Electrical & Systems Engineering

The Department of Electrical & Systems Engineering offers doctoral-level and master's-level degrees in Electrical Engineering and in Systems Science & Mathematics. At the doctoral level, both the PhD and DSc degrees are available, which typically require four to five years of full-time study leading to an original research contribution. At the master's level, the programs require 30 credit hours of study and have both a course option and a thesis option.

Research activity in the department is focused in the following three areas:

- Applied mathematics, systems & control
- Electronics & optics
- Signal processing, imaging & communications

Students working in any of these areas will enjoy the benefits of programs that balance fundamental theoretical concepts with modern applications. In our department, students find ample opportunities for close interactions with faculty members working on cutting-edge research and technology development.

Prospective PhD students with previous degrees in engineering who are interested in PhD studies and research in mathematics or statistics are encouraged to apply for PhD studies in Mathematics and Statistics. For more details, visit the Graduate Programs in Mathematics and Statistics webpage.

Faculty

Interim Chair

R. Martin Arthur
Newton R. and Sarah Louisa Glasgow Wilson Professor of Engineering
PhD, University of Pennsylvania
Ultrasonic imaging, electrocardiography

Associate Chair

Hiroaki Mukai
Professor
PhD, University of California, Berkeley
Theory and computational methods for optimization, optimal control, systems theory, electric power system operations, differential games

Endowed Professors

Arye Nehorai
Eugene and Martha Lohman Professor of Electrical Engineering
PhD, Stanford University
Signal processing, imaging, biomedicine, communications

Joseph A. O’Sullivan
Samuel C. Sachs Professor of Electrical Engineering
PhD, Notre Dame University
Information theory, statistical signal processing, imaging science with applications in medicine and security, and recognition theory and systems

Lan Yang
Edward H. & Florence G. Skinner Professor of Engineering
PhD, California Institute of Technology
Nano/micro photonics, ultra high-quality optical microcavities, ultra-low-threshold microlasers, nano/micro fabrication, optical sensing, single nanoparticle detection, photonic molecules, photonic materials

Professor

Heinz Schaettler
PhD, Rutgers University
Optimal control, nonlinear systems, mathematical models in biomedicine

Associate Professors

Jr-Shin Li
Das Family Distinguished Career Development Associate Professor
PhD, Harvard University
Mathematical control theory, optimization, quantum control, biomedical applications

Robert E. Morley Jr.
DSc, Washington University
Computer and communication systems, VLSI design, digital signal processing
Assistant Professors

ShiNung Ching (https://engineering.wustl.edu/Profiles/Pages/ShiNung-Ching.aspx)
Das Family Distinguished Career Development Assistant Professor
PhD, University of Michigan
Systems and control in neural medicine, nonlinear and constrained control, physiologic network dynamics, stochastic control

Zachary Feinstein (https://engineering.wustl.edu/Profiles/Pages/Zachary-Feinstein.aspx)
PhD, Princeton University
Financial engineering, operations research, variational analysis

Humberto Gonzalez
PhD, University of California, Berkeley
Cyber-physical systems, hybrid dynamical systems, optimization, robotics

Matthew D. Lew (https://engineering.wustl.edu/Profiles/Pages/Matthew-Lew.aspx)
PhD, Stanford University
Microscopy, biophotonics, computational imaging, nano-optics

Jung-Tsung Shen (https://engineering.wustl.edu/Profiles/Pages/Jung-Tsung-Shen.aspx)
Das Family Distinguished Career Development Assistant Professor
PhD, Massachusetts Institute of Technology
Theoretical and numerical investigations on nanophotonics, optoelectronics, plasmonics, metamaterials

Xuan "Silvia" Zhang (https://engineering.wustl.edu/Profiles/Pages/Xuan-%28Silvia%29-Zhang.aspx)
PhD, Cornell University
Robotics, cyber-physical systems, hardware security, ubiquitous computing, embedded systems, computer architecture, VLSI, electronic design automation, control optimization, and biomedical devices and instrumentation

Senior Professors

I. Norman Katz
PhD, Massachusetts Institute of Technology
Numerical analysis, differential equations, finite element methods, locational equilibrium problems, algorithms for parallel computations

Paul S. Min
PhD, University of Michigan
Routing and control of telecommunication networks, fault tolerance and reliability, software systems, network management

William F. Pickard
PhD, Harvard University
Biological transport, electrophysiology, energy engineering

Daniel L. Rode
PhD, Case Western Reserve University
Optoelectronics and fiber optics, semiconductor materials, light-emitting diodes (LEDs) and lasers, semiconductor processing, electronics

Ervin Y. Rodin
PhD, University of Texas at Austin
Optimization, differential games, artificial intelligence, mathematical modeling

Barbara A. Shrauner
PhD, Harvard University (Radcliffe)
Plasma processing, semiconductor transport, symmetries of nonlinear differential equations

Donald L. Snyder
PhD, Massachusetts Institute of Technology
Communication theory, random process theory, signal processing, biomedical engineering, image processing, radar

Barry E. Spielman
PhD, Syracuse University
High-frequency/high-speed devices, RF & MW integrated circuits, computational electromagnetics

Tzyh Jong Tarn
DSc, Washington University
Quantum mechanical systems, bilinear and nonlinear systems, robotics and automation, life science automation

Professors of Practice

Dedric Carter
PhD, Nova Southeastern University
MBA, MIT Sloan School of Management

Dennis Mell
MS, University of Missouri-Rolla

Ed Richter
BSEE, Virginia Tech

Senior Lecturer

Martha Hasting
PhD, Saint Louis University

Lecturers

Randall Brown
PhD, Washington University

Randall Hoven
MS, Washington University

Vladimir Kurenok
PhD, Belarus State University (Minsk, Belarus)
Tsitsi Madziwa-Nussinov  
PhD, University of California, Los Angeles

Jason Trobaugh  
DSc, Washington University

Jinsong Zhang  
PhD, University of Miami  
Wireless communication systems, wireless sensor networks, target tracking/data fusion, machine learning/pattern classification

Research Professor

Julius Goldstein  
PhD, University of Rochester  
Auditory system, hearing perception, modeling auditory perception.

Research Associate Professor

David Corman  
PhD, University of Maryland  
Cyber Physical Systems (CPS), security for CPS, unmanned systems, manufacturing

Research Assistant Professor

Scott Marrus  
MD, PhD, Washington University School of Medicine  
Cardiac electrophysiology

Professors Emeriti

William M. Boothby  
PhD, University of Michigan  
Differential geometry and Lie groups, mathematical system theory

Lloyd R. Brown  
DSc, Washington University  
Automatic control, electronic instrumentation

David L. Elliott  
PhD, University of California, Los Angeles  
Mathematical theory of systems, nonlinear difference, differential equations

Marvin J. Fisher  
PhD, University of Illinois  
Energy conversion, power electronics

Robert O. Gregory  
DSc, Washington University  
Electronic instrumentation, microwave theory, circuit design

Degree Requirements

Please refer to the following sections for information about:
• Doctoral Degrees (p. 3)  
• MS in Electrical Engineering (p. 4)

• MS in Systems Science & Mathematics (p. 4)  
• MS in Data Analytics and Statistics (p. 5)  
• Master of Control Engineering (p. 5)  
• Master of Engineering in Robotics (p. 5)  
• Imaging Science & Engineering (p. 6)

Doctoral Degrees

Students pursuing the Doctor of Philosophy (PhD) or Doctor of Science (DSc) degrees in Electrical Engineering or Systems Science & Mathematics must complete a minimum of 72 credit hours of post-baccalaureate study consistent with the residency and other applicable requirements of Washington University in St. Louis and the Graduate School. These 72 units must consist of at least 36 units of course work and at least 24 units of research, and may include work done to satisfy the requirements of a master's degree in a related discipline. Up to 24 units for the PhD and 30 units for the DSc may be transferred to Washington University in St. Louis from another institution.

Following are stages to the completion of the requirements for a doctoral degree in the Department of Electrical & Systems Engineering. Each candidate for the degree must:
• Complete at least 36 hours of post-baccalaureate course work  
• Pass a written qualifying examination, to be taken before the second academic year of the program  
• Pass an oral preliminary research examination, to be completed within two years of passing the written qualifying examination, and at least one year prior to completion of the dissertation  
• Satisfy the general residency requirement for the Graduate School (PhD) or the School of Engineering & Applied Science (DSc)  
• Satisfy the general teaching requirement for PhD degrees offered by the Graduate School; no teaching requirement for the DSc  
• Write a doctoral dissertation that describes the results of original and creative research in a specialization within electrical engineering or systems science and mathematics  
• Pass a final oral examination in defense of the dissertation research  
• Take ESE 590 Electrical and Systems Engineering Graduate Seminar each semester

The doctoral degree should ordinarily take no more than five years to complete, for students who enter the program with a baccalaureate degree. While individual circumstances will vary, the typical timeline will be as follows:
• Year 1: Course work and written qualifying examination  
• Year 2: Course work, preliminary research, research advisory committee selection  
• Year 3: Course work and preliminary research examination
• Year 4: Research
• Year 5: Research, completion of dissertation, and final oral examination

Students who enter the program with a master’s degree may be able to shorten this timeline by one year or more.

Master’s Degrees

Either a thesis option or a course option may be selected for the master’s degree programs shown below. The special requirements for these options are as follows:

Course Option

This option is intended for those employed in local industry who wish to pursue a graduate degree on a part-time basis, or for full-time students who do not seek careers in research. Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree. Under the course option, students may not take ESE 599 Master’s Research, and with faculty permission may take up to 3 units of ESE 500 Independent Study for the MSEE program and up to 6 units of ESE 500 for the MSSSM, MSDAS, MCE and MER programs.

Thesis Option

This option is intended for those pursuing full-time study and engaged in research projects. Candidates for this degree must complete a minimum of 24 credit hours of course instruction and six (6) credit hours of thesis research (ESE 599). These six (6) credit hours of thesis research can be counted as part of the 15 graduate-level electrical engineering credit hours for the MSEE program and as part of electives for the MSSSM, MSDAS, MCE and MER programs. The student must write a master’s thesis and defend it in an oral examination.

MS in Electrical Engineering

Students pursuing the degree Master of Science in Electrical Engineering must complete a minimum of 30 credit hours of study consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science, and subject to the following departmental requirements.

• A minimum of 15 of these credit hours must be at the graduate level in electrical engineering subjects taught by the Department of Electrical & Systems Engineering (ESE).

The list of courses that may be used to satisfy the 15-credit graduate-level course requirement is:

- ESE 513 Convex Optimization and Duality Theory
- ESE 415 Optimization
- ESE 516 Optimization in Function Space
- ESE 520-529 Applied probability category
- ESE 530-539 Applied physics and electronics category
- ESE 540-549 Control category
- ESE 550-559 Systems category
- ESE 560-569 Computer engineering category
- ESE 570-579 Communications category
- ESE 580-589 Signal and image processing category
- ESE 599 Master’s Research (thesis option only, max 6 units)

• The remaining courses in the program may be selected from senior- or graduate-level courses in ESE or elsewhere in the university. Courses outside of ESE must be in technical subjects relevant to electrical engineering and require the department’s approval. Only one CSE graduate course which does not carry CSE graduate credit may be used to satisfy the MSEE degree.

- A maximum of one 500-level cross-listed ESE course, whose home department is outside of ESE, may be applied toward the 15-credit graduate-level requirement.
- At least 15 units of the 30 total units applied toward the MSEE degree must be in ESE courses which, if cross-listed, have ESE as the home department.
- A maximum of 6 credits may be transferred from another institution and applied toward the MSEE degree. Regardless of subject or level, all transfer courses are treated as electives and do not count toward the requirement of 15 credit hours of graduate-level electrical engineering courses.

- ESE 590 Electrical and Systems Engineering Graduate Seminar must be taken each semester. Master of Science students must attend at least three seminars per semester.
- The degree program must be consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science.
- Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree.

MS in Systems Science & Mathematics

The Master of Science in Systems Science & Mathematics is an academic master’s degree designed mainly for both full-time and part-time students interested in proceeding to the departmental full-time doctoral program and/or an industrial career.

• The MS degree requires 30 units, which may include optionally 6 units for thesis or independent study.
• Required courses (15 units) for the MS degree include:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESE 551</td>
<td>Linear Dynamic Systems I</td>
<td>3</td>
</tr>
<tr>
<td>ESE 553</td>
<td>Nonlinear Dynamic Systems</td>
<td>3</td>
</tr>
<tr>
<td>ESE 520</td>
<td>Probability and Stochastic Processes</td>
<td>3</td>
</tr>
<tr>
<td>ESE 415</td>
<td>Optimization</td>
<td>3</td>
</tr>
<tr>
<td>and one chosen from the following courses:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESE 524</td>
<td>Detection and Estimation Theory</td>
<td>3</td>
</tr>
<tr>
<td>or ESE 544</td>
<td>Optimization and Optimal Control</td>
<td></td>
</tr>
<tr>
<td>or ESE 545</td>
<td>Stochastic Control</td>
<td></td>
</tr>
</tbody>
</table>
or ESE 557  Hybrid Dynamic Systems

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESE 516</td>
<td>15</td>
</tr>
</tbody>
</table>

1. ESE 516 may be substituted for ESE 415.

- The remaining courses in the program may be selected from senior- or graduate-level courses in Electrical & Systems Engineering or elsewhere in the university. Courses outside of Electrical & Systems Engineering must be in technical subjects relevant to systems science and mathematics and require the department's approval.
- ESE 590 Electrical and Systems Engineering Graduate Seminar must be taken each semester. Master of Science students must attend at least three seminars per semester.
- The degree program must be consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science.
- Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree.

**MS in Data Analytics and Statistics**

The MS in Data Analytics and Statistics (MSDAS) is an academic master's degree designed for students interested in learning statistical techniques necessary to make informed decisions based on data analysis.

- The MSDAS degree requires 30 units, which may include optionally 6 units for thesis.
- Required courses (15 units) for the MS degree include:

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESE 520 Probability and Stochastic Processes</td>
<td>3</td>
</tr>
<tr>
<td>or Math 493 Probability</td>
<td></td>
</tr>
<tr>
<td>ESE 524 Detection and Estimation Theory</td>
<td>3</td>
</tr>
<tr>
<td>Math 494 Mathematical Statistics</td>
<td>3</td>
</tr>
<tr>
<td>CSE 514A Data Mining</td>
<td>3</td>
</tr>
<tr>
<td>or CSE 517A Machine Learning</td>
<td></td>
</tr>
<tr>
<td>or CSE 530S Database Management Systems</td>
<td></td>
</tr>
<tr>
<td>ESE 415 Optimization</td>
<td>3</td>
</tr>
<tr>
<td>or ESE 516 Optimization in Function Space</td>
<td></td>
</tr>
<tr>
<td>or ESE 518 Optimization Methods in Control</td>
<td></td>
</tr>
</tbody>
</table>

- Elective Courses (15 units): The 15 units of electives should be courses of a technical nature at the senior and graduate levels approved by the Program Director.
- 6 units may be transferred from another school as electives provided that the courses were not needed for the student's bachelor's degree.
- ESE 590 Electrical and Systems Engineering Graduate Seminar must be taken each semester.
- The degree program must be consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science.
- Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree.

**Master of Control Engineering**

The Master of Control Engineering (MCE) degree is a terminal professional degree designed for students interested in an industrial career.

- The MCE degree requires 30 units, which may include optionally 6 units for thesis or independent study.
- Required courses (15 units) for the MCE degree include:

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESE 441 Control Systems</td>
<td>3</td>
</tr>
<tr>
<td>ESE 543 Control Systems Design by State Space Methods</td>
<td>3</td>
</tr>
<tr>
<td>ESE 520 Probability and Stochastic Processes</td>
<td>3</td>
</tr>
<tr>
<td>or ESE 425 Random Processes and Kalman Filtering</td>
<td></td>
</tr>
<tr>
<td>or ESE 551 Linear Dynamic Systems I</td>
<td></td>
</tr>
<tr>
<td>or ESE 552 Linear Dynamic Systems II</td>
<td></td>
</tr>
<tr>
<td>or ESE 553 Nonlinear Dynamic Systems</td>
<td></td>
</tr>
<tr>
<td>or ESE 547 Robust and Adaptive Control</td>
<td></td>
</tr>
</tbody>
</table>

- Elective Courses (15 units): The 15 units of electives should be courses of a technical nature at the senior and graduate levels approved by the Program Director.
- 6 units may be transferred from another school as electives provided that the courses were not needed for the student's bachelor's degree.
- ESE 590 Electrical and Systems Engineering Graduate Seminar must be taken each semester.
- The degree program must be consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science.
- Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree.

**Master of Engineering in Robotics**

The principal goal of the Master of Engineering (MEng) in Robotics degree program is to prepare individuals for professional practice in robotics engineering by leveraging the technical skills developed in an undergraduate engineering or physical science program. It is designed to be completed in 1.5 years, but it can be completed over a longer time period on a part-time basis. In order to finish in 1.5 years, students should take three courses (9 units) each in fall and spring semesters and four courses (12 units) in the second fall semester. For this program, the supervised project (6 units) is optional.
• The degree requires 30 units. The courses must be 400-level or higher and they must include at least 15 units of 500-level courses.
• Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree.
• Required courses (12 units) for the MEng in Robotics degree include:
  
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESE 446</td>
<td>Robotics: Dynamics and Control (Spring)</td>
<td>3</td>
</tr>
<tr>
<td>ESE 447</td>
<td>Robotics Laboratory (Fall, Spring)</td>
<td>3</td>
</tr>
<tr>
<td>ESE 551</td>
<td>Linear Dynamic Systems I (Fall)</td>
<td>3</td>
</tr>
<tr>
<td>CSE 511A</td>
<td>Introduction to Artificial Intelligence</td>
<td>3</td>
</tr>
<tr>
<td>or CSE 517A</td>
<td>Machine Learning</td>
<td></td>
</tr>
<tr>
<td>ESE 590</td>
<td>Electrical and Systems Engineering Graduate Seminar (must be taken each semester)</td>
<td>0</td>
</tr>
</tbody>
</table>

  Total units 12

• Elective Courses (18 units): At least one elective course must be selected from each of the following three groups. Other courses may be selected as electives with the approval of the Program Director.

  Optimization and Simulation Group
  
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESE 403</td>
<td>Operations Research (Fall)</td>
<td>3</td>
</tr>
<tr>
<td>ESE 407</td>
<td>Analysis and Simulation of Discrete Event Systems (Spring)</td>
<td>3</td>
</tr>
<tr>
<td>ESE 415</td>
<td>Optimization (Spring)</td>
<td>3</td>
</tr>
</tbody>
</table>

  Control Engineering Group
  
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESE 441</td>
<td>Control Systems (Fall)</td>
<td>3</td>
</tr>
<tr>
<td>or MEMS 4301</td>
<td>Modeling, Simulation and Control (Spring)</td>
<td></td>
</tr>
<tr>
<td>ESE 444</td>
<td>Sensors and Actuators (Fall)</td>
<td>3</td>
</tr>
<tr>
<td>ESE 425</td>
<td>Random Processes and Kalman Filtering (Fall)</td>
<td>3</td>
</tr>
<tr>
<td>ESE 543</td>
<td>Control Systems Design by State Space Methods (Fall)</td>
<td>3</td>
</tr>
<tr>
<td>ESE 552</td>
<td>Linear Dynamic Systems II (Spring)</td>
<td>3</td>
</tr>
<tr>
<td>ESE 553</td>
<td>Nonlinear Dynamic Systems (Spring)</td>
<td>3</td>
</tr>
</tbody>
</table>

  Computer Science Group
  
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSE 511A</td>
<td>Introduction to Artificial Intelligence</td>
<td>3</td>
</tr>
<tr>
<td>CSE 517A</td>
<td>Machine Learning</td>
<td>3</td>
</tr>
<tr>
<td>CSE 520S</td>
<td>Real-Time Systems (Fall)</td>
<td>3</td>
</tr>
<tr>
<td>CSE 521S</td>
<td>Wireless Sensor Networks</td>
<td>3</td>
</tr>
<tr>
<td>CSE 546T</td>
<td>Computational Geometry</td>
<td>3</td>
</tr>
<tr>
<td>CSE 553S</td>
<td>Advanced Mobile Robotics (Spring)</td>
<td>3</td>
</tr>
<tr>
<td>CSE 556A</td>
<td>Human-Computer Interaction Methods (Fall)</td>
<td>3</td>
</tr>
<tr>
<td>CSE 568M</td>
<td>Imaging Sensors (Spring)</td>
<td>3</td>
</tr>
</tbody>
</table>

  CSE 559A    Computer Vision (Spring)  3

  • Project Course: The MEng program may include up to 6 units of project in the form of Independent Study as part of elective courses. The independent study could be in the form of a practicum or a special project and it requires approval from the Program Director.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESE 500</td>
<td>Independent Study (Fall, Spring and Summer)</td>
<td>var.</td>
</tr>
<tr>
<td>CSE 500</td>
<td>Independent Study (Fall, Spring and Summer)</td>
<td>var.</td>
</tr>
<tr>
<td>MEMS 500</td>
<td>Independent Study (Fall, Spring and Summer)</td>
<td>var.</td>
</tr>
</tbody>
</table>

Preparation for the MEng in Robotics Program

The required courses assume the following foundations in mechanical engineering and materials science, electrical engineering, systems engineering and computer science. Although they do not count toward the degree program, they are recommended for those students who lack these foundations.

• MEMS 255 Engineering Mechanics II (mechanical engineering and materials science foundation, fall and spring)
• ESE 351 Signals and Systems (electrical and systems engineering foundation, fall and spring)
• ESE 501N Programming Concepts and Practice (computer science foundation, fall)

Graduate Certificate in Imaging Science & Engineering

A certificate program in Imaging Science & Engineering (IS&E) is offered jointly by the departments of Electrical & Systems Engineering, Computer Science & Engineering, and Biomedical Engineering. Built on the strengths in imaging science throughout the university, this multidisciplinary program is constructed to expose students to the breadth of imaging research activities at Washington University. The requirements of the program vary by department, but are flexible in allowing students and their advisers to construct academic programs ideally suited to complement their individual research programs. Students in the program are brought together for a joint seminar course, and all students engage in a practicum in imaging science and engineering. For more information, please refer to either the Department of Electrical & Systems Engineering website (http://ese.wustl.edu) or contact the department directly.

Entering & Completing the Program

Graduate students in participating departments may apply for admission to the IS&E program. Admission requires graduate standing in a participating department, recommendations from
faculty participating in the program, and a demonstrated interest in aspects of imaging.

Upon the awarding of a graduate degree by their home department and by completing certain requirements of the program, students are awarded a certificate indicating their successful participation in the IS&E program. The requirements for receiving a certificate are: acceptance into the IS&E program, completion of core subjects as specified by the student's home department, completion of requirements for a graduate degree in the student's home department, participation in the tutorial seminar required for all students in the IS&E program, and completion of the practicum required of all students in the IS&E program.

Courses of Instruction

Fundamentals underlying imaging science and engineering and the application of these fundamentals to contemporary problems of importance form the theme of the program of instruction in the IS&E program. Topics that can be studied include:

- physics of sources, detectors and devices that yield image data
- instrumentation used to acquire image data
- mathematical models and methods for representing and understanding image data and images produced from such data
- conventional and model-based image processing, restoration and reconstruction
- image-based decision, estimation, cognition and control
- computer architectures, parallel computers, and specialized digital systems for processing and simulating image data
- physics, psychophysics, and technology of image display
- image digitization, compression, storage and transmission
- image representation, interpretation and evaluation

The IS&E program is structured around required and elective courses that are offered in the participating departments. Each participating department specifies required core courses for their students in the program. All students in the program take a tutorial seminar in imaging during their first year, and all participate in a practicum in which they are exposed to research having a strong imaging component.

Courses


E35 ESE 500 Independent Study

Opportunities for graduate students to explore possible areas of interest with individual faculty members. Coordinated study programs dealing with areas not covered by formal course work are possible. Independent study credit can be changed to research credit (ESE 599) any time during the semester if enrollment is appropriate. A final report must be submitted to the department. Credit variable, maximum 3 units.

E35 ESE 501 Mathematics of Modern Engineering I

Introductory mathematics for modern engineering, with emphasis on calculus. Prerequisite: ESE 318 and 319 or equivalent. Credit 3 units.

E35 ESE 502 Mathematics of Modern Engineering II

Continuation of ESE 501. Prerequisite: ESE 318 or equivalent. Credit 3 units.

E35 ESE 503 Operations Research

Introduction to the theory of operations research with emphasis on problem formulation. Prerequisite: ESE 318 and 319 or equivalent. Credit 3 units.

E35 ESE 510 Numerical Analysis

Techniques of solving ordinary differential equations with constant coefficients, Laplace’s Transform, solutions for the heat and wave equations, Laplace’s Equation, Legendre and Bessel Function, Introduction to function of a complex variable, conformal mapping, contour integrals. Prerequisites: ESE 318 and ESE 319 or ESE 317 or equivalent, or consent of instructor. Credit 3 units.

E35 ESE 512 Advanced Numerical Analysis

Special topics chosen from numerical solution of partial differential equations, integral equations, and vector optimization. Prerequisite: ESE 511 or consent of instructor. Credit 3 units.

E35 ESE 513 Convex Optimization and Duality Theory

Graduate introduction to convex optimization with emphasis on convex analysis and duality theory. Topics include: convex sets, convex functions, convex cones, convex conjugates, Fenchel-Moreau theorem, convex duality and biconjugation, directional derivatives, subgradients and subdifferentials, optimality conditions, ordered vector spaces, Hahn-Banach theorem, extension and separation theorems, minimax theorems, and vector and set optimization. Prerequisites: ESE 415, Math 4111. Credit 3 units.

E35 ESE 514 Calculus of Variations

Introduction to the theory and applications of the calculus of variations. Theory of functionals; variational problems for an unknown function; Euler’s equation; variable end-point problems; variational problems with subsidiary conditions; sufficient conditions for extrema: applications to optimum control and/or to...
other fields. A term project is required. Prerequisites: ESE 318 and 319 or ESE 317 or equivalent. Credit 3 units.

E35 ESE 516 Optimization in Function Space

E35 ESE 517 Partial Differential Equations
Linear and nonlinear first order equations. Characteristics, Classification of equations. Theory of the potential linear and nonlinear diffusion theory. Linear and nonlinear wave equations. Initial and boundary value problems. Transform methods. Integral equations in boundary value problems. Prerequisites: ESE 318 and 319 or equivalent or consent of instructor. Credit 3 units. EN: TU

E35 ESE 518 Optimization Methods in Control
The course is divided in two parts: convex optimization and optimal control. In the first part we cover applications of Linear Matrix Inequalities and Semi-Definite Programming to control and estimation problems. We also cover Multiparametric Linear Programming and its application to the Model Predictive Control and Estimation of linear systems. In the second part we cover numerical methods to solve optimal control and estimation problems. We cover techniques to discretize optimal control problems, numerical methods to solve them, and their optimality conditions. We apply these results to the Model Predictive Control and Estimation of nonlinear systems. Prerequisites: ESE 551, and ESE 415 or equivalent. Credit 3 units. EN: TU

E35 ESE 520 Probability and Stochastic Processes
Review of probability theory; models for random signals and noise; calculus of random processes; noise in linear and nonlinear systems; representation of random signals by sampling and orthonormal expansions. Poisson, Gaussian and Markov processes as models for engineering problems. Prerequisite: ESE 326. Credit 3 units. EN: TU

E35 ESE 521 Random Variables and Stochastic Processes I
Mathematical foundations of probability theory, including constructions of measures, Lebesque-measure, Lebesque-integral, Banach space property of Lp, basic Hilbert-space theory, conditional expectation. Kolmogorov's theorems on existence and sample-path continuity of stochastic processes. An in-depth look at the Wiener process. Filtrations and stopping times. Markov processes and diffusions, including semigroup properties and the Kolmogorov forward and backward equations. Prerequisites: ESE 520 or equivalent, Math 411. Credit 3 units.

E35 ESE 522 Special Topics in Applied Probability
This course covers advanced topics in probability, including stochastic processes, stochastic differential equations, optimal control theory, and applications in engineering and finance. Prerequisites: ESE 520. Credit 3 units. EN: TU

E35 ESE 523 Information Theory
Discrete source and channel model, definition of information rate and channel capacity, coding theorems for sources and channels, encoding and decoding of data for transmission over noisy channels. Corequisite: ESE 520. Credit 3 units. EN: TU

E35 ESE 524 Detection and Estimation Theory
Study of detection, estimation and modulation theory; detection of signals in noise; estimation of signal parameters; linear estimation theory. Kalman-Bucy and Wiener filters, nonlinear modulation theory, optimum angle modulation. Prerequisite: ESE 520. Credit 3 units. EN: TU

E35 ESE 525 Random Processes and Kalman Filtering
Review of probability and random variables; random processes; linear dynamic system response to stochastic inputs; mean square estimation; discrete and continuous Kalman filters; extended Kalman filter for nonlinear systems; maximum likelihood; Wiener filtering and special factorization, LQG/LTR control; topics in system identification; particle filters. Control, estimation (Kalman filter), and system identification problems using MATLAB. Prerequisite: ESE 529 or equivalent. Credit 3 units.

E35 ESE 526 Probability and Stochastic Processes
Review of probability theory; models for random signals and noise; calculus of random processes; noise in linear and nonlinear systems; representation of random signals by sampling and orthonormal expansions. Poisson, Gaussian and Markov processes as models for engineering problems. Prerequisite: ESE 326. Credit 3 units. EN: TU

E35 ESE 527 Detection and Estimation Theory
Study of detection, estimation and modulation theory; detection of signals in noise; estimation of signal parameters; linear estimation theory. Kalman-Bucy and Wiener filters, nonlinear modulation theory, optimum angle modulation. Credit 3 units. EN: TU

E35 ESE 528 Special Topics in Applied Probability
This course covers advanced topics in probability, including stochastic processes, stochastic differential equations, optimal control theory, and applications in engineering and finance. Prerequisites: ESE 520. Credit 3 units. EN: TU

E35 ESE 530 Information Theory
Discrete source and channel model, definition of information rate and channel capacity, coding theorems for sources and channels, encoding and decoding of data for transmission over noisy channels. Corequisite: ESE 520. Credit 3 units. EN: TU

E35 ESE 531 Nano and Micro Photonics
This course focuses on the following topics: light and photons, statistical properties of photon sources, temporal and spatial correlations, light-matter interactions, optical nonlinearity, atoms and quantum dots, single- and two-photon devices, optical devices, and applications of nano-photonic devices in quantum and classical computing and communication. Prerequisites: ESE 330 and Physics 217, or permission of instructor. Credit 3 units. EN: TU

E35 ESE 532 Introduction to Nano-Photonic Devices
Introduction to photon transport in nano-photonic devices. This course focuses on the following topics: light and photons, statistical properties of photon sources, temporal and spatial correlations, light-matter interactions, optical nonlinearity, atoms and quantum dots, single- and two-photon devices, optical devices, and applications of nano-photonic devices in quantum and classical computing and communication. Prerequisites: ESE 330 and Physics 217, or permission of instructor. Credit 3 units. EN: TU

E35 ESE 533 Special Topics in Advanced Electrodynamics
This course covers advanced topics in electrodynamics. Topics include electromagnetic wave propagation (in free space, confined waveguides, or along engineered surfaces); electromagnetic wave scattering (off nano-particles or molecules); electromagnetic wave generation and detection (antenna and nano-antenna); inverse scattering problems; and numerical and approximate methods. Prerequisites: ESE 330, or Physics 421 and Physics 422. Credit 3 units. EN: TU
E35 ESE 536 Introduction to Quantum Optics
This course covers the following topics: quantum mechanics for quantum optics, radiative transitions in atoms, lasers, photon statistics (photon counting, Sub-/Super-Poissonian photon statistics, bunching, anti-bunching, theory of photodetection, shot noise), entanglement, squeezed light, atom-photon interactions, cold atoms, atoms in cavities. If time permits, the following topics are selectively covered: quantum computing, quantum cryptography, and teleportation. Prerequisites: ESE 330 and Physics 217 or Physics 421. Credit 3 units. EN: TU

E35 ESE 537 Advanced Electromagnetic Theory
Solution of electromagnetic boundary value problems, applications to engineering analysis and design. First semester: mathematical methods for electrostatics, magnetostatics and electrodynamics, emphasizing Green's function techniques. Second semester: radiation and diffraction; waveguides, antennas and optics. Vector boundary conditions, Green's dyadics, variational techniques. Prerequisite: advanced calculus, ESE 430 or equivalent. Credit 3 units. EN: TU

E35 ESE 538 Advanced Electromagnetic Engineering
This course begins with a brief review of prerequisite topics. The following topics are treated for guided-wave systems: solution for and use of mode sets in planar and cylindrical guided-wave systems; use of alternative mode sets for inhomogeneous guided-wave systems; dielectric-based and surface-guided wave systems. Methods for launching waves in systems are studied, including: modal expansions, current-based launchers using electric or magnetic coupling techniques, and aperture excitation. Perturbational and variational methods are studied for representing important characteristics of guided-wave and resonator systems. Modal expansions are related to a one- and two-port microwave network treatment of obstacles and circuit elements and junctions in guide-wave systems. The course then shifts to the study of modern numerical methods for developing frequency- and time-domain solutions for guided-wave and two-dimensional radiation and scattering problems encountered in electromagnetic engineering applications. The methods learned are applied to a project selected and carried out by each student. Prerequisites: equivalent of ESE 330, ESE 430, and ESE 537 or instructor permission. Credit 3 units.

E35 ESE 543 Control Systems Design by State Space Methods
Advanced design and analysis of control systems by state-space methods: classical control review, Laplace transforms, review of linear algebra (vector space, change of basis, diagonal and Jordan forms), linear dynamic systems (modes, stability, controllability, state feedback, observability, observers, canonical forms, output feedback, separation principle and decoupling), nonlinear dynamic systems (stability, Lyapunov methods). Frequency domain analysis of multivariable control systems. State space control system design methods: state feedback, observer feedback, pole placement, linear optimal control. Design exercises with CAD (computer-aided design) packages for engineering problems. Prerequisite: ESE 351 and ESE 441, or permission of instructor. Credit 3 units. EN: TU

E35 ESE 544 Optimization and Optimal Control
Constrained and unconstrained optimization theory. Continuous time as well as discrete-time optimal control theory. Time-optimal control, bang-bang controls and the structure of the reachable set for linear problems. Dynamic programming, the Pontryagin maximum principle, the Hamiltonian-Jacobi-Bellman equation and the Riccati partial differential equation. Existence of classical and viscosity solutions. Application to time optimal control, regulator problems, calculus of variations, optimal filtering and specific problems of engineering interest. Prerequisites: ESE 551, ESE 552. Credit 3 units. EN: TU

E35 ESE 545 Stochastic Control

E35 ESE 546 Dynamics & Control in Neuroscience & Brain Medicine
This course provides an introduction to systems engineering approaches to modeling, analysis and control of neuronal dynamics at multiple scales. A central motivation is the manipulation of neuronal activity for both scientific and medical applications using emerging neurotechnology and pharmacology. Emphasis is placed on dynamical systems and control theory, including bifurcation and stability analysis of single neuron models and population mean-field models. Synchronization properties of neuronal networks are covered and methods for control of neuronal activity in both oscillatory and non-oscillatory dynamical regimes are developed. Statistical models for neuronal activity are also discussed. An overview of signal processing and data analysis methods for neuronal recording modalities is provided, toward the development of closed-loop neuronal control paradigms. The final evaluation is based on a project or research survey. Prerequisite(s): ESE 553 (or equivalent); ESE 520 (or equivalent); ESE 351 (or equivalent). Credit 3 units. EN: TU
E35 ESE 547 Robust and Adaptive Control
Graduate-level control system design methods for multi-input multi-output systems. Linear optimal-based methods in robust control, nonlinear model reference adaptive control. These design methods are currently used in most industry control system design problems. These methods are designed, analyzed and simulated using MATLAB. Linear control theory (review), robustness theory (Mu Analysis), optimal control and the robust servomechanism, H-infinity optimal control, robust output feedback controls, Kalman filter theory and design, linear quadratic gaussian with loop transfer recovery, the Loop Transfer Recovery method of Lavretsky, Mu synthesis, Lyapunov theory (review), LaSalle extensions, Barbalat's Lemma, model reference adaptive control, artificial neural networks, online parameter estimation, convergence and persistence of excitation. Prerequisite: ESE 543 or ESE 551 or equivalent. Credit 3 units. EN: TU

E35 ESE 549 Special Topics in Control
Credit 3 units.

E35 ESE 551 Linear Dynamic Systems I
Input-output and state-space description of linear dynamic systems. Solution of the state equations and the transition matrix. Controllability, observability, realizations, pole-assignment, observers and decoupling of linear dynamic systems. Prerequisite: ESE 351. Credit 3 units. EN: TU

E35 ESE 552 Linear Dynamic Systems II

E35 ESE 553 Nonlinear Dynamic Systems
State space and functional analysis approaches to nonlinear systems. Questions of existence, uniqueness and stability; LaSalle's and frequency-domain criteria; w-limits and invariance, center manifold theory and applications to stability, steady-state response and singular perturbations. Poincare-Bendixson theory, the van der Pol oscillator, and the Hopf Bifurcation theorem. Prerequisite: ESE 551. Credit 3 units. EN: TU

E35 ESE 554 Advanced Nonlinear Dynamic Systems

E35 ESE 557 Hybrid Dynamic Systems
Theory and analysis of hybrid dynamic systems, which is the class of systems whose state is composed by continuous-valued and discrete-valued variables. Discrete-event systems models and language descriptions. Models for hybrid systems. Conditions for existence and uniqueness. Stability and verification of hybrid systems. Optimal control of hybrid systems. Applications to cyber-physical systems and robotics. Prerequisite: ESE 551. Credit 3 units. EN: TU

E35 ESE 559 Special Topics in Systems
Credit 3 units.

E35 ESE 560 Computer Systems Architecture I
An exploration of the central issues in computer architecture: instruction set design, addressing and register set design, control unit design, microprogramming, memory hierarchies (cache and main memories, mass storage, virtual memory), pipelining, bus organization, RISC (Reduced Instruction Set Computers), and CISC (Complex Instruction Set Computers). Architecture modeling and evaluation using VHDL and/or instruction set simulation. Prerequisites: CSE 361S and CSE 260M. Same as E81 CSE 560M. Credit 3 units. EN: TU

E35 ESE 561 Computer Systems Architecture II
Advanced techniques in computer system design. Selected topics from: processor design (multithreading, VLIW, data flow, chip-multiprocessors, application specific processors, vector units, large MIMD machines), memory systems (topics in locality, prefetching, reconfigurable and special-purpose memories), system specification and validation, and interconnection networks. Prerequisites: CSE 560M or permission of instructor. Same as E81 CSE 561M Credit 3 units. EN: TU

E35 ESE 564 Advanced Digital Systems Engineering
This course focuses on advance sensor design. The class covers various basic analog and digital building blocks that are common in most sensor integrated circuits. The class extensively uses state-of-the-art CAD program Cadence to simulate and analyze various circuit blocks. The first half of the course focuses on analyzing various operational amplifiers, analog filters, analog memory and analog to digital converters. The second half of the course focuses on understanding the basic building blocks of imaging sensors. The class has a final project composed of designing a smart sensor using Cadence tools. Prerequisites: ESE 232 and CSE 362M. Same as E81 CSE 564M Credit 3 units. EN: TU

E35 ESE 565 Acceleration of Algorithms in Reconfigurable Logic
Same as E81 CSE 565M Credit 3 units. EN: TU

E35 ESE 566A Modern System-on-Chip Design
The System-on-Chip (SoCs) technology is at the core of most electronic systems: smart phones, wearable devices, autonomous robots, and cars, aerospace or medical electronics. In these SoCs, billions of transistors can be integrated on a
single silicon chip, containing various components such as microprocessors, DSPs, hardware accelerators, memories, and I/O interfaces. Topics include SoC architectures, design tools and methods, as well as system-level tradeoffs between performance, power consumption, energy efficiency, reliability and programmability. Students gain an insight into the early stage of the SoC design process performing the tasks of developing functional specification, partition and map functions onto hardware and/or software, and evaluating and validating system performance. Assignments include hands-on design projects. Open to both graduate and senior undergraduate students. Prerequisite: ESE 260. Credit 3 units. EN: TU

E35 ESE 567 Computer Systems Analysis
Comparing systems using measurement, simulation and queueing models. Common mistakes and how to avoid them, selection of techniques and metrics, art of data presentation, summarizing measured data, comparing systems using sample data, introduction to experimental design, fractional factorial designs, introduction to simulation, common mistakes in simulations, analysis of simulation results, random number generation, random variate generation, commonly used distributions, introduction to queueing theory, single queues, and queueing networks. The techniques of the course can be used to analyze and compare any type of systems including algorithms, protocols, network or database systems. Students do a project involving application of these techniques to a problem of their interest. Prerequisites: CSE 131 and CSE 260M. Same as E81 CSE 567M Credit 3 units. EN: TU

E35 ESE 569 Parallel Architectures and Algorithms
Several contemporary parallel computer architectures are reviewed and compared. The problems of process synchronization and load balancing in parallel systems are studied. Several selected applications problems are investigated and parallel algorithms for their solution are considered. Selected parallel algorithms are implemented in both a shared memory and distributed memory parallel programming environment. Prerequisites: graduate standing and knowledge of the C programming language. Same as E81 CSE 569M Credit 3 units. EN: TU

E35 ESE 570 Coding Theory
Introduction to the algebra of finite fields. Linear block codes, cyclic codes, BCH and related codes for error detection and correction. Encoder and decoder circuits and algorithms. Spectral descriptions of codes and decoding algorithms. Code performances. Credit 3 units. EN: TU

E35 ESE 571 Transmission Systems and Multiplexing
Transmission and multiplexing systems are essential to providing efficient point-to-point communication over distance. This course introduces the principles underlying modern analog and digital transmission and multiplexing systems and covers a variety of system examples. Credit 3 units. EN: TU

E35 ESE 572 Signaling and Control in Communication Networks
The operation of modern communications networks is highly dependent on sophisticated control mechanisms that direct the flow of information through the network and oversee the allocation of resources to meet the communication demands of end users. This course covers the structure and operation of modern signaling systems and addresses the major design trade-offs that center on the competing demands of performance and service flexibility. Specific topics covered include protocols and algorithms for connection establishment and transformation, routing algorithms, overload and failure recovery and networking dimensioning. Case studies provide concrete examples and reveal the key design issues. Prerequisites: graduate standing and permission of instructor. Credit 3 units. EN: TU

E35 ESE 574 Digital Communications
Representation of signals by orthonormal expansion, spectral characteristic of digitally modulated signals, channel models, source models, results from information theory, efficient signaling with coded waveforms, intersymbol interference, equalization, optimum demodulation, decoding (including Viterbi decoder), probability of error, carrier and symbol synchronization, spread-spectrum methods. Corequisite: ESE 520. Credit 3 units. EN: TU

E35 ESE 575 Fiber-Optic Communications
Introduction to optical communications via glass-fiber media. Pulse-code modulation and digital transmission methods, coding laws, receivers, bit-error rates. Types and properties of optical fibers; attenuation, dispersion, modes, numerical aperture. Light-emitting diodes and semiconductor laser sources; device structure, speed, brightness, modes, electrical properties, optical and spectral characteristics. Prerequisites: ESE 330, ESE 336. Credit 3 units. EN: TU

E35 ESE 577 Design and Analysis of Switching Systems
Networks
Optimal allocation of resources to meet the communication demands of end users. This course covers the structure and operation of modern signaling systems and addresses the major design trade-offs that center on the competing demands of performance and service flexibility. Specific topics covered include protocols and algorithms for connection establishment and transformation, routing algorithms, overload and failure recovery and networking dimensioning. Case studies provide concrete examples and reveal the key design issues. Prerequisites: graduate standing and permission of instructor. Credit 3 units. EN: TU

E35 ESE 577 Design and Analysis of Switching Systems
Switching is a core technology in a wide variety of communication networks, including the internet, circuit-switched telephone networks and optical fiber transmission networks. The last decade has been a time of rapid development for switching technology in the internet. Backbone routers with 10 Gb/s links and aggregate capacities of hundreds of gigabits per second are becoming common, and advances in technology are now making multi-terabit routers practical. This course is concerned with the design of practical switching systems and evaluation of their performance and complexity. Prerequisites: CSE 247, 473S and ESE 326. Same as E81 CSE 577M Credit 3 units. EN: TU

E35 ESE 581 Radar Systems
E35 ESE 582 Fundamentals and Applications of Modern Optical Imaging

Analysis, design, and application of modern optical imaging systems with emphasis on biological imaging. First part of the course focuses on the physical principles underlying the operation of imaging systems and their mathematical models. Topics include ray optics (speed of light, refractive index, laws of reflection and refraction, plane surfaces, mirrors, lenses, aberrations), wave optics (amplitude and intensity, frequency and wavelength, superposition and interference, interferometry), Fourier optics (space-invariant linear systems, Huygens-Fresnel principle, angular spectrum, Fresnel diffraction, Fraunhofer diffraction, frequency analysis of imaging systems), and light-matter interaction (absorption, scattering, dispersion, fluorescence). Second part of the course compares modern quantitative imaging technologies including, but not limited to, digital holography, computational imaging, and super-resolution microscopy. Students evaluate and critique recent optical imaging literature. Prerequisites: ESE 318 and ESE 319 or their equivalents; ESE 330 or Physics 421 or equivalent. Credit 3 units. EN: TU

E35 ESE 584 Statistical Signal Processing for Sensor Arrays

Methods for signal processing and statistical inference for data acquired by an array of sensors, such as those found in radar, sonar and wireless communications systems. Multivariate statistical theory with emphasis on the complex multivariate normal distribution. Signal estimation and detection in noise with known statistics, signal estimation and detection in noise with unknown statistics, direction finding, spatial spectrum estimation, beam forming, parametric maximum-likelihood techniques. Subspace techniques, including MUSIC and ESPRIT. Performance analysis of various algorithms. Advanced topics may include structured covariance estimation, wideband array processing, array calibration, array processing with polarization diversity, and space-time adaptive processing (STAP). Prerequisites: ESE 520, ESE 524, linear algebra, computer programming. Credit 3 units. EN: TU

E35 ESE 585 Optical Imaging

A modern introduction to optical imaging. Topics include: propagation of waves, diffraction, scattering theory, multiple scattering and radiative transport, diffuse light, inverse scattering and other inverse problems, near-field optics. Applications to biomedical problems are discussed. Prerequisites: ESE 330 and ESE 351. Credit 3 units. EN: TU

E35 ESE 586 Tomographic Systems


Application to positron-emission, single-photon emission, X-ray and magnetic-resonance tomography and to high-resolution radar-imaging. Computer architectures for producing tomographic imagery. Prerequisite: ESE 520. Credit 3 units. EN: TU

E35 ESE 587 Ultrasonic Imaging

Propagation of ultrasound in homogeneous media, near-field and far-field descriptions, refraction and diffraction, dispersive media models, acoustic wave equation formulations and solutions. Basic elements of transducer, pulser and receiver design. The use of linear versus logarithmic amplifiers. Time-gain compensation, scan conversion and image generation in single-transducer systems. Phased-array imaging systems. Synthetic-aperture acquisition, synthetic-focus image generation. Ellipsoidal back projection using the complete dataset. Design of restoration filters to compensate for diffraction effects of the transducer. Estimation of media properties from images. Prerequisite: ESE 351. Credit 3 units. EN: TU

E35 ESE 588 Quantitative Image Processing

Introduction to the modeling processing and display of images. Two-dimensional linear systems and linear processing of images. Two-dimensional transform methods. Image acquisition and display technology. Psychophysical aspects of vision. Case studies in image processing (examples: tomography, radiology, ultrasonic imaging). Special algorithms for image processing (examples: boundary detection, segmentation, compression, interactive processing and display). Prerequisites: ESE 326, ESE 482. Credit 3 units. EN: TU

E35 ESE 589 Biological Imaging Technology

This class develops a fundamental understanding of the physics and mathematical methods that underlie biological imaging and critically examine case studies of seminal biological imaging technology literature. The physics section examines how electromagnetic and acoustic waves interact with tissues and cells, how waves can be used to image the biological structure and function, image formation methods, and diffraction limited imaging. The math section examines image decomposition using basis functions (e.g., Fourier transforms), synthesis of measurement data, image analysis for feature extraction, reduction of multidimensional imaging datasets, multivariate regression, and statistical image analysis. Original literature on electron, confocal and two photon microscopy, ultrasound, computed tomography, functional and structural magnetic resonance imaging and other emerging imaging technology are critiqued. Credit 3 units. EN: TU

E35 ESE 590 Electrical and Systems Engineering Graduate Seminar

This pass/fail course is required for the MSc, DSc and PhD degrees in Electrical & Systems Engineering. A passing grade is required for each semester of enrollment and is received by attendance at regularly scheduled ESE seminars. MSc students must attend at least three seminars per semester. DSc and PhD students must attend at least five seminars per semester. Part-time students are exempt except during their year of residency. Any student under continuing status is also exempt. Seminars missed in a given semester may be made up during the subsequent semester.
E35 ESE 596 Seminar in Imaging Science and Engineering
This seminar course consists of a series of tutorial lectures on Imaging Science and Engineering with emphasis on applications of imaging technology. Students are exposed to a variety of imaging applications that vary depending on the semester, but may include multispectral remote sensing, astronomical imaging, microscopic imaging, ultrasound imaging and tomographic imaging. Guest lecturers come from several parts of the university. This course is required of all students in the Imaging Science and Engineering program; the only requirement is attendance. This course is graded pass/fail. Prerequisite: admission to Imaging Science and Engineering program. Same as CSE 596 (when offered) and BME 506. Credit 1 unit.

E35 ESE 597 Practicum in Imaging Science and Engineering
This course provides students in the Imaging Science and Engineering program with opportunities to participate, early in their graduate studies, in projects involving image data. A list of IS&E faculty having potential projects of interest is provided. It is the student’s responsibility to interview with such faculty in order to identify a project for themselves to be completed in one semester. A written report documenting the project goals, relevant literature and results obtained is required at the end of the project. To receive credit for completing the practicum, the report must be accepted by the supervisor of the project and a committee of IS&E faculty. This course is graded pass/fail. Prerequisite: admission to Imaging Science and Engineering program. Credit 1 unit. EN: TU

E35 ESE 599 Master’s Research
Credit variable, maximum 3 units.

E35 ESE 600 Doctoral Research
Credit variable, maximum 9 units.

E35 ESE 883 Master’s Continuing Student Status

E35 ESE 884 Doctoral Continuing Student Status

E35 ESE 885 Master’s Nonresident

E35 ESE 886 Doctoral Nonresident