Degree structure and coursework

Structure of the degree

The Doctor of Science (Tech) degree is 40 ECTS credits of theoretical studies and dissertation thesis which means four years of full-time studies. The Licentiate of Science (Tech) degree is 40 ECTS credits of theoretical studies and licentiate thesis which means two years of full-time studies. The extent of the licentiate and doctoral degrees consist of theoretical studies and research work. The emphasis is on research work.

The degrees of doctor of science and licentiate constitute of three entities or modules which are the thesis, scientific principles and practices -studies and research field studies. Total of coursework is 40 credits.

Dissertation

Doctoral candidates are required to complete a dissertation, which is an individual research composed during the four years of study. The doctoral dissertation is written on a topic related to the research field approved for the doctoral candidate. A doctoral dissertation shall contribute to new scientific knowledge. Dissertation includes a public defence after pre-examination process. Accepted forms of dissertation are article dissertation and monograph.

Aalto University has more detailed instructions concerning the dissertation and its requirements.

A dissertation is a public document and cannot be concealed.

Quality requirements and forms of dissertation are described in Supervision, research and dissertation part.
Licentiate thesis

The Licentiate thesis is written on a topic related to the research field approved for the doctoral candidate. In a Licentiate thesis, doctoral candidate shall demonstrate good conversance with the field of research and the capability of independently and critically applying scientific research methods.

An approved Licentiate thesis may also be a monograph or a number of scientific publications or manuscripts vetted for publication deemed sufficient by the university, which deal with the same set of problems and a paper summarising the findings, or some other work, which meets corresponding scientific criteria. The publications may include co-authored publications if the author's independent contribution to them can be demonstrated.

A Licentiate thesis is a public document and cannot be concealed.

Detailed instructions.

Coursework

Scientific principles and practices module

The extent of module is 5 - 20 ECTS. The individual content of the module is confirmed to each doctoral candidate. Only compulsory course for fulltime doctoral candidates is the course Introduction to doctoral studies (ELEC-L0902). It is organised twice a year.

The aim of the scientific principles and practices studies is to provide students with knowledge of the basic concepts of science, the key characteristics of scientific research and scientific knowledge and to familiarize them with the most important research methods of their research field and develop the transferable skills. In addition, students learn to apply the principles of good scientific practice to their research, apply the basic structure of a scientific publication in their research reports, know the key publication series of their fields and are able to draft an appropriate and suitable structure for their doctoral dissertation.

The study module may include studies in research methodology, research ethics and the history or philosophy of science and principles of scientific writing. Some or all of the module may also consist of pedagogical studies. Language studies in general cannot be included to the degree, except for the specified language and communication studies.

Research fields and studies

The extent of module is 20-35 ECTS. Research field studies should support the writing of the thesis and prepare the doctoral candidates for research and other demanding work that requires expertise. In the Doctoral Programme in Electrical Engineering there are 24 research field to conduct studies in. Research field descriptions, list of professors and links to the research groups descriptions can be found below.

Research field studies need to be mainly post-graduate courses (advanced level) or other studies elegible for doctoral degree. Two master level courses can be included to the research field studies without any additional reasoning. No credits are given for doing research.

The module may include the following studies:

- Attending suitable courses in Aalto University or another university.
- Completing and reporting practical assignments related to the research field.
- Writing a literature review.
- Oral or written examinations based on textbooks.
- Studies in scientific summer and winter schools and courses organised by graduate schools.

Studies in the field of research need to be confirmed in the individual study plan for each doctoral candidate. Read more about the process here.

Eligible studies and courses for doctoral degree

Suitable courses for Scientific principles and practices module

Scientific principles and practices module can include variety of studies but it may not consist totally of presentations in scientific conferences of one’s own field.

For full-time doctoral candidates the only compulsory course is ELEC-L0902 Introduction to doctoral studies.

1 Suitable courses for this module
• Introduction to doctoral studies is compulsory to full-time doctoral candidates who have been admitted after August 1, 2015.
• Research Ethics Course (online course available)
• Pedagogical studies (University level)
• Kon-41.5167 / MEC-E9010 Patents L
• History of Science
• Philosophy of Science
• Philosophy and Systems Thinking, varying content (can be approved once)
• History of Electrical Engineering P
• Law in Digital Society CSE-E4680 / CS-E5370

Following courses by the Aalto Language Center (exact language courses cannot be included to the doctoral degree)

• Presenting Doctoral Research
• Writing Doctoral Research
• Tieteellinen kirjoittaminen tohtoriopiskelijoille L (V) (in Finnish)
• Debating Skills L
• Negotiating Skills L
• Informative Presentations L

For more detailed course information, please see the MyCourses and WebOodi.

2 Learning university practices (teaching and guidance), scientific preparatory tasks and pedagogic studies

• 1-3 credits for acting as the assistant for exercises or teaching.
  • Credits may be earned for assisting on a maximum of three different courses
  • the maximum number of credits is 3 x 3 credits

Also at most 2 cr bachelor’s thesis advisor duties
• when doctoral candidate is nominated officially as bachelor thesis advisor.
• University lecturer Markus Turunen confirms these study attainments as responsible teacher for bachelor´s seminar at ELEC

• Master thesis advisor duties can be included to doctoral degree
• professor confirms the study attainment
• The credits are assigned by the supervising professor case by case depending on the workload and requirements.
• The participation in pedagogic training (YOOp courses or Aalto University pedagogic education) grants a maximum of 15 cr.

The credits are recorded for the general codes reserved for the doctoral studies of the research field, see details.

3 Presentations in an international conference of the field

Please note that the study module may not consist totally of presentations in scientific conferences of one’s own field.

• Study attainment includes: a rehearsal presentation in Finland, presenting a poster or giving an oral presentation at a conference and active participation in the conference: is worth 1-2 cr /conference.
• Credits may be earned for maximum of three different conferences, so the maximum number of credits is 3 x 2 credits

These credits are registered by using the general codes reserved for the doctoral studies of the research field.

• ELEC006Z-LZ Postgraduate studies (Automation, systems and control engineering)
• S016Z-LZ Postgraduate studies (Communications Engineering)

Suitable courses for research field studies

In the programme level there are no specific course requirements for this module. Courses should be post-graduate courses are marked letter L/P in the course name, with letter L in the course code or as “doctoral” in the course description.

• ELEC-E8101 - Digital and Optimal Control P
• ELEC-L0902 - Introduction to Doctoral Studies

Two master level courses can be included to the research field studies without any additional reasoning.

Bachelor level courses cannot be included to the doctoral degree but these are considered are prerequisite courses.

For more detailed course information, please see the MyCourses and WebOodi.
### Research field descriptions, list of professors and links to the research groups

<table>
<thead>
<tr>
<th>Code</th>
<th>Name of the research field in three languages</th>
<th>Professors in charge (alphabetical order)</th>
<th>Research groups of the field</th>
</tr>
</thead>
</table>
| S001Z | Akustika ja äänenkäsittelyteknikka
Akustik och ljudbehandlingsteknik
Acoustics and Audio Signal Processing | Prof. Ville Pulkki
Prof. Vesa Välimäki | • Communication acoustics: spatial sound and Psychoacoustics
• Audio signal processing group |
Doctoral studies in acoustics and audio signal processing focus on spatial sound technologies, digital music signal processing, and acoustic virtual reality, among others. Current trends are digitisation, such as the replacement of sound production tools with software, and novel communication and entertainment systems, which employ telepresence technologies.

Research in this field requires good signal processing and programming skills in practice. Furthermore, it is necessary to have an understanding of subjective testing, especially listening tests. Doctoral research will give you a chance to go deep into your favourite acoustic or audio topics and create new findings. Doctoral candidates will get a chance to use the outstanding measurement facilities of the Aalto Acoustics Lab, such as our three anechoic chambers and a modern artificial head.

Currently, research topics in this field are multidisciplinary and often related to virtual reality, physical modelling of audio devices, acoustics and modelling of concert halls, psychoacoustics of spatial sound, and acoustic measurements. Professors Ville Pulkki and Vesa Välimäki are well known internationally and widely networked. Their doctoral candidates will become part of the global community of audio researchers and will have opportunities to participate in international conferences. The Aalto Acoustics Lab collaborates actively with audio companies and with acoustics research groups of top universities.

Doctoral candidates can include in their theoretical studies several regular courses in this research field and can participate in the acoustics and audio technology seminar, which has a different theme each year. In addition, doctoral studies in this field may include courses on signal processing, speech and language processing, machine learning, and mathematics, for example. Anyone with a doctoral degree in acoustics and audio signal processing will readily find a job in a high-tech company, consulting firm, or university in Finland or abroad. Some of our doctors become entrepreneurs.
Doctoral studies in Automation, Systems and Control Engineering include research in intelligent software and hardware solutions for industrial automation, marine industry automation, intelligent robotic systems, robotic vision, micro- and nanorobotic manipulation, and autonomous vehicles. Current trends in the field include distributed internet-inspired automation architectures, the industrial internet of things, use of artificial intelligence, autonomous vehicles, human-robot and robot-robot interaction, microrobotic instruments, as well as cooperative control and manipulation.

The research in this field requires extensive knowledge of mechatronics, signals and systems, optimisation, and programming and software skills. Additionally, the research often requires deep understanding of particular application fields, and multidisciplinary approaches are often required. The doctoral research provides opportunities for students to delve into their favourite theoretical topics or develop novel scientific and engineering methods with high-impact real-world applications. Doctoral students will access the outstanding equipment and facilities of the research groups in the field of automation, systems and control engineering. These include state-of-the-art automation systems, robotic systems from macro scale to micro scale, and various autonomous vehicles, engines and drones.
The research topics in this field are highly multidisciplinary, related not only to subfields of engineering, (e.g. wireless and distributed automation, networked control systems, cooperative robotics, autonomous vehicles, micro- and nanoscale automation), but also to wide application fields, from electrical and diesel engines and manufacturing of products in the marine industry, to health-and-wellbeing, pharmaceuticals, materials technology and biotechnology. The professors in Automation, Systems and Control Engineering are well known internationally and widely networked. Their doctoral students will become part of the global community through participating in international conferences and active collaboration and exchange with top international and Finnish universities and companies.

The doctoral students can include in their studies regular courses of this field (control theory, robotics, machine learning, and mathematics), relevant seminars organised by research groups, and if necessary, courses that are important to their research from other departments, schools or universities. After successful completion of the research training, a doctor of Automation, Systems and Control Engineering will readily find a job in a wide variety of high-tech engineering companies and consulting firms, or pursue an academic career at a university, or become a successful entrepreneur.
Doctoral studies in space science and technology focus on space technology, Earth observation, space physics, and radio astronomy. Our research topics include the designing and building of satellite systems and space instruments, Earth observation by airborne and spaceborne microwave instruments, analysis of data from Earth observation and space physics, space weather and solar system dynamics, radio astronomical techniques, and the study of active galactic nuclei and galactic objects. Space-related services such as weather forecasts, environmental monitoring, and navigation and telecommunication services are rapidly growing, with nanosatellite technologies providing access to space at low cost and short time.

Finnish investments in space have risen anew, with several cubesat programs in orbit and under development, and commercial nano- and microsatellites coming to market with a wide variety of services. This highlights the need to understand the electromagnetic and plasma environment of space in order to design and operate space assets in a way that protects their operative capabilities. The analysis of long time series of satellite data to understand environmental and climate changes, or monitoring the data of active galactic nuclei are among Aalto’s current focus areas.

Doctoral students typically include advanced astronomy, plasma and space physics, and space technology courses in their theoretical studies. Mathematics, programming, and statistics courses support the skills required of a researcher in these fields. The students get unique hands-on experience in designing, building, testing and operating nanosatellites, in designing and building ground-based and space-based space research instrumentation, or e.g. in making radio astronomical observations with the Metsähovi Radio Observatory’s large telescope. Students can also be involved in observations made with instruments aboard European Space Agency (ESA) missions or Aalto’s space instruments aboard its own small satellites, or participate in developing and using state-of-the-art space-weather computer simulations. Students typically include these data and results in their theses.
Students are integrated into the research teams, many of them highly international, and are able to establish their own networks through research work, and participate in conferences and summer schools. Doctors in space science and technology will be qualified for research work in one of the focus areas, for work in large space organisations, or for work in the industry or public sector.

<table>
<thead>
<tr>
<th>Bioelektronik och instrumentering</th>
<th>Prof. Leo Kärkkäinen</th>
<th>Prof. Ilkka Laakso</th>
<th>Prof. Simo Särkkä</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioelectronics and Instrumentation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doctoral studies in bioelectronics and instrumentation focus on the development of methods for measuring, modelling, analysing, and intervening in the human body. The research topics are, e.g., magnetic resonance imaging, biosignal analysis, neuroscientific applications, and applications of electromagnetic fields in medicine and their safety issues.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The research in bioelectronics and instrumentation requires a strong background in physics and mathematics as well as good programming skills. The multidisciplinary nature makes the research field suitable for students with various backgrounds, for example, in electrical engineering, computer science, mathematics, and biomedical engineering.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doctoral studies and research work within bioelectronics and instrumentation are multidisciplinary and related to the development of computational methods, medical imaging, theoretical analysis, modelling of biophysical phenomena, modelling of the interaction between electromagnetic fields and biological media, and application of numerical electromagnetics in health technologies.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The doctoral student will gain deep understanding of the measurement, analysis and modelling of electrophysiological signals and phenomena, which are invaluable skills in modern health technologies. Graduated doctors are typically employed as experts in medical technology companies, and many of our doctors become entrepreneurs.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Electromagnetics in Health Technology
- Health Factory
- Health technology
- Sensor informatics and medical technology
PhD studies in electronics integration and reliability focus on different aspects of microsystem technology, materials physics and chemistry, biosensing and the physics of various failure mechanisms encountered in microelectronics. Various types of modelling methods are also of key importance. Current trends in the field include different carbon nanostructures and their utilisation, new thin film materials in micro/nanoelectronics, computational material science, advanced failure analysis methods, and biocompatible sensors. The various methods of machine learning are also increasingly being utilised.

In practice, research in the field requires strong physics and/or chemistry skills and sufficient mathematical abilities. In addition, general knowledge of designing electronics and laboratory work experience are beneficial. Doctoral research can be directed in several directions in this wide application area. Examples include biosensing, carbon nanomaterials or microelectromechanical (MEMS) systems to name just a few possible paths.

Doctoral students can use the world-class facilities and equipment offered by Aalto University and VTT's joint Microelectronics Research Center Micronova and the analytical services provided by the Nanomicroscope Center. In addition, the computing resources offered by IT Centre for Science (CSC) are widely used.

Nowadays, topics of doctoral dissertations in the field are often very multidisciplinary and relate, for example, to the measurement of neurotransmitters from brain tissue, to the development and characterisation of new piezoelectric films or to the design of new types of carbon hybrid materials.
Professors in the field of Electronics Integration and Reliability, Tomi Laurila and Mervi Paulasto-Kröckel, are internationally renowned and widely networked researchers, with whom doctoral students can become part of the global research community and have access to top international conferences. We frequently carry out research in close collaboration with industry and various research groups from the top universities around the world.

Doctoral students can include in their theoretical studies a wide range of courses in materials science, computational science, chemistry, physics, electronics, machine learning and mathematics. PhDs in Electronics Integration and Reliability are well employed nationally and internationally in high technology companies, consultancy offices, research institutes and universities. There is also a strong culture of entrepreneurship in the field and many of our students have set up their own businesses.
Description

Information theory, often defined as the study of communication, quantification, and storage of information, forms a fundamental basis for information and communication technology (ICT) and contains a wide variety of subfields subject to active research at Aalto University School of Electrical Engineering. In addition to communication, signals and storage, the field also intersects with computer science, economics, mathematics, physics and statistics.

The fundamental, mathematical nature of information theory makes the research field suitable for students with a background in automation, computer science, electrical engineering, information technology, mathematics and physics. It is not uncommon that students migrate to this field from other universities, schools and disciplines.

The professors in charge cover different parts of this large area. The work of professors Themistoklis Charalambous, Jyri Hämäläinen, and Olav Tirkkonen covers communication theory with applications, and the work of professor Patric Östergård covers coding theory, discrete mathematics and algorithms. The professors in charge have many ongoing projects in which new students participate fully.

In addition to a few basic courses, the choice of courses to be included in the doctoral studies will to a large extent be guided by the research of the student with the agreement of the supervising professor. With the large number of supporting fields and courses lectured on in the many schools and departments of Aalto University, there are many possibilities and a lot of flexibility to support the research and studies that the student finds appealing.

An understanding of the basis of ICT and the capability to conduct fundamental research are invaluable skills in the modern and future world and provide an opportunity for a successful career. Doctors are typically employed in academia or as experts in information security, software or telecom companies.
The doctoral studies in advanced materials and photonics are focused on applications. Novel materials such as graphene as well as many other thin 2-dimensional materials have important applications in both electronics and photonics. These materials can also be realised by modifying the properties of existing materials, especially on the nanoscale. New directions in photonics include ultrafast lasers, new light sources, fast transfer of data and even quantum communication.

The doctoral students make extensive use of the state-of-the-art clean rooms of Micronova, and related measurement and characterisation infrastructure. The students learn to perform theoretical simulations and modelling, and to develop micro- and nanotechnology-based novel sensor and laser applications. The professors in this research field have extensive collaboration with the leading universities, research organisations and companies. Their offices are located in the Micronova building: Ilkka Tittonen, Harri Lipsanen, Hele Savin, Markku Sopanen, and Zhipei Sun. Erkki Ikonen is located in Maarintie 8.

- Artificial Materials
- Electron Physics
- Micro and Quantum Systems
- Nanoscience and Advanced Materials
- Nanostructured electromagnetic metamaterials
- Optoelectronics
- Photonics
Rapid advances in hardware, algorithms, software, and networks have opened remarkable new possibilities for human use of information technology. Doctoral studies in user interfaces prepare leaders, experts, and academics who use advanced theories and technical methodology to design and develop information technology for the benefit of people.

Research on human-computer interaction (HCI) is cross-disciplinary and seeks a principled understanding of how to improve the human use of interactive computing. The field of HCI is one of the largest fields in computer science and applied across a multitude of other fields, ranging from robotics to speech technology. Doctoral candidates can include in their theoretical and methodological studies our regular courses, seminars, reading groups, and summer schools in the above fields. The emphasis between theoretical or applied studies varies depending on the student’s background and thesis topic.

The doctoral education draws on methods used in computer science, engineering design, machine learning, cognitive sciences and electrical engineering. The focus is on principled modelling and algorithmic solution of interaction problems. A PhD candidate will have a background that combines rigorous methods in computational and engineering disciplines with leading trends in user interface technology and interaction design. Research requires both top-down (system level) and bottom-up (analysis and experimentation) and attention to detail. Technical skills involved include programming, statistical and mathematical modelling, experimental research, and electrical engineering. Doctoral candidates will work closely in a research group and collaborate with leading universities and industrial partners.
Micro- and Nanoelectronic Circuit Design

Description

Doctoral studies in micro- and nanoelectronic circuit design deepen the student’s knowledge and skills relating to integrated circuit design. In micro- and nanoelectronics, students can focus on analogue, digital, radio frequency, millimetre-wave or mixed-mode signal design. Current trends in this field are the replacement of accurate analogue circuits with digitally assisted mixed-mode circuits and the utilisation of high frequency (>100GHz) circuits in wireless and imaging applications.

The design of integrated circuits requires a versatile knowledge of design software, and a practical knowledge of integrated circuit measurements, in addition to theoretical skills. Doctoral research will give the student a chance to specialise in a favourite topic, like sensor circuits, integrated transceivers, energy harvesting or A/D and D/A converters, and thereby generate new results. Doctoral students will get a chance to use Aalto’s outstanding measurement facilities, such as the integrated-circuit measurement laboratory and the industry-compatible nanoscale circuit design environment.

In integrated circuit design, we collaborate closely with national and international companies. Hence, the topics of the doctoral studies are typically linked to applications currently being developed by industry for their future products, including digital transceivers, radio-frequency circuits for multi-antenna systems and low-power sensor circuits. Professors Kari Halonen and Jussi Rynänen are globally networked and their students introduce their research results in top journals and conferences.

Doctoral students can include in their theoretical studies several regular courses in this research field. In addition, the doctoral studies may include courses on signal processing, microwave engineering or e.g. the nanotechnology of data science. Our students with a doctoral degree in micro- and nanoelectronic design will typically find a job in a high-tech company, research institute, or university in Finland or abroad.
Description

The doctoral studies of micro- and nanosciences focus on the development of structures and small-scale devices with numerous applications in the field of physics, chemistry and biology. The internationally renowned cleanroom facilities of Micronova provide a research environment for their state-of-the-art fabrication and characterisation. The researchers learn to apply atomic layer deposition (ALD) for a wide range of purposes, electron beam lithography (EBL) for building ultrasmall structures, and MOVPE for fabricating bright LEDs and various quantum structures.

New directions include the use of graphene and other 2-dimensional materials for various sensor developments and for ultrafast photonics.

The professors in this research field have extensive collaboration with leading international universities, research organisations and companies. Their offices are located in the Micronova building. Ilkka Tittonen, Harri Lipsanen, Hele Savin, Markku Sopanen and Zhipei Sun.
### Measurement Science and Technology

**Description**

Doctoral studies in measurement science and technology focus on optical metrology. Key research topics include development of state-of-the-art light detectors, challenges related to new energy-efficient lighting products, degradation of materials due to optical radiation and the measurement of very small light intensities. The research work is often cross-disciplinary; in addition to optical measurements, it may also include design of electronics and measurement devices, material research and computer simulations. One aspect of the research is international collaboration with top universities, research institutions and companies.

Optical metrology has applications in most industrial sectors. Most of the electrical appliances utilise visible or infrared light in displays, communications and sensors. On the other hand, the development of more energy-efficient lighting is an essential topic. Due to the importance and wide-range of the research field, the job opportunities are diverse.

Doctoral students may choose their postgraduate courses quite freely. Study topics may include semiconductor and laser physics, photonics or applied electronics. Professors Erkki Ikonen and Ilkka Tittonen are widely networked and well known internationally. Thus, their doctoral students will become part of the global community of optical metrology and have the opportunity to take part in international conferences and research projects.

<table>
<thead>
<tr>
<th>Professor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erkki Ikonen</td>
</tr>
<tr>
<td>Ilkka Tittonen</td>
</tr>
</tbody>
</table>

- Metrology
We are surrounded by wireless devices and the amount of wirelessly transmitted data is growing exponentially. Radio engineering is at the core of this development and our post-graduate students will be the future trailblazers in this field.

Our focus areas cover a wide range of radio engineering subjects – antenna and propagation, artificial materials, systems and components, circuits, and terahertz and measurement techniques. Depending on the focus area, the post-graduate studies may necessitate a solid background in mathematics, physics, circuit analysis and electromagnetic field theory.

Research related to post-graduate studies in radio engineering may be either academic or applied in nature, depending on the focus area. Research into artificial materials, for instance, may aim at finding new electromagnetics functionalities of materials in general, whereas antenna research may focus on antenna solutions for future mobile devices. Applied research is typically done in close collaboration with companies.

Research in radio engineering relies on theories, numerical simulations and experiments. Numerical simulation and design tools have particularly improved during the past decades and they are now widely used in various design tasks. Our research activity is also fully supported by extensive radio frequency measurement facilities which are capable of working up to terahertz. Our graduates are employed well in companies and academia.

<table>
<thead>
<tr>
<th>Focus Area</th>
<th>Professors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antennas and propagation</td>
<td>Prof. Katsuyuki Haneda</td>
</tr>
<tr>
<td>Millimetre wave and THz techniques</td>
<td>Prof. Constantin Simovski</td>
</tr>
<tr>
<td>Nanostructured electromagnetic metamaterials</td>
<td>Prof. Sergei Tretyakov</td>
</tr>
<tr>
<td>Wireless sensors</td>
<td>Prof. Ville Viikari</td>
</tr>
</tbody>
</table>

- Antennas and propagation
- Millimetre wave and THz techniques
- Nanostructured electromagnetic metamaterials
- Wireless sensors
Signal Processing Technology is a multidisciplinary research field with strong connections to applied mathematics, machine learning, information theory, data analysis and electrical engineering. Topics of our research groups cover a broad spectrum of research areas, including wireless communications, advanced radar technologies, statistical signal processing, cognitive systems, large-scale data analysis, statistical learning, optimisation theory, smart grids, localisation systems and technologies, multisensor systems, and the Internet of Things.

Professors in the field are internationally recognised researchers with a large network of research partners at top universities in the US, Europe and Asia. Research visits of our doctoral students to our collaborators abroad are very common and highly encouraged. We often collaborate in projects with industry and have contacts to many leading ICT and data-analysis companies in Finland.

Our doctoral students can include in their theoretical studies and seminars lectured on by our professors or given at international summer schools. Since many other research fields are related to signal processing, other courses given by Aalto departments – for example, in applied mathematics, machine learning or radio science – can be included in doctoral studies as well. Due to the broad applicability of signal processing methods and its importance as a driving force of digitalisation, our doctoral graduates have good prospects for employment in a variety of R&D, management or academic jobs, both in Finland and abroad. Some of our graduates have also founded successful start-up companies.
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEC007Z</td>
<td>Electromagnetics and Circuit Theory</td>
<td>Postgraduate studies within electromagnetics lead to a deep understanding of theoretical electrical engineering and radio science, and the ability to apply this theoretical understanding to engineering and design projects. The basis of electrophysics is formulated in Maxwell equations, which describe the behaviour of electromagnetic fields from the nanoscale all the way to the phenomena of deep space. Mastering electromagnetics provides tools for successful professional engineering and research duties in application areas like wireless communications, remote sensing, electromagnetic compatibility, complex and optical materials, radio astronomy, and bioelectrical phenomena. The recent rapid development of computer power and numerical algorithms has also made possible more effective and universal simulation methods. Numerical simulations have indeed become an integral part of the design and development of new systems and devices, in addition to the traditional experimental work. However, a productive and reliable use of simulation software requires, in addition to deep knowledge in the substance of the application area, expertise on the fundamentals of numerical algorithms. Studies and the research work within electromagnetics and circuit theory focus much on analytical and numerical modelling and simulation of electromagnetic phenomena, development of computational methods, interaction between fields and matter, and the role of electromagnetics in practical applications. Graduated doctors and licentiates in electromagnetics and circuit theory find employment in academia and research institutes. Recently, more and more of the graduates find their career in the private sector.</td>
</tr>
<tr>
<td>S038Z</td>
<td>Electromechanics</td>
<td>Studied and the research work within electromechanics and circuit theory focus much on analytical and numerical modelling and simulation of electromagnetic phenomena, development of computational methods, interaction between fields and matter, and the role of electromagnetics in practical applications. Graduated doctors and licentiates in electromechanics and circuit theory find employment in academia and research institutes. Recently, more and more of the graduates find their career in the private sector.</td>
</tr>
</tbody>
</table>
The doctoral studies in electromechanics focus on the design and modelling of energy conversion devices, where the medium of conversion is a magnetic field, such as in electric motors and generators. The scientific emphasis is on the numerical modelling of the electromagnetic field in the presence of nonlinear materials with hysteresis, the properties of which are coupled with other physical quantities such as mechanical stresses or thermal fields. The trend in electromechanics research is towards multi-physics models based on the behaviour of the underlying materials. The ultimate goal is the accurate modelling of the electromechanical energy conversion process, accounting for all the side effects, such as energy losses, mechanical vibrations, and acoustic noise with the view to developing reliable and energy efficient devices.

Besides engineering skills related to electrical machines, research in electromechanics requires a strong background in physics and mathematics as well as good programming skills. A major proportion of the doctoral candidates will have to conduct extensive experimental work at the laboratory level. The doctoral studies and research give tools for a deepening understanding of how electromagnetic fields are used the energy conversion, how to model them and how to create new devices and methods to deal with them. The doctoral students will get a chance to use the outstanding measurement facilities of the Aalto Power Hub, such as the well-equipped electrical machine hall and the state-of-the-art magnetic material characterisation devices.
Currently, the research topics in electromechanics are multidisciplinary and often related to energy efficiency, physical modelling of electrical machines, numerical modelling of electromagnetic fields, and characterisation and modelling of magnetic materials under mechanical stresses. Professors Antero Arkkio and Anouar Belahcen are well known internationally and widely networked. Their doctoral students will become part of the global electromechanics and electrical machines community. They will participate in well-established international conferences and have opportunities to spend periods as visiting researchers with research groups of top universities in the field.

The doctoral students can include in their theoretical studies several regular courses of electromechanics, mathematics, and physics and participate in related yearly-organised seminars where top researchers are invited. Graduates from the doctoral programme in the field of electromechanics easily find jobs in technology companies, Finnish and foreign universities as well as national and international research centres. Some of our doctors become entrepreneurs, too.

Sähköverkot ja suurjännitetekniikka
Elektriska energisystem och högspänningsteknik
Power Systems and High Voltage Engineering

Prof. Matti Lehtonen
Prof. Edris Pouresmaeil

• Power systems and High Voltage Engineering
Energy is the biggest challenge of mankind. It is the basic prerequisite of any industrial activity, a necessity for the functioning of human communities and the necessary requirement for food production. As the population grows, the demand for energy is drastically increased. At the same time, our planet is coming up against the limits of sustainability. Climate change has accelerated and raw materials are being depleted. To meet the above challenges, there is today a radical transition around the world towards sustainable energy that combines smartness, flexibility and environmental performance with customer acceptance and engagement. New energy systems will be a complex combination of central and local resources, including energy production and storage, and new, efficient and flexible loads. This calls for new thinking about primary energy sources, energy production, energy markets, energy transmission, energy use and customers as producer-consumers (prosumers).

Electrical power systems are at the focus of the above development. In research, the field of power systems combines the engineering of energy systems and electrical systems in order to produce new sustainable system-level solutions for renewable energy utilisation and system integration. Topical research questions are responses to the demand for the management of balanced energy systems, the integration of distributed, renewable power generation in power and energy systems, smart grids, and self-healing networks. In the area of high voltage engineering, the focus is on developing new solutions for distribution and transmission networks and for their individual components.

Doctoral candidates are expected to have a strong background in electrical systems. The research is done in close collaboration with the energy and power industry as well as with manufacturing companies and vendors of energy and power system components and services. Close collaboration includes other energy research groups at Aalto University as well as internationally.
### Power Electronics and Electric Drives

**Description**

Power electronics enables the conversion of electrical energy from one form into another (from DC to multi-phase AC, for example) with very good efficiency. If a power-electronic converter is used to control an electric motor or generator, the system is referred to as an electric drive. Power electronics and electric drives are needed in consumer electronics, electric vehicles, industry applications and, to an increasing extent, in power systems (distributed generation, energy storages, etc.).

Our research is focused on developing main-circuit topologies, applying next-generation power semiconductor devices, and on developing advanced control methods for power converters and electric drives. In addition to theoretical considerations, research typically involves experimental work and the development of prototypes. Research is conducted in cooperation with leading companies and some of the best university groups in the field. Doctoral students can present their research results at various international flag-ship conferences.

In addition to the courses on power electronics and electric drives, doctoral students may include in their theoretical studies courses on systems engineering, signal processing, electromechanics, power systems or electronics, for example. Our graduated doctors have been very well employed at established companies in the field as well as at start-up companies, consultancy firms and universities.

**Institute of Intelligent Power Electronics**

- Prof. Marko Hinkkanen
- Prof. Jorma Kyyrä
- Prof. Edris Pouresmaeil
- Prof. Mikko Routimo *
The topics of doctoral dissertation are related to ultra-reliable low-latency communications, future generations of radio communication systems, and applications of communications theory and data transfer methods in other fields, such as automation. The professors of telecommunications technology are internationally known experts and widely networked researchers. With the help of their professors, the doctoral student can become a member of the global research community, publishing in top-tier journals and giving talks at international conferences. Aalto's communications engineering research is often conducted in close collaboration with leading industrial stakeholders and academic partners of international calibre.

Doctoral students can attend courses in their theoretical studies in communications engineering and networking technology and participate in seminars on telecommunications technology. Also well suited to theoretical studies are courses on signal processing, information technology, machine learning and other mathematics courses. Doctors in communications engineering can find employment at home and abroad in high technology companies, consultancy offices and universities. Some of our graduated doctoral students also become successful entrepreneurs.

Doctoral studies in telecommunication technology focus, inter alia, on wireless radio communication networks, multi-antenna technologies, spectrum management, and channel coding methods. Current trends in the field include software-defined radio and cloud-based radio access networks, the internet of things, millimetre-wave radios, machine-learning-based cognitive networks and quantum communication.

Communications engineering research requires extensive knowledge of telecommunication systems, where the role of individual technology as a part of the whole is clearly understood. A strong mathematical background and knowledge of signal processing is essential for the development of physical-layer data-transfer methods. Programming competence in all the layers of data transfer is important.
Doctoral research gives the opportunity to develop new methods to improve future telecommunication systems. Doctoral students have access to the well-equipped laboratories at Aalto University, enabling them also to do experimental research.
The discipline of signal processing is in many ways similar to applied mathematics. Wireless communications presents one of the most important and successful applications of signal processing techniques. In the protocol stack of wireless communication systems, signal processing methods typically fall into two groups, the physical layer and the layer of medium access control. The application areas we are exploring include the Internet of Things, multisensor systems, sensor networks, future radar systems, high-volume and high-dimensional data analysis on wireless networks, future wireless communication systems and networks, massive multi-antenna configurations and techniques, in-band full-duplex transceivers, network control, agile spectrum use, spectrum sharing, cognitive radio, wireless localisation and security applications, as well as automatic signal recognition and classification. Our toolbox includes methods and techniques from statistical inference, estimation and detection theory, linear algebra, data science, optimisation theory, information theory, communication theory, machine learning and harmonic analysis, as well as stochastic and differential geometry.

Our research focus is predominantly on the theory and methods of signal processing. The derived theoretical results and the methods and algorithms that are developed are typically verified with Matlab. In addition, we are building hardware-in-the-loop proof-of-concept systems using programmable platforms such as software-defined radios. We have an extensive network of collaborators from world-leading research universities in the United States and the rest of the Americas, Europe and Asia. We provide world-class researcher training to our diverse group of doctoral students. Our graduates are employed in academia in Finland and abroad, and hold key positions in various equipment and chip vendor companies in the areas of wireless communication and the ICT industry. Doctoral studies require very good analytical and problem-solving skills as well as programming skills.
<table>
<thead>
<tr>
<th>Code</th>
<th>Course</th>
<th>Description</th>
<th>Professors</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETA001Z</td>
<td>Tietoverkkotalous</td>
<td>Network Economics</td>
<td>Prof. Heikki Hämmäinen</td>
</tr>
<tr>
<td></td>
<td>Nätverksekonomi</td>
<td>Doctoral studies in network economics focus on the techno-economics of wireless and internet networks and services, from user, customer and provider viewpoints. Current trends include 5G small cell networks, quality of experience, virtualisation, block chains and application of machine learning. Research in this field requires system-level and top-down thinking with the ability to zoom into relevant levels of detail as necessary. Technical skills such as programming, communication protocols and statistics as well as understanding microeconomics are necessary for successful system-level research. Doctoral research will allow you to combine technology and economic theories with practical industrial problems emerging in our research projects. Doctoral candidates will be closely connected to Aalto’s leading communication technology expertise, top industrial companies and our partner teams in leading foreign universities. Doctoral candidates can include in their theoretical studies our regular courses, variable content seminars and foreign summer schools in this research field. The emphasis between technical and economics courses varies depending on student’s background and thesis topic. Our doctors have become managers, analysts, consultants and entrepreneurs in fields such as service providers, equipment providers and software houses.</td>
<td></td>
</tr>
<tr>
<td>S041Z</td>
<td>Tietoverkkotekniikka</td>
<td>Networking Technology</td>
<td>Prof. Raimo Kantola&lt;br&gt;Prof. Jarno Limnell *&lt;br&gt;Prof. Jukka Manner&lt;br&gt;Prof. Pekka Nikander *&lt;br&gt;Prof. Stephan Sigg&lt;br&gt;Prof. Tarik Taleb&lt;br&gt;Prof. Yu Xiao</td>
</tr>
</tbody>
</table>
In the past few decades, networks, both wireless and fixed, have evolved at an astonishing pace. Concealed from everyday users, the fixed network provides connectivity to the wireless network's base stations—the backhaul network. Innovations and challenges include the softwarisation of networks (SDN, network slicing, network function virtualisation), content-centric and delay-tolerant networking, backhaul for femtocells, efficient transport of small packets, simultaneous transmission from multiple base stations and self-deploying backhaul for future networks. In wireless networks, mobile data traffic is quickly catching up with wired traffic, as people are replacing their wired connections with mobile broadband and as 5G promises to offer unprecedented performance and novel services. The challenges and innovations involve: the energy efficiency of hardware, software and protocols; massive Internet of Things (IoT) networks; service provisioning at the edge of mobile networks; improvements for mobile security, such as attribute-based encryption, as well as multipath transport to use multiple access networks simultaneously.

Research in this field requires good networking and programming skills. Furthermore, it is necessary to have an understanding of the challenges in networking involving security, emerging applications and recent developments in wireless and fixed networking. Doctoral research will give you a chance to go deep into your favourite networking topics and create new findings. Doctoral students will get a chance to use outstanding networking facilities, such as a sliced 5G test network, access to crowd-sourced network measurement data, our own data centre, etc.

Research topics in this field are multidisciplinary and often related to security, network softwarisation, constrained IoT and wearable nodes. Professors in the area of networking technology have wide international networks of contacts, and the work is tied to other international research groups, research visits and conferences.
Doctoral students can include regular courses from this field in their theoretical studies and can participate in seminars with different annual themes. In addition, doctoral studies in this field may include courses on networking security, machine learning and mathematics. Graduates in networking technology with both theoretical and practical skills are highly appreciated by the industry, in Finland and internationally. Some of our doctors have started their own companies based on their research results.

<table>
<thead>
<tr>
<th>S049Z</th>
<th>Valaistustekniikka ja sähköinen talotekniikka</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Belysningsteknik och elektrisk husteknik</td>
</tr>
<tr>
<td></td>
<td>Illumination Engineering and Electrical Building Services</td>
</tr>
</tbody>
</table>

**Description**

Doctoral studies in Illumination Engineering and Electrical Building Services focus on aspects related to the impact of light and lighting on the living environment and the wellbeing of society at a global level. As an inherently cross-disciplinary field, the candidate needs to develop a basic understanding of a variety of topics related to light as a phenomenon and as a versatile tool. Therefore, the doctoral studies focus on topics such as light and vision, light and human wellbeing, lighting control, lighting design, energy efficiency, photometry, lighting technologies, lighting measurements, as well as electrical installations and automation systems in buildings.

Due to the cross-disciplinary nature of the field, the candidate has the opportunity to combine doctoral-level courses in automation and electrical engineering with courses from other field of studies at Aalto University, such as building technology, business, arts, design and architecture. The lighting and building sectors needs experts and academics who have a wide understanding of illumination engineering.

N.N.

*prof. Jaakko Ketomäki*

- **Illumination engineering**
- **Smart building technologies and services**
Digitalisation, connected lighting and human-centric lighting are growing trends in the lighting field. The combination of new lighting technologies with artificial intelligence, control and communication systems enable developing lighting systems that can respond to users' needs such as route-finding, getting information, aesthetics, and creating atmosphere. Candidates are encouraged to focus on factual knowledge and theoretical understanding, but they are also encouraged to perform practical experiments to challenge existing concepts and to suggest new theories on light and lighting in different contexts.

Light is indispensable for the existence of life on earth as well as being an important factor for socio-economic development and a crucial cue not only for humans, but also in ecosystems. For instance, as light pollution and food security are globally growing concerns, doctoral candidates may, depending on their interests, also focus their research on the influence of light on food plants, living organisms and the environment.

The building sector and lighting are major global consumers of electricity, accounting for 50% and 19% of the total electricity consumption, respectively. As such, it is logical that the doctoral studies include energy efficiency and other sustainability aspects at different levels and contexts.

The lighting industry in Finland is continually growing in many application areas generating a need for qualified experts in the field. The lighting research group has good cooperation with the local industry, to whom it also provides measurement and R&D services. The research group is very active in international collaboration with top universities, research institutions and companies. Doctoral candidates will have the possibility to work in international projects and collaboration with industry.

Yhteiset monitieteelliset tutkimusalat - Gemensamma multidisciplinära forskningsområden - Concereted multidisciplinary research fields

SCI has equal research field
Speech and language technology (SLT) refers to information technology that processes and utilizes spoken and written language. SLT has many applications in the area of AI and ICT, particularly those related to man–machine interfaces and communications technology. Examples of applications for SLT are speech recognition, speech synthesis, speech coding and enhancement, automatic language translation and information retrieval.

Postgraduate studies in SLT call for good skills in signal processing and machine learning. In addition, courses taken in mathematics as well as in acoustics and audio signal processing are recommended. SLT is an interdisciplinary study area where the student can take relevant courses also from outside Aalto University in subjects such as psychology, linguistics, phonetics or logopedics.

Doctoral graduates in SLT will readily find work in Finnish and international ICT companies, research institutes, start-ups and universities. Examples of areas where recent Aalto PhDs have continued working after graduation include: statistical parametric speech synthesis, robust feature extraction, automatic speech recognition in difficult environments, and morph-based speech recognition.