Using Course and Program Matrices as Components in a Quality Assurance System

Svante Gunnarsson, Helena Herbertsson and Håkan Örman

Conference article

USING COURSE AND PROGRAM MATRICES AS COMPONENTS IN A QUALITY ASSURANCE SYSTEM

Svante Gunnarsson, Helena Herbertsson, Håkan Örman

Linköping University, Sweden

ABSTRACT

The CDIO framework is an integrated and important part of the new quality assurance system within the Faculty of Science and Engineering at Linköping University. Both the CDIO Syllabus and the CDIO Standards are used extensively in the system. First, the paper presents the development and use of the second generation of course matrices (previously denoted ITU-matrices) and program matrices, which build upon an adapted and extended version of the CDIO Syllabus. The extension is made to also include bachelor's and master's program in subjects outside the engineering field. Second, the paper presents how the CDIO Standards are used in the quality reports, which are vital parts of the quality assurance systems. As a result, the CDIO framework is used for the design, management, and quality assurance of all education programs (approximately 60 programs) within the Faculty of Science and Engineering at Linköping University.

KEYWORDS

Quality assurance, CDIO Syllabus, CDIO Standards, course matrix, program matrix, Standards: 1-8, 11

INTRODUCTION

Design, execution, evaluation, and quality assurance of engineering education are complex and demanding tasks. The tasks have many dimensions such as the mix of knowledge and skills needed for the graduates to be prepared for the professional career, the progression of knowledge and skills over time during the education program, the desired level of knowledge in various fields according to some taxonomy, and the complexity of the problems studied. Keeping in mind that these aspects do not fully allow themselves to be put in a geometric structure, two-dimensional structures (matrices) can be of great value and enable structured work and processes. Already from the start of the CDIO Initiative, several such matrices and similar structures have been proposed. Within the CDIO framework one of the fundamental documents is the CDIO Syllabus, see Crawley (2001), which in many approaches is a key element when designing such matrices. The report presents several matrices representing the mapping between the CDIO Syllabus and other reference systems, such as the ABET criteria. Notable is also that the report presents early applications of the Syllabus survey, which is a useful tool based on the CDIO Syllabus. In addition, Bankel et al. (2003) extended the

application of the Syllabus survey by applying it to three Swedish engineering education programs. Bankel et al. (2005) introduced a second dimension via the steps Introduce (I), Teach (T), and Utilize (U), leading to the so-called ITU matrices. These matrices were introduced as a tool for benchmarking an existing curriculum using the CDIO Syllabus as reference frame. To some extent, this gives a way to characterize progression over time in the program. Simply, there should be more I's in the beginning and more U's at the end of the education program. Bankel et al. (2005) represents the starting point of the use of this type of matrix within the engineering education at Linköping University, and the first generation was presented by Gunnarsson et al. (2007). Experiences and results from systematic use of the CDIO Syllabus for developing program goals and learning outcomes were described by Gunnarsson et al. (2009). Related types of matrices were presented by Malmqvist et al. (2006), who employed a systematic procedure for setting up program goals and mapping them to individual courses.

Another interesting contribution was reported by Willcox and Huang (2017), where a visualization tool was used to interactively illustrate the connections between various courses and the items of the CDIO Syllabus. The connections are given by the information encoded in the corresponding course (there denoted ITU) matrices. It should be stressed that there are numerous other examples of the use of different types of matrices based on the CDIO Syllabus, and it is not the aim to give a complete overview in this paper. Additional information can be obtained via the link *Knowledge library* at the CDIO web site.

Within Linköping University, a successive development of these tools has been undertaken in order to meet regulations by authorities in higher education and to be able to use the same tools for other types of programs in related fields as natural sciences and biomedicine, see Fahlgren et al. (2018). The more official use of the matrices in the model for quality assurance has triggered further development of the LiTH Syllabus, which is a local adaptation of the CDIO Syllabus. (LiTH is an acronym for the Swedish name of the Faculty of Science and Engineering.) In addition, the CDIO Standards, which is the second fundamental document of the CDIO framework, has been used for a long time within the Faculty of Engineering and Science. For example, the self-evaluation based on the Standards has been carried out for most of the programs. As a result of the close connection between the Standards and the ESG criteria, the Standards have become an important tool when writing the quality reports that are important parts of the quality assurance system. This will be discussed in more detail below.

This paper has two main messages: First, to present and illustrate how the CDIO framework, including both the CDIO Syllabus and the CDIO Standards, is an integrated part of the quality assurance system covering all education programs within the Faculty of Engineering and Science at Linköping University. Second, to present the process for developing the second generation of course and program matrices based on the adapted version of the CDIO Syllabus. The paper is organized as follows. The first two sections present brief introductions to the new Swedish quality assurance system and the CDIO framework, respectively. The following section describes the adaption of the CDIO Syllabus within the Faculty of Science and Engineering, with respect to the needs, contents, and development process. The last section describes the use of CDIO Standards in the quality assurance system together with comments on how the standards relates to the ESG criteria. The paper ends with discussions and conclusions.

THE NEW SWEDISH QUALITY ASSURANCE SYSTEM AND ITS APPLICATION

Quality assurance of higher education in Sweden is assessed by the Swedish Higher Education Authority (UKÄ). A new model, consisting of four components, has recently been implemented, and the keynote in the new model is the shared responsibility for quality assurance between the Higher Education Institutions (HEIs) and the Authority. Additional information can be obtained via the link *Quality assurance of higher education and research* (2018). The new national model is based on the Higher Education Act, the Higher Education Ordinance and the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG).

One of the components, which is in focus in this report, is institutional reviews of the quality assurance processes. The others are appraisal of applications for degree-awarding powers, thematic evaluations and specific program evaluations.

The main part of the quality assurance efforts is completed by the HEIs and the responsibility of the Authority is to assess that the HEIs have systematic quality assurance processes that are sharp enough to really ensure that education at all levels maintains a high quality. The six assessment areas are:

- governance and organisation
- preconditions
- design, implementation and outcomes
- student and doctoral student perspective
- working life and collaboration
- gender equality

The application of the new model for quality assurance at Linköping University

At Linköping University (LiU), a new system for quality assurance has been launched and a pilot study was performed in 2017. This new focus resulted in a more systematic approach to quality assurance as well as quality enhancement. The LiU model is consistent throughout the university but with a certain degree of freedom for the faculties, when it comes to how the quality promotion is organised. All programs and courses offered at LiU are to undergo in-depth quality assurance every sixth year. Since this systematic approach is new, even the model itself will be evaluated and adjusted in a continuous manner over the next years. For each program under review, a quality report is written. More information about q*uality assurance at LiU* (2018) can be found at the LiU website. The criteria for first-cycle and second-cycle educational levels are:

i. The design, execution and examination of the education ensure that the students have achieved all learning outcomes in question, when the degree is awarded.
ii. The design and execution of the education promote the students´ learning and encourage students to play an active role in the learning processes.
iii. There is a clear coupling between teaching and research in the educational environment.
iv. The number of teachers and their collective expertise are sufficient and are proportional to the contents and execution of the education.
v. The education is applicable and prepares students for a career characterized by change.

vi. The education strives to ensure that the students participate actively in improving the education.
vii. A perspective of gender equality is integrated in the design and execution of the education.

The written reports containing descriptions of how the criteria are fulfilled as well as follow-ups of some key indicators, are discussed in a program dialogue between the board of studies (represented by the chairperson and the faculty program director) and the faculty management (the dean, the pro-dean for education and the head of the faculty office) in the presence of student representatives. The program dialogue leads to an assessment by the dean, which results in a plan of action for each object evaluated.

All material from each year and all faculties: quality reports, approved plans of action, and a summary of an analysis that focuses on strengths as well as challenges for each faculty, are submitted by the deans to the vice-chancellor annually. Thus, action plans can be compiled at the program level, at the faculty level, as well as on the university level and become part of the strategic agenda at all levels.

The CDIO framework as a basis for Quality Assurance at the Faculty of Science and Engineering

At the Faculty of Science and Engineering, the CDIO framework (Syllabus and Standards) has been an important tool in structuring the programs when it comes to aspects like design, implementation and outcomes as well as student-centered learning, learning resources and faculty competencies. These aspects are covered in ESG 1.2 Design and approval of programs, 1.3 Student-centered learning, teaching and assessment, 1.5 Teaching staff and 1.6 Learning resources and student support. For more information on ESG, follow the link *Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG)* (2015). The ESG Standards mentioned above directly overlap with assessment areas in the national Swedish model for Quality Assurance as well as with several criteria in the LiU model for Quality Assurance. The CDIO framework and the use of the Syllabus and Standards are presented in more detail below.

THE CDIO FRAMEWORK

The fundamental aim of the CDIO framework is to educate students who are “ready to engineer” and to raise the quality of engineering programs, see Crawley et al. (2014) and the web site CDIO Initiative (2019). The CDIO framework is thus not a Quality Assurance System, but a systematic approach to enhance the quality of an educational program. The framework relies on four key components:

- A “definition” of the role of an engineer.
- Clearly defined and documented goals for the desired knowledge and skills of an engineer listed in the document the CDIO Syllabus (2019), which serves as a specification of learning outcomes.
- Clearly defined and documented goals for the properties of the engineering education program collected in the document CDIO Standards (2019), which works as guidelines of how to design a well-functioning engineering education. For example, CDIO Standard 12 Program Evaluation emphasizes the importance of continuous improvement.
- An engineering approach to the development and management of education programs.

According to the CDIO framework, see Crawley et al. (2014) page 50, the goal of engineering education is that every graduating engineer should be able to

> *Conceive-Design-Implement-Operate complex value-added engineering products, processes, and systems in a modern, team-based environment.*

This formulation can serve as a definition providing the basis for the entire CDIO framework. Adopting the definition, it is natural to design and run an engineering education program with this in focus. The CDIO Syllabus is a list of the desired knowledge and skills of a graduated engineer. The document can be found via the CDIO web site, and it consists of the following four main sections:

1. Disciplinary knowledge and reasoning
2. Personal and professional skills and attributes
3. Interpersonal skills: Teamwork and communication
4. Conceiving, designing, implementing, and operating systems in the enterprise, societal, and environmental context – The innovation process

Via the sub-sections and sub-sub-sections, the document offers an extensive list of knowledge and skills, which can be used to specify learning outcomes of individual courses or education programs. The CDIO Standards (2019), which also can be found and explained in detail via the CDIO web site, is a set of twelve components that are necessary for designing and running an engineering program that enables the students to reach the desired knowledge and skills.

ADAPTING THE CDIO SYLLABUS

The LiTH Syllabus

As mentioned in the Introduction, the first generation of an adapted version of the CDIO Syllabus was developed more than ten years ago. Triggered by the new quality assurance system, the first step in the development of the new generation of course matrix was to develop a new version of the LiTH Syllabus. The document is based on a translated version of CDIO Syllabus 2.0, see the web site *CDIO Initiative* (2019), and then adapted to also cover education programs outside the engineering field. The revision has consisted of three main parts:

- A thorough revision of the wordings and formulations
- A revision of section 5, for non-engineering programs
- Introduction of subsection 1.4 and 1.5 concerning disciplinary knowledge and reasoning

The first item is of editorial type, but for items two and three some additional comments are motivated. Section 5 of the Syllabus was introduced 2007 to cover programs within natural sciences, as an alternative to development of products and systems, which is the focus in Section 4, the emphasis was on design and execution of research projects. Since then new programs have been introduced, and this made it motivated to widen the scope of Section 5. The focus in the new version of Section 5 is on “knowledge development” and “design, execution, presentation, and evaluation of research and development projects”. Section 5 also starts with subsections corresponding to 4.1 and 4.2, i.e., the societal and economical context, including sustainability issues. Subsections 1.4 and 1.5 were introduced to match the requirements about deeper disciplinary knowledge and insight into research work for five-year engineering programs.

Development process

The development has been carried out within the advisory group for education (LGU) at the Faculty of Science and Engineering, which is a group including the chairpersons of the five boards of studies, the dean and the pro-dean for education, the faculty program directors and student representatives. LGU meets every week, and the group is vital for the coordination and development of all education programs within the Faculty of Science and Engineering. The new version of the LiTH Syllabus has also been approved by the Faculty Board. The document, which is in Swedish, can be accessed via the web site *CDIO Introduction* (2019).

Mappings between the LiTH Syllabus and the Degree Ordinance

Another step in the process has been to revise and design mapping matrices that connect the learning outcomes in the Degree Ordinance and the items in the LiTH Syllabus. As mentioned in the Introduction, Crawley (2001) presented such mappings between the CDIO Syllabus and for example the ABET criteria. Within the Swedish system, Johan Malmqvist at Chalmers University of Technology, did initial work setting up similar mapping matrices between the Degree Ordinance and the CDIO Syllabus. These ideas have been applied and extended within the Faculty of Science and Engineering at Linköping University, which has resulted in mapping matrices for four different types of education programs: engineering programs over three or five years, bachelor's, and master's programs. The resulting document can be accessed via the web site *CDIO Introduction* (2019).

Course matrix workshops and information about the CDIO framework

Since the course matrices are important components of the quality assurance system, it is important that the course matrices themselves have high quality. Therefore, several different activities are carried out to support the individual teachers in the generation and development of the matrices for their courses. This involves workshops and other types of information activities for the teachers. A web site, presenting the main ideas of the CDIO framework, has been made accessible, see *CDIO Introduction* (2019), and relevant documents be can accessed via the web site. Workshops for teachers have been arranged at the campuses where the Faculty of Science and Engineering runs education programs.

Program matrices

The purpose of the course matrices is to be a tool to show that the learning activities and examination in the individual courses contribute to the fulfillment of the overall program goals, and, of course, also of the goals in the Degree Ordinance. This is done as a combination of a top-down and a bottom-up approach. The top-down approach starts from a high-level formulation of the goals for the "LiTH Engineer", structured according to the sections of the LiTH Syllabus. These goals are then elaborated for each individual education program and expressed on level x.y of the Syllabus. Hence, for each of the items x.y, the program goal document, i.e. the Program Syllabus, contains a formulation about the expected level of proficiency of the graduates of the program for the type of knowledge and skill covered by item x.y. In the bottom-up process the contents of the course matrices of the individual courses in a program are collected in a program matrix. The courses in the program are listed along one dimension and the subsections x.y of the LiTH Syllabus define the other dimension. Depending on how the individual course matrices have been filled in one can check to what extent the overall goal corresponding to that subsection is covered in the program simply by checking that the columns of the program matrix is "filled" in a satisfactory way. The program matrix is

hence an essential and very useful tool for verifying that criterion (i) (see above) in the quality assurance framework is fulfilled. An example of a program matrix based on the first generation of the LiTH Syllabus is given in Gunnarsson et al. (2007).

USING THE CDIO STANDARDS

The CDIO Standards in comparison to ESG

The national Swedish quality assurance system is developed and implemented in accordance with national legislation as well as with the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG). Part 1 of the ESG standards and guidelines handles internal aspects and are recommendations for the HEIs. The Standards provide guidance on important areas and issues to have control of in order to give a high-quality education. The focus is on teaching and learning, including well-functioning learning environments and links between the education and related research as well as stimulation of innovative competencies. Several ESG Standards can be recognized from CDIO Standards. However, there is not a 1:1 match, and some ESG Standards are not corresponding to any CDIO Standard, as seen in the Table 1.

Table 1: The correlation between ESG Standards and CDIO Standards. The ESG Standards are at the left and the CDIO Standards at the top.

	1. The context	2. Learning out-comes	3. Integrated curriculum	4. Introduction to engineering	5. Design-implement	6. Engineering workspaces	7. Integrated learning	8. Active learning	9. Enhancement of faculty	10. Enhancement of faculty teaching	11. Learning assessment	12. Program evaluation
1.1 Policy for Quality Assurance												x
1.2 Design and approval of programmes	x	x	x	x	x		x	x			x	
1.3 Student-centered learning, teaching and assessment		x	x	x	x		x	x			x	
1.4 Student admission, progression, recognition and certification												
1.5 Teaching staff									x	x		
1.6 Learning resources and student support						x			x	x		
1.7 Information management												x
1.8 Public information												
1.9 On-going monitoring and periodic review of programmes												x
1.10 Cyclical external quality assurance												

The ESG Standards are more focused on the student life cycle at the university than the CDIO Standards, which are more closely connected to the education itself. Thus, the ESG Standards are suitable for quality assurance on a higher level than the CDIO Standards that are more suitable for program evaluation, which of course is an extremely important part of the students experience at the university and for their working life as engineers.

Using the CDIO Standards for quality assurance and enhancement

To be able to use CDIO Standards to evaluate the progress of quality enhancement, a self-evaluating tool has been developed based on the CDIO Standards, see Kontio (2016). A key function is to follow how effective the program is to reach its intended goals. Beyond, using the tool for self-evaluation, it has also been used for cross-evaluation and cross-sparring, meaning more of learning from and supporting each other in the process, by inviting external CDIO community members to take part.

At the Faculty of Science and Engineering at Linköping University, the CDIO evaluation tool has been used earlier, but not in a systematic way. To adopt to the new quality system at the university, the CDIO Standards, especially Standards 3-8 and 11, have been valuable in writing parts of the quality reports mentioned above. These CDIO Standards include integrated curriculum, introduction to engineering, design-implement experiences, engineering work-spaces, integrated learning experiences, active learning, and learning assessment. All together they meet the criteria (ii) and (v), i.e. the design and execution of the education promote the students' learning and encourage students to play an active role in the learning processes as well as that the education is applicable and prepares students for a career characterized by change. For each program under evaluation, comments on how the CDIO Standards are met have been requested. The information is valuable in itself but has also enabled a structured analysis of how the different parts of the curriculum work and are linked to each other, which is a good start for further development. In addition, the knowledge about the Standards and the underlying rationale have increased, and a common language has been established.

DISCUSSION

The Linköping University system for quality assurance is aimed as a combined instrument for quality assurance and quality enhancement. Seeking to achieve both may seem obvious when such a tool is developed, but because of their different natures, this is also a challenging task. For example, Williams (2016), has given an account for different perspectives on their relationship: from non-related, completely separate processes through competing or even reciprocally harmful practices to symbiotic coexistence. Elton (1992) characterized these processes as quality A's associated with control and quality E's associated with internal drive for change, respectively: Assurance, Accountability, Audit, and Assessment versus Enhancement, Empowerment, Enthusiasm, Expertise, and Excellence.

As a quality model, that is, a framework or theory of learning that helps us operationalize teaching aims and manage learning activities (Biggs 2001), the CDIO Syllabus and CDIO Standards provide linkage between the A's and the E's. More specifically, they translate the quality assurance perspective imposed by the Degree Ordinance, with quality seen as fulfilling a minimum set of standards (see Harvey & Green 1993) into a quality enhancement perspective with quality as transformation—enhancing the participant (ibid.). For example, the Degree Ordinance requirement "demonstrate the ability to identify, formulate and deal with complex issues autonomously and critically and with a holistic approach and also to participate in research and development work and so contribute to the formation of knowledge" are itemized into Syllabus entities such as 2.1.1 Problem Identification and Formulation and 2.1.4 Analysis with Uncertainty. The latter is a more natural basis for designing and developing learning activities.

Likewise, the Standards proved to be a suitable tool for grasping the complexities of educational programs. In the context of describing the design and execution of the programs, they serve as a means for rediscovering them—a framework for a qualitative analysis focused on learning that is typically associated with quality enhancement (Biggs 2001). This is especially valuable to new teachers as an introduction to the program rationales, but experienced teachers may also benefit from a reminding expansion of their views of the program they work within. We are not always aware of the bigger pictures.

An essential aspect of the CDIO components is that they are developed by engineers for engineers, thereby offering a sense of familiarity; they contextualize the quality processes into something that matters to engineering teachers. This community aspect has also been emphasized in the work presented in this paper: the new version of the Syllabus was developed in cooperation among teachers, students, and administrators.

CONCLUSIONS

Over the years the CDIO framework has turned out to a robust and very useful framework for various aspects of management of educations programs within the Faculty of Science and Engineering at Linköping University. More recently the use of the framework has been extended and deepened via the new quality assurance system as reported above. One of the main benefits is that the framework provides a common language when discussing program management and quality issues. The framework has a strong support in the organization, ranging from student representation in boards and groups to decisions in the Faculty board about the use of the framework. In addition, the close connection to other frameworks, such as ABET and ESG, gives additional credibility to the framework.

REFERENCES

Bankel J., Berggren K.-F., Blom K., Crawley E., Wiklund I., and Östlund S. (2003*). The CDIO Syllabus: a comparative study of expected student proficiency*. European Journal of Engineering Education. Vol 28, No. 3, 2003.

Bankel J., Berggren K.-F., Engström M., Wiklund I., Crawley E., Soderholm D., El Gaidi K., and Östlund S. (2005*). Benchmarking engineering curricula with the CDIO syllabus*. International Journal of Engineering Education. Vol 21, No. 1, 2005.

Biggs J. (2001). The Reflective Institution: Assuring and Enhancing the Quality of Teaching and Learning. *Higher Education, 41(3), 221-238.*

CDIO Initiative (2019) http://www.cdio.org/, accessed in Jan 2019.

CDIO Introduction (2019) https://www.lith.liu.se/internwebb/cdio?l=sv, accessed Jan 2019. (In Swedish.)

CDIO Syllabus (2019) http://www.cdio.org/, accessed in Jan 2019.

CDIO Standards (2019) http://www.cdio.org/, accessed in Jan 2019.

Crawley E., (2001) The CDIO Syllabus. *A statement of goals for undergraduate engineering education.* Springer. MIT Report, 2001.

Crawley E., Malmqvist J., Östlund S., Brodeur D., and Edström K.. (2014) *Rethinking Engineering Education*. The CDIO Approach. Springer. 2nd edition, 2014.

Elton L. (1992). Quality Enhancement and Academic Professionalism. *The New Academic, 1(2), 3-5.*

Fahlgren A., Thorsell A, Kågedahl K., Lindahl M., and Gunnarsson S. (2018). *Adapting the CDIO Framework to Biomedicine Education*. 14th International CDIO Conference, Kanazawa Institute of Technology, Japan, June 28 - July 2, 2018.

Gunnarsson S., Wiklund I., Svensson T., Kindgren A., and Granath S. (2007). *Large scale use of the CDIO Syllabus in formulation of progam and course goals*. 3rd International CDIO Conference, MIT, Cambridge, Massachusetts, June 11-14, 2007

Gunnarsson S., Herbertsson H., Kindgren A., Wiklund I., Willumsen L., and Vigild M. (2009). *Using the CDIO Syllabus in formulation of program goals – experiences and comparisons*. 5th International CDIO Conference, Singapore Polytechnic, Singapore, June 7-10, 2009.

Harvey L. & Green D. (1993). Defining Quality. *Assessment & Evaluation in Higher Education, 18(1),* 9-34.

Kontio J. (2016). *Enhancing quality together with CDIO Community*, 12th International CDIO Conference, Turku University of Applied Sciences, Finland, June 12-16, 2016.

Malmqvist J., Östlund S., and Edström K. (2006*). Integrated program descriptions – A tool for communicating goals and design of CDIO programs*. 2nd International CDIO Conference, Linköping University, Linköping, Sweden, June 13 – 14, 2006.

Quality assurance of higher education and research (2018) http://english.uka.se/quality-assurance/quality-assurance-of-higher-education.html, accessed in Jan 2019.

Quality assurance at LiU (2018) https://liu.se/en/about-liu/quality, accessed in Jan 2019.

Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG) (2015), https://enqa.eu/wp-content/uploads/2015/11/ESG_2015.pdf, accessed I Jan 2019.

Willcox K. E. and Huang L. (2017). *Mapping the CDIO curriculum with network models*. 13th International CDIO Conference, University of Calgary, Calgary, Canada, June 18 – 22, 2017.

Williams J. (2016). Quality Assurance and Quality Enhancement: Is There a Relationship?, *Quality in Higher Education, 22(2)*, 97-102

BIOGRAPHICAL INFORMATION

Svante Gunnarsson, is a professor of automatic control at Linköping University, Sweden. His main research interests are modelling, system identification, and control in robotics. He is also the CDIO coordinator within the Faculty of Engineering and Science. He served as chair of the organizing committee of the 2nd International CDIO Conference in 2006.

Helena Herbertsson is a senior lecturer in chemistry at Linköping University, Sweden, and serves as pro-dean for education within the Faculty of Engineering and Science.

Håkan Örman is a senior lecturer in biomedical engineering at Linköping University, Sweden, and serves as chair of the Board of Studies for Electrical Engineering, Physics, and Mathematics at the Faculty of Engineering and Science.

Corresponding author

Professor Svante Gunnarsson
Linköping University
Department of Electrical Engineering
SE-58183 Linköping, Sweden
+46 70 399 48 47
svante.gunnarsson@liu.se