FPGA and Embedded PC Based Module for Research and Education

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ABSTRACT

This paper presents a versatile experimental and educational module, which can be used both for prototyping of embedded PC based electronic devices, and for teaching of computer engineering. The FPGA chip may be used to implement or to emulate wide range of hardware devices, while the embedded PC, able to run the Linux OS, provides an efficient environment for controlling this hardware using different techniques.

Keywords: FPGA, embedded systems, embedded PC, experimental module, teaching aid, computer engineering

1. INTRODUCTION

In both - educational and the research activity it is very useful to have a versatile prototyping platform allowing for practical verification of different hardware and software projects.

In teaching of computer engineering, especially in topics related to the low level programming, like device drivers development, there is a need for a computer system with possibility to implement or to emulate many different peripherals. Such a system may be used for demonstration of different programming techniques or for verification of students' projects.

In teaching of digital systems or eg. cryptography it is useful to have a device with a programmable logic chip, which can be used to implement various custom hardware (eg. the cryptographical engine), and an efficient user interface allowing to control and debug that hardware.

In the research activity there is often a need to connect a nonstandard device to the data acquisition system. Eg. the authors have faced the problems of receiving data from the medical device using a fast nonstandard serial interface. The solution may be a system, combining a programmable logic chip with the microcomputer system, where the programmable logic is used to implement a dedicated receiver, and microcomputer may be used for preprocessing of data.

The next sections will show the concept, and the implementation of the simple module matching the above requirements.

2. CONCEPT OF THE MODULE

The FPGA chip is a good platform for prototyping of the digital hardware. However it can not be used alone. It requires some hardware to be configured after powerup, it also need some interfaces to the external world - for debugging or to provide the user inteface.

Configuration of the FPGA chips may be performed with very simple devices, like the Altera's ByteBlasterMV.[1] Such simple configuration interface may be easily included in the module, and it could be even used for debugging (eg. using the JTAG or user protocol), but its performance would be poor. To achieve better debugging capabilities one can implement a communication interface in the FPGA chip itself. There are free implementations of the USB controller,[2] the Ethernet controller[3] or the PCI bridge.[4] Unfortunately such communication interface consumes a lot of FPGA resources, so it would be necessary to use more complex and more expensive FPGA, to leave reasonable amount of resources for the user hardware.

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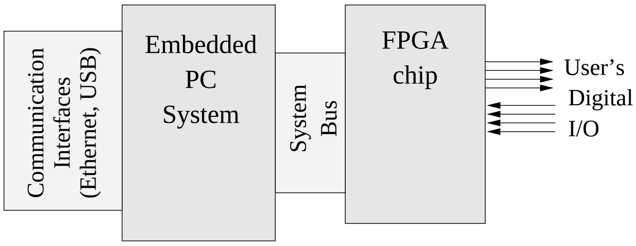

Figure 1. The general concept of the educational and research module

The good solution may be to integrate the configuration interface, the debugging interface and the user interfase in single hardware device. It can be done eg. with a relatively simple and cheap microcontroller device like EZ-USB FX2™manufactured by Cypress.[5] This chip may be easily used to implement both – the configuration interface, and the very fast USB 2.0 link for debugging and user communication purposes.

However using more powerfull CPU, tightly integrated with the FPGA chip may assure better performance and offers quite new possibilities. If the FPGA is connected to the bus of the embedded PC-like system, running under control of any standard operating system, than the resulting device may be used as an efficient development system for both hardware and software designs.

The block diagram of such device is shown in the Fig. 1.

3. IMPLEMENTATION OF THE MODULE

To implement the described module it was necessary to select the proper components, both hardware and software.

3.1. Selection of the embedded PC

There are many embedded PCs available on the market.[6] Therefore the selection of the proper one is not an easy task. The final decision was taken considering the following factors:

- price and availability in Poland
- number of different external interfaces
- efficiency of communication with external circuits (solutions with easily accessible CPU bus were preferred).

Finally the ETRAX 100LX Multi Chip module (ETRAX MCM),[7] manufactured by the AXIS,[8] has been chosen. This embedded PC (in fact a Single Chip Computer - SCM) offers many external interfaces:

- 4 asynchronous serial ports RS232/485
- 2 synchronous serial ports with configurable word length (8/16/24/32 bits), selectable bit order, and user definde signals' polarities
- 2 parallel ports
- 10/100 Mb/s Ethernet interfaces
- 2 USB 1.1 Interfaces
- Fast (up to 200 MB/s) 32-bit CPU bus available for connecting of external devices (eg. FPGA)
- Efficient DMA controller with scatter/gather mode
- Additionally it is possible to connect IDE devices, SCSI devices and additional SDRAM and FLASH memories.

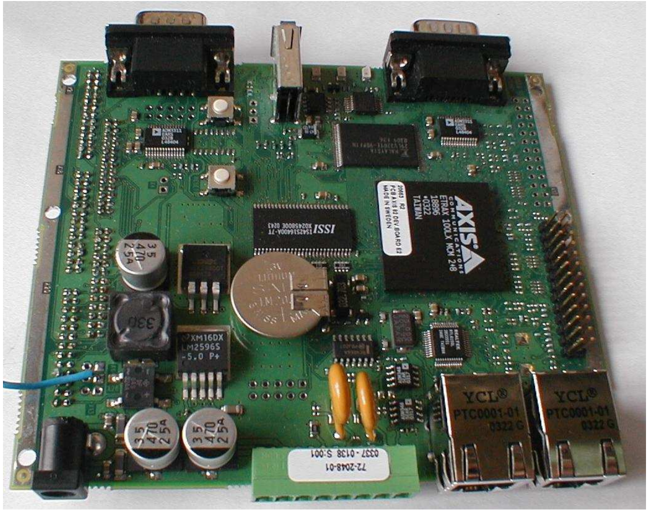

Figure 2. View of the Axis 82 board

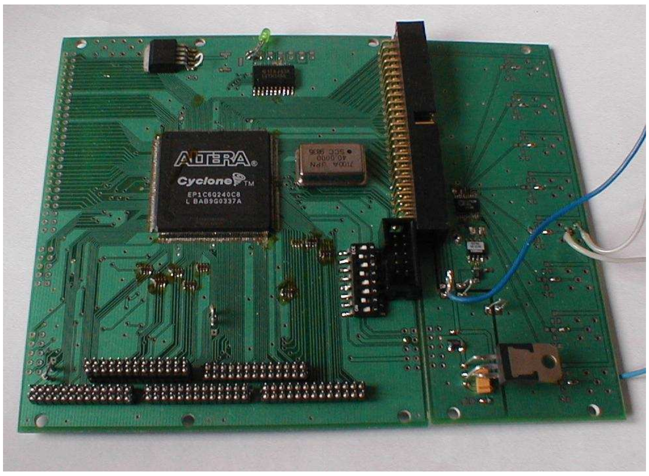

Figure 3. View of the daughterboard with the FPGA, configuration interface and power supply circuit. An additional A/D module connected to the daughterboard

The last but not least reason to use the ETRAX MCM was the fact, that it has been succesfully used in others designs developed by one of the authors and his cooperators.[9]

In fact in the prototype implementation a ready to use Axis 82 Development Board[10] has been used, to speed-up the project development. However the final version should be based on the pure ETRAX MCM chip.

The Axis 82 board, shown in the Fig. 2 offers some additional interfaces (eg. the second Ethernet interface and the level converters for serial ports), and more memory (4 MB of FLASH and 16 MB of SDRAM, comparing to 2 MB of FLASH and 8 MB of SDRAM in the ETRAX MCM itself *).

The Axis 82 was extended with an additional daughterboard, shown in the Fig. 3, containing FPGA, configuration interface, external connectors and power supply circuits. The assembled module (Axis 82 with the daughterboard) is shown in the Fig. 4.

*Currently also a new version: ETRAX 100LX MCM 4+16 is manufactured and is recommended for new designs. This version is equipped with 16MB of internal SDRAM and 4 MB of internal FLASH

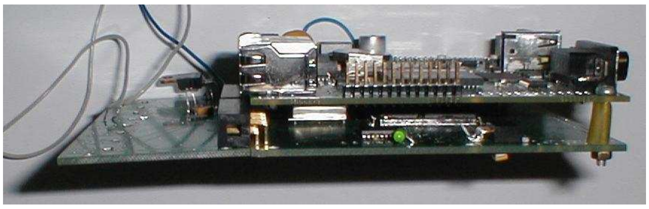

Figure 4. View of the assembled module. An additional A/D module connected to the daughterboard

To avoid damages caused by the misconfiguration of the FPGA chip, interconnections between the ETRAX bus and the FPGA chip have been protected with the series resistors.

3.2. Selection of the operating system

Choice of the ETRAX MCM chip was associated with a decision to use the GNU/Linux[11] OS, as this is a recommended OS for this CPU. However the selections of both - embedded PC and the Operating System were tightly interconnected, and in fact the possibility of running Linux was also an important advantage of ETRAX MCM.

Linux offers many advantages as an OS for the described module. First of all it is a “free software” which is very important in both educational and research use. It is also an “open source software” so it is very didactical - the students may investigate all the internals of the OS, and can even modify it if necessary.

Additionally Linux is well documented and is supported with many free development tools, so it is easy to create a software environment for the students lab.

There are also real-time versions of Linux[12] available, which are well suited for control and data acquisition applications.

Finally Linux features an efficient TCP/IP stack, which is very important if the module should be accessed via the network to provide the debugging, control and communication interface.

It is also very important that Linux may be booted via the network and works perfectly with network mounted root filesystem, which is very useful in the prototyping and educational use.

3.3. Selection of the FPGA chip

In the research and educational module like this, only the SRAM configured FPGA chips may be used. Only these chips may handle the numerous changes of configuration, associated with educational use and with extensive prototyping. When selecting the FPGA chip the following factors were considered:

- price and availability in Poland
- availability of free development tools (both for synthesis and simulation)
- price/capacity ratio and availability of different capacity chips with compatible pinouts.

Finally the Altera Cyclone FPGA was selected, but this choice is not critical, and the design can be easily tuned eg. for Xilinx FPGAs (however it requires redesign of the PCB).

The block diagram of the final implementation of the prototype module is shown in the Fig. 5.

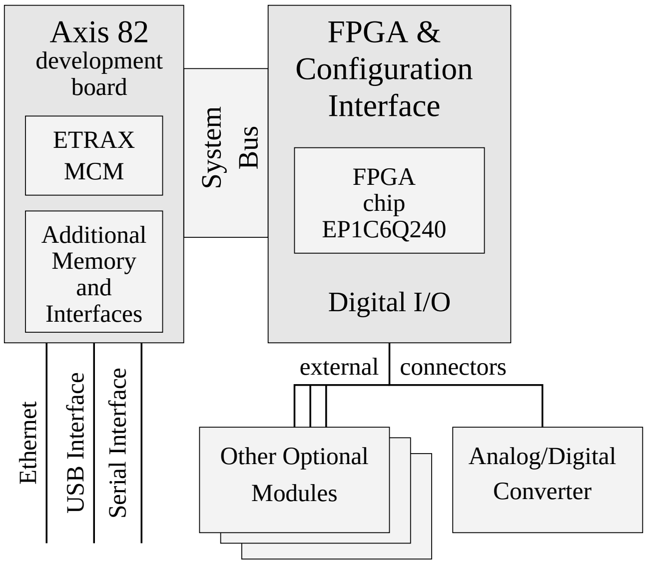

Figure 5. The block diagram of the implemented educational and research module

4. EDUCATIONAL AND RESEARCH PROPERTIES OF THE MODULE

4.1. Educational applications

One of planned educational applications of the module is teaching of the "Device Drivers - Programming Fundamentals" at the Warsaw University of Technology. The student may configure the FPGA with the ready to use IP core, implementing different peripherals (or may prepare her/his own IP core), and then can develop and debug the device driver for that peripheral. The ETRAX MCM offers such features like scatter/gather DMA, interrupts, caching, so the student can deal with all typical problems associated with development of the device drivers.

The development work is conveniently performed on the standard PC, connected to the module via the TCP/IP network. The system crashes, which are normal when learning such low level system programming, do not affect the workstation, but only the educational module, which may be quickly rebooted. The additional serial interface allows to monitor the kernel messages.

All student developed drivers and user software may be loaded from the NFS mounted filesystem, so the development does not cause wearing off of the module's FLASH memory.

The module may also be used to implement the complete USB connected peripheral, so the students can learn to develop drivers for USB devices.

The module may be also used in teaching of digital systems and in teaching of subjects related to algorithms implemented in the digital systems (eg. DSP and cryptography).

The only problem with wider use of the prototype module is its price, resulting from use of the Axis 82 board. However the price may be significantly reduced by using the ETRAX MCM itself, as described in Sect. 5.

4.2. Research applications

The current setup includes a simple A/D converter based on the AD7928 chip.[13] It is possible to use it as a simple data acquisition system, where some data processing algortihms may be implemented in the FPGA, and some in the software.

The FPGA allows to implement different interfaces for connecting external hardware devices. In such use, the module may be a "hub" collecting data from different measurement devices and sending them (together with time markers) over the TCP/IP network to the computer system for further off-line analysis.

The high speed, and parallel operation of the FPGA implemented digital systems allows to generate signals with timings which would be impossible to obtain in the pure PC+software solution. Therefore the presented module may be used for prototyping of different controllers. In this case the embedded PC provides excellent debugging capabilities.

The similar system has been successfully as an add-on daughterboard to replace the VME interface in electronic systems developed for high energy physics experiments.[14]

5. FUTURE IMPROVEMENTS

The presented module is only a prototype solution. Its price is relatively high because the standard development board (Axis 82) has been used. It is possible to reduce the price by using of the ETRAX MCM chip itself, placed together with FPGA and necessary interface chips on the dedicated PCB, like in the system described in [9] and [14].

For some applications (eg. for the prototyping of the DSP systems) a more capable (and more expensive) FPGA should be used.

6. CONCLUSIONS

The presented module, combining the embedded PC system with the FPGA chip may be a very useful teaching aid and a research tool.

It is a good development platform for digital systems, for low level system programming and for complex control and data processing algorithms, requiring decomposition into hardware and software implemented parts.

The price of the module implemented on the dedicated PCB should allow its wide use in the students lab and in research work.

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