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Modelling, Control and Management of Thermal Effects in Circuits of the Future

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Final report on the organization and the execution of the courses

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References

IPCA – Therminator Consortium Agreement

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Contents

Introduction

The dissemination of the knowledge gathered and created by FP7 projects is an important task. The purpose of this task is to make it possible for engineers, scientists and everyone who is interested in the areas the project is concerned with to get acquainted with the work done in the frames of the THERMINATOR project.

Two different level of courses are organized to allow everyone to choose the depth and scope of his or her needs. The introductory course addresses interested designers and researchers having low or no experience in thermal-aware design. This course has an extended theoretical background section and a state-of-the-art presentation section. New design techniques originating from the R&D work in the THERMINATOR project are embedded in the latter section. EDA methodologies, tools and flows are only briefly reviewed. The advanced course targets designers with thermal design experience rather than researchers. After a short introduction, consisting of theoretical background and state-of-the-art design techniques, the design solutions and technologies developed within the project are covered in details. The thermal-aware EDA tools and flows, as well as their potential integration into existing design flows are also discussed deeply.

This deliverable describes the following:

- The list of course materials provided throughout the project
- The courses and workshops organized in 2012
- A summary of the courses organized in frames of the Therminator project

The course materials

Thus the list of the materials available for trainings in the project is the following:

1. Synopsys design flow (advanced)
2. High-level thermal estimation flow by Offis (advanced)
3. Introductory Course: Modeling and Characterization of Thermal Effects in Si-LDMOSTs by NXP (introductory)
4. Introduction to electro-thermal simulation (methods, tools, examples) by BME (introductory)
5. WiCkeD 6.3 Training by MunEDA (advanced)
6. Tutorials of the Intel course (23. Sept. 2010. Munich) (advanced)
7. Tutorials of the Polito course (6-7. Dec. 2010. Torino) (introductory and advanced)
8. Thermal and Electro-Thermal Simulation: Achievements and Trends by Synopsys (advanced)
9. Simulator engines developed by BME in the frames of Therminator (final results)

The materials can be downloaded from the project's website (http://www.fp7-therminator.org/). They can be found under WP8, the title of the entry is “D8.3.2 - Course materials in electronic form”.

The evaluation of the courses

Trainee satisfaction was measured using the Kirkpatrick training evaluation model. Nine statements had to be valued in the form of numbers between 1 and 7. From 1 to 3 the answers correspond to a decreasing level of disagreement, 4 means that one is neutral on the issue and 5-7 corresponds to an increasing level of agreement.

The nine statements were the following:

1. The main goals of the training were clearly stated.
2. The main goals of the training were achieved.
3. I can describe the course contents.
4. The expected topics were all addressed during the course.
5. Course's contents will be useful to my working activities.
6. The manual and the tools used during the training were useful.
7. The methodologies used in the training were effective (lessons, exercises, activities).
8. The training planning and organization was in line with my expectation.
9. The teacher was effective.

The charts in the document show the summarized results of such tests except for the two POLITO courses (13-14. December) where the questions were slightly different and the interval for the answers was 1-5. These charts are in red, the results of the Kirkpatrick tests are shown in blue.

Courses organized in 2012

Training course at the IMEC headquarters (22-23. March)

Electronic devices of the latest generations, being those integrated circuits or discrete components, are often required to operate in harsh environmental conditions, where the temperature may reach over hundred degrees centigrade. Obviously, this has negative impact on several parameters of the electronic devices, ranging from slow-down and transient, recoverable errors to permanent failures and device breakdown. To complicate the picture, electronic components tend to get warmer on their own as they operate, due to the fact that the power drawn by the devices from the power supply is dissipated by Joule effect.

As time passes, heat and temperature management is becoming increasingly problematic. Packages that are able to sustain high temperatures are very expensive, and so are heat-sinks and cooling systems. In addition, high operating temperatures tend to cause malfunctioning of circuits and components and to shorten their lifetimes, thus impacting the reliability of the electronic products which incorporate such devices.

The thermal problem has several facets, thus it needs to be addressed in a comprehensive manner. The THERMINATOR course will address the following major challenges:

1. Innovative thermal models usable at different levels of abstraction, and their integration into existing simulation and design frameworks.
2. Thermal-aware design solutions, customized for the different technologies and application domains of interest.
3. Thermal-aware add-on tools that will enable designers to address temperature issues during their daily work and with their usual design flows.

DAY 1: March 22nd 2012, 10h00-17h00

- 10h00-10h20: Introduction, Geert Van der Plas - IMEC
- 10h20-11h00: TCAD simulations of nano-CMOS including self-heating, Alex Burenkov - FhG IISB
- 11h00-11h45: Device level: TCAD: Modeling of CMOS degradation mechanisms and modeling/calibration of FinFET devices including thermal effects, Axel Erlebach - Synopsys
- 11h45-12h30: Discretes: SNPS TCAD GaN presentation, Axel Erlebach - Synopsys
- 13h45-14h45: Systems: Thermal analysis and design of 3D systems, Geert Van der Plas, Herman Oprins - IMEC
- 14h45-15h45: Discretes: Modeling and characterization of thermal effects in Si-LDMOSTs and GaN HEMTs, Stephen Sque - NXP
- 16h00-17h00: Discretes: GaN, Steve Stoffels, Herman Oprins - IMEC

DAY 2: March 23rd 2012, 09h00-12h30

- 09h00-12h30: Systems: High-level thermal estimation flow including basic thermal-aware design techniques for digital ICs, Patrick Knocke – Offis

Therminator Special Session at LATW (10-13 April)

Friday, April 13th 2012 – **SPECIAL SESSION 3: Thermal Aware Design and Test**

- **Acquiring real-time heating of cells in standard cell designs** Andras Timar, Marta Rencz – Budapest University Of Technology And Economics
- **Simulation Framework for Multilevel Power Estimation and Timing Analysis of Digital Systems Allowing the Consideration of Thermal Effects** Gergely Nagy, András Poppe – Budapest University Of Technology And Economics

Therminator Special Session at Therminic (25-27 September)

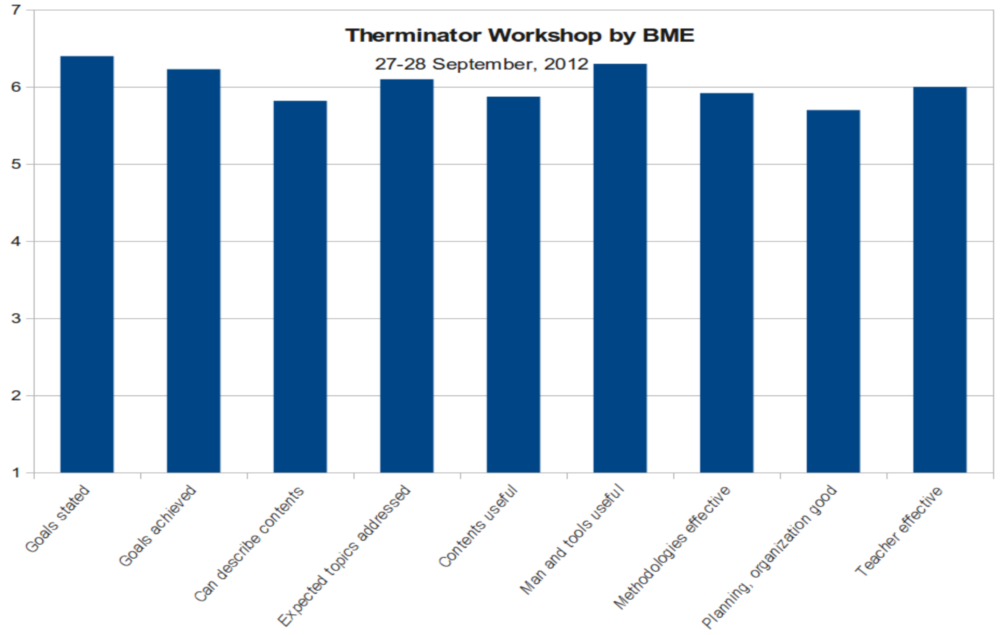
Day 2, 26 September, Wednesday – Session 8: Therminator

- Thermal aware design methodology for small signal discrete products, Steffen Holland, Martin Röver, Hans-Jürgen Kühl, Hans-Jürgen Witt, Remo Quade, NXP Semiconductors (Germany)
- Coupled electro-thermal model for simulation of GaN power switching HEMTs in circuit simulators, Steve Stoffels, Herman Oprins, Denis Marcon, Karen Geens, Xuanwu Kang, Marleen Van Hove and Stefaan Decoutere, Imec (Belgium)
- Temperature dependent timing in standard cell designs, Andras Timár, Márta Rencz, BME DED (Hungary)
- Layout Constrained Body-Biasing for Thermal Clock-Skew Compensation, Valerio Tenace, Sandeep Miryala, Andrea Calimera, Alberto Macii, Enrico Macii, Massimo Poncino, Politecnico di Torino (Italy)
- A quasi-SPICE electro-thermal simulator, Albin Szalai, Zoltán Czirkos, Vladimír Székely, Budapest University of Technology and Economics, Department of Electron Devices (Hungary)
- Yield enhancement by logi-thermal simulation based testing, Gergely Nagy, László Pohl, András Timár, András Poppe, BME DED (Hungary)

Therminator Workshop held by BME (27-28 September)

- **Participants: 21**
- **Trainers:** Marta Rencz, Andras Poppe
- **General introduction**
    - Role of circuit simulation
    - Electro-thermal simulation
    - Simulation methods
        - Physical level simulation, simulator coupling, simultaneous simulation.

- **Simultaneous simulation**
  - Operation of a circuit simulator
    - Structure of a simulator
    - The nodal solution method
    - Generating the equations to be solved
      - Linear DC - admittance matrix
      - Non-linear DC - the Jacobian matrix
    - Device models
  - Electro-thermal device models
  - Thermal model of the chip
- **Implementation example**
  - Introduction to an existing electro-thermal simulator



Internal Courses on Technology CAD held in STMicroelectronics (Catania Site)

TCAD Fundamental – 1-5th October

- **Trainer:** Cristina Miccoli / Dario Sutera (ST)
- **Students:** 5 (ST designers)
- **Description:** Technology CAD simulator provides general capabilities for numerical, physically-based, simulation of the entire process flow of semiconductor devices. Process simulation reproduces all the fabrication steps (implantation, deposition,

diffusion …) needed to get the complete device from the bulk silicon wafer. Device simulation allows simulating the electrical characteristics of the device (built with the process simulator) by using mathematical models describing charge transport in semiconductor materials.

Introduction to Synopsys TCAD – 15-19th October

- **Trainer:** Valeria Cinnera Martino (ST)
- **Students:** 6 (ST designers)
- **Description:** This is an introduction course on Sentaurus TCAD (Synopsys) tools and syntax. Useful for people that are already able to perform technological simulations using Silvaco platform and are interested to have a more wide knowledge on TCAD tools and methodologies. At the end of this course, the attendees will be able to perform simple 1D and 2D simulation using Synopsys platform.

Therminator Workshop at NXP (5th December)

09:00 10:00 Presentation of sresults

- What is Flotherm
- What is Sentaurus
- Overview why this is done
- Approach for calibration
- Measurements
- Results

10:00 10:30 Measurement setup

- tour through the lab: Rth lab equipment

10:45 12:15 Detailed tool presentation Flotherm

- How to use FloTherm
- Model building
    - drawing board, parameter definition, meshing, definition of transient mesh
- Simulation
    - steady state, transient, parameter extraction for Sentaurus

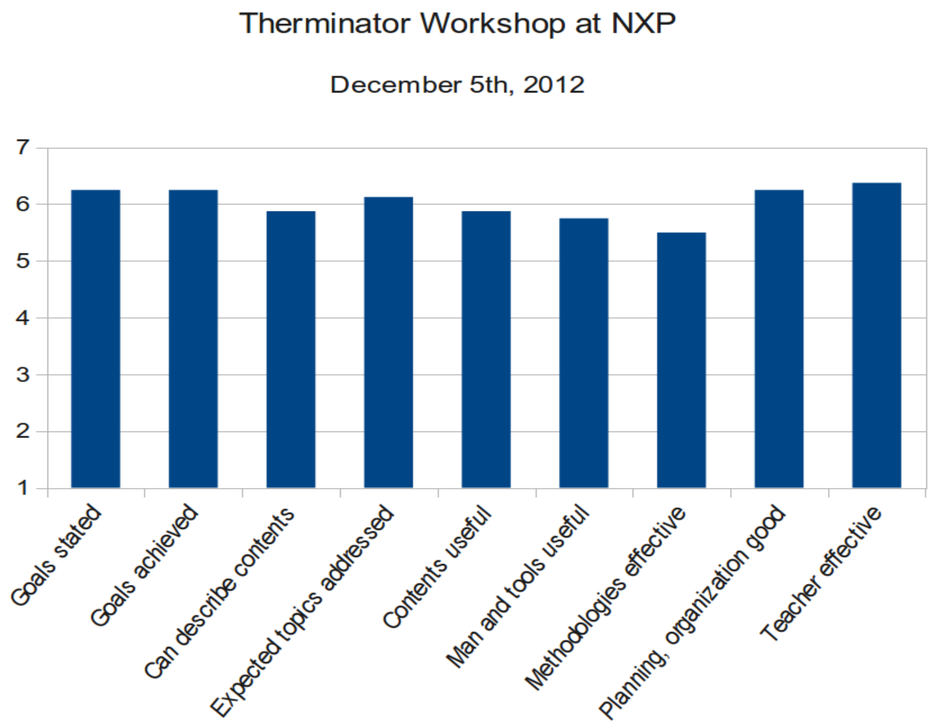
13:15 14:45 Detailed tool presentation Sentaurus

- How to use Sentaurus
- Structure editor
    - Meshing, Electrode placement, Pitfalls

- Sdevice
  - Structure, mixed mode, dc simulation, transient simulation, Pitfalls

14:45 15:30 Discussion and outlook

- open discussion



Thermal-aware design techniques – Introductory course by POLITO (13th December)

Participants:

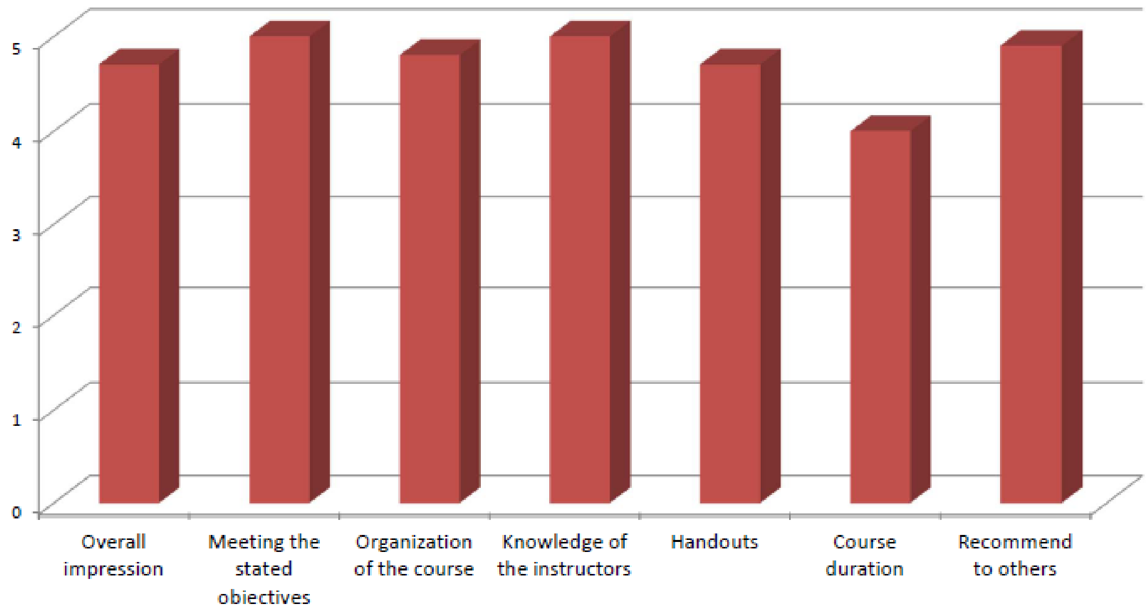
- 37 Students
  - 20 Phd students
  - 17 Undergrad
- 9 Postdocs
- 12 Professors
- 2 from Industry

Technical contents:

1. Introduction and motivation.
2. Thermal trends
   a) The importance of temperature as a design consideration

   b) Thermal issues in integrated circuits

3. Thermal models
   a) Background
   b) Heat transfer basics
   c) Thermal modeling of circuits
      i. Die vs. Package
4. Thermal analysis and estimation
5. Therma-aware design
   a) Classes of approaches
   b) Design-time techniques
   c) Run-time techniques
   d) Techniques for interconnects
6. Conclusions



Circuit and Physical Level Thermal Aware Design Techniques for Digital ICs – Advanced course by POLITO (14th December)

Participants:

- 29 Students
  - 19 Phd students
  - 10 Undergrad
- 7 Postdocs
- 10 Professors

- 2 from Industry

Technical contents:

Part 1: Circuit-Level Thermal Modeling.

Part 2: Fundamentals of thermal-aware design flows.

Part 3: Circuit-Level Temperature-driven optimization:

a. Thermal-aware synthesis of low-leakage circuits;

b. Thermal-aware floorplanning and placement;

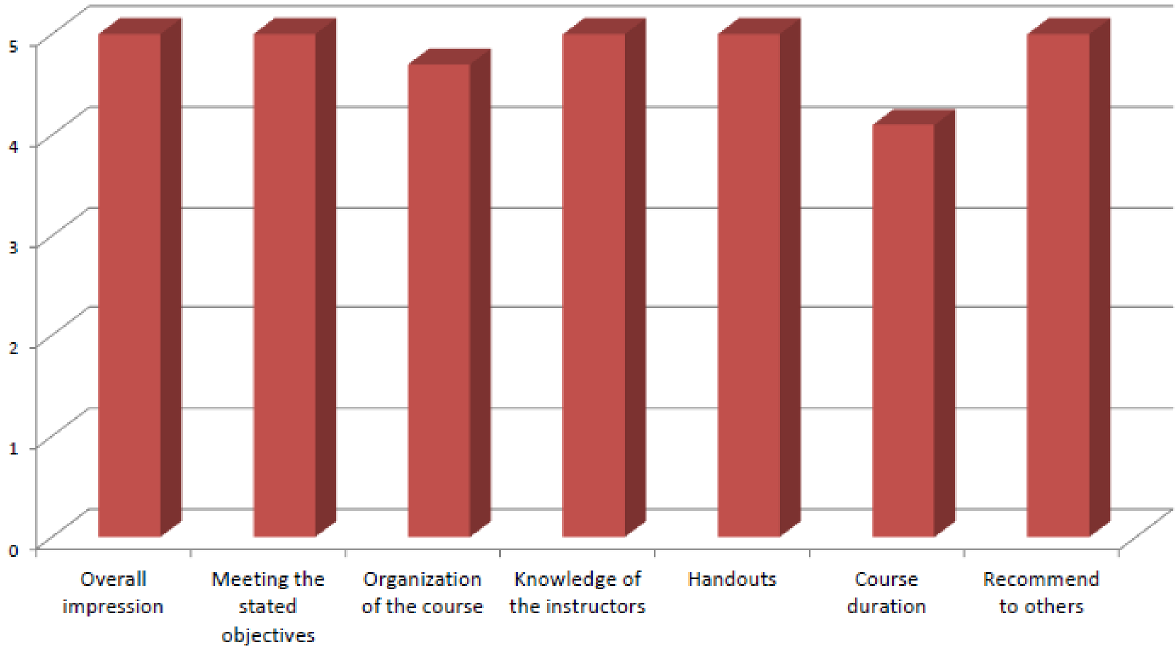
c. Post-placement temperature-driven area management;

Part 4: Mitigation of Thermally-induced effects:

a. Dynamic compensation of thermally-induced clock-skew;

b. Negative Bias Temperature Instability (NBTI) characterization;

c. NBTI Aware Low-Power Design for circuits and memories.



TCAD course by Synopsys (cancelled, material provided)

- *Electro-thermal 2D and 3D TCAD simulation*
  - introductory course
  - The presentation shows how to use TCAD tools for the simulation of electro-thermal problems in semiconductor devices. The lecture starts from the generation and meshing of the 2D or 3D structure, introduces and dis-cusses the device models, and ends with the discussion of simulation results.
- *Temperature effects in device models - separation and extraction of temperature effectss*

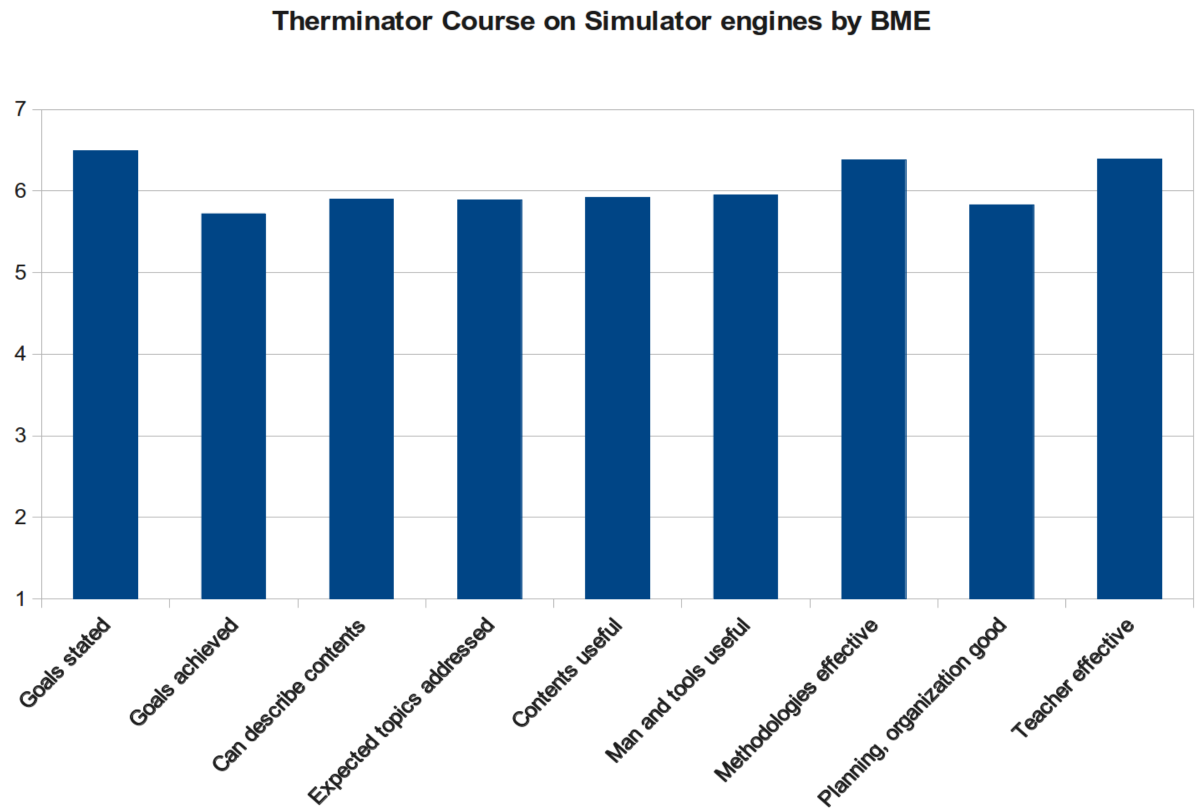
        - advanced course
        - The presentation presents and discusses the state of the art device simulation models with respect to their temperature dependence. Ways to calibrate model parameters and to extract temperature dependence of compact model parameters from device simulation are discussed.

TCAD course (overview of final results) by Synopsys (15th February 2013)

- 10.00-12.00: Technology-CAD (TCAD) Simulation methodologies developed and used in the Therminator project
- 13.00-15.00: Important Technology-CAD (TCAD) application examples in the Therminator project

Simulator engines course (overview of final results) by BME

- Trainers: Zoltan Czirkos, Gergely Nagy, Andras Timar,
- The basics of designing electro-thermal and logi-thermal simulators
    - Logi-thermal simulation
    - The logic engine
    - Thermal simulatorsLinear electric simulator
- The CellTherm logi-thermal simulator engine
    - CellTherm logi-thermal simulator
    - Real-time thermal and electronic co-simulation
    - Temperature-dependent delays
- A quasi-spice electro-thermal simulators
    - Principles of the analog simulation flow
    - Requirements towards an electro-thermal solver
    - Current status of qSPICE
    - Examples
        - µA741
        - MOS differential pair


Therminator Course on Simulator engines by BME
7
6
5
4
3
2
1
Goals stated
Goals achieved
Can describe contents
Expected topics addressed
Contents useful
Man and tools useful
Methodologies effective
Planning, organization good
Teacher effective

Conclusion

According to the plans outlined in the Description of Work (DoW) for the task, introductory and advanced courses were organised, advertised and held by the partners participating in the project at various premises.

Courses were held by academic and industry partners as well both at an introductory level which aims engineers and researchers having little experience in these fields, and at advanced level for research partners and other specialized professionals.

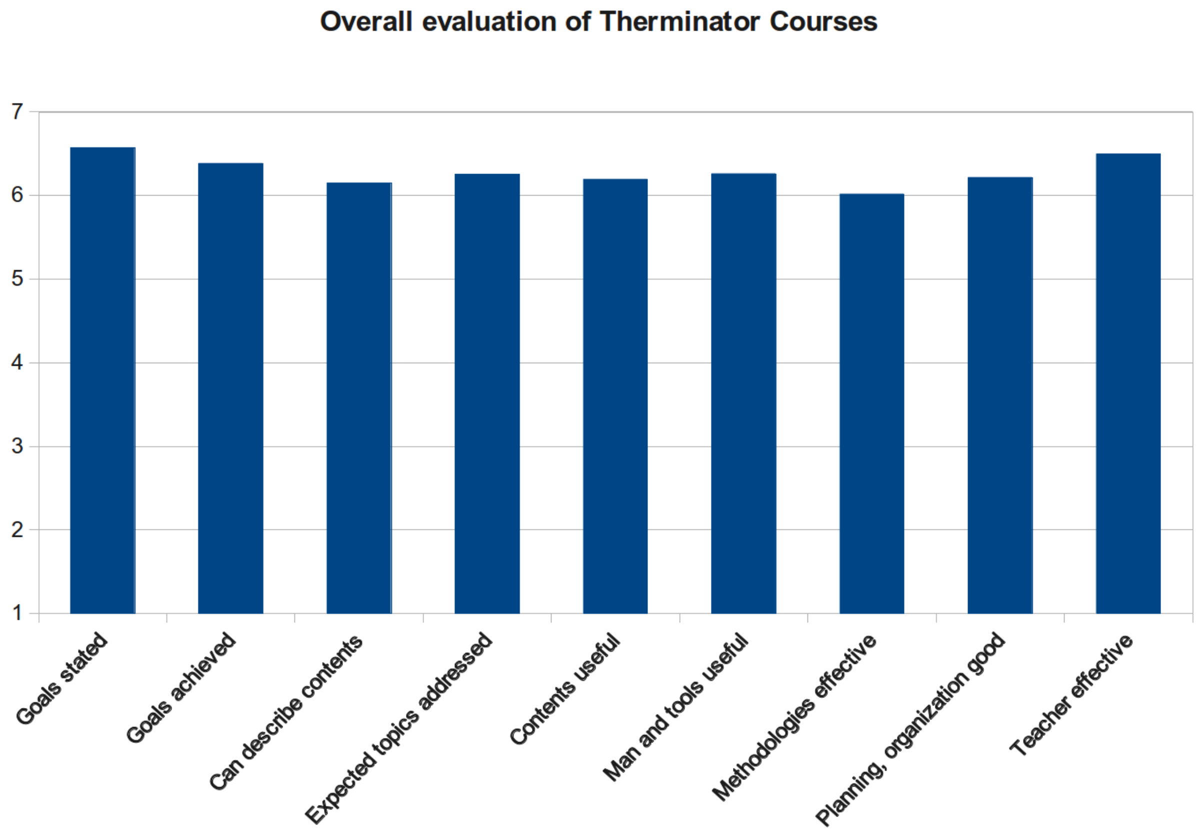
The THERMINATOR project partners also undertook to organize special sessions and workshops at major design and EDA conferences.

Planned in the DoW						
Year	2010		2011		2012	
Course type	introductory	advanced	introductory	advanced	introductory	advanced
Therminic			1		1	
Other workshops						
NXP						1
IMC						1
ST			1	1	1	1
public editions			2	1	2	1

Courses performed in the frames of THERMINATOR						
Year	2010		2011		2012	
Course type	introductory	advanced	introductory	advanced	introductory	advanced
Therminic			1		1	
Other workshops (name)			1 (LATW)		1 (LATW)	
NXP				1		1
IMC				1		
ST				3	2	2
MunEDA				5		

IMEC					1	1
Synopsys					1	1
POLITO			1	1	1	1
BME					2	
Public editions[1] **(premises)**			1 (POLITO)	6 (POLITO, Infineon, NXP)	4 (IMEC, BME,POLITO)	2 (IMEC, POLITO)

A chart summarizing the evaluation results of the courses can be seen below.



[1] The numbers in the „Public editions" line are not additional courses, they show the number of the courses in the lines above that were made public.