conditions can be added as well as other features available on today logic analysers. The simple program that allows the acquired data presentation and instrument control is available.
- digital scope
  This is again an instrument known to students that attended the subject microprocessors in instrumentation. By the simple addition of a flash A/D converter to the breadboard the digitising instruments can be built. The scope implementation should provide not only the basic features, but also either the more complex triggering, the simple implementation of the DPO (digital phosphor oscilloscope) technology or different sampling methods implementation. The software for data presentation and instrument control is available.
- transient recorder
  This is a variant of the previous design. Student should focus on the highest possible sampling rate as well as on the flexible and complex trigger condition setting. Again the software necessary for instrument control and data presentation can be used.

The complexity of particular implementation depends on the student's activity and intellect. FPGA based design allows flexible changes in design and rising the task complexity when the simple solution is successfully finished.

For students that prefer more theoretical projects the interesting designs are being prepared focused on the DSP algorithm implementation (digital filters, FFT…). These designs can also be tested in practice when compared with the simulation results.

Also the tasks that are not specialised on the instrumentation will be offered to fit the needs of students from other specialities. They will include e.g. an MP3 decoder, communication controllers, simple VGA controller and other devices that will fit to the needs of students and breadboard possibilities.

All the tasks can be realised either using FPGA or PCI Breadboards. They both mostly allow the same applications but PCI Breadboard provides much more powerful implementations. The PCI Breadboard is not intended for the simple designs and thus it does not provide the pushbuttons, LED display, beeper and so on. The breadboards are described in the next chapter.

5. TECHNICAL SUPPORT

Each subject with a laboratory practice requires a special technical support. It can be provided either by the own development or the necessary tools can be bought. We decided to develop the hardware tools that would satisfy our needs as well as the software for instrument data presentation and instrument control. The software for the FPGA design comes from the chip manufacturer.

5.1. Hardware support

To allow fast and easy development the specialised FPGA Breadboard was designed (Fig. 1), which provides all the common features required by student's designs. It is built around the Altera's ACEX line FPGA circuit in a 144-pin TQFP package. It allows the use of several circuits with different logic capacity (and the same footprint) to cover both the simple and complex designs and simultaneously keep the costs low. These circuits contain not only the logic, but also the memory blocks and PLL circuitry that can be used in designs as well.

Besides the FPGA there is a microprocessor (AT89C52) on the breadboard with an internal monitor program. It allows easy software download and debugging using a standard RS-232 interface. The processor can use 32 kB of static RAM and up to the 128 kB of the FLASH memory; both these memories can still be directly used by the FPGA designs. Of course, there is an internal connection between the microprocessor and the FPGA, which allows designing any type of peripheral circuit and its microprocessor interface into the FPGA. Additionally, the board is equipped with a number of peripherals; most of them can be controlled from both the microprocessor and the FPGA circuit. The push buttons, 4-digit LED display, beeper, 1-bit D/A converter with an analogue filter and amplifier, PS/2 mouse or keyboard interface and VGA monitor output belong to them. Another peripherals, especially the A/D and D/A converters and analogue comparators can be connected to 40 general-purpose I/O pins. The board is also equipped with its own clock generator, but the external clock input that can use the PLL circuitry is available as well.

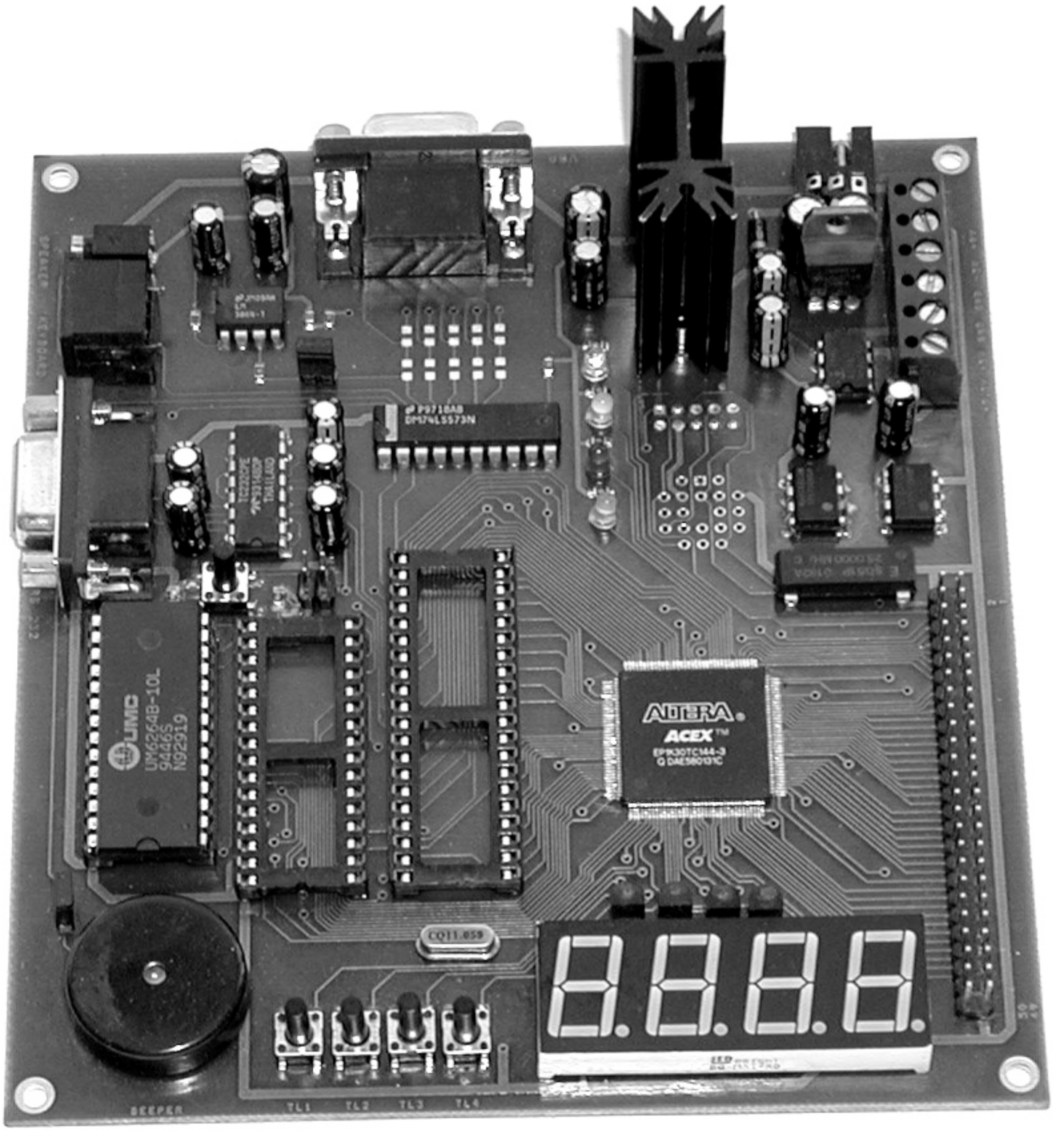

Figure 1. The FPGA Breadboard

There are two ways of FPGA programming. The first, used within the development phase, uses the PC parallel interface together with the ByteBlaster cable for downloading the program. This is very flexible and design in the FPGA can be changed in 15 seconds. When the FPGA program development is finished and final version does exist, it can be burned into the serial configuration memory and automatically loaded at the power-up.

As mentioned above, the FPGA Breadboard is also equipped with a local microprocessor of the same type as used in subject focused on microprocessors in instrumentation. The same development tools for programming and debugging are used. It is therefore possible (when building a complex instrument) to divide the application into two parts (hardware implemented in FPGA and software implemented in microprocessor) and develop and debug them together.

The breadboard is powered from the single 12 V DC supply, all the necessary voltages are provided locally by the voltage regulators and converters. The power supply levels of ±5 V, +9 V and +3,3 V are available at the power supply output in order to supply the additional hardware connected to the general purpose I/Os. They are equipped with an over-current protection and withstand a short circuit at the output. It is an important feature as the use of the contact arrays for an additional hardware could lead to either circuit or breadboard damage, when an external power source is used.

Besides the FPGA Breadboard described above, another development tool called PCI Breadboard is available. It is a simple PCI card equipped with the same FPGA circuit, which is used at the FPGA Breadboard. It is focused on the rapid development of the PCI devices and students with an advanced knowledge can use it to design PCI plug-in card based instruments. It is not equipped with the simple peripherals like display or pushbuttons but provides the on-board A/D and D/A channels, that allows easy implementation of generator or acquisition (scope) type instruments.

A PCI Target function from our own development is available, students thus can focus just on the instrument functions implementation and not on the PCI design. FPGA I/Os that are not used by the PCI or A/D and D/A channels are connected to the connector, available on the board bracket. These pins can be used to connect a special hardware, necessary for the required instrumentation. All the digital part of the design can and should be implemented in the FPGA together with a PCI interface.

Development of the PCI based instrument is more difficult than that with the FPGA Breadboard, as the application software support is not so strong. Students have also program a low-level interface between their PCI based solution and application programs (arbitrary waveform generator, digital pattern generator, logic analyser, digital oscilloscope, and transient recorder) in order to exchange data between them. As Windows 98 are used, the device drivers are not necessary (a direct access to the hardware is allowed). In the future with the planned migration to Windows NT/2k/XP systems, the simple universal device driver will be provided so that students will be able to access their hardware.

For very advanced students (or rather group of them) that already have experience with the FPGA design the special offer exists. They can use a high performance breadboard with the APEX family FPGA circuit with a large amount of logic, memory and other circuits inside. Two breadboards are available and they allow real system-on-chip development (the NIOS microprocessor core can be placed in the FPGA). The complex software support (development and debug tools) is available too. We expect an exceptional use of these breadboards (one group at maximum), as their use requires quite large knowledge and experience. They will more probably find their place in solving the diploma works, for which this subject seems to be a good prerequisite.

5.2. Software support

The FPGA structure is primarily designed using the Altera's MAXPlus2 software, which is available free of charge and supports both the AHDL and VHDL languages. As we participate in Altera's University program, the Quartus and specialised versions of Leonardo and Synplicity design tools are available too (require more powerful computers). The MAXPlus2 software is easy to use and we recommend it especially for beginners. If any student knows some of the other design tools, he is free to use it.

6. CONCLUSION

As mentioned in chapter 2, we have a positive experience in teaching subjects that combine more common knowledge (e.g. microprocessor technique) with specialised knowledge focused on instrumentation. The above described subject (FPGA circuits in instrumentation) should increase the range of similarly oriented education, give students information about new technology and simply improve their expertise in instrumentation. As it is intended not only for students focused on instrumentation, alternative laboratory tasks are being prepared that respect their specialisation.

REFERENCES

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