

CDIO PROJECTS IN DTU'S B.ENG. IN ELECTRONICS STUDY PROGRAMME

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ABSTRACT

This paper describes the four cross disciplinary CDIO semester projects in the B.Eng. in Electronics study at DTU, and – along with similar papers describing the other six B.Eng. programs – provides documentation to accompany an exposition with students demonstrating their projects, furthermore the paper is meant as an inspiration to others working on implementing cross disciplinary projects in their curriculum.

In the B.Eng. in Electronics programme each of the first 4 semester contains a cross disciplinary project, two of these are CDIO Design Build courses which are placed in the 1st and 4th semesters. Additionally almost all courses contain projects of various size.

The 4 cross disciplinary projects are described with emphasis on the two design build projects, the learning objectives are listed for each of the courses and the results of from the course evaluation (performed at the end every course) are listed for the 1st and 2nd semester courses where sufficient material exists

Keywords – Design-build projects, cross disciplinary projects, student-demonstrations, CDIO-based curriculum

INTRODUCTION

In 2006 the DTU B.Eng. programme in electronics went through a major revision in order to assure a better progression in its courses. At the same time a plan for implementing CDIO standards in the B.Eng. programmes was introduced. Based on this knowledge, the 2006 study programme was designed containing placeholders, for what would later be the CDIO cross disciplinary projects.

The basic idea was to push elective courses towards the end of the 7 semesters programme, and focus on a broad mandatory range of courses on the first part. Having implemented the 2006 programme it was fairly easy to implement the CDIO curriculum required projects in 2008.

DTU B.Eng. Education in Electronics					
1. Semester	2. Semester	3. Semester	4. Semester	5. Semester	6 + 7. Semester
Calculus and algebra 1	Matematics 2	Probability and Statistics	Physics	Elective Courses	Elective Courses
Calculus and algebra 2	Advanced Programming	Engineering Electromagnetics	Design of Digital Systems		
Elementary Programming	Analog Electronics		Analogue design		
Electrotechnics		Digital and Data Technique	Linear Systems, Digital Signal Processing and Signal Processors		
	Electrical Energy Systems				
Project in Electrotechnics					Industrial Internship
					Final Project

Figure 1 DTU B.Eng. program in electronics, 1st to 4th semester are CDIO based.

- White** : Cross Disciplinary Projects (CDP)
- Light orange** : Contributors to CDP
- Light grey** : Minor or no contribution to CDP
- Dark grey** : No contribution to CDP

It was decided, that all courses on the 4 first semesters were compulsory [3] followed by 3 semesters containing industry internship, final B.Eng. project, and elective courses.

The B.Eng. programme has 30 ECTS elective courses on the 5th semester, and 15 ECTS elective courses, on the 6th and 7th semesters. These in total 45 ECTS must be selected from a list of close to 60 course's, in order to assist the students in their choice 4 recommended 45 ECTS programmes are offered [1]. Furthermore the 6th and 7th semester programme contains a 30 ECTS industrial internship and the 15 ECTS B.Eng. final project. The final B.Eng. project follows the internship contents closely and is normally carried out in the same industrial company as the internship, only very few final B.Eng. projects are carried out on campus.

In the programme all courses contains projects of various size, and each of the first 4 semesters contain a cross disciplinary project as depicted in Figure 1, two of these are CDIO Design Build courses, which are placed in the 1st and 4th semesters.

The aim of this paper is to describe the four CDIO semester projects in the B.Eng. in Electronics study, and – along with similar papers describing the other six B.Eng. programs – to provide documentation to accompany an exposition with students demonstrating their projects. The 4 cross disciplinary projects are described with emphasis on the two design build projects, the learning objectives are listed for each of the courses and the results from the course evaluation (performed at the end every course) are listed for the 1st and 2nd semester courses, where sufficient material exists

CROSS DISCIPLINARY PROJECTS

1st semester "Gyro oven"

In high precision analog circuits the systems sensitivity to temperature has to be taken into account in the design process. One way to reduce the temperature influence is to heat up the critical component to a temperature higher than any ambient temperature foreseen. As the first semester design build project, a system to control the temperature of a small gyro sensor is developed. The sensor is imagined to be mounted on a small aluminum block with an integrated power transistor and a semiconductor thermal sensor as depicted in figure 2. An analogue amplifier ensures the selected heating power and a digital system with analogue to digital conversion, is used to perform the temperature control.

All courses on the first semester contribute to the project. The main contributor to the project is the electrotechnics course, this course teaches the subjects of circuit theory and digital electronics. In order to facilitate the understanding of building blocks within digital electronics we design the digital circuit using discrete integrated CMOS circuits, this is in contrast to other approaches using FPGA's and hardware descriptive languages as VHDL from the very beginning of the curriculum. In our chosen concept the students are able to actually measure the voltages deep inside their circuits which train the students in measuring techniques instead of relying solely on simulations which is the method when using the VHDL approach. In the elementary programming course a simulation tool is developed and used to estimate the oven temperature and in the calculus and algebra course an alternative model is developed.

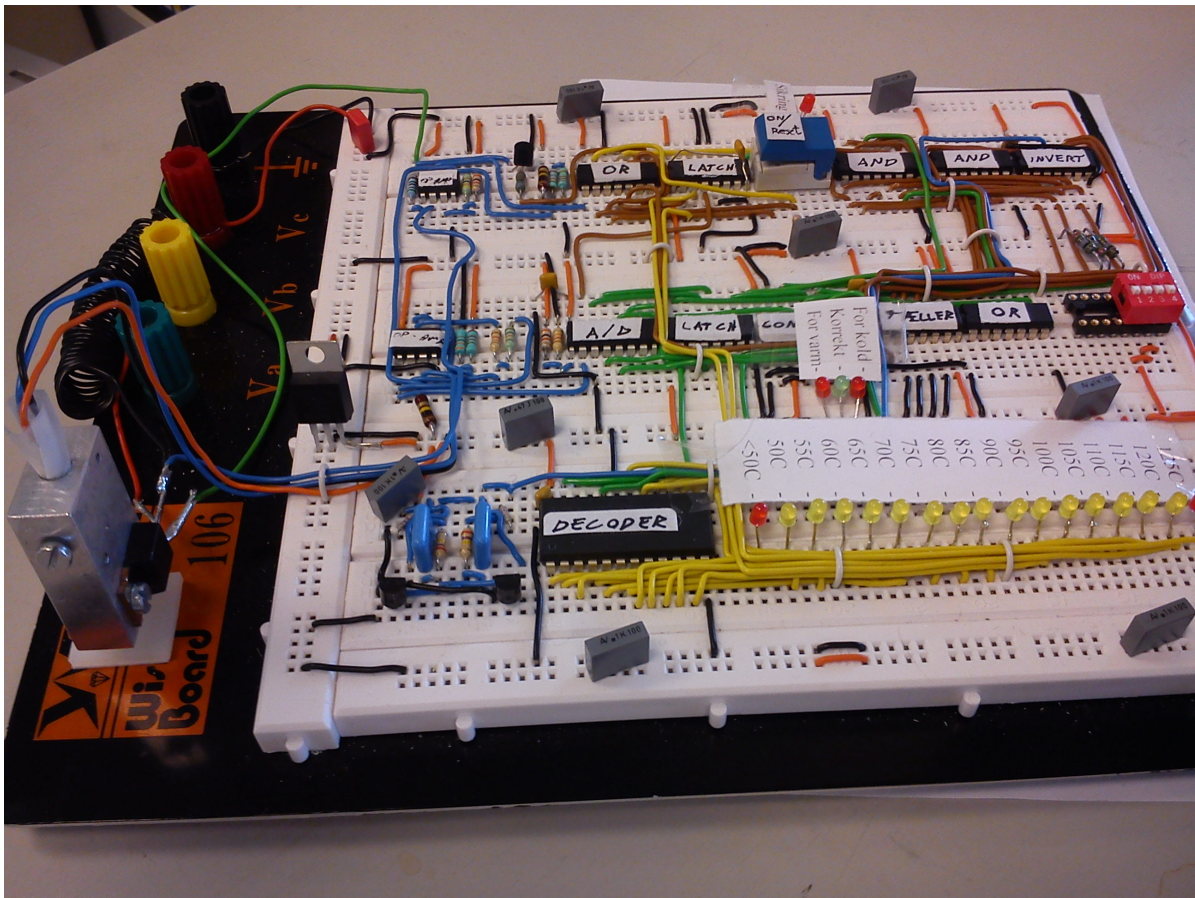


Figure 2 First semester design build project, the gyro oven

The gyro oven project is build in groups of 2 students using ordinary breadboard techniques and commonly available components, the students gain familiarity with this technique in the electrotechnics course and the components are for the most parts well known from exercises performed during the course, the concept of a larger system is on the other hand new to the students and some means of guidance is necessary to assure, that all groups reaches the end of the project with satisfactory results, this part is important as one of the goals with the project is to give the students a good feeling of achievement (after 5 month they can build a complex system), so they are well motivated when continuing their study. The gyro oven circuit structure are shown in figure 3 which is presented to the students at the introduction to the course. The circuit contains a heater which can be turned on and off, a reference temperature input to set the user specified temperature, a linear sensor amplifier, an analog to digital converter, a temperature scale, some logic to decide whether the oven heater has to be turned on or off and various indicators to inform the user of the state of operation, is the heater on or off, and has an overheat error occurred.

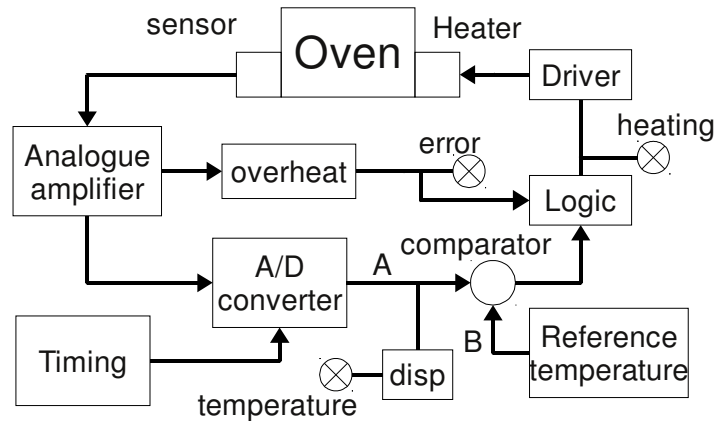


Figure 3. Block diagram of the oven controller system

Given this general structure and a set of performance requirements the students has to conceive design and implement the various sub circuits, test them and connect them into a complete functioning circuit. One of the challenges in the project is the heating of the aluminium block, see figure 4, the temperature as function of time is dependent on the surrounding air temperature, the mass of the oven, the temperature of the surrounding parts, the properties of the surface of the oven block and the power dissipated into the block. The calculus and algebra and elementary programming courses on the first semester helps with this problem, as the non linear differential equation necessary for describing the temperature as function of time is solved using Taylor expansion and used as mini project in the mathematics course. In the elementary programming course the differential equation is solved using numerical integration and a program to do this is designed in a mini project. The students in the Design Build projects are then using one or both methods in their project to estimate oven parameters and to document performance requirements.

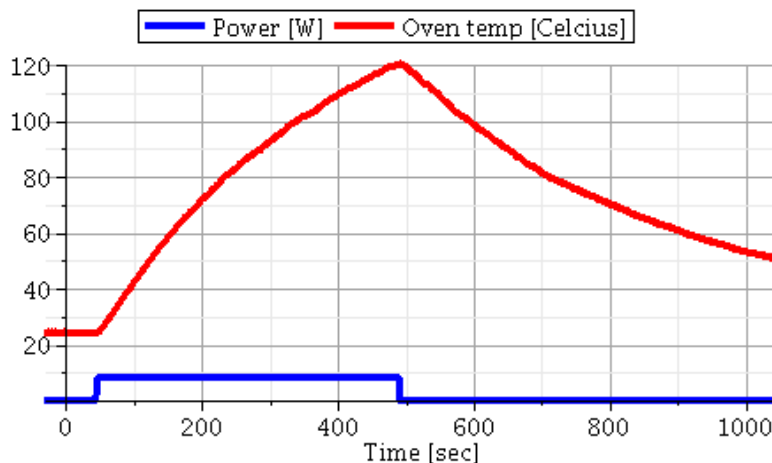


Figure 4 Heating characteristics for the oven block

General course objectives [5]:

The aim of the course is to make the student able to combine analog and digital techniques in the design of a small electronic circuit. Additionally to practice use of requirement specifications in the design, test and documentation of circuit elements as well as the combined circuit.

Learning objectives:

CDIO Syllabus (1)

A student who has met the objectives of the course will be able to:

- identify and compile functional requirements into a requirement specification
- paraphrase functional requirements from the expected real world usage of the circuit
- investigate design possibilities for a circuit that fulfils the requirements
- design an analog amplifier that fulfils specific requirements to offset, gain and voltage intervals
- design a combinatory circuit using counters, simple logic and AD converter
- analyse transient constructions describable by simple time constants

CDIO syllabus (2-4)

- produce and debug the designed circuit
- use measurement instruments to investigate circuit functionality
- explain measurements in relation to circuit function and function requirements
- explain the circuit purpose and function in writing
- relate the achieved results to the requirement specification - in writing

Evaluation

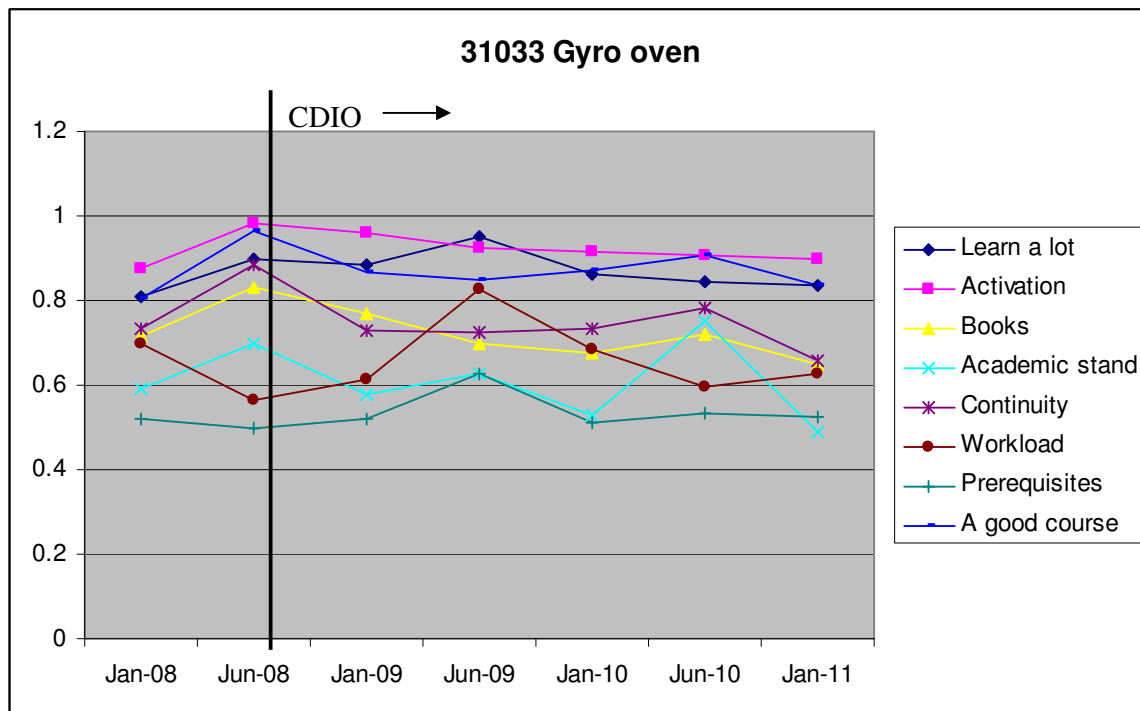


Figure 5 Development in average student evaluation of the 31033 project in the electrotechnics course.

The student evaluation of the course is shown on Figure 5.

The CDIO elements were introduced in the fall 2008 [2]. Six of the eight questions were formulated positive on the subjects indicated on figure 5, where 1 is strongly agree to the question and 0 strongly disagree. For the work load the scale is 0 for much less and 1 for much more than the norm for 5 ECTS points. For Prerequisite requirements the scale is 0 for too low and 1 for too high.

The evaluation shows an increase in workload and a slight increase in “A good course” so the students satisfaction are maintained on a constantly high level after the implementation of CDIO and the Design Build project. Generally the curves are smooth except for the Jun-09 dataset, as no severe changes has been applied to the course in that particular period, the variation could be caused by variation in the student intake, information from other courses seems to support that suspicion (compare with Jan-10 in figure 8 for course 30080).

Teachers comment:

The integration with programming and mathematics has taken some iteration's to be beneficial for all parties, the 1st semester teachers team forum were the basis for these iterations. The increased focus on report writing has, also according to the course censor, improved the student's ability to explain their design.

Student comments from evaluation:

- An exciting course. I learned a lot, and there is a good relation to the courses at 1st semester. It is enjoyable that there is a high degree of design freedom, so that we are not bound to any particular design. I am pleased with the experience I have gained in report writing.
- I have learned extremely much in these tree weeks, both about group work and the technical part. It is incredible exciting to explore a problem in depth, and really be focused.

2nd semester "Audio measuring system"

A measuring system to characterize the frequency response (Bode Plot) of an analog circuit is developed. The system generates a test signal from a FPGA based digital sine wave generator, the test signal is sent through a filter circuit which is developed in the analog electronics course, and the response is collected by a micro processor using its integrated A/D converter. The micro processor transmits raw data via a communication protocol to a PC, where a software program displays the measurement results graphically - see figure 6 and 7.

The project encompasses topics from all courses on the second semester. The main contributor to the project is the digital and data technique course 30080 and the analog electronics 31022 course is secondary. The course in advanced programming 02319 contributes with understanding the PC software, and the course in mathematics 2 01964 contributes with understanding the time domain to frequency domain transformation.

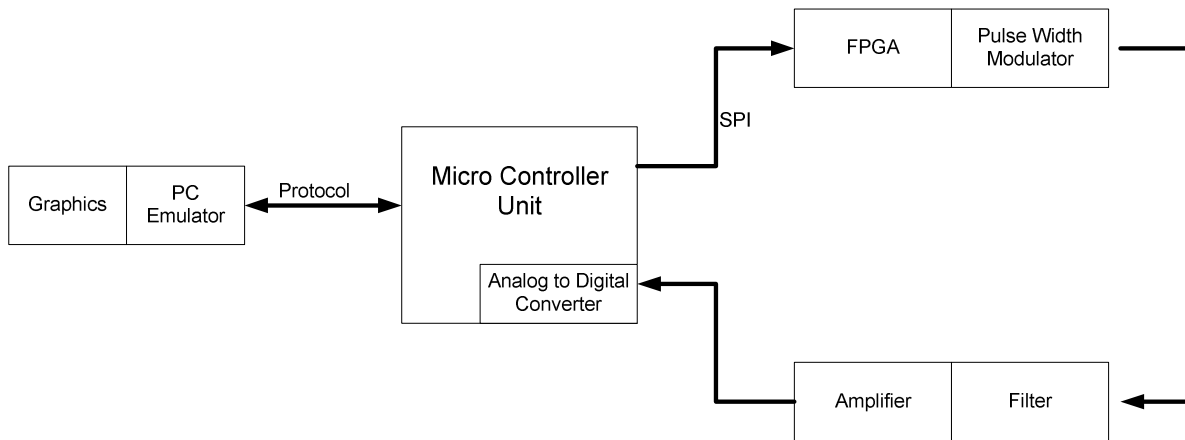


Figure 6, The 2nd semester cross disciplinary project, the Bode plotter

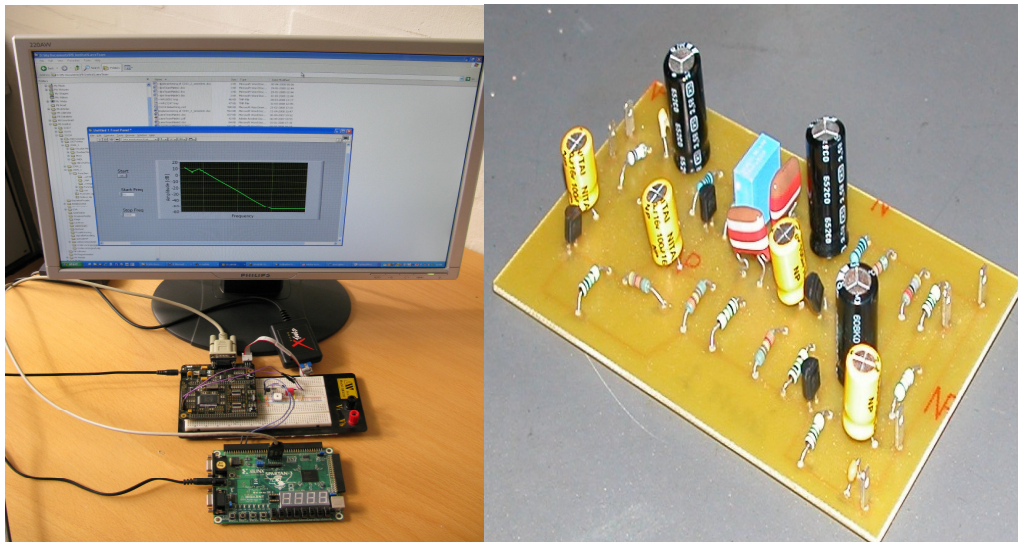


Figure 7 The 2nd semester cross disciplinary project, showing the FPGA and microcontroller hardware and the PC display/control software at the left, to the right the analog filter circuit build to test the bode plotter system

The project is organized as a part of the digital and data technique course but is mainly located in the 3-week period. The project embraces broadly as all courses at the semester is contributing components to it. Second semester includes the following courses:

01964 Mathematics 2 for Diplom E
02319 Advanced Programming for Diplom-E
31022 Analog electronics
31080 Digital and Data technique

The project is built around three elements: a function generator, a transistor amplifier and an oscilloscope. The two measuring instruments (function generator and oscilloscope) has been a naturally part of the exercises and projects on the first semester, and students have in advance a good knowledge on how to use of this type of instruments. Amplification using transistors and frequency analysis of electronic circuits are issues which have traditionally been placed at 2nd semester, and training and knowledge about the transistor amplifier and frequency response are thus a competence, the students have after 2nd semester.

Frequency response is usually measured by manually scanning a frequency range using a function generator, while noting the signal response from an oscilloscope. In this project, students will link the two instruments together in order to make an automatic frequency response analyzer. Seen from the student's point of view, it will be a relevant project, and the motivation to complete the project will therefore be high.

Much of the teaching at 2nd semester deals with time-varying signals. The mathematics 2 course introduces the Laplace transform which can be used to describe a system's signal response (impulse, step and frequency response), and the analog electronics course introduces the complex symbolic method and bode plot used to analyze an electrical circuit's ability to transfer sinusoidal signals. The idea behind the three elements of the project is that the two measuring instruments can be used to analyze the amplifier's frequency response.

The project itself, however, deals more with the design and build of the three elements.

The transistor amplifier is a PCB which the students builds in the analog electronics course, the function generator is a pre designed PCB containing a programmable digital chip (FPGA card) and the oscilloscope part is based on a single-chip computer (a MCU card) which contains an analog-to-digital converter. The latter two are included in digital teaching at 2nd semester.

To visualise the oscilloscope signals a PC is connected to the MCU card using a serial connection. The PC contains a program that reads information from serial port and displays a graphical oscilloscope image.

General course objectives:

The goal of the course is to enable the students to combine hardware programming and digital design in an integrated hardware/software solution.

Learning objectives:

CDIO Syllabus (1)

A student who has met the objectives of the course will be able to:

- apply a hardware description language (VHDL) to program digital chips
- apply standard registers and combinatorial logic to construct simple synchronous networks
- develop synchronous state machines and construct simple coupled digital systems
- demonstrate the function of a digital system by simulation
- describe the function and the architecture of a microprocessor system
- develop simple programs (in C) for programming of single chip computers
- apply some build-in functions of single chip computers
- illustrate how information can be exchanged between digital systems

CDIO Syllabus (2-4)

- organize teamwork with regards to common goal, time schedule and work sharing
- decode an open assignment and set delimited requirements to a problem to be solved
- describe pro and con by different solutions within digital electronics and predict errors and problems in these solutions
- construct an overall solution of a smaller system from the functional requirements and explain the solution orally to a small audience

Evaluation

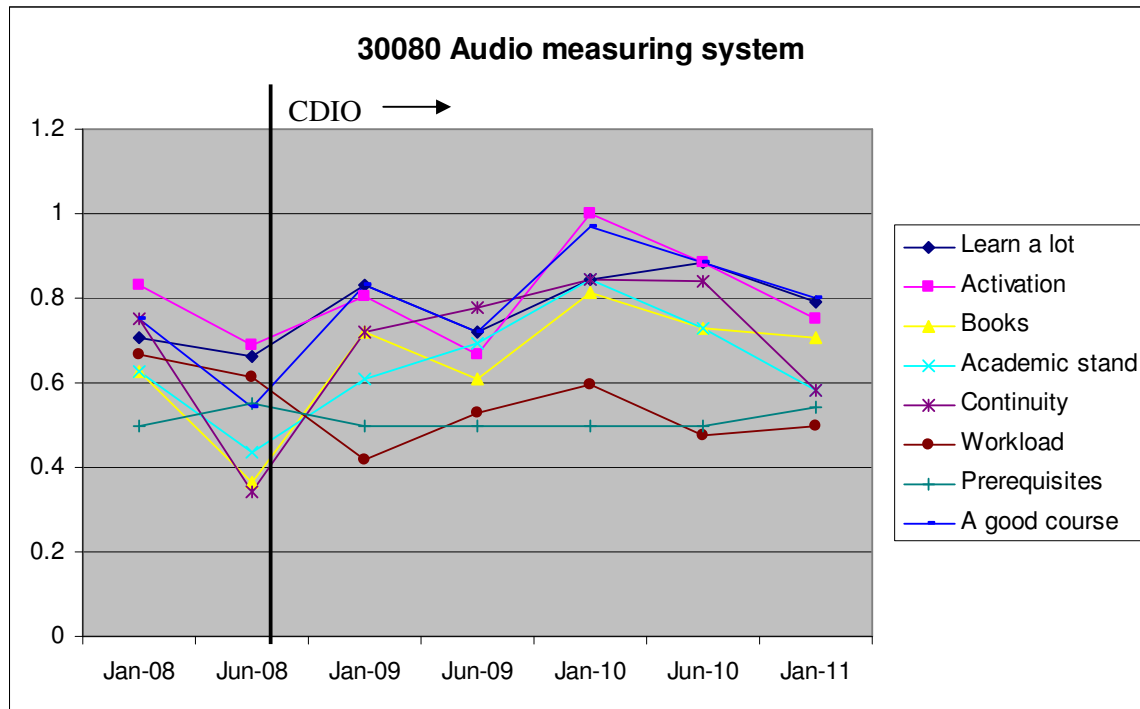


Figure 8 Development in average student evaluation of the 30080 digital and data technique course.

The evaluation shows a general lift in scores of all questions after implementation of CDIO except workload and prerequisites, which both with small variations lies around 0.5. For these two questions 0.5 is the normal situation which is completely acceptable. For “Learn a lot” there is a significant increase and also “Books”, which includes all teaching material, has gone up in score.

The student intakes in September and February are in general different populations, the September intake is normally twice as large as the February intake. The February intake consists of students which are older than average and often with some kind of prior education. The graph has some variation between the January and June evaluations and January evaluations scores higher than June which implies, that the February intakes show a better score than the September intake.

3rd semester "Oticon hearing aid"

A system to transmit data to the radio receiver of a hearing aid system is developed. The system consists of an external transmitter system and digital filtering algorithms implemented in the hearing aid. In the project the transmitter and receiver antennas are designed. A correction algorithm is developed for shortcomings in the communication system and is implemented in the Digital Signal Processing (DSP) of the hearing aid. The main contributor to the project is the linear systems, digital signal processing and signal processor course and the engineering electromagnetics course is secondary. There is an active collaboration with the hearing aid company Oticon A/S during the project

During the 13 week semester the students are working in groups on several of the hearing aid sub circuits, they work on a theoretical basis using the theory from the lectures and books and performs the necessary calculations and simulations using Matlab software, they write a report on each of 4 subjects, towards the end of the semester the students are introduced to DSP hardware and the supporting software, this prepares them to the 3 week period, where they implement their hearing aid design on the hardware platform and test the performance using the appropriate measuring instruments.

At the same semester in the parallel course engineering electromagnetics the students are, as one of several projects in this field, working on wireless communication using loosely coupled inductors, this particular subject is used in the hearing aid field, when the hearing aid user needs to listen to for instance a radio or the sound from a television, furthermore it is possible via this wireless link to digitally communicate the setup data, that holds the personal adjustments in the hearing aid, that compensates for the particular carriers hearing deficiency.

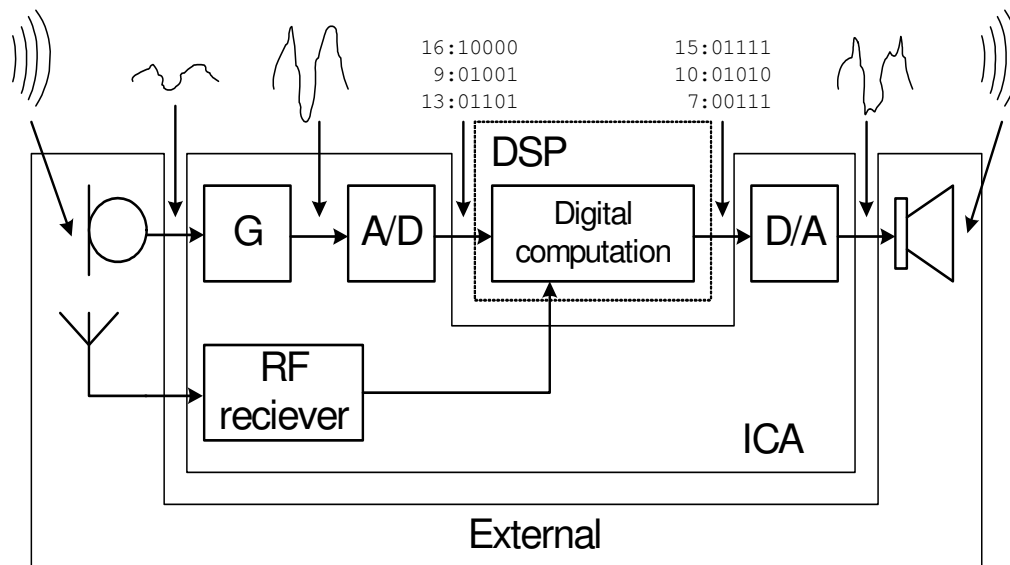


Figure 9 3rd semester cross disciplinary project, wireless communication with hearing aid

General course objectives:

The aim of the course is to enable the student to master the following three disciplines constituting a chain of prerequisites: linear systems, digital signal processing, and application of digital signal processors.

Thus the student achieves understanding and application knowledge about the fundamental methods and signal processing algorithms for electronic products, it-systems, communication systems, and medical systems.

To obtain experience with a high-tech system from an electrical engineering company, work on a project throughout the course is performed with respect to design, implementation, and test of central system parts for a modern electrical engineering product.

Learning objectives:

CDIO Syllabus (1)

- A student who has met the objectives of the course will be able to:
- Describe and analyze linear electronics systems.
- Apply theory for spectral analysis of signals - both continuous time and discrete time.
- Apply simple modulation/demodulation in communication systems.
- Apply modern lab tools (from Matlab) for linear systems and digital signal processing.
- Analyze discrete time signals and discrete time systems in time-, z-, and frequency domain.
- Describe classical sampling and reconstruction of e.g. speech signals and understand multirate systems, allowing signal transfer between different electronic units.
- Analysis and implementation discrete time systems.
- Describe fundamental principles of stochastic signal processing.
- Design of classical and optimal digital filters.
- Apply power density spectrum estimation methods, and - computational efficient spectral analysis methods.
- Apply high-speed hardware systems based on digital signal processor.

CDIO Syllabus (2-4)

- Plan and perform project, collaboration, and project presentation regarding design, implementation and test of an electrical engineering system.

The teacher of the course commented:

“In the dialogue with the students in the course, I feel a strong enthusiasm for the CDIO concept, the company visit related to the project, and on the system the students work on. The students of this course have traditionally a very good reputation in industry, so it is good to see, that the professional skills outcome are maintained on a high level as it was before the implementation of CDIO and with the bonus that there is an increase in the students motivation, furthermore the mandatory reports with feedback has clearly increased the students report writing skills”

A student following the course commented

“I have always been exited when theory and practical lab work are mixed, this is one of the really good things with the CDIO Concept. Our project was a hearing aid from the Danish company Oticon A/S, on a DSP development board we had to recreate filter banks, delay compensation and wireless communication circuit functions in real time. There were great challenges regarding use of measuring equipment, programming theory, making the mini reports to be used in the project part of the course, and especially in the cooperation with other students.

All in all a super project that convinced me to continue in this field, and write my bachelor thesis within the field of DSP for hearing aids”

4th semester "Energy producing system"

The 4th semester Design Build project is placed in the 13 week + the 3 week period of the electrical energy systems course. During the semester the students work on the energy converting system depicted in figure 10. An electrical heated container produces steam, the amount of steam is regulated using a valve, and the steam drives a steam engine. The angular velocity is measured and regulated. A generator produces electrical power that via a switch mode converter delivers energy to an energy storage unit, from this unit, power is converted to a load invariant voltage. Groups of up to 10 students work on the project, so there is focus on project management. Smaller individual group's designs parts of the whole circuit, using self evaluation and the project documentation the individual students in the groups are evaluated [4].

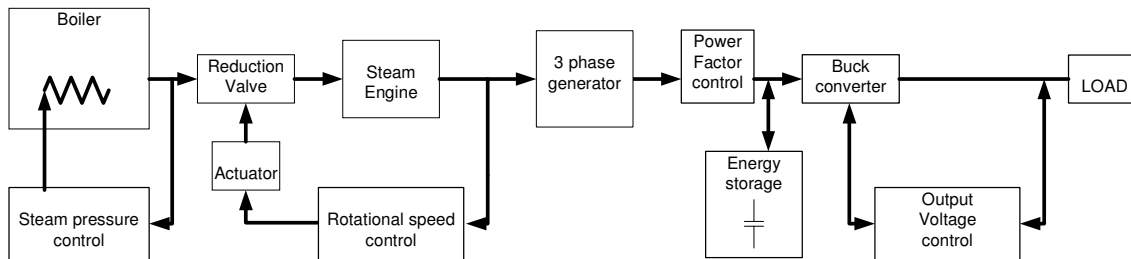


Figure 10 4th semester design build project, an energy generating system

The task given to the students is relatively open. "The system must be able to deliver a series of short 10mS pulses of 5 Volts in a resistive 5 ohm's load"

The basic system mimics the real world's problems of delivering power in an efficient and environmentally acceptable way.

It's a well known problem, that sustainable energy sources are in fact not sustainable, the sun is not always shining, and the wind is not always blowing, so either we must adapt society to use energy when its available, or provide some means of energy storage facility to harvest energy when its available, and release it when its needed, the latter is exactly what the project is focused on.

We have an energy producing system in form of a steam engine and a 3 phase generator, the output power is low and less than we need in our requirements for the system. It is therefore necessary to harvest energy and save it, and then deliver the energy in the required 10 ms bursts, the efficiency of the design are expressed in the number of 10 ms pulses, that can be delivered in a given time period.

General course objectives:

The aim of the course is

- to give the student a basic understanding for electrical energy systems, ranging from production, distribution, and control of electrical energy to construction of rectifier circuits with accompanying power supply circuits , with or without galvanic isolation
- to train the students in project / group work working with all CDIO elements from conceive to the finished functional model.

Learning objectives:

CDIO Syllabus (1)

A student who has met the objectives of the course will be able to:

- carry out basic calculations on an AC power grid
- determine complex power conditions in one and three phase systems
- use equivalent circuits for wires, transformers and asynchronous machines
- explain the workings and operation of the power grid and its components
- define and apply the meaning of RMS value and mean value for periodic currents and voltages

- explain the workings of inductors and capacitors in electronic circuits
- determine voltages and currents as function of time and deduce the transfer functions for basic converter topologies
- apply transformers in galvanic separated topologies
- independently combine his/hers professional skills to design a large energy converting system

CDIO Syllabus (2-4)

- divide a larger task into smaller subtasks and distribute the responsibility for solving the subtasks between the participants in at large group of 10 students.
- document the obtained results on a precise and short way in form of a poster
- analyze the performance of a larger system with the aim of optimizing the systems function

Student comments from the evaluation:

- the steam engine project is a super good task with many exiting challenges.
- the project itself is basically good. There is a great potential for learning in the fields of electrical energy supply and power electronics.
- our group has put in great effort in assuring good cooperation between the subgroups.
- good meeting discipline and willingness to help across subgroups and subtasks. Good documentation of the sub groups work provides understanding and knowledge to the other sub groups, this assures that the whole group have understanding of what is going on in the project.
- the project has clearly potential to be a great project, but there has been several ambiguities in the process.
- a very free course with many opportunities to influence the project.
- It is good that the project is open. Good to see that all solutions seems to be accepted
- a great exiting project that really would have worked if it had been a little better prepared from the start.
- the cooperation in and among the groups was a good experience.
- group work and the independent handling of the project was a good experience.

CONCLUSION

Four cross disciplinary projects has been developed and introduced.

Due to some constraints in the curriculum, the 2 first semesters are given each semester i.e. both February and September, whereas the 3rd and 4th semester project are given once a year on alternating semesters, this means that the steam engine project has only been given once, and the Oticon hearing aid project twice.

The first semester Design Build project shows good results and is fully implemented, and its evaluation results are very good.

The second semester cross disciplinary project shows good results in the cross disciplinary fields microcontroller and FPGA. The link towards the analog electronics course is not fully exploited and some further work is needed on this interface. Looking at the evaluations there seems to be a general lift in the evaluation scores after the introduction of CDIO and the cross disciplinary project.

The third semester cross disciplinary projects is also performing well, as the course has only been given twice there are not sufficient data available in the evaluation database, but comments from students and teacher gives the impression that the course is on the right track.

The fourth semester Design Build course, the energy producing system, is a very ambitious project taking up the challenge of working in large groups with a very open project description, furthermore grading of the students skills are partially done using student self evaluation. The students finds the project as such very exiting, but they have experienced some difficulties with the open project, and the self evaluation, and it seems that further work in developing the course is necessary.

References:

- [1] Kjærgaard Claus, Brauer Peter, Andersen Jens Christian "CDIO AS THE EDUCATIONAL AND CULTURAL STRUCTURING ELEMENT IN THE DTU B.ENG. IN ELECTRONICS EDUCATION". 7th International CDIO Conference 2011 at DTU, Copenhagen, Denmark
- [2] Vigild, Martin Etchells; Willumsen, Louise Engberg; Borchersen, Egil; Clement, Karsten; Bjerregaard Jensen, Lotte; Kjærgaard, Claus; Klit, Peder; Sparsø, Jens "COMPARISON AND CLASSIFICATION OF DESIGN BUILD PROJECTS IN DIFFERENT ENGINEERING BACHELOR PROGRAMS". Proceedings of the 5th International CDIO Conference, Singapore 2009.
- [3] Kjærgaard Claus, Brauer Peter, Andersen Jens Christian, Jacobsen Michael "Implementering af CDIO på Diplom-E uddannelsens første og andet Semester" Rev. 3, Juni 2008; DTU.
- [4] Træholt Chresten, Holbøll Joachim, Thomsen Ole, Kjærgaard Claus "CDIO – THE STEAM ENGINE POWERING THE ELECTRIC GRID". 7th International CDIO Conference 2011 at DTU, Copenhagen, Denmark
- [5] www.kurser.dtu.dk

Biographical Information

Claus Kjærgaard received the B.Eng. (hon.) in electronics engineering from the Danish Engineering Academy 1984. In 1987 he joined the Danish Engineering Academy, which is now part of DTU. He is currently an Associate Professor at the Department of Electrical Engineering, DTU. For many years his research was focused on reliability of repairable electronic systems. During the last 10 years his work has been focused on teaching and developing courses and study plans in the field of analog electronics and hybrid microelectronics and on research in these fields. In 2006 he received the reward as best teacher in the B.Eng. educational programs at DTU. Since 2005 he has been head of studies for the B.Eng. program in electronics and has been responsible for the implementation of CDIO in this program.

Jens Christian Andersen received his B. Eng in electronics engineering from Københavns Teknikum in 1982. After a career in engineering in the Danish Airforce he finished his Master in 2003 from DTU, and in 2007 he was awarded a PhD. in mobile robotics from DTU. He is currently Assistant Professor at the Department of Electrical Engineering at DTU. His research field is mobile robotics. His teaching portfolio include a number of fundamental courses in electronics at the B. Eng education. He received the annual reward for "excellent course and teacher" in 2010.

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