Curriculum for the Master’s Programme in Signal Processing and Acoustics

Aalborg University
September 2018
Preface:
Pursuant to Act 261 of March 18, 2015 on Universities (the University Act) with subsequent changes, the following curriculum for the Master's programme in Signal Processing and Acoustics is stipulated. The programme also follows the Joint Programme Regulations and the Examination Policies and Procedures for The Technical Faculty of IT and Design.
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Chapter 1: Legal Basis of the Curriculum, etc.

1.1 Basis in ministerial orders
The Master’s programme in Signal Processing and Acoustics is organised in accordance with the Ministry of Higher Education and Science’s Order no. 1328 of November 15, 2016 on Bachelor’s and Master’s Programmes at Universities (the Ministerial Order of the Study Programmes) and Ministerial Order no. 1062 of June 30, 2016 on University Examinations (the Examination Order). Further reference is made to Ministerial Order no. 111 of January 30, 2017 (the Admission Order) and Ministerial Order no. 114 of February 3, 2015 (the Grading Scale Order) with subsequent changes.

1.2 Faculty affiliation
The Master’s programme falls under the Technical Faculty of IT and Design, Aalborg University.

1.3 Board of Studies affiliation
The Master’s programme falls under the Board of Studies for Electronics and IT.

1.4 Body of External examiners
The programme is affiliated with the body of external examiners for engineering educations: electro (In Danish: censorkorps for Ingeniøruddannelsernes landsdækkende censorkorps; elektro).

Chapter 2: Admission, Degree Designation, Programme Duration and Competence Profile

2.1 Admission
Applicants with a legal claim to admission (retnskrav):
Applicants with one of the following degrees are entitled to admission:

- Bachelor of Science in Engineering (Electronic Engineering and IT with specialisation in Signal Processing), Aalborg University
- Bachelor of Science in Engineering (Internet Technologies and computer Engineering with specialisation in Signal Processing), Aalborg University

Applicants without legal claim to admission:
Bachelor’s programmes qualifying students for admission:

- Bachelor of Science (BSc) in Engineering (Electronic Engineering and IT with specialisation in Communication Systems) (AAU)
- Bachelor of Science (BSc) in Engineering (Electronic Engineering and IT with specialisation in Informatics) (AAU)
- Bachelor of Science in Engineering (Electronic Engineering and IT with specialisation in Control Engineering), (AAU)
- Bachelor of Science (BSc) in Engineering (Internet Technologies and Computer Engineering with specialization in Communication Systems) (AAU)
- Bachelor of Science (BSc) in Engineering (Internet Technologies and Computer Engineering with specialization in Informatics) (AAU)
- Bachelor of Science (BSc) in Engineering (Internet Technologies and computer Engineering with specialisation in Control Engineering), (AAU)
- Bachelor of Science (BSc) in Engineering (Mathematical Engineering) (AAU)

2.2 Degree designation in Danish and English
The Master’s programme entitles the graduate to one of the designation depending on the specialisation:
2.3 The programme’s specification in ECTS credits
The Master’s programme is a 2-year, research-based, full-time study programme. The programme is set to 120 ECTS credits.

2.4 Competence profile on the diploma
The following competence profile will appear on the diploma:

A Candidatus graduate has the following competency profile:
A Candidatus graduate has competencies that have been acquired via a course of study that has taken place in a research environment. A Candidatus graduate is qualified for employment on the labour market on the basis of his or her academic discipline as well as for further research (PhD programmes). A Candidatus graduate has, compared to a Bachelor, developed his or her academic knowledge and independence so as to be able to apply scientific theory and method on an independent basis within both an academic and a professional context.

2.5 Competence profile of the programme:

The graduate of the Master’s programme:

Knowledge

Common:

- Has knowledge of methods for data acquisition and measurements, including physical sensors, their construction and application, data analysis and processing.
- Has knowledge of stochastic processes and signals, how they are generated, their distributional characteristics, how they can be modeled mathematically, and how such models can be applied according to limitations and constrains.
- Has knowledge of different classes of optimization problems typically found in signal processing, and associated methods for continuous and discrete optimization.
- Has knowledge about basic acoustic quantities and their physical significance, sound emission and reception, acoustical filters and acoustical transducers in the acoustical, mechanical and electrical domain.
- Has knowledge of signal processing concepts applied to multiple signals, non-stationary signals, and signals with multiple sample rates.
- Has knowledge of methods and tools for fast, efficient, and reliable numerical simulation of signal processing algorithms.
and systems on parallel computers.

- Has knowledge in one or more of the subject areas that is based on the highest international research in acoustics or signal processing.
- Can understand and, on a scientific basis, reflect on the knowledge within acoustics or signal processing, and identify scientific problems.

Signal processing and computing:
- Has knowledge of theories and methods associated with fundamental and advanced machine learning.
- Has knowledge of theories and methods for design and implementation of resource optimal real-time digital signal processing systems on reconfigurable and/or low power hardware/software platforms.

Acoustics and audio technology:
- Has a broad knowledge in the area of acoustics and audio, including physics, electronics, signal processing, transmission, hearing, perception and effects.
- Has knowledge in the field of sound and audio technologies including sound production, measurement and instrumentation.
- Has specialized knowledge about human sound perception, and the instrumental measures used to describe various perceptual dimensions.
- Has specialized knowledge about the human hearing, its anatomy and physiology, and its significance for human sound perception.

Skills

Common:
- Can apply methods for advanced signal analysis and processing.
- Can select and apply analytical, numerical and experimental methods for analysis and design of complex systems.
- Can apply methods and tools for performance/resource optimization of signal processing algorithms and implementation platforms given specific objective functions.

Signal processing and computing:
- Can apply scientific methods and tools to design, simulate, test and document signal processing systems operating on stochastic stationary or non-stationary signals.
- Can, based on given design criterions, critically assess and select among scientific theories and methods for analysis, design and implementation of signal processing algorithms and associated non real-time and real-time hardware/software platforms.
- Can, based on a scientifically founded working methodology, advance new solutions and analysis models for an initial
problem which requires signal processing concepts and efficient computing platforms in its solution.

- Can assess the results and quality of a design and the applied design trajectory, including experimental test and verification of signal processing systems.

**Acoustics and audio technology:**

- Can apply scientific methods, tools and general skills related to the solution of acoustic problems, including design, simulation, implementation, test, evaluation, and documentation of the solutions.
- Can demonstrate insight into and has the ability to assess various topics in the area of sound and vibration.
- Can use appropriate measurement and signal analysis techniques to investigate and solve advanced acoustic problems.
- Can use appropriate psycho physical methods for subjective evaluations of sound.
- Can apply the understanding of the hearing and the human sound perception to the design and evaluation process of engineering solutions.

**Competencies**

**Common:**

- Can independently take responsibility for own professional development and specialization.
- Can manage work and development situations that are complex, unpredictable and require new solutions.
- Can communicate research-based knowledge and discuss professional and scientific problems with both peers and non-specialists using the correct terminology.
- Can independently initiate and implement discipline-specific and interdisciplinary cooperation and assume professional responsibility.

**Signal processing and computing:**

- Can identify scientific problems within signal processing and computing, and select and apply suitable scientific theories, methods and tools for their solution.
- Can develop, advance, test and document new solutions to engineering problems within signal processing and computing.
- Can explain scientific hypotheses and results related to signal processing and computing.
- Can work in international industry and academia engaged in development, research and education of state-of-the-art signal processing and computing.

**Acoustics and audio technology:**

- Can conduct individually research and development in international companies within the acoustics and audio technology.
industry.

- Can conduct individually consultancy related to acoustics and audio primarily within environmental noise and architectural acoustics.
- Can contribute to legislation and standardization work within the acoustics and audio area.
- Can contribute to research and development in the audiology industry and the health care systems with diagnosis and solutions related to the human auditory system.
Chapter 3: Content and Organization of the Programme

The programme is structured in modules and organised as a problem-based study. A module is a programme element or a group of programme elements, which aims to give students a set of professional skills within a fixed time frame specified in ECTS credits, and concluding with one or more examinations within specific exam periods. Examinations are defined in the curriculum.

The programme is based on a combination of academic, problem-oriented and interdisciplinary approaches and organised based on the following work and evaluation methods that combine skills and reflection:

- lectures
- classroom instruction
- project work
- workshops
- exercises (individually and in groups)
- teacher feedback
- reflection
- portfolio work
Overview of the programme:

All modules are assessed through individual grading according to the 7-point scale or Pass/Fail. All modules are assessed by external examination (external grading) or internal examination (internal grading or by assessment by the supervisor only).

<table>
<thead>
<tr>
<th>Semester</th>
<th>Module</th>
<th>P/C</th>
<th>ECTS</th>
<th>Assessment</th>
<th>Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>Applied Signal Processing</td>
<td>P</td>
<td>15</td>
<td>7-point scale</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Stochastic Processes</td>
<td>C</td>
<td>5</td>
<td>7-point scale</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Fundamentals of Acoustics and</td>
<td>C</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Electro-acoustics</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Optimization Methods</td>
<td>C</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>Scientific Computing</td>
<td>P</td>
<td>20</td>
<td>7-point scale</td>
<td>External</td>
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<tr>
<td></td>
<td>(elective)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Reconfigurable Computing</td>
<td>P</td>
<td>20</td>
<td>7-point scale</td>
<td>External</td>
</tr>
<tr>
<td></td>
<td>(elective)</td>
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<tr>
<td></td>
<td>Reconfigurable and Low Energy</td>
<td>C</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Systems</td>
<td></td>
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<tr>
<td></td>
<td>Sound Technology for the</td>
<td>P</td>
<td>20</td>
<td>7-point scale</td>
<td>External</td>
</tr>
<tr>
<td></td>
<td>Normal Hearing (elective)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Sound Technology for the</td>
<td>P</td>
<td>20</td>
<td>7-point scale</td>
<td>External</td>
</tr>
<tr>
<td></td>
<td>Hearing-impaired (elective)</td>
<td></td>
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<tr>
<td></td>
<td>Human Sound Perception and</td>
<td>C</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Audio Engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Numerical Scientific Computing</td>
<td>C</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>Signal Processing and</td>
<td>P</td>
<td>20</td>
<td>7-point scale</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Acoustics</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Array and Sensor Signal Processing</td>
<td>C</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td>A</td>
<td>SPC</td>
<td></td>
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<tr>
<td></td>
<td>Machine Learning</td>
<td>C</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Architectural &amp; Environmental</td>
<td>C</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Acoustics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Academic Internship</td>
<td>P</td>
<td>20&lt;sup&gt;1&lt;/sup&gt;, 25&lt;sup&gt;2&lt;/sup&gt;, 30</td>
<td>7-point scale</td>
<td>Internal</td>
</tr>
<tr>
<td>B</td>
<td>Long Master’s Thesis</td>
<td>P</td>
<td>+20&lt;sup&gt;3&lt;/sup&gt;</td>
<td>7-point scale</td>
<td>External</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>Master’s Thesis</td>
<td>P</td>
<td>30</td>
<td>7-point scale</td>
<td>External</td>
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<tr>
<td>Total</td>
<td></td>
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</tbody>
</table>

1. If choosing a 20 ECTS academic internship the student must earn the remaining credits on the 3<sup>rd</sup> semester by following the course Array and Sensor Signal Processing and the course within the specialisation listed under option A.
2. If choosing a 25 ECTS academic internship the student must earn the remaining credits on the 3<sup>rd</sup> semester by following the course within the specialisation listed under option A.
3. If choosing to write a long master’s thesis the student must earn the remaining credits on the 3<sup>rd</sup> semester by following the course Array and Sensor Signal Processing and the course within the specialisation listed under option A.
Descriptions of modules:

1st Semester

Applied Signal Processing (P) (15 ECTS)
Anvendt signalbehandling

Objective:

Students who complete the module:

Knowledge

• Must have knowledge about the field of signal processing and how and when to apply this on real-world signals.
• Must have knowledge about the nature of real-world signals impaired by noise, such as additive noise, convolutional noise, and non-linear noise.
• Must have knowledge about stochastic signals, how they can be modelled mathematically, as well as the possibilities provided and the constraints imposed by such models.
• Must understand the scientific communication processes related to conference presentations and related to publishing in peer-reviewed scientific journals.
• Must know how to organize a scientific publication.

Skills

• Must be able to apply fundamental methods for one or more of 1) signal detection in order to extract information from a signal, 2) optimization problems related to signal processing or signal analysis, 3) selecting and using the correct transducers and equipment based on their properties and limitations.
• Must be able to perform either 1) a parametric spectral analysis in order to derive the spectral content of a stochastic signal, and compare and evaluate the result against non-parametric methods, e.g., based on Fourier analysis, or 2) carry out calibrated capturing and playback of acoustical signals, either by a computer or by dedicated electronic equipment.
• Must be able to identify which problem-specific parameters are of importance and which are not, e.g. positioning of transducers, surroundings, sensitivity to noise etc.
• Must be able to test to which extent the given set-up follows the set of requirements as defined by the project.
• Must be able to identify and select between deterministic and stochastic methods to the project-specific problem(s).
• Must be able to identify and describe the project relevant challenges with respect to the given application and signal processing solutions.
• Can explain the process of and criteria for peer reviewed scientific communications,
• Can write a paper for a scientific conference/journal.
• Can prepare and give an oral and poster presentation for a scientific conference.

Competencies

• Must be able to read and understand selected scientific literature and then apply the theories, methods, and/or tools in order to solve a problem.
• Must be able to decide which basic theories and practical methods to apply to real-world signals.
• Must be able to present the problem, the suggested solution(s), experiments and simulation results, as well as the overall conclusion in terms of a scientific paper and a poster.
• Must be able to present orally the main contribution and conclusion of the work in terms of a 15 minutes conference presentation.
• Are able to judge and prioritize the validity of various sources of scientific information.
• Can apply internationally recognized principles for acknowledging and citing work of others properly.
• Can formulate and explain scientific hypotheses and results achieved through scientific work.
• Are able to analyze results and draw conclusions on a scientific basis.

Type of instruction:
Students are organized in groups of up to six members working according to the POPBL concept at Aalborg University. Each group will be supervised by at least one staff member doing research within the main topic(s) addressed in the project. On this Semester the project has to be documented in the following forms (all in English):

• A scientific article
• An oral presentation
• A poster
• Edited worksheets, providing all relevant project details

For further information see the introduction to Chapter 3.

Exam format:
Oral examination with grades in accordance to the 7-point grading scale. The exam is based on questions that take their starting points in the written documentation: a scientific article, slides from the oral presentation at the student conference (SEMCON), a poster and edited worksheets.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Stochastic Processes (5 ECTS)
Stokastiske processer

Objective:
Students who complete the module must:

Knowledge
- Have knowledge about the theoretical framework in which stochastic processes are defined.
- Be able to understand the properties of the stochastic processes introduced in the course, such as wide-sense stationary (WSS) processes, Auto Regressive Moving Average (ARMA) processes, Markov models, and Poisson point processes.
- Be able to understand how WSS processes are transformed by linear time-invariant systems.
- Be able to understand the theoretical context around the introduced estimation and detection methods ((non-parametric and parametric) spectral estimation, Linear Minimum Mean Square Error (LMMSE) estimation, Wiener filter, Kalman filter, detection of signals, ARMA estimation, etc.)

Skills
- Be able to apply the stochastic processes taught in the course to model real random mechanisms occurring in engineering problems.
- Be able to simulate stochastic processes using a standard programming language.
- Be able to apply the taught estimation and detection methods to solve engineering problems dealing with random mechanisms.
- Be able to evaluate the performances of the introduced estimation and detection methods.

Competencies
- Have the appropriate “engineering” intuition of the basic concepts and results related to stochastic processes that allow – for a particular engineering problem involving randomness – to design an appropriate model, derive solutions, assess the performance of these solutions, and possibly modify the model, and all subsequent analysis steps, if necessary.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Fundamentals of Acoustics and Electro-acoustics (C) (5 ECTS)
Grundlæggende akustik og elektro akustik

Objective:
Students who complete the module:

Knowledge
- Must have knowledge about the basic acoustic quantities, their physical significance, and their role in the description of an acoustic process.
- Must be able to understand the relationship between the acoustic variables and the theoretical basis for the development of the wave equation.
- Must have knowledge about the principles of sound emission and reception.
- Must have knowledge of the construction, mechanisms and use of different types of acoustic transducers.
- Must be able to understand how acoustical transducers work in three domains: The electrical, the mechanical and the acoustical, and thus be able to transform between the three domains.
- Must have knowledge of the different measurement procedures and techniques used in acoustics.
- Must have knowledge of signal processing techniques in acoustic measurement to obtain time and frequency characteristics of acoustic signals.
- Must have knowledge about acoustical filters and their use.

Skills
- Must be able to identify relevant acoustic variables for a given sound source and sound field.
- Must be able to apply the proper assumptions in the calculation or estimation of relevant acoustic variables.
- Must be able to select the proper analytical description for the behavior of sound waves in rooms and cavities.
- Must be able to model and measure acoustical transducers.
- Must be able to measure the electro-acoustic parameters of loudspeakers.
- Must be able to calibrate and use electro-acoustic transducers to obtain reproducible measurement.
- Must be able to select and use exiting transducers based on their parameters.
- Must be able to choose and calibrate the adequate equipment for a given measurement and to be able to identify and eliminate sources of error.

Competencies
- Must be able to apply theoretical acoustic principles to model the behavior of acoustic systems, such as pipes, resonators, musical instruments, rooms and other enclosures, ventilation ducts, smartphones etc.
- Must be able to design, carry out and document repeatable acoustic measurements.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.
Evaluation criteria:
As stated in the Joint Programme Regulations
Optimization Methods (5 ECTS)
Optimeringsmetoder

Objective:
Students who complete the module:

Knowledge
- Must have knowledge about different classes of optimization problems.
- Must have knowledge about objective function, global/local minima, constrained/unconstrained, convex/non-convex functions and sets.
- Must have knowledge about the consequences of dimensionality.
- Must have knowledge about gradient and optimal gradient methods.
- Must have knowledge about Newton and interior-point methods for constrained optimization.
- Must have knowledge about line search methods and stop criteria.
- Must have knowledge about tools for non-linear optimization.
- Must have knowledge about methods for solving combinatorial optimization problems, such as Simulated Annealing (SA), Genetic Algorithms (GA), ant colony optimization, and Integer Linear Programming (ILP).

Skills
- Must be able to identify problem classes.
- Must be able to apply optimization methods in order to design and implement algorithms for continuous and discrete optimization.
- Must be able to evaluate the performance of optimization algorithms.
- Must be able to transform optimization problems to standard form and use off-the-shell optimization software.
- Must be able to evaluate and understand numerical aspects of optimization algorithms.

Competencies
- Must have an understanding of how to formulate optimization problems in signal processing.
- Must have competencies in applying optimization in signal processing applications.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
2nd Semester

Scientific Computing (Elective) (20 ECTS)
Videnskabelig beregning

Recommended academic prerequisites:
The module adds to the knowledge obtained in the 1st Semester.

Objective:
Students who complete the module:

Knowledge
• Must have knowledge of computer architecture classification (Flynn’s taxonomy).
• Must have knowledge about typical scientific computing problems with non-real-time constraints.
• Must have knowledge of parallel computing techniques.
• Must have knowledge of the relation between physical world problems and mathematical models.
• Must have knowledge of different computational platforms for different types of scientific computing problems.

Skills
• Must be able to select suitable hardware platforms for different computational problems.
• Must be able to program solutions for scientific computing problems by use of various computational platforms (single and multi-core processing units, graphics processing units, compute clusters etc.).
• Must be able to debug and performance optimize (e.g., time and/or memory consumption) the developed software.
• Must be able to use various computing platforms to solve different scale computational problems.
• Document the developed software including validation of the desired functionality.

Competencies
• Must be able to solve problems where scientific computing is applied.
• Using the above mentioned knowledge and skills, the student must be able to identify, prioritize, and apply in a structured manner the set of tasks needed for solving a scientific computing problem, which in its solution naturally involves or require high-performance simulation capabilities.
• The student must be able to create and plan the work and development processes as needed for solving systematically such a problem.
• The student must be able to select the most appropriate project management method(s) and tool(s) for solving the problem.
• Must be able to initiate the above mentioned task independently, critically, and responsibly.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Oral examination. The examination is based on questions that take their starting points in the written documentation for the project module.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Reconfigurable Computing (Elective) (20 ECTS)
Rekonfigurerbare systemer

Recommended academic prerequisites:
The module adds to the knowledge obtained in the 1st Semester.

Objective:
Students who complete the module:

Knowledge
- Must have knowledge about methodologies applied for resource optimal mapping of Digital Signal Processing (DSP) algorithms onto application specific reconfigurable hardware/software (HW/SW) platforms.
- Must have knowledge about analytical, numerical, experimental and simulation based methods for assessing selected cost function parameters typically associated with such real-time systems.

Skills
- Must be able to apply analysis/design/implementation/test methods and -tools for the optimization of 1) performance and 2) resource usage when mapping DSP algorithms onto dedicated real-time HW and/or SW architectures.
- Must be able to apply theories, methods, and techniques for analysis, design, implementation, and test of reconfigurable real-time hardware systems.
- Must be able to evaluate, compare, and optimize the quality of selected parts of the overall system in terms of e.g., chip area, execution time, memory usage, energy consumption, and/or numerical properties.
- Must be able to present, justify, and argue for the methodological, structural (system component related), and physical (technological) choices made when analyzing, designing, implementing, and testing reconfigurable and/or low energy DSP systems.
- The student must be able to select the most appropriate tool(s) for solving the problem.

Competencies
- Using the above mentioned knowledge and skills, the student must be able to identify, prioritize, and apply in a structured manner the set of tasks needed for solving a DSP problem which in its solution naturally involves or require a reconfigurable real-time HW/SW platform.
- The student must be able to create and plan the work and development processes as needed for solving systematically such a problem.
- Must be able to initiate the above mentioned task independently, critically, and responsibly.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Oral examination
The examination is based on questions that take their starting points in the written documentation for the project module.
For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Objective: Students who complete the module:

Knowledge
Must have knowledge about:
- Representation of Digital Signal Processing (DSP) algorithms
- Cost functions, models of computation and complexity
- Iteration bounds
- Pipelining and retiming
- Folding and unfolding
- Scheduling and allocation
- Data path, control path, Finite State Machine with Data path (FSMD)
- Functional unit arithmetic
- Low power design methods

Skills
- Must be able to apply advanced terms, concepts, and methods, in the context of time-, area-, or energy optimal/constrained mapping of DSP algorithms onto real-time HW/SW architectures.

Competencies
- The student must be able to apply the proper terminology in oral and written communication and documentation within the scientific domains of DSP algorithms, and application specific HW/SW architectures.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Sound Technology for the Normal Hearing (P) (Elective) (20 ECTS)
Lydteknologi for normalthørende

**Recommended academic prerequisites:**
The Module adds to the knowledge obtained in the 1st Semester.

**Objective**
Students who complete the module:

**Knowledge**
- Must have broad knowledge in the area of acoustics, audio engineering, hearing and human sound perception.
- Must have knowledge in the field of sound and audio technologies including multi-channel sound recording and reproduction, measurement, instrumentation and standards.
- Must demonstrate insight into the area of human sound perception.
- Must demonstrate insight into existing everyday standard and advanced solutions in audio systems, e.g. HiFi, public address, CarFi, communication systems, and personal hearing devices (incl. portable devices).

**Skills**
- Must be able to select and apply analytical, numerical and experimental methods for analysis and design of complex audio systems.
- Must be able to initiate and implement appropriate technical implementations for audio solutions, e.g. within binaural or multi-channel recording and reproduction techniques.
- Must be able to consider the impact of normal loudness perception and possible masking phenomena in the engineering solution(s).
- Must be able to consider spatial aspects of the sound image in the engineering solution(s).

**Competencies**
- Must be able to apply proper technical solutions in the field of audio engineering based on normal human sound perception.
- Must be able to communicate the results of the project work in a project report
- Must be able to contribute successfully to teamwork within the problem area and make a common presentation of the result of the project work.

**Type of instruction:**
Project work.

**Exam format:**
Oral examination based on a written report

**Evaluation criteria:**
As stated in the Joint Programme Regulations.
Sound Technology for the Hearing-impaired (P) (Elective) (20 ECTS)
Lydteknologi for hørehæmmede

Recommended academic prerequisites:
The module adds to the knowledge obtained in the 1st Semester

Objective:
Students who complete the module:

Knowledge
- Must have broad knowledge in the area of acoustics, audio engineering, normal and impaired human sound perception.
- Must have insight in most common hearing pathologies, and the personal and social consequences of hearing loss.
- Must have knowledge of hearing diagnosis tools and their application.
- Must have knowledge in the field of sound and hearing aid technologies.
- Must have insight into multi-channel sound recording and reproduction, measurement, instrumentation and standards.
- Must have knowledge in the field of general audiology.
- Must have insight into auditory models and their applications.
- Must demonstrate insight into the area of impaired hearing.
- Must demonstrate insight in existing everyday standard and advanced solutions in audio systems, e.g. HiFi, Public address, CarFi, personal assisted hearing devices (portable devices, incl. hearing aids and smartphones).

Skills
- Must be able to select and apply analytical, numerical and experimental methods for analysis and design of complex audio systems.
- Must be able to apply different methods for hearing diagnosis, e.g. hearing thresholds, tympanometry, oto-acoustic emission measurements.
- Must be able to initiate and implement appropriate technical implementations, incl. advanced signal processing for the hearing impaired.
- Must be able operate and calibrate audiological equipment.

Competencies
- Must be able to design and conduct an audiological experiment with human subjects.
- Must be able to apply proper technical solutions in the field of audio engineering based on impaired human sound perception.
- Must be able to communicate the results of the project work in a project report
- Must be able to contribute successfully to teamwork within the problem area and make a common presentation of the result of the project work

Type of instruction:
Project work.

Exam format:
Oral examination based on a written report

Evaluation criteria:
As stated in the Joint Programme Regulations.
Human Sound Perception and Audio Engineering (C) (5 ECTS)
Menneskets lydopfattelse og audio teknik

Objective:
Students who complete the module:

Knowledge
- Must have knowledge about the anatomy and physiology of the human ear.
- Must have knowledge about hearing diagnosis and disorders.
- Must have knowledge about fundamental properties of human sound perception (e.g. Loudness, pitch, masking, spatial hearing and time / frequency resolution).
- Must have basic knowledge about modern audio engineering including recording, reproduction and signal processing techniques (perceptive coding principles and formats, audio effects).
- Must have knowledge about multi-channel recording, storage and reproduction of sound.
- Must have knowledge about public address techniques.
- Must have insight in digital audio interfaces and standards.
- Must have insight in low noise audio design and interconnections.

Skills
- Must be able to set up audio systems for recording or reproduction in an appropriate way to optimize the system and minimize noise.
- Must be able to set up audio systems according to relevant standards.

Competencies
- Based on the acquired knowledge, the student should be able to critically evaluate systems and specifications within audio and acoustics with a basis in human sound perception.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Numerical Scientific Computing (5 ECTS)
Numerisk videnskabelig beregning

Objective:
Students who complete the module:

Knowledge
• Must have knowledge about hardware and software platforms for scientific computing.
• Must have knowledge about the possible speedup by using parallelization (Amdahls law / Gustafson-Barsis' law) under different conditions.
• Must have knowledge about message and data passing in distributed computing.
• Must have knowledge about programming techniques, profiling, benchmarking, code optimization etc.
• Must have knowledge about numerical accuracy in scientific computing problems.
• Must have knowledge about what typically characterizes problem-specific scientific computing software vs. general, user-oriented commercial software
• Must have knowledge about one or more software development methods of relevance to development of scientific computing software

Skills
• Must be able to translate the covered principles regarding scientific computing and software development to practice in the programming language(s) utilized in the course
• Must be able to implement software programs to solve scientific computational problems using parallel computing.
• Must be able to implement software programs to solve scientific computational problems using distributed computing units or high-performance specialized computing units (such as GPU)
• Must be able to debug, validate, optimize, benchmark and profile developed software modules.
• Must be able to assess the performance of different hardware architectures for scientific computing problems.

Competencies
• The student must be able to apply the proper terminology in oral and written communication and documentation within the scientific domains of numerical scientific computing
• Must be able to assess and weigh resources spent on software development against total subsequent computing time for concrete scientific computing problems.
• Must be able to reflect on different software development methods and independently select and combine elements thereof for use in concrete scientific computing problems.
• Must be able to independently adapt and apply the covered methods and principles for complex scientific computing problems within the students’ professional field.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
3rd Semester

Signal Processing and Acoustics (20 ECTS)
Signalbehandling og akustik

Recommended academic prerequisites:
The module adds to the knowledge obtained in the 1st and 2nd semester.

Objective:
Within one or more of the educations core domains the student:

Knowledge
- Must have knowledge about contemporary research and development.
- Must have knowledge about appropriate methods and/or algorithms and their implementation and/or simulation.
- Must have knowledge about relevant standards.
- Must have knowledge of appropriate measurements and/or evaluation methods.

Skills
- Must be able to analyze, design and implement engineering solutions to solve advanced problems.
- Must be able to determine the necessary requirements.
- Can apply adequate tools and methods for data acquisition, analysis, simulations and/or implementation.
- Must be able carry out measurements and/or evaluations according to relevant standards and requirements.
- Must be able to select among multiple solutions using well-defined criteria.
- Must be able to organize, schedule, conduct, evaluate, and document a thorough test- and validation procedure for the complete solution.

Competencies
- Can read, understand, and apply theories, methods, algorithms, and tools published in the relevant scientific literature.
- Can discuss obtained results with respect to further work.
- Can communicate the results of the project work in a project report.
- Can contribute successfully to teamwork within the problem area and make a common presentation of the result of the project work.

Type of instruction:
Project work.

Exam format:
Oral examination based on a written report.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Array and Sensor Signal Processing (5 ECTS)
Array- og sensor signalbehandling

Objective:
Students who complete the module:

Knowledge
- Must have knowledge about the Cramér-Rao lower bound (CRLB) as well as (asymptotic) optimal unbiased estimators such as minimum variance unbiased estimator, maximum likelihood, and least-squares.
- Must have knowledge about 1- and 2-dimensional spectral estimation methods such as the periodogram, the Yule-Walker equations, subspace-based methods (MUSIC and ESPRIT), and filter-bank methods (Capon’s method and Amplitude and Phase Estimation (APES)).
- Must have knowledge about fundamental terms and methods applied for design and analysis of adaptive filter such as Steepest descent, least-mean-square (LMS), normalized LMS (NLMS), affine projections (AP), recursive least-squares (RLS), transient and steady-state performance.
- Must have knowledge about terms and methods applied for design and analysis of multi-rate signal processing systems, such as Hilbert transform, Noble identities, poly-phase decomposition, commutators, re-sampling, as well as up- and down-sampling.

Skills
- Must be able to compare the estimation performance of unbiased estimators by using the CRLB.
- Must be able to apply methods and algorithms for parametric and non-parametric spectral estimation on 1- and 2-dimensional signals.
- Must be able to implement fundamental adaptive filters such as the (normalized) least-mean-square filter, the affine projection filter, and the recursive least-squares filter.
- Must be able to apply fundamental methods for analysis, design, and implementation of poly-phase filters.

Competencies
- Must have competencies in analyzing a given problem which in its solution requires advanced signal processing methodologies and next identify appropriate methods and algorithms to solve the problem.
- Must have competencies in understanding the strengths and weaknesses of the methods.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations
Machine Learning (5 ECTS)

Objective:
The course gives a comprehensive introduction to machine learning, which is a field concerned with learning from examples and has roots in computer science, statistics and pattern recognition. The objective is realized by presenting methods and tools proven valuable and by addressing specific application problems.

Students who complete the module:

Knowledge
- Must have knowledge about supervised learning methods including K-nearest neighbors, decision trees, linear discriminant analysis, support vector machines, and neural networks.
- Must have knowledge about unsupervised learning methods including K-means, Gaussian mixture model, hidden Markov model, EM algorithm, and principal component analysis.
- Must have knowledge about probabilistic graphical models, variational Bayesian methods, belief propagation, and mean-field approximation.
- Must have knowledge about Bayesian decision theory, bias and variance trade-off, and cross-validation.
- Must be able to understand reinforcement learning.

Skills
- Must be able to apply the taught methods to solve concrete engineering problems.
- Must be able to evaluate and compare the methods within a specific application problem.

Competencies
- Must have competencies in analyzing a given problem and identifying appropriate machine learning methods to the problem.
- Must have competencies in understanding the strengths and weaknesses of the methods.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Architectural & Environmental Acoustics (5ECTS)
Rum- og Bygningsakustik samt Miljøakustik

Recommended academic prerequisites:
The module adds to the knowledge obtained in Fundamentals of Acoustics and Electro-acoustics (1st semester)

Objective:
Students who complete the module:

Knowledge
Must have knowledge of
- Room acoustics
  - Sound fields in rooms
  - Absorption and reflection (e.g. impedance, absorption coefficient, porous and resonating absorbers)
  - Room modes (e.g. standing waves, distribution and classification of modes)
  - Geometrical and statistical acoustics (e.g. ray tracing, mirror image modelling, sound field build-up and decay, reverberation time: Sabine+Eyring)
- Concert hall acoustics (Room acoustical parameters like e.g.: $T_{60}, T_{30}, T_{20}$, EDT, $C_{80}, C_{50}$, D, IACC, Subjective parameters, conditioning of rooms, Echo)
- Speech intelligibility (e.g. STI and RASTI index)
- Building acoustics
  - Sound transmission between rooms
  - Sound transmission into buildings (facade insulation)
  - Air borne sound transmission (e.g. Single wall Double walls, measurement of transmissions loss)
  - Structural borne sound transmission (e.g. waves in solids, attenuation, impact noise, measurement of impact sound insulation)
- Environmental Acoustics
  - Effect of noise on humans (annoyance and damage) (Physiological reactions, sleep disturbance, work performance, assessment via questionnaires)
- Noise Classification (types of noise, influence of surroundings, SPL, Frequency and time average, equivalent and exposure levels)
- Noise from installations
- Noise barriers
- Noise assessment (ratings and noise descriptors, calculation of loudness, assessment of annoyance and hearing impairment)

Skills
Must be able to
- calculate and measure relevant room and building acoustical parameters
- measure and calculate relevant noise assessment parameters
- carry out measurements and calculations on noise barriers

Competencies
Can make assessments of:
- Sound fields in rooms
- Sound transmission into rooms
- Noise impact on humans based on relevant theories, standards, measurement and prediction methods.
Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination
For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
**Academic internship**  
*Projektorienteret forløb i en virksomhed*

**Recommended academic prerequisites:**  
An academic internship agreement approved by the company, an AAU supervisor and the study board for electronics and it (ESN).

The academic internship must have a scope that correspond the ECTS load.

**Purpose:**  
The student stays in a company with the purpose of learning and applying theories and methods to address engineering problems in an industrial context. In addition, the student will be introduced to business procedures and policies.

**Objectives:**  
After completing the module, the student should have the following knowledge, skills and competencies:

**Knowledge**
- Has knowledge about the organization of the company and business procedures and policies.
- Has knowledge about performance measures in the company.
- Has developed a fundamental business sense.
- Has knowledge of the competence profile of the program and how the academic internship contributes to the competence profile.
- Has gained deepened knowledge into engineering theories and methods within the program.

**Skills**
- Can initiate and ensure the completion of an agreement for the academic internship, with learning objectives corresponding to the semester at the master’s program.
- Can apply analytic, methodological and/or theoretic skills to address advanced engineering problems in an industrial context.
- Can contribute in a professional manner to company objectives as an individual and in teams in accordance with the project management model applied in the company.
- Can collaborate and communicate with peers, managers and others.
- Can document the academic internship in a report and defend it orally.

**Competencies**
- Can discuss and reflect on the learning outcomes of the academic internship.
- Can discuss the need for knowledge transfer between academia and industry.
- Has a deepened understanding of the academic interests to pursue in the master’s thesis and possible job positions to aim at after graduation.

**Type of instruction:**  
Project work

**Exam format:**  
Oral examination based on a written report.

**Evaluation criteria:**  
As stated in the Framework Provisions.
4th Semester

Master's Thesis (30, possibly 50 ECTS)

Kandidatspeciale

The master thesis can be conducted as a long master thesis. If choosing to do a long master thesis, it has to include experimental work and has to be approved by the study board. The amount of experimental work must reflect the allotted ECTS.

Recommended academic prerequisites:
The module adds to the knowledge obtained in the 1st – 3rd Semester

Objective:
Students who complete the module:

Knowledge
- Have knowledge, at the highest international level of research, of at least one of the core fields of the education.
- Have comprehension of implications of research (research ethics).

Skills
- Are able to reflect on a scientific basis on their knowledge.
- Can argue for the relevance of the chosen problem to the education including specifically account for the core of the problem and the technical connections in which it appears.
- Can account for possible methods to solve the problem statements of the project, describe and assess the applicability of the chosen method including account for the chosen delimitation and the way these will influence on the results of the product.
- Can analyze and describe the chosen problem applying relevant theories, methods and experimental data.
- Are able to describe the relevant theories and methods in a way that highlights the characteristics and hereby document knowledge of the applied theories, methods, possibilities and delimitations within the relevant problem area.
- Have the ability to analyze and assess experimental data, including the effect the assessment method has on the validity of the results.

Competencies
- Are able to communicate scientific problems in writing and orally to specialist and non-specialist.
- Are able to control situations that are complex, unpredictable and which require new solutions.
- Are able to independently initiate and to perform collaboration within the discipline and interdisciplinary as well, and to take professional responsibility.
- Are able to independently take responsibility for his or her own professional development and specialization.

Type of instruction:
As described in the introduction to Chapter 3.

Problem based project oriented project work individual or in groups of 2-3 persons.

Exam format:
Oral examination. An external censor is appointed.

The examination is based on questions that take their starting points in the written documentation for the project module.
For further information concerning the examination procedure, refer to the Joint Programme Regulations.

**Evaluation criteria:**
As stated in the Joint Programme Regulations
Chapter 4: Entry into Force, Interim Provisions and Revision

The curriculum is approved by the Dean of The Technical Faculty of IT and Design and enters into force as of September 2018.

Students who wish to complete their studies under the previous curriculum from 2017 must conclude their education by the summer examination period 2019 at the latest, since examinations under the previous curriculum are not offered after this time.

Chapter 5: Other Provisions

5.1 Rules concerning written work, including the Master's thesis
In the assessment of all written work, regardless of the language it is written in, weight is also given to the student's spelling and formulation ability, in addition to the academic content. Orthographic and grammatical correctness as well as stylistic proficiency are taken as a basis for the evaluation of language performance. Language performance must always be included as an independent dimension of the total evaluation. However, no examination can be assessed as ‘Pass’ on the basis of good language performance alone; similarly, an examination normally cannot be assessed as ‘Fail’ on the basis of poor language performance alone.

The Board of Studies can grant exemption from this in special cases (e.g., dyslexia or a native language other than Danish).

The Master’s thesis must include an English summary.\(^4\) If the project is written in English, the summary must be in Danish.\(^5\) The summary must be at least 1 page and not more than 2 pages (this is not included in any fixed minimum and maximum number of pages per student). The summary is included in the evaluation of the project as a whole.

5.2 Rules concerning credit transfer (merit), including the possibility for choice of modules that are part of another programme at a university in Denmark or abroad
The Board of Studies can approve successfully completed (passed) programme elements from other Master’s programmes in lieu of programme elements in this programme (credit transfer). The Board of Studies can also approve successfully completed (passed) programme elements from another Danish programme or a programme outside of Denmark at the same level in lieu of programme elements within this curriculum. Decisions on credit transfer are made by the Board of Studies based on an academic assessment. See the Joint Programme Regulations for the rules on credit transfer.

5.3 Rules for examinations
The rules for examinations are stated in the Examination Policies and Procedures published by the Technical Faculty of IT and Design on their website.

All students who have not participated in Aalborg University’s PBL introductory course during their Bachelor’s degree must attend the introductory course “Problem-based Learning and Project Management”. The introductory course must be approved before the student can participate in the project exam. For further information, please see the School of Information and Communication Technology’s website.

\(^4\) Or another foreign language (upon approval from the Board of Studies)
\(^5\) The Board of Studies can grant exemption from this.
5.4 Exemption
In exceptional circumstances, the Board of Studies study can grant exemption from those parts of the curriculum that are not stipulated by law or ministerial order. Exemption regarding an examination applies to the immediate examination.

5.5 Rules and requirements for the reading of texts
It is assumed that the student can read academic texts in his or her native language as well as in English and use reference works etc. in other European languages.

5.6 Additional information
The current version of the curriculum is published on the Board of Studies' website, including more detailed information about the programme, including exams.