Degree structure and coursework

- Doctoral thesis
- Licentiate thesis
- Coursework
  - Research field
  - General research studies (Prev. Scientific practices and principles)
  - Research field descriptions and list of professors

Structure of the degree

Doctoral studies at Aalto University consist of an approved thesis and study modules. In the field of technology, the study modules comprise research field studies as well as scientific practices and principles in total of 40 ECTS.

The Doctor of Science (Tech) degree consists of a doctoral thesis and 40 ECTS of theoretical studies which equals to four years of full-time studies.

The Licentiate of Science (Tech) degree consists of a licentiate thesis and 40 ECTS of theoretical studies which equals to two years of full-time studies.

Doctoral thesis

The doctoral thesis is written on a topic related to the research field that the doctoral candidate has chosen and that has been approved by the supervising professor and the doctoral programme committee of the School of Electrical Engineering. The thesis shall contribute to new scientific knowledge. Approval of the thesis includes a public defence after a pre-examination process. Accepted forms of theses are article based theses and monographs.

A doctoral thesis is a public document and is kept for public display at the university. Doctoral theses are evaluated on a scale of Pass/Fail.

Quality requirements and forms of doctoral theses

Licentiate thesis

The licentiate thesis is written on a topic related to the research field that the doctoral candidate has chosen and that has been approved by the supervising professor and the doctoral programme committee of the School of Electrical Engineering. The thesis shall demonstrate good conversance with the field of research and the capability of independently and critically applying scientific research methods. Approval of the thesis includes a public presentation at the department.

A licentiate thesis is a public document and is kept for public display at the university. Licentiate theses are evaluated on a scale of Pass/Fail.

Forms of licentiate thesis
Coursework (40 ECTS in total)

The degree contains 40 ECTS of theoretical studies. If you have more credits, they need to be put in the extracurricular studies.

The courses included in the doctoral degree must be doctoral level courses or master level courses suitable for the doctoral degree. Courses suitable for the doctoral degree are indicated with the letter L in the course code (doctoral level course, e.g., ELEC-L1234) or with a letter D in the end of the name of the course (ELEC-E1234 Interesting course D). For special reasons provided by the supervising professor, two master level courses may be included in the degree. These courses have the letter E in the course code (e.g., ELEC- E1234), but no letter D in the end of the name of the course. No bachelor level courses (with letters A or C in the course code) can be included in the degree, but these are considered are prerequisite courses. No credits are given for doing research.

Research field studies 20-35 ECTS

Research field studies should support the writing of the thesis and prepare the doctoral candidate for research and other demanding work that requires expertise. In the Doctoral Programme in Electrical Engineering there are 13 research fields to conduct studies in. Research field descriptions, list of professors and links to the research groups descriptions can be found below.

After completing the research field studies, the doctoral candidate:

- has knowledge of the background to their research field at an advanced level
- knows the key publication series of their fields
- has specific research methodology knowledge appropriate to their research focus
- has experience of the practical implementation of appropriate research methodologies in a learning environment

The module may include the following studies:

- courses offered by the Aalto University School of Electrical Engineering,
- courses/seminars offered by the departments,
- courses offered in other Aalto Schools or in other universities,
- individual study attainments, to be agreed on with the supervising professor
- Individual study attainments, to be agreed with the supervising professor. There is no maximum number of credits of individual studies in this module, but it is highly recommended that the module does not consist only of individual studies. The module may include for example the following individual studies:
  - summer/winter schools, 2–3 ECTS/week
  - self-study (books, journal or conference articles; written/oral exam, or review/report to demonstrate learning)

Search for courses in MyCourses, SISU or courses.aalto.fi.

Evaluation of the module

No grade is given for the module. Individual courses and study attainments are graded either as Pass/Fail or as grades 1-5.

General research studies 5-20 ECTS

The aim of the general research studies (previously called scientific practices and principles 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.

After completing the general research studies, doctoral candidates:

- are able to apply the principles of good scientific practice to their research,
- are able to apply the basic structure of a scientific publication in their research reports,
- have gained the ability to draft an appropriate and suitable structure for their doctoral thesis.
- know the principles of scientific writing and communication
- have transferable skills according to their career plans

The module may include for example the following studies:

- General courses:
  - ELEC-L0902 Introduction to doctoral studies, highly recommended for all doctoral candidates. Compulsory to full-time doctoral candidates who have been admitted between August 1, 2015 and July 31 2020.
  - LC-L1010 Aalto Research Ethics, highly recommended
  - MEC-E9020 Patents D
  - CS-E5370 Law in Digital Society D
  - Research methodology
  - Research writing
    - LC-1330 Presenting Doctoral Research
    - LC-1335 Preparing for the Doctoral Defence
    - LC-1336 Popularize your Research
    - LC-1350 Writing Doctoral Research for Engineering and Science
    - LC-L1017 Asiantuntijaesittäminen valmennus jatko-opiskelijalle
    - LC-L1018 Tutkimusraportinmin tekstitiettity jatko-opiskelijalle
  - Aalto University Communication courses organized by the Aalto Languae Center. Language courses cannot be included to the doctoral degree.
- Communication
• LC-0550 Communication Skills
• LC-0320 Public speaking skills
• LC-0530 Public speaking and stage fright
• LC-0520 Impact and argumentation
• LC-0340 Communication Competence in the Workplace
• LC-0330 Leadership Communications
• LC-0224 Negotiation Skills
• LC-0510 Conference Presentations
• LC-0610 Intercultural Communication
• LC-0611 Teamwork and Leadership in the 21st Century
• LC-0613 Developing Intercultural Competence

**Aalto University Communication courses** organized by the Aalto Language Center. Language courses cannot be included to the doctoral degree.

• Pedagogical studies
  • Pedagogical studies (max 20 ECTS)
  • Transferable skills (independent online courses available from findocnet.fi)
    • Research Ethics for Doctoral Students D, LC-L1010 (1-2 ECTS)
    • Open Science for Doctoral Students D, LC-L1011 (1 ECTS)
    • Business Skills for Doctoral Students D, LC-L1012 (1 ECTS)
    • Career Course for Doctoral Students D, LC-L1013 (1 ECTS)
    • Interactive Leadership Skills for Doctoral Students D, LC-L1014 (1 ECTS)
    • Project Management for Doctoral Students D, LC-L1015 (1 ECTS)
    • Writing Research Grant Applications for Doctoral Students D, LC-L1016 (1 ECTS)

• Individual study attainments, to be agreed with the supervising professor

**Evaluation of the module**

No grade is given for the module. Individual courses and study attainments are graded either as Pass/Fail or as grades 1-5.

**Research field descriptions, list of professors and links to the research groups**

1.8.2022-31.7.2024

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<td>Group of Prof. Alku</td>
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Acoustics and audio signal processing focuses 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.

Professors: Tapio Lokki, Ville Pulkki, Vesa Välimäki

Speech and language technology refers to information technology that processes and utilises spoken and written language. It has many applications in the area of AI and ICT, particularly those related to man-machine interfaces and communications technology. Examples of applications are speech recognition, speech synthesis, speech coding and enhancement, automatic language translation and information retrieval.

Professors: Paavo Alku, Tom Bäckström, Mikko Kurimo
In the past few decades, networks, both wireless and fixed, have evolved at an astonishing pace. Mobile networks are bringing new capabilities that extend the scope of the technology far beyond voice and data transfer. Mobile technology holds a great promise to revolutionize connectivity in various vertical sectors including automotive, smart cities, health care and industrial sectors to name a few. More research is needed to support the evolution of mobile networks to better meet the demands of the new applications, to manage the ever-increasing complexity of the mobile communication systems as well as to improve the network security and energy efficiency. The communications engineering and networking technology research spans from information and communications technologies to cloud networking, Internet protocols and network business.

Doctoral students in communications engineering and networking technology focus inter alia on fundamentals of information and communications theory, quantum communications, wireless communications and sensing, mobile communication systems, network softwarization and orchestration, software defined radio, software defined networking, cloud networking, Internet technologies, network security, and the technoeconomics of the overall communications ecosystem.

The supervising professors 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 and networking technology 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 have also become successful entrepreneurs.

Doctoral research gives the opportunity to develop new methods to improve future telecommunication systems. Doctoral students have access to the well-equipped laboratories and campus wide test mobile network at Aalto University, enabling them also to do experimental research.

Communications engineering and networking technology 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. Research topics in networking technology are multidisciplinary and often related to security, network softwarisation, constrained IoT and wearable nodes. Programming competence in all the layers of data transfer is important.
### ELEC02 4Z  
**Electrical Power and Energy Engineering**  
Sähkö- ja energiateknikka  
Elkraft- och energiteknik

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<tr>
<th>Prof. Anouar Belahcen</th>
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<td>Prof. Marko Hinkkanen</td>
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<td>Prof. Jorma Kyyrä</td>
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<td>Prof. Matti Lehtonen</td>
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<td>Prof. Mehdi Pourakbari Kasmaei</td>
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<td>Prof. Edris Poureemael</td>
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### ELEC02 2Z  
**Electronic and Digital Systems**  
Elektroniset ja digitaaliset järjestelmät  
Elektroniska och digitala system

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<th>Prof. Mervi Paulasto-Kröckel</th>
<th>Group of Prof. Paulasto-Kröckel</th>
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<td>Prof. Simo Särkkä</td>
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<td>Prof. Ivan Vujaklija</td>
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### ELEC02 5Z  
**Electronics**  
Elektronik

**Electronics**

Doctoral studies in electronics deepen the student's knowledge on electronic circuits focusing on skills relating to integrated circuit design. In electronics, 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 utilization of high frequency (>100GHz) circuits in wireless and imaging applications or the development of energy-efficient circuits for embedded artificial intelligence.

The design of integrated circuits and electronics 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 specialize in a favorite topic, like sensor circuits, integrated transceivers, energy harvesting or A/D and D/A converters or machine-learning hardware accelerators, 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 Karl Halonen, Jussi Rynänen and Martin Andraud 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 electronics design will typically find a job in a high-tech company, research institute, or university in Finland or abroad.

ELEC03 Interactive Systems
Vuorovalutteiset Järjestelmät

Interaktíva system

Rapid advances in sensing, hardware, algorithms, software, and networks have opened remarkable new possibilities for interactive technology and smart environments. PhD studies in Interactive technologies comprise technical principles of novel technology, theory of algorithms and software while bridging towards interdisciplinary areas such as Human-Computer Interaction, Augmented and Virtual Reality, as well as Mobile, Pervasive and Ubiquitous Computing. The program educates future experts and leaders who use advanced methodology and technology to innovate and improve information technology for the benefit of people.

Doctoral students in Interactive technologies focus, among others, on energy efficient mobile, pervasive and ubiquitous computing, augmented, virtual and mixed reality, crowdsourcing, ambient intelligence, applied machine learning, artificial intelligence, wearable technology, environmental sensing and perception, usable security, concept creation, interface technologies, algorithms, data, modeling, communications and networking.

The supervising professors are internationally known experts and widely networked researchers. They support doctoral students to become a member of the global research community, publishing in top-tier journals and giving talks at international conferences. Aalto’s Interactive technologies research is conducted in close collaboration with internationally renowned academic experts and leading industrial players.

Doctoral students can attend courses in their theoretical and experimental studies in Interactive technologies and participate in seminars on selected advanced topics. Well suited to doctoral studies are courses on user research, user interface design, machine learning and other math courses. PhDs in Interactive technologies are employed in high technology companies, consultancy offices and universities. Some of our graduated doctoral students have also become successful entrepreneurs.

Doctoral research gives the opportunity to develop new methods to create future interactive systems. Doctoral students have access to the well-equipped laboratories and a campus wide test mobile network at Aalto University, enabling them also to do experimental research.

Interactive technologies research requires extensive knowledge, for instance, in the fields of algorithms for optimization and model training, human computer interaction, or distributed systems. A strong mathematical background and knowledge of machine learning tools is essential for the development of interactive technology and smart interaction methods. Research topics in Interactive technologies are multidisciplinary and, for instance, related to extended reality, user research, cloud/edge/fog computing, (usable) security, sensing, human-computer interaction, constrained IoT and wearables. Programming proficiency is important.

ELEC02 Photonics and Nanotechnology
Fotoniikka ja nanotekniikka

Fotonik och nanoteknik

The doctoral studies in photonics and nanotechnology focus on fundamentals and applications of advanced nanomaterials and their hybrid nanostructures. For example, novel materials such as graphene and many other thin two-dimensional materials have important applications in both electronics and photonics. Many other functional and even quantum materials can also be realised by modifying their structures and properties of existing materials, especially on the nanoscale. New directions in photonics include new laser sources, fast data interconnection, novel sensors and imaging systems, and quantum technologies.

The doctoral students make extensive use of the national infrastructure Otanano (state-of-the-art clean room and related measurement and characterisation infrastructure). The students learn to develop micro- and nanotechnology-based novel applications and to perform theoretical simulations and modelling. The professors in this research field have extensive collaboration with the leading universities, research organisations and companies. Their offices and laboratories are located in the Micronova building in Tietotie 3 and at Maarintie 8.

Prof. Antti Oulasvirta
Group of Prof. Oulasvirta

Prof. Stephan Sigg
Group of Prof. Sigg

Prof. Yu Xiao
Group of Prof. Xiao

Prof. Erkki Ikonen
Group of Prof. Ikonen

Prof. Harri Lipsanen
Group of Prof. Lipsanen

Prof. Hele Savin
Group of Prof. Savin

Prof. Caterina Soldano
Group of Prof. Soldano

Prof. Markku Sopanen
Group of Prof. Sopanen

Prof. Zhipei Sun
Group of Prof. Sun

Prof. Ilkka Tittonen
Group of Prof. Tittonen
### Radio Science and Engineering

We are surrounded by wireless devices and the amount of wirelessly transmitted data is growing exponentially. Radio science and 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 science and engineering subjects – antennas and propagation, artificial materials, systems and components, circuits, numerical and theoretical electromagnetism 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 science and 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 science and 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.

Professors in Radio Science and Engineering include:

- Prof. Viktar Asadchy
- Prof. Katsuyuki Haneda
- Prof. Keijo Nikoskinen
- Prof. Arl Siivola
- Prof. Constantin Simovski
- Prof. Sergei Tretyakov
- Prof. Zachary Taylor
- Prof. Ville Viikari

Group of Asadchy
Group of Haneda
Group of Nikoskinen
Group of Siivola
Group of Simovski
Group of Tretyakov
Group of Taylor
Group of Viikari

### Robotics and Autonomous Systems

Doctoral studies in Robotics and Autonomous Systems include research in intelligent software and hardware solutions for robots and autonomous systems of all sizes ranging from miniaturized robotic instruments to heavy mobile machinery and application areas from industrial automation to service robotics. Current trends in the field include artificial intelligence, autonomous vehicles, human-robot interaction as well as distributed and decentralized systems.

Research in this field requires knowledge of signals and systems, optimisation, mechatronics, 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 world-class equipment and facilities of the research groups. These include state-of-the-art automation systems, robotic systems from miniature to macro scale, and various autonomous vehicles, engines and drones.

Professors in Robotics and Autonomous Systems 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 national universities and companies.

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 when applicable, courses that are important to their research from other departments, schools or universities. After successful completion of the research training, a doctor of Robotics and Autonomous Systems will readily find a job in a wide variety of high-tech engineering companies and consulting firms, pursue an academic career at a university, or become a successful entrepreneur.

Professors in Robotics and Autonomous Systems include:

- Prof. Tomasz Kucner
- Prof. Ville Kyrki
- Prof. Joni Pajarinen
- Prof. Simo Särkkä
- Prof. Arto Visala
- Prof. Valeriy Vyatkin
- Prof. Quan Zhou

Group of Kucner
Group of Kyrki
Group of Pajarinen
Group of Särkkä
Group of Visala
Group of Vyatkin
Group of Zhou
Signal Processing and Data Analytics

Signal Processing 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: Visa Koivunen, Esa Ollila, Sergiy Vorobyov, Risto Wichman

Measurement science at SPA focuses 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.

Professors: Erkki Ikonen

Space Science and Technology

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 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.

Professors: Esa Kallio, Anne Lähteenmäki, Jaan Praks, Miina Rautiala

More research groups can be found here:

Department of Communications and Networking
Department of Electronics and Nanoengineering
Department of Electrical Engineering and Automation
Department of Signal Processing and Acoustics

2020-2022
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In the past few decades, networks, both wireless and fixed, have evolved at an astonishing pace. Mobile networks are bringing new capabilities that extend the scope of the technology far beyond voice and data transfer. Mobile technology holds a great promise to revolutionize connectivity in various vertical sectors including automotive, smart cities, health care and industrial sectors to name a few. More research is needed to support the evolution of mobile networks to better meet the demands of the new applications, to manage the ever-increasing complexity of the mobile communication systems as well as to improve the network security and energy efficiency. The communications engineering and networking technology research spans from information and communications technologies to cloud networking, internet protocols and network business.

Doctoral students in communications engineering and networking technology focus inter alia on fundamentals of information and communications theory, quantum communications, wireless communications and sensing, mobile communication systems, network softwareization and orchestration, software defined radio, software defined networking, cloud networking, internet technologies, network security, and the techno-economics of the overall communications ecosystem.

The supervising professors 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 and networking technology 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 have also become successful entrepreneurs.

Doctoral research gives the opportunity to develop new methods to improve future telecommunication systems. Doctoral students have access to the well-equipped laboratories and campus wide test mobile network at Aalto University, enabling them also to do experimental research.

Communications engineering and networking technology 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. Research topics in networking technology are multidisciplinary and often related to security, network softwareization, constrained IoT and wearable nodes. Programming competence in all the layers of data transfer is important.
**ELEC02**

**Electronics**

**Elektronik**

**Elektronika**

Doctoral studies in electronics deepen the student’s knowledge on electronic circuits focusing on skills relating to integrated circuit design. In electronics, 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 utilization of high frequency (>100GHz) circuits in wireless and imaging applications or the development of energy-efficient circuits for embedded artificial intelligence.

The design of integrated circuits and electronics 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 specialize in a favorite topic, like sensor circuits, integrated transceivers, energy harvesting or A/D and D/A converters or machine-learning hardware accelerators, 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 Karl Halonen, Jussi Ryynänen and Martin Andraud 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 electronics design will typically find a job in a high-tech company, research institute, or university in Finland or abroad.


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**ELEC03**

**Interactive Systems**

**Vuorovaikutteiset järjestelmät**

**Interaktiva system**

Rapid advances in sensing, hardware, algorithms, software, and networks have opened remarkable new possibilities for interactive technology and smart environments. PhD studies in interactive technologies comprise technical principles of novel technology, theory of algorithms and software while bridging towards interdisciplinary areas such as Human-Computer Interaction, Augmented and Virtual Reality, as well as Mobile, Pervasive and Ubiquitous Computing. The program educates future experts and leaders who use advanced methodology and technology to innovate and improve information technology for the benefit of people.

Doctoral students in Interactive technologies focus, among others, on energy efficient mobile, pervasive and ubiquitous computing, augmented, virtual and mixed reality, crowdsourcing, ambient intelligence, applied machine learning, artificial intelligence, wearable technology, environmental sensing and perception, usable security, concept creation, interface technologies, algorithms, data, modeling, communications and networking.

The supervising professors are internationally known experts and widely networked researchers. They support doctoral students to become a member of the global research community, publishing in top-tier journals and giving talks at International conferences. Aalto’s Interactive technologies research is conducted in close collaboration with internationally renowned academic experts and leading industrial players.

Doctoral students can attend courses in their theoretical and experimental studies in Interactive technologies and participate in seminars on selected advanced topics. Well suited to doctoral studies are courses on user research, user interface design, machine learning and other math courses. PhDs in interactive technologies are employed in high technology companies, consultancy offices and universities. Some of our graduated doctoral students have also become successful entrepreneurs.

Doctoral research gives the opportunity to develop new methods to create future interactive systems. Doctoral students have access to the well-equipped laboratories and a campus wide test mobile network at Aalto University, enabling them also to do experimental research.

Interactive technologies research requires extensive knowledge, for instance, in the fields of algorithms for optimization and model training, human computer interaction, or distributed systems. A strong mathematical background and knowledge of machine learning tools is essential for the development of interactive technology and smart interaction methods. Research topics in Interactive technologies are multidisciplinary and, for instance, related to extended reality, user research, cloud/edge/fog computing, (usable) security, sensing, human-computer interaction, constrained IoT and wearables. Programming proficiency is important.

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### ELEC02

#### Photonics and Nanotechnology

- **Fotoniikka ja nanotekniikka**
- **Fotonik och nanoteknik**

The doctoral studies in photonics and nanotechnology focus on fundamentals and applications of advanced nanomaterials and their hybrid nanostructures. For example, novel materials such as graphene and many other thin 2-dimensional materials have important applications in both electronics and photonics. Many other functional and even quantum materials can also be realised by modifying their structures and properties of existing materials, especially on the nanoscale. New directions in photonics include new laser sources, fast data interconnection, novel sensors and imaging systems, and quantum technologies.

The doctoral students make extensive use of the national infrastructure Otanano (state-of-the-art clean room and related measurement and characterisation infrastructure). The students learn to develop micro- and nanotechnology-based novel applications and to perform theoretical simulations and modelling. The professors in this research field have extensive collaboration with the leading universities, research organisations and companies. Their offices and laboratories are located in the Micronova building in Tietotie 3 and at Maarintie 8.

### ELEC02

#### Radio Science and Engineering

- **Radiotiede ja -tekniikka**
- **Radiovetenskap och radioteknik**

We are surrounded by wireless devices and the amount of wirelessly transmitted data is growing exponentially. Radio science and 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 science and engineering subjects – antennas and propagation, artificial materials, systems and components, circuits, numerical and theoretical electromagnetism 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 science and 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 science and 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 working up to terahertz. Our graduates are employed well in companies and academia.

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Doctoral studies in Robotics and Autonomous Systems include research in intelligent software and hardware solutions for robots and autonomous systems of all sizes ranging from miniaturized robotic instruments to heavy mobile machinery and application areas from industrial automation to service robotics. Current trends in the field include artificial intelligence, autonomous vehicles, human-robot interaction as well as distributed and decentralized systems.

Research in this field requires knowledge of signals and systems, optimisation, mechatronics, 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 world-class equipment and facilities of the research groups. These include state-of-the-art automation systems, robotic systems from miniature to macro scale, and various autonomous vehicles, engines and drones.

Professors in Robotics and Autonomous Systems 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 national universities and companies.

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 when applicable, courses that are important to their research from other departments, schools or universities. After successful completion of the research training, a doctor of Robotics and Autonomous Systems will readily find a job in a wide variety of high-tech engineering companies and consulting firms, pursue an academic career at a university, or become a successful entrepreneur.

Signal Processing 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.

Measurement science at SPA focuses 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.

Professors: Visa Koivunen, Esa Ollila, Sergiy Vorobyov, Risto Wichman

Professors: Erkki Ikonen

Professors: Erkki Ikonen
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.
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, psychosoundscapes 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.
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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.
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.

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.

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.

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.
Information Theory

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.
Advanced materials and photonics

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.

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**Prof. Harri Lipsanen**
**Prof. Hele Savin**
**Prof. Konstantin Smolovskii**
**Prof. Markku Sopanen**
**Prof. Zhipei Sun**
**Prof. Ilkka Tittonen**
**Prof. Sergei Tretyakov**
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.
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 Karl Halonen and Jussi Ryynänen 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.

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 Tiltonen, Harri Lipsanen, Hele Sävin, Markku Sopanen and Zhipei Sun.
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.
Radio Engineering

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.
Signal Processing Technology

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.
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.

The doctoral studies in electromechanics focus on the design and modelling of 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 deeper understanding of how electromagnetic fields are used in 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.
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 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.
The topics of doctoral thesis 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.
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.

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 dig 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.
Illumination Engineering and Electrical Building Services

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 need experts and academics who have a wide understanding of illumination engineering.

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.
Speech and language technology (SLT) refers to information technology that processes and utilises 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.