Electrical & Systems Engineering

Phone:	314-935-5565
Website:	https://ese.wustl.edu/academics/undergraduate-programs/index.html

Courses

Visit online course listings to view semester offerings for E35 ESE.

E35 ESE 105 Introduction to Electrical and Systems Engineering
This course will offer students a rigorous introduction to fundamental mathematical underpinnings of ESE and their relationship to a number of contemporary application areas. Major emphasis will be placed on linear algebra and associated numerical methods, including the use of MATLAB. Topics covered will include vector spaces, linear transformations, matrix manipulations and eigenvalue decomposition. Students will learn how this mathematical theory is enacted in ESE through the completion of four case studies spanning application areas: (i) Dynamical Systems and Control, (ii) Imaging, (iii) Signal Processing, and (iv) Circuits.
Credit 4 units. EN: TU

E35 ESE 2001 Experience Research in ESE
This course provides students with an initial exposure to research in ESE. This is a mentored experience and requires the agreement of an ESE faculty member to serve in a mentorship role. Students must identify a mentor and obtain their agreement before registering for this course. Activities are to be designed by the student in conjunction with the faculty mentor, and will amount to 2-4 hours of commitment per week. Examples of such activities include, but are not limited to, observation of laboratory experiments, attendance of weekly group meetings, discussions with the mentor, or independent readings. The course is suitable for students at all levels.
Credit 1 unit.

E35 ESE 205 Introduction to Engineering Design
This is a hands-on course in which students, in groups of two or three, will creatively develop projects and solve problems throughout the semester using tools from electrical and systems engineering. Groups will work under the supervision of an academic team consisting of faculty and higher-level students. Project objectives will be set by the academic team in collaboration with each student group. Evaluation will consider completion of these objectives as well as the originality and innovation of the projects. A weekly 90-minute lab with the academic team is required. Prerequisites: CSE 131, Physics 197, or equivalent. Corequisite Course(s): ESE 105, Phy192
Credit 3 units. EN: TU

E35 ESE 217 Differential Equations and Dynamical Systems Modeling in Engineering
This course will provide students with an introduction to differential equations in the context of electrical and systems engineering. Students will gain a foundation in the use of differential equations to describe, model and engineer systems and devices. The course will cover fundamental mathematical principles of ordinary differential equations including: (i) existence of solutions, (ii) elementary solution strategies, and (iii) the conceptual foundation for frequency domain solution techniques. An introduction to early concepts in dynamical systems theory, such as state-space analysis, equilibria and stability, will also be provided. Finally, students will obtain an initial introduction to partial differential equations in ESE in the context of wave propagation. Mathematical developments will be closely accompanied by computational implementations and numerical simulations. Further, students will engage several case studies, in which students will use the mathematical theory to perform analysis and design within ESE contexts spanning systems, circuits and applied physics. Prerequisites: ESE 105
Credit 3 units.

E35 ESE 2180 Linear Algebra and Component Analysis
Linear algebra is the foundation of scientific computing across many disciplines of engineering. This course will introduce the numerical and computational issues that arise from solving large-scale problems, with motivation from data science, machine learning, and signal processing. Topics to be covered include least-squares problems, eigenvalue/eigenvector analysis, singular value decomposition, component analysis, rotation of bases, and concepts of computational complexity and numerical stability. A focus of the class will be studying concepts from signal processing and machine learning such as K-means, Fourier analysis, wavelet analysis, and sampling within the framework of linear algebra. The course will include case studies touching on a broad range of topics including systems science, signals and imaging, devices and circuits, and quantum science/applied physics. Prerequisites: Linear algebra at the level of ESE 105; familiarity with Matlab.
Credit 3 units.

E35 ESE 2190 Vector Calculus and Dynamics of Physical Systems
This course will explore fundamental concepts in vector calculus and partial differential equations with a focus on their practical applications and conceptual understanding. We will derive the Laplace, diffusion, and wave equations and explore their solutions in different coordinate systems. The course will emphasize computational solutions and data visualization in case studies involving applications to areas such as electrostatics, heat conduction in solids , transmission lines, antennas, and wave propagation, providing hands-on experience in solving partial differential equations in real-world scenarios. Prerequisites: ESE 217 or Math 217, and ESE 2180, or permission of the instructor
Credit 3 units.

E35 ESE 230 Introduction to Electrical and Electronic Circuits
Electrical energy, current, voltage, and circuit elements. Resistors, Ohm's Law, power and energy, magnetic fields and DC motors. Circuit analysis and Kirchhoff's voltage and current laws. Thevenin and Norton transformations and the superposition theorem. Measuring current, voltage and power using ammeters and voltmeters. Energy and maximum electrical power transfer. Computer simulations of circuits. Reactive circuits, inductors, capacitors, mutual inductance, electrical transformers, energy storage, and energy conservation. RL, RC and RLC circuit transient responses. AC circuits, complex impedance, RMS current and voltage. Electrical signal amplifiers and basic operational amplifier circuits. Inverting, non-inverting, and difference amplifiers. Voltage gain, current gain, input impedance, and output impedance. Weekly laboratory exercises related to the lectures are an essential part of the course. Prerequisite: L31 Phys192 and 192L Corequisite: L24 Math 217
Credit 4 units. EN: TU

E35 ESE 232 Introduction to Electronic Circuits
Analysis and design of linear and nonlinear electronic circuits. Detailed analysis of operational amplifier circuits, including non-ideal characteristics. Terminal characteristics of active semiconductor devices. Incremental and DC models for diodes, metal-oxide-semiconductor field effect transistors (MOSFETs), and bipolar junction transistors (BJTs). Design and analysis of single- and multi-stage

amplifiers. Introduction to CMOS logic as well as static and dynamic memory circuits. Students will be required to design, analyze, build and demonstrate several of the circuits studied, including frequency response analysis and use of simulation tools. Prerequisite: ESE 230.
Credit 3 units. EN: TU

E35 ESE 260 Introduction to Digital Logic and Computer Design
Introduction to design methods for digital logic and fundamentals of computer architecture. Boolean algebra and logic minimization techniques; sources of delay in combinational circuits and effect on circuit performance; survey of common combinational circuit components; sequential circuit design and analysis; timing analysis of sequential circuits; use of computer-aided design tools for digital logic design (schematic capture, hardware description languages, simulation); design of simple processors and memory subsystems; program execution in simple processors; basic techniques for enhancing processor performance; configurable logic devices.
Prerequisites: CSE 131
Same as E81 CSE 260M
Credit 3 units. EN: TU

E35 ESE 2971 Introduction to Research in ESE
This course provides students with an introductory experience with research in ESE. This is a mentored experience and requires the agreement of an ESE faculty member to serve in a mentorship role. Students must identify a mentor and obtain their agreement before registering for this course. Activities are to be designed by the student in conjunction with the faculty mentor, and will amount to 4-6 hours of commitment per week. The research activities will enable the student to gain a deeper understanding of ongoing research related to the mentor's field, or in an area mutually agreed upon by the mentor and the student. The student may also have an opportunity to actively participate in ongoing research activities, such as through assistance of graduate students or postdoctoral associates. Because activities may be unstructured, this course is will require strong time-management skills and self-discipline. The final grade will be determined on the basis of a set of deliverables that are agreed upon by the student and faculty member.
Credit 2 units.

E35 ESE 3050 Special Topics in Robotics: Practicum in Robotic Systems Design
This is an exciting hands-on course where teams of students (in groups of 4-6) will put a broad range of their engineering skills to use by designing, constructing, and debugging a complex electro-mechanical robotic system. The robotic system will be targeted at some proposed real-world application. Each team will engineer and implement their own solution to the problem. This course is designed to teach students how to apply their theory-based classroom engineering knowledge by exposing students to the design/test/debug/iterate process needed to develop a working integrated system. Some of the topics/skills experienced in the class will include feedback control, real sensor/actuator implementation, circuit design/layout, soldering, asynchronous programming, project management, Design-For-Manufacturability, and more. Students will use the WUSTL Maker Space in this class to learn other valuable hands-on skills (e.g. CAD, CNC machining, 3D printing, laser cutting, etc.). This course will consist of one weekly lecture and a weekly lab component. Course Prerequisites: ESE205 or instructor permission
Credit 3 units. EN: TU

E35 ESE 3090 Special Topics in Systems Engineering: Modeling and Design of Social Choice Systems
Social choice systems are all around us, from how we decide to split the check to who becomes president. This course introduces many conceptual and computational problems in the study of systems of social choice and offers a variety of tools to understand them. We will consider both micro and macro social choice systems; for the latter drawing on modern statistical techniques to understand (and reframe) questions like "what is a fair map of congressional districts?" In order to address modeling and design challenges in social choice systems we will explore mathematical and software tools such as game theory, linear optimization, Monte Carlo / MCMC methods, and geographical data representation in Python. Prerequisites: ESE 105, or Math 309, or working knowledge of linear algebra and scientific computing, or permission of instructor.
Credit 3 units.

E35 ESE 318 Engineering Mathematics A
Laplace transforms; matrix algebra; vector analysis; eigenvalues and eigenvectors; vector differential calculus and vector integral calculus in three dimensions. Prerequisites: Math 233 and Math 217 or their equivalents.
Credit 3 units.

E35 ESE 319 Engineering Mathematics B
Power series and Frobenius series solutions of differential equations; Legendre's equation; Bessel's equation; Fourier series and Fourier transforms; Sturm-Liouville theory; solutions of partial differential equations; wave and heat equations. Prerequisites: Math 233 and Math 217 or their equivalents.
Credit 3 units.

E35 ESE 326 Probability and Statistics for Engineering
Study of probability and statistics together with engineering applications. Probability and statistics: random variables, distribution functions, density functions, expectations, means, variances, combinatorial probability, geometric probability, normal random variables, joint distribution, independence, correlation, conditional probability, Bayes theorem, the law of large numbers, the central limit theorem. Applications: reliability, quality control, acceptance sampling, linear regression, design and analysis of experiments, estimation, hypothesis testing. Examples are taken from engineering applications. Prerequisites: Math 233 or equivalent.
Credit 3 units. EN: TU

E35 ESE 330 Engineering Electromagnetics Principles
Electromagnetic theory as applied to electrical engineering: vector calculus; electrostatics and magnetostatics; Maxwell's equations, including Poynting's theorem and boundary conditions; uniform plane-wave propagation; transmission lines, TEM modes, including treatment of general lossless lines, and pulse propagation; introduction to guided waves; introduction to radiation and scattering concepts.Prerequisites: Physics 198 and ESE 318 En Math A. Co-requisite: ESE 319 En Math B.
Credit 3 units. EN: BME T, TU

E35 ESE 3301 Electromagnetics Laboratory: Spectrum from Radio to Photonics
Engineering electromagnetics focuses on applying electromagnetic theory to modern technologies including communication, sensing, imaging and medical engineering. This laboratory course provides students with hands-on and practical exposure to the topics covering the electromagnetic spectrum from microwave to optics. Weekly labs will cover topics such as the following: microwave propagation and coupling, transmission line, antenna, RF circuits, basic optoelectronic devices, Fourier optics, light microscopy, holography,

light polarization, electro-optics and fiber optics. Students are expected to carry out tests and measurements; analyze, interpret and present experiment data; learn how to perform engineering analysis and design when electromagnetic principles are applied; and gain in-depth understanding of the physics and mathematics underlying the techniques. Corequisite: E35 ESE 330, E35 ESE 351
Credit 3 units. EN: BME T, TU

E35 ESE 331 Electronics Laboratory
Laboratory exercises provide students with a combination of hands-on experience involving electronic circuits. Students will use a variety of real instruments, analysis techniques and circuit simulation tools to summarize measurement results in written reports that clearly communicate laboratory results. A sequence of lab experiments provide hands-on experience in: properties of diodes and transistors, realistic operational amplifier characteristics, grounding and shielding techniques, signal analysis, and op amp based active filter design and characterization. Students will gain experience working with: sampling oscilloscopes to make measurements in the time and frequency domains, signal generators, digital multimeter and frequency measurements, and in creating circuits and making connections on contemporary circuit boards. The course concludes with a hands-on project to design, demonstrate and document the design of an electronic component. Prerequisite: ESE 232
Credit 3 units. EN: BME T, TU

E35 ESE 332 Power, Energy, and Polyphase Circuits
Fundamental concepts of power and energy; electrical measurements; physical and electrical arrangement of electrical power systems; polyphase circuit theory and calculations; principal elements of electrical systems such as transformers, rotating machines, control, and protective devices, their description and characteristics; elements of industrial power system design. Prerequisite: ESE 230.
Credit 3 units. EN: BME T, TU

E35 ESE 351 Signals and Systems
This course presents an introduction to concepts and methodology of linear dynamic systems in relation to discrete- and continuous-time signals. Topics include mathematical modeling; representation of systems and signals; Fourier, Laplace, and Z-transforms and convolution; input-output description of linear systems, including impulse response and transfer function; time-domain and frequency-domain system analysis, including transient and steady-state responses, system modes, stability, frequency spectra, and frequency responses; and system design, including filter, modulation, and sampling theorem. Continuity is emphasized from analysis to synthesis. MATLAB will be used. Prerequisites: Physics 117A-118A, Math 217, CSE 131, Matlab, matrix addition and multiplication, and ESE 105 or ESE 230; Corequisite: ESE 318.
Credit 3 units. EN: BME T, TU

E35 ESE 359 Signals, Data and Equity
This course introduces the design of classification and estimation systems for equity -- that is, with the goal of reducing the inequities of racism, sexism, xenophobia, ableism, and other systems of oppression. Systems that change the allocation of resources among people can increase inequity due to their inputs, the systems themselves, or how the systems interact in the context in which they are deployed. This course presents background in power and oppression to help predict how new technological and societal systems might interact and when they might confront or reinforce existing power systems. Measurement theory -- the study of the mismatch between a system's intended measure and the data it actually uses -- is covered. Multiple examples of sensing and classification systems that operate on people (e.g., optical, audio, and text sensors) are covered by implementing algorithms and quantifying inequitable outputs. Prerequisite: ESE 105 or CSE 217A or CSE 417T. Background readings will be available.
Credit 3 units. EN: BME T, TU

E35 ESE 362 Computer Architecture
This course explores the interaction and design philosophy of hardware and software for digital computer systems. Topics include: Processor architecture, Instruction Set Architecture, Assembly Language, memory hierarchy design, I/O considerations, and a comparison of computer architectures. Prerequisite: CSE 260M.
Same as E81 CSE 362M
Credit 3 units. EN: BME T, TU

E35 ESE 400 Independent Study
Opportunities to acquire experience outside the classroom setting and to work closely with individual members of the faculty. A final report must be submitted to the department. Not open to first-year or graduate students. Consult adviser. Hours and credit to be arranged.
Credit variable, maximum 3 units.

E35 ESE 401 Fundamentals of Engineering Review
A review and preparation of the most recent NCEES Fundamentals of Engineering (FE) Exam specifications is offered in a classroom setting. Exam strategies will be illustrated using examples. The main topics for the review include: engineering mathematics, statics, dynamics, thermodynamics, heat transfer, mechanical design and analysis, material science and engineering economics. A discussion of the importance and responsibilities of professional engineering licensure along with ethics will be included.
Same as E37 MEMS 4001
Credit 1 unit.

E35 ESE 403 Operations Research
Introduction to the mathematical aspects of various areas of operations research, with additional emphasis on problem formulation. This is a course of broad scope, emphasizing both the fundamental mathematical concepts involved, and also aspects of the translation of real-world problems to an appropriate mathematical model. Subjects to be covered include linear and integer programming, network problems, and dynamic programming. Prerequisites: CSE 131, Math 309, and ESE 326, or permission of instructor.
Credit 3 units. EN: BME T, TU

E35 ESE 4031 Optimization for Engineered Planning, Decisions and Operations
The goal of the course is to introduce students to discrete optimization and decision-making methods as well as their application domains ranging from finance to robotics. This course will cover linear programming, integer programming, and dynamic programming from theoretical and application perspectives. Special emphasis will be given on modeling real-world problems as optimization problems as well as on designing techniques to address them. The use of methods will be demonstrated on numerous concrete examples (e.g., scheduling, operation management, robot planning and control) solved using MatLab or Python. Prerequisites: E35 ESE 105 (or both E81 CSE 131 and L24 Math 309), L24 Math 217; E35 ESE 326; or permission of the instructor.
Credit 3 units. EN: BME T, TU

E35 ESE 404 Applied Operations Research
Application of operations research techniques to real-world problems. Emphasis is given to integer linear programming and computational methods. Real-world examples of integer programs will be studied in areas such as network flow, facility location, partitioning, matching, and transporation. Special emphasis will be placed on techniques used to solve integer programs. Prerequisites: ESE 403 and CSE 131.
Credit 3 units. EN: BME T, TU

E35 ESE 405 Reliability and Quality Control
An integrated analysis of reliability and quality control function in manufacturing. Statistical process control, acceptance sampling, process capability analysis, reliability prediction, design, testing, failure analysis and prevention, maintainability, availability, and safety are discussed and related. Qualitative and quantitative aspects of statistical quality control and reliability are introduced in the context of manufacturing. Prerequisite: ESE 326 or equivalent.
Credit 3 units. EN: BME T, TU

E35 ESE 415 Optimization
Optimization problems with and without constraints. The projection theorem. Notions of convexity. Lagrange multipliers and Kuhn-Tucker-type conditions. Duality. Computational methods. Applications of optimization in engineering. Prerequisites: Solid understanding of multivariable calculus notions, including gradients. Solid understanding of linear algebraic concepts, including eigen decomposition (eigenvalues & eigenvectors), matrix algebraic operations, and properties of symmetric matrices.
Credit 3 units. EN: BME T, TU

E35 ESE 417 Introduction to Machine Learning and Pattern Classification
This course provides a broad introduction to machine learning and statistical pattern classification. Students will study theoretical foundations of learning and several important supervised and unsupervised machine learning methods and algorithms, including linear model of regression and classification, logistic regression, Bayesian learning methods, neural networks, nearest neighbor method, support vector machines methods, clustering methods and principal component analysis. Students will also learn to use Python programming language to implement learned models and methods to solve pattern classification problems. Prerequisites: ESE 326, Math 233, and Python programming experience.
Credit 3 units. EN: BME T, TU

E35 ESE 419 Special Topics in Optimization and Learning
Credit 3 units. EN: TU

E35 ESE 425 Random Processes and Kalman Filtering
Probability and random variables; random processes, autocorrelation, power spectral density; transient and steady-state analysis of linear dynamic systems and random inputs, filters, state-space, discretization; optimal estimation; the discrete Kalman filter; linearization and the extended Kalman filter for nonlinear dynamic systems; related MATLAB exercises. Prerequisite: ESE 326 and ESE 351 or equivalent.
Credit 3 units. EN: BME T, TU

E35 ESE 4261 Statistical Methods for Data Analysis with Applications to Financial Engineering
Introduction to modern methods of statistical data analysis. Data will be used primarily from the financial industry. The course is both computational and mathematical in nature. Most facts will be stated in a rigorous manner, motivated by applications and justified at an intuitive level, but usually not proven rigorously. Emphasis will be on the relevance of concepts and the practical use of tools. A broad range of topics will be covered, including some standard techniques of univariate and multivariate data analysis (histograms, kernel density estimators, Q-Q plots), Monte Carlo simulations and calculations, analysis of heavy tailed data, use of copulas, various parametric and non-parametric regression models, both local and nonlocal, as well as analysis of time series data and Kalman filtering. Methods will be demonstrated on numerous concrete examples, with extensive use of the programming language R. Prerequisite: ESE 326
Credit 3 units. EN: BME T, TU

E35 ESE 427 Financial Mathematics
This course is a self-contained introduction to financial mathematics at the undergraduate level. Topics to be covered include pricing of the financial instruments such as options, forwards, futures and their derivatives along with basic hedging techniques and portfolio optimization strategies. The emphasis is put on using of discrete, mostly binary models. The general, continuous case including the concepts of Brownian motion, stochastic integral, and stochastic differential equations, is explained from intuitive and practical point of view. Among major results discussed are the Arbitrage Theorem and Black-Scholes differential equations and their solutions. Prerequisites: ESE 326 or the consent of the instructor.
Credit 3 units. EN: BME T, TU

E35 ESE 429 Basic Principles of Quantum Optics and Quantum Information
This course provides an accessible introduction to quantum optics and quantum engineering for undergraduate students. This course covers the following topics: Concept of photons, quantum mechanics for quantum optics, radiative transitions in atoms, lasers, photon statistics (photon counting, Sub-/Super-Poissionian photon statistics, bunching, anti-bunching, theory of photodetection, shot noise), entanglement, squeezed light, atom-photon interactions, cold atoms, atoms in cavities. The course will also provide an overview for quantum information processing: quantum computing, quantum cryptography, and teleportation. Prerequisite Course: ESE 318 or equivalent.
Credit 3 units. EN: BME T, TU

E35 ESE 4301 Quantum Mechanics for Engineers
This course provides an accessible introduction to quantum mechanics and quantum engineering for undergraduate students. Examples are drawn from practical areas of applications of quantum engineering. This course covers the following topics and examples: quantum mechanics and nano-technology, Schrodinger's equation, electron transport in various potential profiles, quantum dots and defects, harmonic oscillator, nano-mechanical oscillator and quantum LC circuit, Stark effect in semiconductors, Bloch theorem, crystal and band structures, Kronig-Penney and tight-binding models, semiclassical and quantum descriptions of light-atom interactions, spontaneous and stimulated emissions, quantum flip-flops, approximate methods in quantum mechanics, spin, quantum gyroscope, spin transistor, and many-particle quantum mechanics for bosons and fermions. Prerequisites: Simple differential equations and matrix algebra at the level of ESE 318/319 Engineering Mathematics A/B or equivalent and familiarity with a modern scientific computing software package (e.g., MATLAB, Mathematica).
Credit 3 units. EN: BME T, TU

E35 ESE 431 Introduction to Quantum Electronics
Describing the flow of electrical current in nanodevices involves a lot more than just quantum mechanics; it requires an appreciation of some of the most advanced concepts of non-equilibrium statistical mechanics. In the past decades, electronic devices have been shrinking steadily to nanometer dimensions, and quantum transport has accordingly become increasingly important not only to physicists but

also to electrical engineers. Traditionally, these topics are spread out over many physics/chemistry/engineering courses that take many semesters to cover. The main goal of this course is to condense the essential concepts into a one-semester course that is accessible to both senior-level undergraduate and junior-level graduate students. This course will be accessible to students with diverse backgrounds in electrical engineering, physics, chemistry, biomedical engineering, and mathematics. Prerequisites: Math 217 or ESE 217, and ESE 105 or ESE 2180 or Math 309, and scientific computing ability, e.g., Matlab or Mathematica, or permission of instructor.
Credit 3 units. Art: NSM EN: TU

E35 ESE 433 Radio Frequency and Microwave Technology for Wireless Systems
Focus is on the components and associated techniques employed to implement analog and digital radio frequency (RF) and microwave (MW) transceivers for wireless applications, including: cell phones; pagers; wireless local area networks; global positioning satellite based devices; and RF identification systems. A brief overview of system-level considerations is provided, including modulation and detection approaches for analog and digital systems; multiple-access techniques and wireless standards; and transceiver architectures. Focus is on RF and MW: transmission lines; filter design; active component modeling; matching and biasing networks; amplifier design; and mixer design. Prerequisite: ESE 330.
Credit 3 units. EN: BME T, TU

E35 ESE 434 Solid-State Power Circuits and Applications
Study of the strategies and applications power control using solid-state semiconductor devices. Survey of generic power electronic converters. Applications to power supplies, motor drives, and consumer electronics. Introduction to power diodes, thyristors, and MOSFETs. Prerequisites: ESE 232, 351.
Credit 3 units. EN: BME T, TU

E35 ESE 435 Electrical Energy Laboratory
Experimental studies of principles important in modern electrical energy systems. Topics include: AC power measurements, electric lighting, photovoltaic cells and arrays, batteries, DC-DC and DC-AC converters, brushed and brushless DC motors and three-phase circuits. Each experiment requires analysis, simulation with MultiSim, and measurement via LabVIEW and the Elvis II platform. Prerequisites: ESE 230 and 351
Credit 3 units. EN: BME T, TU

E35 ESE 436 Semiconductor Devices
This course covers the fundamentals of semiconductor physics and operation principles of modern solid-state devices such as homo- or hetero-junction diodes, solar cells, inorganic/organic light-emitting diodes, bipolar junction transistors, and metal-oxide-semiconductor field-effect transistors. These devices form the basis for today's semiconductor and integrated circuit industry. In addition to device physics, semiconductor device fabrication processes, new materials, and novel device structures will also be briefly introduced. At the end of this course, students will be able to understand the characteristics, operation, limitations and challenges faced by state-of-the-art semiconductor devices. This course will be particularly useful for students who wish to develop careers in the semiconductor industry. Prerequisite: ESE 232.
Credit 3 units. EN: BME T, TU

E35 ESE 438 Applied Optics
Topics relevant to the engineering and physics of conventional as well as experimental optical systems and applications explored. Items addressed include geometrical optics, Fourier optics such as diffraction and holography, polarization and optical birefringence such as liquid crystals, and nonlinear optical phenomena and devices. Prerequisite: ESE 330 or equivalent.
Credit 3 units. EN: BME T, TU

E35 ESE 439 Introduction to Quantum Communications
This course covers the following topics: quantum optics, single-mode and two-mode quantum systems, nonlinear optics, and quantum systems theory. Specific topics include the following: Dirac notation quantum mechanics; harmonic oscillator quantization; number states, coherent states, and squeezed states; direct, homodyne, and heterodyne detection; linear propagation loss; phase insensitive and phase sensitive amplifiers; entanglement and teleportation; field quantization; quantum photodetection; phase-matched interactions; optical parametric amplifiers; generation of squeezed states, photon-twin beams, non-classical fourth-order interference, and polarization entanglement; optimum binary detection; quantum precision measurements; and quantum cryptography. Prerequisites: ESE 330, or PHY 421; Physics 217 or equivalent.
Credit 3 units. EN: TU

E35 ESE 441 Control Systems
Introduction to the theory and practice of automatic control for dynamical systems. Dynamical systems as models for physical and observed phenomena. Mathematical representation of dynamical systems, such as state-space differential and difference equations, transfer functions, and block diagrams. Analysis of the time evolution of a system in response to control inputs, steady-state and transient responses, equilibrium points and their stability. Control via linear state feedback, and estimation using Leunberger observers. Relating the time response of a system to its frequency response, including Bode and Nyquist plots. Input-output stability and its relation to the stability of equilibrium points. Simple frequency-based controllers, such as PID and lead-lag compensators. Exercise involving the use of MATLAB/Simulink (or equivalent) to simulate and analyze systems. Prerequisites: CSE 131, and either ESE 351 or MEMS 431.
Credit 3 units. EN: BME T, TU

E35 ESE 444 Sensors and Actuators
The course provide engineering students with basic understanding of two of the main components of any modern electrical or electromechanical system; sensors as inputs and actuators as outputs. The covered topics include transfer functions, frequency responses and feedback control. Component matching and bandwidth issues. Performance specification and analysis, Sensors: analog and digital motion sensors, optical sensors, temperature sensors, magnetic and electromagnetic sensors, acoustic sensors, chemical sensors, radiation sensors, torque, force and tactile sensors. Actuators: stepper motors, DC and AC motors, hydraulic actuators, magnet and electromagnetic actuators, acoustic actuators. Introduction to interfacing methods: bridge circuits, A/D and D/A converters, microcontrollers. This course is useful for those students interested in control engineering, robotics and systems engineering. Prerequisites: one of the following 4 conditions:(1) ESE 230, ESE 351 (corequisite); (2) ESE 230, ESE 318 and MEMS 255; (3) ESE 351 or MEMS 4310; (4) permission of instructor.
Credit 3 units. EN: BME T, TU

E35 ESE 446 Robotics: Dynamics and Control
Homogeneous coordinates and transformation matrices. Kinematic equations and the inverse kinematic solutions for manipulators, the manipulator Jacobian and the inverse Jacobian. General model for robot arm dynamics, complete dynamic coefficients for six-link

manipulator. Synthesis of manipulation control, motion trajectories, control of single- and multiple-link manipulators, linear optimal regulator. Model reference adaptive control, feedback control law for the perturbation equations along a desired motion trajectory. Design of the control system for robotics. Prerequisites: ESE 351 or MEMS 4310, knowledge of a programming language. Corequisite: ESE 441 or MEMS 4301
Credit 3 units. EN: BME T, TU

E35 ESE 448 Systems Engineering Laboratory
This course involves the experimental study of real and simulated systems and their control. Topics include identification, input-output analysis, and design and implementation of control systems; noise effects; and the design and implementation of control laws for specific engineering problems. Knowledge of a programming language is expected. Corequisite: ESE 441 or permission of instructor.
Credit 3 units. EN: BME T, TU

E35 ESE 4480 Control Systems Design Laboratory
This course involves the experimental study of real and simulated systems and their control. Topics covered will include modeling; identification; model validation and control of systems, including noise effects, using a two-link robotic manipulator as an experimental testbed; mathematical modeling of robotic systems; nonlinear and linearized models; input-output and state-space techniques; model validation and simulation; and stabilization using linear and nonlinear control techniques. Prerequisite: ESE 351 or MEMS 4310. Corequisite or prerequisite: ESE 441 or MEMS 4301
Credit 3 units. EN: BME T, TU

E35 ESE 4481 Autonomous Aerial Vehicle Control Laboratory
This course covers the integration of dynamical systems and control engineering principles toward the manipulation of a quadrotor unmanned aerial vehicle (UAV), sometimes referred to as a drone. Students will analytically transform a nonlinear description of the UAV system used for dynamic simulation into a conventional, linear state space system. Students will use key control engineering concepts -- including system identification, state estimation and control synthesis -- to command their UAVs to hover, climb, and orbit. In addition to principles of estimation and identification, students will learn about the theory of guidance and navigation, with projects such as flight planning and execution, collision avoidance, and competitive or cooperative tasks (e.g., formation flight). The overall objective is to expose students to the fusion of control, estimation, and identification techniques that are fundamental to systems theory. Prerequisites: ESE 441 and knowledge of a programming language, or permission of instructor.
Credit 3 units. EN: BME T, TU

E35 ESE 449 Digital Process Control Laboratory
Applications of digital control principles to laboratory experiments supported by a networked distributed control system. Lecture material reviews background of real-time programming, data acquisition, process dynamics, and process control. Exercises in data acquisition and feedback control design using simple and advanced control strategies. Experiments in flow, liquid level, temperature, and pressure control. Term project. Prerequisite: E35 ESE 441 or E44 EECE 401 or permission of instructor
Same as E44 EECE 424
Credit 3 units. EN: BME T, TU

E35 ESE 460 Switching Theory
Advanced topics in switching theory as employed in the synthesis, analysis, and design of information processing systems. Combinational techniques: minimization, multiple output networks, state identification and fault detection, hazards, testability and design for test are examined. Sequential techniques: synchronous circuits, machine minimization, optimal state assignment, asynchronous circuits, and built-in self-test techniques. Prerequisite: CSE 260M
Same as E81 CSE 460T
Credit 3 units. EN: BME T, TU

E35 ESE 461 Design Automation for Integrated Circuit Systems
Integrated circuit systems provide the core technology that power today's most advanced devices and electronics: smart phones, wearable devices, autonomous robots, and cars, aerospace or medical electronics. These systems often consist of silicon microchips made up by billions of transistors and contain various components such as microprocessors, DSPs, hardware accelerators, memories, and I/O interfaces, therefore design automation is critical to tackle the design complexity at the system level. The objectives of this course is to 1) introduce transistor-level analysis of basic digital logic circuits; 2) provide a general understanding of hardware description language (HDL) and design automation tools for very large scale integrated (VLSI) systems; 3) expose students to the design automation techniques used in the best-known academic and commercial systems. Topics covered include device and circuits for digital logic circuits, digital IC design flow, logic synthesis, physical design, circuit simulation and optimization, timing analysis, power delivery network analysis. Assignments include homework, mini-projects, term paper and group project. Prerequisites: ESE 232; ESE 260.
Credit 3 units. EN: BME T, TU

E35 ESE 462 Computer Systems Design
Introduction to modern design practices, including FPGA and PCB design methodologies. Student teams use Xilinx Vivado for HDL-based FPGA design and simulation and do schematic capture, PCB layout, fabrication, and testing of the hardware portion of a selected computation system. The software portion of the project uses Microsoft Visual Studio to develop a user interface and any additional support software required to demonstrate final projects to the faculty during finals week. Prerequisites: CSE 361S and 362M from Washington University in St. Louis or permission of the instructor. Revised: 2019-02-22
Same as E81 CSE 462M
Credit 3 units. EN: BME T, TU

E35 ESE 463 Digital Integrated Circuit Design and Architecture
This is a project-oriented course on digital VLSI design. The course material focuses on bottom-up design of digital integrated circuits, starting from CMOS transistors, CMOS inverters, combinational circuits and sequential logic designs. Important design aspects of digital integrated circuits such as propagation delay, noise margins and power dissipation are covered in the class, and design challenges in sub-micron technology are addressed. The students design combinational and sequential circuits at various levels of abstraction using a state-of-the-art CAD environment provided by Cadence Design Systems. The goal of the course is to design a microprocessor in 0.5 micron technology that will be fabricated by a semiconductor foundry. Prerequisites: CSE 260M and ESE 232.
Same as E81 CSE 463M
Credit 3 units. EN: BME T, TU

E35 ESE 465 Digital Systems Laboratory
Hardware/software co-design; processor interfacing; procedures for reliable digital design, both combinational and sequential; understanding manufacturers' specifications; use of test equipment. Several single-period laboratory exercises, several design projects, and application of microprocessors in digital design. One lecture and one laboratory period a week. Prerequisites: ESE 260
Credit 3 units. EN: BME T, TU

E35 ESE 467 Embedded Computing Systems
This course introduces the issues, challenges, and methods for designing embedded computing systems -- systems designed to serve a particular application and which incorporate the use of digital processing devices. Examples of embedded systems include cellular phones, appliances, game consoles, automobiles, and drones. Emphasis is given to aspects of design that are distinct to embedded systems. The course examines hardware, software, and system-level design. Hardware topics include microcontrollers, digital signal processors, memory hierarchy, and I/O. Software issues include languages, run-time environments, and program analysis. System-level topics include real-time operating systems, scheduling, power management, and wireless sensor networks. Students will perform a course project on a real embedded system testbed. Prerequisites: CSE 260M (and either CSE 132 or ESE 205).
Same as E81 CSE 467S
Credit 3 units. EN: TU

E35 ESE 469 Fundamentals of Machine Learning Hardware
Thsi course provides an overview of machine learning algorithms and hardware; inference engines; training engines; emerging hardware architectures; performance analysis; and testing of machine learning accelerators. Prerequisites: ESE 417 or equivalent, ESE 260 or equivalent, and working knowledge of MATLAB.
Credit 3 units. EN: BME T, TU

E35 ESE 471 Communications Theory and Systems
Introduction to the concepts of transmission of information via communication channels. Amplitude and angle modulation for the transmission of continuous-time signals. Analog-to-digital conversion and pulse code modulation. Transmission of digital data. Introduction to random signals and noise and their effects on communication. Optimum detection systems in the presence of noise. Elementary information theory. Overview of various communication technologies such as radio, television, telephone networks, data communication, satellites, optical fiber, and cellular radio. Prerequisites: ESE 351 and ESE 326.
Credit 3 units. EN: BME T, TU

E35 ESE 474 Introduction to Wireless Sensor Networks
This is an introductory course on wireless sensor networks for senior undergraduate students. The course will use a combination of lecturing and reading and discussion of research papers to help each student to understand the characteristics and operations of various wireless sensor networks. Topics covered include sensor network architecture, communication protocols on Medium Access Control and Routing, sensor network operation systems, sensor data aggregation and dissemination, localization and time synchronization, energy management, and target detection and tracking using acoustic sensor networks. Prerequisite: ESE 351 (Signals and Systems)
Credit 3 units. EN: BME T, TU

E35 ESE 482 Digital Signal Processing
Introduction to analysis and synthesis of discrete-time linear time-invariant (LTI) systems. Discrete-time convolution, discrete-time Fourier transform, z-transform, rational function descriptions of discrete-time LTI systems. Sampling, analog-to-digital conversion, and digital processing of analog signals. Techniques for the design of finite impulse response (FIR) and infinite impulse response (IIR) digital filters. Hardware implementation of digital filters and finite-register effects. The Discrete Fourier Transform and the Fast Fourier Transform (FFT) algorithms. Prerequisite: ESE 351.
Credit 3 units. EN: BME T, TU

E35 ESE 488 Signals and Imaging Laboratory
Hands-on design and analysis that motivates ESE research and courses in signals, communications and imaging. Projects in digital audio signal processing, communication systems, and computational imaging and inverse problems in optics. Prerequisite: ESE 351.
Credit 3 units. EN: BME T, TU

E35 ESE 497 Undergraduate Research
Undergraduate research under the supervision of a faculty member. The scope and depth of the research must be approved by the faculty member prior to enrollment. Final deliverables include a poster presentation at a departmental event, submission of the poster in electronic form for archiving, and written documentation at the discretion of the instructor.
Credit variable, maximum 3 units.

E35 ESE 4971 Honors Thesis Research
This is the premier research experience for students in ESE, offering a challenging but rewarding opportunity for committed students to work at the cutting edge of engineering research. This is a mentored experience and requires the agreement of an ESE faculty member to serve in a mentorship role. To register for this course, students must obtain the nomination of two faculty members, including their proposed mentor. Nomination must reflect strong academic preparation, interest in research and ability to manage time and work independently. During this course, students will work within their mentor's research group or laboratory to pursue one or more specific research aims. Research is expected to result in a podium presentation and a thesis document that will be archived. Students completing honors thesis will participate in a departmental recognition event.
Credit 4 units.

E35 ESE 498 Electrical Engineering Capstone Design Projects
Capstone design project supervised by the course instructor. The project must use the theory, techniques, and concepts of the student's major: electrical engineering or systems science & engineering. The solution of a real technological or societal problem is carried through completely, starting from the stage of initial specification, proceeding with the application of engineering methods, and terminating with an actual solution. Collaboration with a client, typically either an engineer or supervisor from local industry or a professor or researcher in university laboratories, is encouraged. A proposal, an interim progress update, and a final report are required, each in the forms of a written document and oral presentation, as well as a Web page on the project. Weekly progress reports and meetings with the instructor are also required. Prerequisite: ESE senior standing and instructor's consent. Note: this course will meet at the scheduled time only during select weeks. If you cannot attend at that time, you may still register for the course.
Credit 3 units. EN: BME T, TU

E35 ESE 499 Systems Science and Engineering Capstone Design Project
Capstone design project supervised by the course instructor. The project must use the theory, techniques, and concepts of the student's major: electrical engineering or systems science & engineering. The solution of a real technological or societal problem is carried through completely, starting from the stage of initial specification, proceeding with the application of engineering methods, and terminating with an actual solution. Collaboration with a client, typically either an engineer or supervisor from local industry or a professor or researcher in university laboratories, is encouraged. A proposal, an interim progress update, and a final report are required, each in the forms of a written document and oral presentation, as well as a Web page on the project. Weekly progress reports and meetings with the instructor are also required. Prerequisite: ESE senior standing and instructor's consent. Note: this course will meet at the scheduled time only during select weeks. If you cannot attend at that time, you may still register for the course.
Credit 3 units. EN: BME T, TU

E35 ESE 500 Independent Study
Opportunities to acquire experience outside the classroom setting and to work closely with individual members of the faculty. A final report must be submitted to the department. Prerequisite: Students must have the ESE Research/Independent Study Registration Form approved by the department.
Credit variable, maximum 3 units.

E35 ESE 5001 Research Rotation for ESE Masters Students
Masters students in Electrical and Systems Engineering may complete a rotation their first semester with research mentors acceptable to the Department. The rotations must be mutually agreeable to both the student and faculty member. The grade will be assigned based on a written report from the rotation. The rotation allows students to sample different research projects and laboratory working environments, to enable matching masters students and research mentors with whom they will carry out thesis research.
Credit 3 units.

E35 ESE 501 Mathematics of Modern Engineering I
Matrix algebra: systems of linear equations, vector spaces, linear independence and orthogonality in vector spaces, eigenvectors and eigenvalues; Vector calculus: gradient, divergence, curl, line and surface integrals, theorems of Green, Stokes, and Gauss; Elements of Fourier analysis and its applications to solving some classical partial differential equations, heat, wave, and Laplace equation. Prerequisite: ESE 318 and ESE 319 or equivalent or consent of instructor. This course will not count toward the ESE doctoral program.
Credit 3 units. EN: BME T, TU

E35 ESE 502 Mathematics of Modern Engineering II
This course covers Fourier series and Fourier integral transforms and their applications to solving some partial differential equations and heat and wave equations. It also presents complex analysis and its applications to solving real-valued problems, including analytic functions and their role, Laurent series representation, complex-valued line integrals and their evaluation (including the residual integration theory), and conformal mappings and their applications. Prerequisites: ESE 318 and ESE 319 or equivalent, or permission of instructor. This course will not count toward the ESE doctoral program.
Credit 3 units. EN: BME T, TU

E35 ESE 513 Large-Scale Optimization for Data Science
Large-scale optimization is an essential component of modern data science, artificial intelligence, and machine learning. This graduate-level course rigorously introduces optimization methods that are suitable for large-scale problems arising in these areas. Students will learn several algorithms suitable for both smooth and nonsmooth optimization, including gradient methods, proximal methods, mirror descent, Nesterov's acceleration, ADMM, quasi-Newton methods, stochastic optimization, variance reduction, and distributed optimization. Throughout the course, we will discuss the efficacy of these methods in concrete data science problems, under appropriate statistical models. Students will be required to program in Python or MATLAB. Prerequisites: CSE 247, Math 309, (Math 3200 or ESE 326), ESE 415.
Credit 3 units. EN: TU

E35 ESE 520 Probability and Stochastic Processes
This course covers a 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; and Poisson, Gaussian, and Markov processes as models for engineering problems. Prerequisite: ESE 326.
Credit 3 units. EN: BME T, 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: BME T, TU

E35 ESE 524 Detection and Estimation Theory
Study of detection and estimation of signals in noise. Linear algebra, vector spaces, independence, projections. Data independence, factorization theorem and sufficient statistics. Neyman-Pearson and Bayes detection. Least squares, maximum-likelihood and maximum a posteriori estimation of signal parameters. Conjugate priors, recursive estimation, Wiener and Kalman filters. Prerequisite: ESE 520.
Credit 3 units. EN: BME T, TU

E35 ESE 527 Practicum in Data Analytics & Statistics
In this course, students will learn through hands-on experience the application of analytics to support data-driven decisions. Through lectures and the execution of a project (to be defined at the beginning of the semester), students will learn to use descriptive, predictive, and prescriptive analytics. Lectures will focus on presenting analytic topics relevant to the execution of the project, including analytic model development, data quality and data models, review of machine learning algorithms (unsupervised, supervised, and semi-supervised approaches), model validation, insights generation and results communication, and code review and code repository. Students are expected to demonstrate the application of these concepts through the execution of a one-semester project. Students can propose their own projects or choose from a list of projects made available by the lecturer. Projects should reflect real-world problems with a clear value proposition. Progress will be evaluated and graded periodically during the semester, and the course will include a final presentation open to the academic community. Prerequisites: ESE 520 (or Math 493 and 494), ESE 417 or CSE 417T, ESE 415, and declaration of the MS in DAS.
Credit 3 units. EN: BME T, TU

E35 ESE 531 Nano and Micro Photonics
This course focuses on fundamental theory, design, and applications of photonic materials and micro/nano photonic devices. It includes review and discussion of light-matter interactions in nano and micro scales, propagation of light in waveguides, nonlinear optical effect and optical properties of nano/micro structures, the device principles of waveguides, filters, photodetectors, modulators and lasers. Prerequisite: ESE 330.
Credit 3 units. EN: BME T, 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. Prerequisite: ESE 330 and Physics 217, or permission of instructor.
Credit 3 units. EN: BME T, TU

E35 ESE 5331 Nanophotonic Optical Media - From Metamaterials to Photonic Crystals and Beyond
The nanometer length scale holds a unique significance for optical engineering because it is home to the wavelengths of visible and infrared light. The behavior of a light wave is particularly sensitive to structural features formed at or below the scale of its wavelength and, as a consequence, nanophotonics encompasses many new and useful phenomena not found in macroscopic systems. In this course, we will explore the physics of light-matter coupling before using it as a guide to engineer new optical material properties via nanofabrication, with applications in computing, telecommunications, biomedical sensing, solar energy harvesting, robotics and more. Key topics covered in the course include Mie resonant dielectric antennas, plasmonic antennas, negative and zero refractive index metamaterials, chiral metamaterials, metasurface lenses and holograms, nonlinear and time dependent metasurfaces, Bragg mirrors, 3D photonic crystals, photonic crystal slab waveguides and cavities, guided mode resonators, photonic crystal lasers.
Credit 3 units.

E35 ESE 5332 Hardware & Devices: RF and Microwave Component and System Design
The course aims at provide understanding of the passive and active design for modern-day RF and microwave wireless systems. The lecture-based learning in the course will be coupled with simulation in professional circuit simulators including ADS and Cadence Virtuoso, and literature review of recent advances in RFIC design. Topics in Passive Design Include Transmission Line Theory, S-parameters, Smith Chart for matching network design, Inductors, Capacitors, Power Dividers, Directional Couplers, Isolators, and Circulators. Topics in Active Design include RF transistor modelling, Power Gain, Stability, Noise, Non-linearity, Low Noise Amplifiers, Mixers, small signal amplifiers, and Oscillators. Topics in System Design include Modern Receiver architectures and design considerations, course project. Prerequisites: ESE 433 or equivalent
Credit 3 units.

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-Poissionian 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 will be selectively covered: quantum computing, quantum cryptography, and teleportation. Prerequisites: ESE 330 and Physics 217 or Physics 421
Credit 3 units. EN: BME T, TU

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: BME T, 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: BME T, TU

E35 ESE 545 Stochastic Control
Introduction to the theory of stochastic differential equations based on Wiener processes and Poisson counters, and an introduction to random fields. The formulation and solution of problems in nonlinear estimation theory. The Kalman-Bucy filter and nonlinear analogues. Identification theory. Adaptive systems. Applications. Prerequisites: ESE 520 and ESE 551
Credit 3 units. EN: BME T, TU

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. Prerequisites: ESE 553 or equivalent; ESE 520 or equivalent; ESE 351 or equivalent
Credit 3 units. EN: BME T, 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 will be 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, On-line parameter estimation, convergence, and Persistence of Excitation. Prerequisite: ESE 543 Control Systems Design by State Space Methods or ESE 551 Linear Dynamic Systems or equivalent
Credit 3 units. EN: BME T, TU

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: BME T, TU

E35 ESE 553 Nonlinear Dynamic Systems
State space and functional analysis approaches to nonlinear systems. Questions of existence, uniqueness, and stability; Lyapunov 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: BME T, TU

E35 ESE 559 Special Topics in Systems and Control
This course provides a rigorous introduction to recent developments in systems and controls. Focus is on the discussion of interdisciplinary applications of complex systems that motivate emerging topics in dynamics and control as well as state-of-the-art methods for addressing the control and computation problems involving these large-scale systems. Topics to be covered include the control of ensemble systems, pseudospectral approximation and high-dimensional optimization, the mathematics of networks, dynamic learning and topological data analysis, and applications to biology, neuroscience, brain medicine, quantum physics, and complex networks. Both model-based and data-driven approaches are introduced. Students learn about state-of-the-art research in the field, and they ultimately apply their knowledge to conduct a final project. Prerequisites: Math 429 or equivalent, ESE 415, ESE 551, ESE 553, and ESE 520.
Credit 3 units. EN: TU

E35 ESE 5591 Special Topics in Engineering and Neuroscience
Credit 2 units. EN: TU

E35 ESE 5592 Data-Driven Control Methods and Reinforcement Learning
Modeling and control approaches of the past decades are usually concerned with analytically described control systems with relatively mild complexity, which allows for a highly successful treatment by rigorous systems theoretic methods. Recent years, however, have witnessed a significant shift towards the consideration of far more complicated control systems in which purely analytical approaches are infeasible. This is a research-focused course that will introduce and explore systematic approaches towards augmenting the core foundations of systems and control theoretic frameworks with data-integrating and learning-based capabilities to efficiently harness the vast amounts of valuable operational data and computing resources in order to solve challenging control tasks that escape the traditional setting. The starting point for these new developments are specific macroscopic considerations of dynamical systems associated with transfer operators and Koopman operators. After reviewing these operator-theoretic frameworks, we will explore a family of sample-based approaches that emerge out of the macroscopic viewpoint. These sample-based approaches not only mitigate drawbacks of the original operator-theoretic approaches but also facilitate more direct and efficient data-integrated paths for elucidating important features of dynamical systems with applications to control and estimation. Moreover, connections with established methods from Reinforcement Learning will be integrated into the course material. Prereqs: ESE 415 Optimization, ESE 551 Linear Dynamic Systems, ESE 553 Nonlinear Dynamic 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, memory hierarchies (cache and main memories, virtual memory), pipelining, instruction scheduling, and parallel systems. The course emphasizes understanding the performance implications of design choices, using architecture modeling and evaluation using simulation techniques. Prerequisites: CSE 361S and CSE 260M.
Same as E81 CSE 560M
Credit 3 units. EN: BME T, TU

E35 ESE 562 Analog Integrated Circuits
This course focuses on fundamental and advanced topics in analog and mixed-signal VLSI techniques. The first part of the course covers graduate level materials in the area of analog circuit synthesis and analysis. The second part of the course covers applications of the fundamental techniques for designing analog signal processors and data converters. Several practical aspects of mixed-signal design, simulation and testing are covered in this course. This is a project-oriented course and it is expected that the students apply the concepts learned in the course to design, simulate and explore different circuit topologies. Prerequisite: E35 ESE 232
Credit 3 units. EN: TU

E35 ESE 566A Modern System-on-Chip Design
The System-on-Chip (SoC) technology is at the core of most electronic systems: smartphones, wearable devices, autonomous robots and cars, and aerospace and 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 trade-offs between performance, power consumption, energy efficiency, reliability, and programmability. Students will gain an insight into the early stages of the SoC design process by performing the tasks of developing functional specifications, applying partitions and map functions to hardware and/or software, and then evaluating and validating system performance. Assignments include hands-on design projects. This course is open to both graduate and senior undergraduate students. Prerequisite: ESE 461.
Credit 3 units. EN: BME T, TU

E35 ESE 567 Computer Systems Analysis
A comprehensive course on performance analysis techniques. The topics include common mistakes, selection of techniques and metrics, summarizing measured data, comparing systems using random data, simple linear regression models, other regression models, experimental

designs, 2**k experimental designs, factorial designs with replication, fractional factorial designs, one factor experiments, two factor full factorial design w/o replications, two factor full factorial designs with replications, general full factorial designs, introduction to queueing theory, analysis of single queues, queueing networks, operational laws, mean-value analysis, time series analysis, heavy tailed distributions, self-similar processes, long-range dependence, random number generation, analysis of simulation results, and art of data presentation. Prerequisites: CSE 260M
Same as E81 CSE 567M
Credit 3 units. EN: BME T, 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 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 which 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: BME T, TU

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 course will focus 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 course will compare modern quantitative imaging technologies including, but not limited to, digital holography, computational imaging, and super-resolution microscopy. Students will evaluate and critique recent optical imaging literature. Prerequisites: ESE 318 and ESE 319 or their equivalents; ESE 330 or PHY 421 or equivalent.
Credit 3 units. EN: TU

E35 ESE 5830 Nonlinear Optical Microscopy
This course will cover the theoretical and practical knowledge needed to design, construct, and use a nonlinear optical microscope. The course will focus on the relevant optical physics and instrumentation for different types of nonlinear optical microscopy, and additionally provide some information on applications and image processing. Topics include: ultrafast lasers, detectors, nonlinear susceptibility, nonlinear wave equation, quantum theory of nonlinear optics, harmonic generation, multiphoton fluorescence, fluorescence lifetime, optical metabolic imaging, coherent Raman scattering, and multimodal nonlinear optical microscopy. Prerequisites: Electromagnetism, at the level of ESE 330, and familiarity with Python or Matlab
Credit 3 units.

E35 ESE 585A Sparse Modeling for Imaging and Vision
Sparse modeling is at the heart of modern imaging, vision, and machine learning. It is a fascinating new area of research that seeks to develop highly effective data models. The core idea in sparse modeling theory is a novel redundant transform, where the number of transform coefficients is larger compared to the original data dimension. Together with redundancy comes an opportunity for seeking the sparsest possible representation or the one with the fewest non-zeros. This core idea leads to a series of beautiful theoretical and practical results with many applications, such as regression, prediction, restoration, extrapolation, compression, detection, and recognition. In this course, we will explore sparse modeling by covering theoretical as well as algorithmic aspects with applications in computational imaging and computer vision. Prerequisites: ESE 318, Math 233, Math 309, and Math 429 (or equivalents), as well as coding experience with MATLAB or Python.
Credit 3 units. EN: BME T, TU

E35 ESE 589 Biological Imaging Technology
This class will develop 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 will examine 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 will examine image decomposition using basis functions (e.g. Fourier transforms), synthesis of measurement data, image analysis for feature extraction, reduction of multi-dimensional 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 will be critiqued.
Credit 3 units. EN: BME T, TU

E35 ESE 590 Electrical & Systems Engineering Graduate Seminar
This satisfactory/unsatisfactory course is required for the master's, DSc, and PhD degrees in Electrical & Systems Engineering. A satisfactory grade is required for each semester of enrollment, and this is achieved by student attendance at regularly scheduled seminars. Master's students must attend at least three seminars per semester, except for first-year master's students, who must attend four. DSc and PhD students must attend at least five seminars per semester, except for first-year PhD students who must attend six. Part-time students are exempt except during their year of residency. Any student under continuing status is also exempt.

E35 ESE 591 Biomedical Optics I: Principles
This course covers the principles of optical photon transport in biological tissue. This course covers the principles and applications of optical photon transport in biological tissue. Topics include a brief introduction to biomedical optics, single-scatterer theories, Monte Carlo modeling of photon transport, convolution for broad-beam responses, radiative transfer equation, diffusion theory and applications, sensing of optical properties and spectroscopy, and photoacoustic imaging principles and applications. Prerequisite: Familiarity with Differential equations and partial differential equations
Same as E62 BME 591
Credit 3 units. EN: TU

E35 ESE 5931 Mathematics of Imaging Science
This course will expose students to a unified treatment of the mathematical properties of images and imaging. This will include an introduction to linear vector space theory, operator theory on Hilbert spaces, and concepts from applied functional analysis. Further, concepts from generalized functions, Fourier analysis, and radon transform will be discussed. These tools will be applied to conduct deterministic analyses of imaging systems that are described as continuous-to-continuous, continuous-to-discrete, and discrete-to-discrete mappings from object properties to image data. In addition, imaging systems will be analyzed in a statistical framework where stochastic models for objects and images will be introduced. Familiarity with Engineering-level mathematics, Calculus, Linear algebra, introduction to Fourier analysis is expected. Prerequisite: Senior standing or permission of instructor.
Same as E62 BME 570
Credit 3 units.

E35 ESE 5932 Computational Methods for Imaging Science
Inverse problems are ubiquitous in science and engineering, and they form the basis for modern imaging methods. This course will introduce students to the mathematical formulation of inverse problems and modern computational methods employed to solve them. Specific topics covered will include regularization theory, compressive sampling, variational calculus, and a survey of relevant numerical optimization methods. The application of these methods to tomographic imaging problems will be addressed in detail. Prerequisite: ESE 5931 or permission of instructor.
Credit 3 units. EN: BME T, TU

E35 ESE 5933 Theoretical Imaging Science
Imaging science encompasses the design and optimization of imaging systems to quantitatively measure information of interest. Imaging systems are important in many scientific and medical applications and may be designed for one specific application or for a range of applications. Performance is quantified for any given task through an understanding of the statistical model for the imaging data, the data processing algorithm used, and a measure of accuracy or error. Optimal processing is based on statistical decision theory and estimation theory; performance bounds include the receiver operating characteristic and Cramer-Rao bounds. Bayesian methods often lead to ideal observers. Extensions of methods from finite-dimensional spaces to function space are fundamental for many imaging applications. A variety of methods to assess image quality and resulting imaging system optimization are covered. Prerequisite: permission of instructor.
Credit 3 units. EN: TU

E35 ESE 5934 Practicum in Imaging Science
Students develop research results in computational imaging and write a conference paper on the results. This course involves the process of research project design and implementation in imaging science, participation in research teams, the development of milestones for a project, and the process of meeting expectations. The role of machine learning, computational methods, theoretical methods, datasets, and experiments in imaging science research are covered. Prerequisite: Permission of instructor.
Credit 3 units. EN: TU

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 E81 CSE 596 (when offered) and E62 BME 506.
Credit 1 unit.

E35 ESE 599 Masters Research
Prerequisite: Students must have the ESE Research Registration Form. approved by the department. The form must contain a brief description of the work that is expected to be completed during the course.
Credit variable, maximum 3 units.

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

E35 ESE 601 Research Rotation for ESE Doctoral Students
Doctoral students in Electrical and Systems Engineering are required to complete two rotations during their first year and may complete three rotations, with research mentors acceptable to the separtment. The rotations must be mutually agreeable to both the student and the faculty member. The grade will be assigned based on a written report from one of the rotations. The rotations allow students to sample different research projects and laboratory working environments and to enable the matching of doctoral students with the research mentors with whom they will carry out PhD dissertation research.
Credit 3 units.