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Introducing Field Programmable Gate Arrays with Deeds Projects

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The software tools presented are available free of charge to all interested parties at: http://www.esng.dibe.unige.it/deeds/



Introduction

- The introduction of *Field Programmable Gate Arrays* (FPGA) in a first year course of digital design in ICT engineering is nowadays advisable.
- It is not easy to build good foundations on logic design just by completely migrating the traditional schematic, simulation and bread-board based prototyping to VHDL based FPGA design flow.
- Deeds (Digital Electronics Education and Design Suite) makes the process of FPGA configuration straightforward and compatible with the beginners' skills.
- Tutorials guide students in the process and, at the same time, provide a synthetic introduction to FPGA projects.



FPGA and beginners' skills

- Our approach fills an important learning gap in early exposure to FPGA, by skipping the pre-requisite of a hardware description language or the proficiency in highlevel programming languages.
- Deeds integrates FPGA configuration and testing into its interactive design and simulation flow, making combinational and sequential design, as well as microprocessor core programming, demonstrable through physical FPGA boards.
- The process achieves appreciable effects and it is fully compatible with the beginner's skills.



Tutorials and projects

- Tutorials and projects, designed for flexibility and ease of self-learning, open up many possibilities to hands-on experiments.
- Students experience digital system designs of different complexities, involving combinational logic, FSM and microprocessor programming.
- Freshman level students can easily understand the lowlevel behavior of embedded systems, a good foundation for successive courses on design languages, IP cores, hardware-software co-design.





- **Deeds** is developed at DITEN (ex DIBE), University of Genoa
- Presented at IEDEC last year
- The suite is composed by three simulators and a wide collection of associated *learning material* to learn-by-doing and practice with:
 - **Combinational and sequential logic networks**
 - Finite state machine design
 - Embedded microcomputer interfacing and programming
 - FPGA programming (exporting projects to EDA tools)



Deeds: the simulation tools

- d-DcS Digital Circuit Simulator
- d-FsM Finite State Machine Simulator
- d-McE Microcomputer Emulator

• The three simulators are *fully integrated*, to design and simulate *digital systems* with *standard logic*, *finite state machines* and *microcomputers.*



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Deeds: FPGA prototyping

- Deeds allows testing of projects by implementing them in FPGA boards (Altera DE2 in the picture)
- The process does not require the user to be familiar with FPGAspecific development software.





Deeds: FPGA tutorials and projects

#	Deeds Introduction to Field Programmable Gate Arrays							
1	Tutorials: Circuit Prototyping on Altera DE2 Board New! Sequential Circuit Testing on Altera DE2 Board New! Microcomputer Testing on Altera DE2 Board New!							
2	Analysis and implementation on FPGA of a 12-bits counter New!							
3	A light controller on FPGA							
4	Serial Transmitter and Receiver on FPGA							
5	Asynchronous Serial Transmitter and Receiver, on FPGA New!							
6	Push-button controlled byte generator on FPGA New!							
7	Emulation of a Register/Counter on FPGA New!							
8	Emulation of a Universal Shift Register on FPGA New!							
9	Asynchronous Serial Transmitter and Receiver, interrupt based, on FPGA New!							
10	Digital Waveform Generator, on FPGA New!							
11	Asynchronous Serial Line Data Processor, on FPGA New!							



First Tutorial: Circuit Prototyping on FPGA

The first tutorial provides instructions on how to transfer a Deeds project to the board.

With the **Test on FPGA** dialog window the user can assign board resources to the Deeds schematic.

By clicking on Generate Project...

Test On FPGA (Project: "TestCircuit.pbs") FPGA Board / Brand: Altera Corporation "DE2" (Quartus® II Softw	Deeds Project Folder: D:\DeedsProject\WebSite\Deeds\LearningMaterials\LM\Tutori. FPGA Project Subfolder: D:\DeedsProject\WebSite\Deeds\LearningMaterials\LM\Tutori.
Inputs Outputs	DE2 board - Altera Corporation / TerAsic 🔒 🕫 🕫 🔍
B7B0	Pin: 0 1 2 3 4 5 6 7
Board Assignments Project Files Assignment	Summary Generate Project Test On FPGA Close Help



First Tutorial: Circuit Prototyping on FPGA

...by clicking on Generate Project the Deeds will create all the VHDL code and the project files necessary for the Altera Quartus® II software.

Students, at this time (if they wish so), can examine the VHDL code but...

...they can just launch Quartus® II from the dialog box.





The project in Quartus is ready to be compiled

In this first tutorial, the file **TestCircuit.vhd** is the *structural* description of the digital network schematic.

The file **Components.vhd** collects the VHDL **behavioral** descriptions of all the components used by the network.

After the compilation of the project, Quartus® II allows to transfer the generated file to the DE2 FPGA board.





Board view of the I/O of the circuit under test



The switches, pushbuttons and LEDs of the FPGA board are proposed as a "control panel" for testing simple networks.



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Second tutorial: Sequential Circuit Testing

Deeds schematic editor and timing simulation of the sequential network: a three bits binary counter





State chart of the FSM-based light controller



A medium complexity FSM, controlling the pressure and release of push-buttons, a common task in many consumer devices, finalized here to control the activation of a few LEDs.



Board view of the sequential circuit under test

It is possible to set a programmable clock generator.

In the **control panel** are highlighted the clock generator controls.

The **Slow Clock Mode**, allows to test state-bystate.





Third tutorial on Microcomputer Testing

The "Test on FPGA" dialog window, to set the debugging environment for the microcomputer





Simple Projects on FPGA: FSM as controller of a digital system

The first serial communication project





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Asynchronous serial communication system



A more complex Serial Transmitter and Receiver: two FSM-based devices work together to obtain a sort of remote control system.



Asynchronous Serial Tx-Rx (FSM-based)

Two separated groups of students can interconnect with a cable their own FPGA boards and check the exchange of data.

It is interesting to observe how the teams react when something goes wrong



(portion of the schematics)



Microcomputer-based serial com. system

The specifications are similar to the FSM-based laboratory but the communication system is entirely done by software.

DMC8 is the microcomputer of the Deeds.

The system employs an interrupt based approach, and can be considered as an introductory example of both real time processing and embedded systems





Microcomputer-based digital signal generator

The general purpose 8-bit microcomputer is programmed to work as a DSP, implementing by software a lowfrequency digital waveform generator that fits on the FPGA boards.



The project includes a sine wave generator, a modulator and a display system. The digital output of the generator drives a row of LEDs, available on the board. Students like the resulting display, that resembles the movement of a pendulum.



Timing simulation of the signal generator

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The output of the generator can be observed on the *Deeds* simulator <u>Timing Diagram</u>, almost as it were an analog signal.



Tentative assessment of results

- In our teaching activity the introduction of novel or updated technical and pedagogical material is almost continuous. Therefore, comparisons with former educational situations or, worse, quantitative evaluations of the results are not possible.
- We can summarize here the observations resulting from our deep interaction with students activities.
- Deeds FPGA extension works properly. Students have no problems with the compilation of the files and the operation of the DE2 boards.
- The tutorial material guiding the experiments proved to be exhaustive and easy to understand.
- Students show a very strong interest for the laboratory sessions using the FPGA.



Deeds FPGA experience: conclusions

- Deeds has the possibility to export and test project on FPGA boards without the need of familiarity with FPGA and its development tools.
- Our approach is a solid introduction to understanding the low-level behavior of embedded system, bridging the gap with the design of more complex systems, using high level languages, IP modules, hardware-software co-design.
- The VHDL code generated by Deeds facilitates the transition from schematic entry to hardware description languages.



Impact of Deeds (1)

- Deeds is the work mainly of one man (Giuliano Donzellini) who wrote its more than 200,000 lines of code and maintains and expands it continuously.
- Deeds has been made available free of charge to institutions and person and it has been adopted by universities and secondary techical education schools.
- Tutorials and projects are available in Italian and English.
- Deeds educational materials have been translated and published in Turkish (Çizgi Elektronik, Istanbul), Spanish, Catalan.



Impact of Deeds (2)

The Deeds has been and it is used now in several European universities:

- •Metropolia University(Helsinki, Finland)
- •University of Deusto (Bilbao, Spain)
- •School of Business and Engineering Vaud (Switzerland)
- Inholland University of Applied Sciences (Netherlands)
- •Universidad de Las Palmas de Gran Canaria
- •University of York (U.K)
- •University of Sofia, Bulgaria
- •Technological Education Institute of Piraeus, Athens



Impact of Deeds (3)

- Deeds has been used by thousands of students in Italy and abroad, from hands-on tutored laboratories to project-based learning and distance education.
- The addition of the PFGA prototyping has provided new life to its existing large depository of projects.
- The fact that teachers roles overlaps with developers roles guarantees the continuity between the tools and the educational situations.



How to get tools and materials (for free)

- All Deeds projects (in English and Italian) are available at:
 - http://www.esng.dibe.unige.it/deeds/LearningMaterials
- FPGA projects are indexed here:
 - http://www.esng.dibe.unige.it/deeds/FPGA

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Thank you for your attention!



We thank Altera Corporation for the generous donation of the DE2 development boards that have made possible an extensive experimentation in the lab.

"The Deeds of Gallant Knights" This image from a picture of G. David, XVI Century Paris, Musèe de l'Armèe

