

ELECTRICAL & SYSTEMS ENGINEERING (ESE)

ESE 099 Undergraduate Research and/or Independent Study

An opportunity for the student to become closely associated with a professor in (1) a research effort to develop research skills and technique and/or (2) to develop a program of independent in-depth study in a subject area in which the professor and student have a common interest. The challenge of the task undertaken must be consistent with the student's academic level. To register for this course, the student and professor jointly submit a detailed proposal to the undergraduate curriculum chairman no later than the end of the first week of the term.

One-term course offered either term

Activity: Independent Study

1 Course Unit

Notes: A maximum of 2 c.u. of ESE 099 may be applied toward the B.A.S. or B.S.E. degree requirements

ESE 111 Atoms, Bits, Circuits and Systems

Introduction to the principles underlying electrical and systems engineering. Concepts used in designing circuits, processing signals on analog and digital devices, implementing computation on embedded systems, analyzing communication networks, and understanding complex systems will be discussed in lectures and illustrated in the laboratory. This course provides an overview of the challenges and tools that Electrical Engineers and Systems Engineers address and some of the necessary foundations for students interested in more advanced courses in ESE.

Course usually offered in fall term

Activity: Lecture

1 Course Unit

Notes: FOR FRESHMEN ONLY

ESE 112 Engineering Electromagnetics

This course covers basic topics in engineering electromagnetics, namely, electric charge, electric field, electric energy, conductors, insulators, dielectric materials, capacitors, electric current, magnetic field, inductors, Faraday's law of induction, alternating current (AC), impedance, Maxwell's equations, electromagnetic and optical wave propagation, with emphasis on engineering issues. Relevant engineering topics are emphasized in our lectures in order to prepare students for other courses in ESE that rely on the contents on this course. Several laboratory experiments accompany the course to provide hands-on experience on some of the topics in the lecture and prepare students for the capstone project.

One-term course offered either term

Activity: Lecture

1.5 Course Unit

ESE 150 Digital Audio Basics

Primer on digital audio. Overview of signal processing, sampling, compression, human psychoacoustics, MP3, intellectual property, hardware and software platform components, and networking (i.e., the basic technical underpinnings of modern MP3 players and cell phones).

Course usually offered in spring term

Activity: Lecture

1 Course Unit

Notes: FOR FRESHMEN ONLY

ESE 190 Silicon Garage: Introduction to Open Source Hardware and Software Platforms

Project-centric learning course for non-ESE majors on microprocessor control of physical systems using open-source hardware and software platforms. Students will work in teams to develop software controlled systems based on the Arduino and Raspberry-Pi that interface with the real world (sensors, actuators, motors) and each other (networking).

One-term course offered either term

Prerequisites: High School Physics and Math

Activity: Lecture

0.5 Course Units

ESE 204 Decision Models

This first course in decision models will introduce students to quantitative models for decision making, using optimization and monte-carlo simulation. Examples will be drawn from manufacturing, finance, logistics and supply chain management. Students will use EXCEL and @Risk to build and analyze models.

Course usually offered in fall term

Prerequisite: MATH 104

Activity: Lecture

1 Course Unit

ESE 210 Introduction to Dynamic Systems

This first course in systems modelling covers linear and nonlinear systems in both continuous and discrete time. Topics covered include linearization and stability analysis, elementary bifurcations, and an introduction to chaotic dynamics. Extensive applications to mechanical, electrical, biological, social, and economic/financial systems are included. The course will use both analytical and numerical/symbolic tools.

Course usually offered in fall term

Corequisite: MATH 240

Activity: Lecture

1 Course Unit

ESE 215 Electrical Circuits and Systems

This course gives an introduction of modern electric and electronic circuits and systems. Designing, building and experimenting with electrical and electronic circuits are challenging and fun. It starts with basic electric circuit analysis techniques of linear circuits. Today mathematical analysis is used to gain insight that supports design; and more detailed and accurate representations of circuit performance are obtained using computer simulation. It continues with 1st order and 2nd order circuits in both the time and frequency domains. It discusses the frequency behavior of circuits and the use of transfer functions. It continues with introduction of non-linear elements such as diodes and MOSFET (MOS) transistors. Applications include analog and digital circuits, such as single stage amplifiers and simple logic gates. A weekly lab accompanies the course where concepts discussed in class will be illustrated by hands-on projects; students will be exposed to state-of-the-art test equipment and software tools (LabView, Spice).

Course usually offered in fall term

Prerequisites: PHYS 150, PHYS 151

Corequisite: MATH 240

Activity: Lecture

1.5 Course Unit

ESE 218 Electronic, Photonic, and Electromechanical Devices

This first course in electronic, photonic and electromechanical devices introduces students to the design, physics and operation of physical devices found in today's applications. The course describes semiconductor electronic and optoelectronic devices, including light-emitting diodes, photodetectors, photovoltaics, transistors and memory; optical and electromagnetic devices, such as waveguides, fibers, transmission lines, antennas, gratings, and imaging devices; and electromechanical actuators, sensors, transducers, machines and systems.

Course usually offered in fall term

Prerequisites: PHYS 150, PHYS 151

Corequisite: MATH 240

Activity: Lecture

1.5 Course Unit

ESE 224 Signal and Information Processing

Introduction to signal and information processing (SIP). In SIP we discern patterns in data and extract the patterns from noise. Foundations of deterministic SIP in the form of frequency domain analysis, sampling, and linear filtering. Random signals and the modifications of deterministic tools that are necessary to deal with them. Multidimensional SIP where the goal is to analyze signals that are indexed by more than one parameter. Includes a hands-on lab component that implements SIP as standalone applications on modern mobile platforms.

Course usually offered in spring term

Prerequisite: MATH 104

Corequisite: MATH 240

Activity: Lecture

1.5 Course Unit

ESE 290 Introduction to Electrical and Systems Engineering Research Methodology

Introduction to the nature and process of engineering research as represented by ongoing ESE faculty (and collaborating colleagues' and industrial partners') research projects. Joint class exercises in how to pursue effective background technical reading, pitch a proposal, and aim for the discovery of new human knowledge to complement the individually mentored topic specific project work.

Course usually offered in spring term

Prerequisites: MATH 240, PHYS 150, ESE 215 and ESE 218, or ESE 204 and 210, or ESE 215 and CIS 240

Corequisite: ESE 291

Activity: Lecture

0.5 Course Units

ESE 291 Introduction to Electrical and Systems Engineering Research and Design

Students contract with a faculty mentor to conduct scaffolded original research in a topic of mutual interest. Prepare project report on research findings.

One-term course offered either term

Corequisite: ESE 290

Activity: Laboratory

1 Course Unit

ESE 292 Introduction to Electromechanical Prototyping

This is a project-centric course for ESE majors to engage in circuit layout and prototype design skills. Students will work in teams to develop printed circuit boards using industry standard tools like Altium and learn mechanical prototyping skills using Solidworks . Emphasis will be on developing sound printed circuit board layout practices using circuitry knowledge that they acquire in ESE 215 and ESE 370. A module on using Cypress PSoC will introduce students to recent developments in analog/digital co-design.

One-term course offered either term

Activity: Lecture

0.5 Course Units

ESE 296 Study Abroad

Activity: Lecture

1 Course Unit

ESE 301 Engineering Probability

This course introduces students to the mathematical foundations of the theory of probability and its rich applications. The course begins with an exploration of combinatorial probabilities in the classical setting of games of chance, proceeds to the development of an axiomatic, fully mathematical theory of probability, and concludes with the discovery of the remarkable limit laws and the eminence grise of the classical theory, the central limit theorem. The topics covered include: discrete and continuous probability spaces , distributions, mass functions, densities; conditional probability; independence; the Bernoulli schema: the binomial, Poisson, and waiting time distributions; uniform, exponential, normal, and related densities; expectation, variance, moments; conditional expectation; generating functions, characteristic functions; inequalities, tail bounds, and limit laws. But a bald listing of topics does not do justice to the subject: the material is presented in its lush and glorious historical context, the mathematical theory buttressed and made vivid by rich and beautiful applications drawn from the world around us. The student will see surprises in election-day counting of ballots, a historical wager the sun will rise tomorrow, the folly of gambling, the sad news about lethal genes, the curiously persistent illusion of the hot hand in sports, the unreasonable efficacy of polls and its implications to medical testing, and a host of other beguiling settings.

Course usually offered in spring term

Prerequisite: MATH 114

Activity: Lecture

1 Course Unit

ESE 302 Engineering Applications of Statistics

Principles and engineering applications of statistical inference. The basic topics covered are parameter estimation, confidence intervals, and hypothesis testing. Additional topics may include analysis of variance (ANOVA) and/or linear regression. Each method is treated both from theoretical and applied viewpoints, including software analysis of selected data sets.

One-term course offered either term

Prerequisite: ESE 301 or equivalent course in Probability

Activity: Lecture

1 Course Unit

ESE 303 Stochastic Systems Analysis and Simulation

Stochastic systems analysis and simulation (ESE 303) is a class that explores stochastic systems which we could loosely define as anything random that changes in time. Stochastic systems are at the core of a number of disciplines in engineering, for example communication systems and machine learning. They also find application elsewhere, including social systems, markets, molecular biology and epidemiology. The goal of the class is to learn how to model, analyze and simulate stochastic systems. With respect to analysis we distinguish between what we could call theoretical and experimental analysis. By theoretical analysis we refer to a set of tools which let us discover and understand properties of the system. These analysis can only take us so far and is usually complemented with numerical analysis of experimental outcomes. Although we use the word experiment more often than not we simulate the stochastic system in a computer and analyze the outcomes of these virtual experiments. The class's material is divided in four blocks respectively dealing with Markov chains, continuous time Markov chains, Gaussian processes and stationary processes. Emphasis is placed in the development of toolboxes to analyze these different classes of processes and on describing their applications to complex stochastic systems in different disciplines. Particular examples include: (i) the problem of ranking web pages by a search engine; (ii) the study of reputation and trust in social networks; (iii) modeling and analysis of communication networks; (iv) the use of queues in the modeling of transportation networks; (v) stochastic modeling and simulation of biochemical reactions and gene networks; (vi) arbitrages, pricing of stocks, and pricing of options through Black-Scholes formula; and (vii) linear filtering of stochastic processes to separate signals of interest from background noise. For more information visit the class's web page at <http://alliance.seas.upenn.edu/~ese303/wiki/>.

Course usually offered in fall term

Prerequisites: ESE 301 or equivalent and one computer language

Activity: Lecture

1 Course Unit

ESE 304 Optimization of Systems

Model Building and Linear Programming: Graphical Methods and The Simplex Method, the LINDO and LINGO Computer Packages, Degeneracies, Minimization and the BigM and the Two-Phase Methods, and Goal Programming. Sensitivity Analysis: Geometric and Algebraic Approaches, The Computer and Sensitivity Analysis, The Dual of An LP Problem, The Dual Theorem, Shadow Prices, Complementary Slackness, The Dual Simplex Method, and The Revised Simplex Method. Integer Programming: The Branch and Bound Method, Enumeration Methods, and the Cutting Plane Method. Nonlinear Programming: Review of Differential Calculus, Convex and Concave Functions, Solving NLP Problems with One Variable, Unconstrained Nonlinear Optimization with Several Variables, Lagrange Multipliers and Constraint Nonlinear Optimization with Several Variables, The Kuhn-Tucker Conditions and Quadratic Programming.

Course usually offered in spring term

Corequisite: MATH 240

Activity: Lecture

1 Course Unit

ESE 305 Foundations of Data Science

Introduction to a broad range of tools to analyze large volumes of data in order to transform them into actionable decisions. Using case studies and hands-on exercises, the student will have the opportunity to practice and increase their data analysis skills.

Course usually offered in fall term

Prerequisite: EAS 205 or MATH 312; CIS 120; ESE 301

Activity: Lecture

1 Course Unit

ESE 310 Electric and Magnetic Fields I

This course examines concepts of electromagnetism, vector analysis, electrostatic fields, Coulomb's Law, Gauss's Law, magnetostatic fields, Biot-Savart Law, Ampere's Law, electromagnetic induction, Faraday's Law, transformers, Maxwell equations and time-varying fields, wave equations, wave propagation, dipole antenna, polarization, energy flow, and applications.

Course usually offered in spring term

Prerequisites: PHYS 151 and MATH 114

Activity: Lecture

1 Course Unit

ESE 319 Fundamentals of Solid-State Circuits

Analysis and design of basic active circuits involving semiconductor devices including diodes and bipolar transistors. Single stage, differential, multi-stage, and operational amplifiers will be discussed including their high frequency response. Wave shaping circuits, filters, feedback, stability, and power amplifiers will also be covered. A weekly three-hour laboratory will illustrate concepts and circuits discussed in the class.

Course usually offered in spring term

Prerequisite: ESE 215

Activity: Lecture

1.5 Course Unit

ESE 321 Physics and Models of Semiconductor Devices

Semiconductor materials form the basis of modern electronic technology. This course develops the physics of semiconductor devices, the evolution of modern semiconductor technology, device engineering considerations, and introduces emerging technologies. The course stresses intuitive understanding of the physics through interactive exercises, instructional videos, in-class examples and a research project. Topics covered include an introduction to quantum mechanics and band theory of solids; physics governing charge carriers in semiconductors; fundamental operating mechanisms for p-n junctions, bipolar and field-effect transistors, and optoelectronic devices; and an introduction to nanoscale devices and the limits of transistor scaling.

Course usually offered in fall term

Prerequisite: ESE 218 or by permission of the instructor

Activity: Lecture

1 Course Unit

ESE 325 Fourier Analysis and Applications in Engineering, Mathematics, and the Sciences

This course focuses on the mathematics behind Fourier theory and a wide variety of its applications in diverse problems in mathematics, engineering, and the sciences. The course is very mathematical in content and students signing up for it should have junior or senior standing. The topics covered are chosen from: functions and signals; systems of differential equations; superposition, memory, and non-linearity; resonance, eigenfunctions; the Fourier series and transform, spectra; convergence theorems; inner product spaces; mean-square approximation; interpolation and prediction, sampling; random processes, stationarity; wavelets, Brownian motion; stability and control, Laplace transforms. The applications of the mathematical theory that will be presented vary from year to year but a representative sample include: polynomial approximation, Weierstrass's theorem; efficient computation via Monte Carlo; linear and non-linear oscillators; the isoperimetric problem; the heat equation, underwater communication; the wave equation, tides; testing for randomness, fraud; nowhere differentiable continuous functions; does Brownian motion exist?; error-correction; phase conjugate optics and four-wave mixing; cryptography and secure communications; how fast can we compute?; X-ray crystallography; cosmology; and what the diffusion equation has to say about mathematical finance and arbitrage opportunities.

Course usually offered in fall term

Prerequisites: MATH 240, Junior or Senior Standing

Activity: Lecture

1 Course Unit

ESE 350 Embedded Systems/Microcontroller Laboratory

An introduction to interfacing real-world sensors and actuators to embedded microprocessor systems. Concepts needed for building electronic systems for real-time operation and user interaction, such as digital input/outputs, interrupt service routines, serial communications, and analog-to-digital conversion will be covered. The course will conclude with a final project where student-designed projects are featured in presentations and demonstrations.

Course usually offered in spring term

Prerequisite: Knowledge of C programming or permission of the instructor

Activity: Lecture

1.5 Course Unit

ESE 370 Circuit-Level Modeling, Design, and Optimization for Digital Systems

Circuit-level design and modeling of gates, storage, and interconnect. Emphasis on understanding physical aspects which drive energy, delay, area, and noise in digital circuits. Impact of physical effects on design and achievable performance.

Course usually offered in fall term

Prerequisites: ESE 150, ESE 215

Activity: Lecture

1 Course Unit

ESE 400 Engineering Economics

This course investigates methods of economic analysis for decision making among alternative courses of action in engineering applications. Topics include: cost-driven design economics, break-even analysis, money-time relationships, rates of return, cost estimation, depreciation and taxes, foreign exchange rates, life cycle analysis, benefit-cost ratios, risk analysis, capital financing and allocation, and financial statement analysis. Case studies apply these topics to actual engineering problems. One-term course offered either term

Also Offered As: ESE 540

Prerequisite: Knowledge of Differential Calculus

Activity: Lecture

1 Course Unit

ESE 407 Introduction to Networks and Protocols

This is an introductory course on packet networks and associated protocols, with a particular emphasis on IP-based networks such as the Internet. The course introduces design and implementation choices that underlie the development of modern networks, and emphasizes basic analytical understanding of the concepts. Topics are covered in a mostly "bottom-up" approach starting with a brief review of physical layer issues such as digital transmission, error correction and error recovery strategies. This is followed by a discussion of link layer aspects, including multiple access strategies, local area networks (Ethernet and 802.11 wireless LANs), and general store-and-forward packet switching. Network layer solutions, including IP addressing, naming, and routing are covered next, before exploring transport layer and congestion control protocols (UDP and TCP). Finally, basic approaches for quality-of-service and network security are examined. Specific applications and aspects of data compression and streaming may also be covered.

One-term course offered either term

Also Offered As: ESE 507

Prerequisite: ESE 301 or equivalent

Activity: Lecture

1 Course Unit

Notes: Course open to Seniors in SEAS and Wharton

ESE 419 Analog Integrated Circuits

Design of analog circuits and subsystems using primarily MOS technologies at the transistor and higher levels. Transistor level design of building block circuits such as op amps, comparators, sample and hold circuits, voltage and current references, capacitors and resistor and class AB output stages. The Cadence Design System will be used to capture schematics and run simulations using Spectre for some homework problems and for the course project. Topics of stability, noise, device matching through good layout practice will also be covered. Students who take ESE419 will not be able to take ESE572 later. More will be expected of ESE572 students in the design project.

Course usually offered in fall term

Also Offered As: ESE 572

Prerequisite: ESE 319 or permission of the instructor

Activity: Lecture

1 Course Unit

ESE 420 Agent-Based Modeling and Simulation

Agents are a new technique for trying to model, simulate, and understand systems that are ill-structured and whose mathematics is initially unknown and possibly unknowable. This approach allows the analyst to assemble models of agents and components where micro-decision rules may be understood; to bring the agents and components together as a system where macro-behavior then emerges; and to use that to empirically probe and improve understanding of the whole, the interrelations of the components, and synergies. This approach helps one explore parametrics, causality, and what-ifs about socio-technical systems (technologies that must support people, groups, crowds, organizations, and societies). It is applicable when trying to model and understand human behavior - consumers, investors, passengers, plant operators, patients, voters, political leaders, terrorists, and so on. This course will allow students to investigate and compare increasingly complex agent based paradigms along three lines - math foundations, heuristic algorithms/knowledge representations, and empirical science. The student will gain a toolbox and methodology for attempting to represent and study complex socio-technical systems.

Course usually offered in fall term

Also Offered As: ESE 520

Activity: Lecture

1 Course Unit

ESE 421 Control For Autonomous Robots

This course introduces the hardware, software and control technology used in autonomous ground vehicles, commonly called "self-driving cars." The weekly laboratory sessions focus on development of a small-scale autonomous car, incrementally enhancing the sensors, software, and control algorithms to culminate in a demonstration in a realistic outdoor operating environment. Students will learn basic physics and modeling; controls design and analysis in Matlab and Simulink; software implementation in C and Python; sensor systems and filtering methods for IMUs, GPS, and computer vision systems; and path planning from fixed map data.

One-term course offered either term

Also Offered As: MEAM 421

Prerequisite: CIS 110 or CIS 120 or ENGR 105; ESE 210 or ESE 215 or MEAM 211 or permission of the instructor

Activity: Lecture

1.5 Course Unit

ESE 444 Project Management

The course emphasizes a systems engineering approach to project management including the cycle costing and analysis, project scheduling, project organization and control, contract management, project monitoring and negotiations. In addition, the course will also examine management issues in large infrastructure projects like non-recourse or limited recourse project financing. Examples from the logistics planning process and global software project management will be used to highlight the course topics.

Two terms. student may enter either term.

Also Offered As: ESE 544

Prerequisite: ESE 304 or equivalent

Activity: Lecture

1 Course Unit

ESE 450 Senior Design Project I - EE and SSE

This is the first of a two-semester sequence in electrical and systems engineering senior design. Student work will focus on project/team definition, systems analysis, identification alternative design strategies and determination (experimental or by simulation) or specifications necessary for a detailed design. Project definition is focused on defining a product prototype that provides specific value to a least one identified user group. Students will receive guidance on preparing professional written and oral presentations. Each project team will submit a project proposal and two written project reports that include coherent technical presentations, block diagrams and other illustrations appropriate to the project. Each student will deliver two formal Powerpoint presentations to an audience comprised of peers, instructors and project advisors. During the semester there will be periodic individual-team project reviews.

Course usually offered in fall term

Prerequisite: Senior Standing or permission of the instructor

Activity: Lecture

1 Course Unit

ESE 451 Senior Design Project II - EE and SSE

This is the second of a two term sequence in electrical and systems engineering senior design. Student work will focus on completing the product prototype design undertaken in ESE 450 and successfully implementing the said product prototype. Success will be verified using experimental and/or simulation methods appropriate to the project that test the degree to which the project objectives are achieved. Each project team will prepare a poster to support a final project presentation and demonstration to peers, faculty and external judges. The course will conclude with the submission of a final project written team report. During the semester there will be periodic project reviews with individual teams.

Course usually offered in spring term

Prerequisite: ESE 450

Activity: Lecture

1 Course Unit

ESE 460 Principles of Microfabrication Technology

A laboratory-based course on fabricating microelectronic and micromechanical devices using photolithographic processing and related fabrication technologies. Lectures discuss: clean room procedures; microelectronic and microstructural materials; photolithography; diffusion, oxidation; materials deposition; etching and plasma processes. Basic laboratory processes are covered for the first two thirds of the course with students completing structures appropriate to their major in the final third. Students registering for ESE 574 will be expected to do extra work (including term paper and additional project).

Course usually offered in fall term

Also Offered As: ESE 574, MEAM 564

Prerequisites: Any of the following: ESE 218, MEAM 333, CBE 351, PHYS 250 or permission of the instructor

Activity: Lecture

1 Course Unit

ESE 500 Linear Systems Theory

This graduate-level course focuses on continuous and discrete n -dimensional linear systems with m inputs and p outputs in a time domain based on linear operators. The course covers general discussions of linear systems such as, linearization of non-linear systems, existence and uniqueness of state-equation solutions, transition matrices and their properties, methods for computing functions of matrices and transition matrices and state-variable changes. It also includes z -transform and Laplace transform methods for time-invariant systems and Floquet decomposition methods for periodic systems. The course then moves to stability analysis, including: uniform stability, uniform exponential stability, asymptotic stability, uniform asymptotic stability, Lyapunov transformations, Lyapunov stability criteria, eigenvalues conditions and input-output stability analysis. Applications involving the topics of controllability, observability, realizability, minimal realization, controller and observer forms, linear feedback, and state feedback stabilization are included, as time permits.

Course usually offered in fall term

Prerequisites: Open to graduates and undergraduates who have taken undergraduate courses in linear algebra and differential equations.

Activity: Lecture

1 Course Unit

ESE 501 Networking - Theory and Fundamentals

Networks constitute an important component of modern technology and society. Networks have traditionally dominated communication technology in form of communication networks, distribution of energy in form of power grid networks, and have more recently emerged as a tool for social connectivity in form of social networks. In this course, we will study mathematical techniques that are key to the design and analysis of different kinds of networks. First, we will investigate techniques for modeling evolution of networks. Specifically, we will consider random graphs (all or none connectivity, size of components, diameters under random connectivity), small world problem, network formation and the role of topology in the evolution of networks. Next, we will investigate different kinds of stochastic processes that model the flow of information in networks. Specifically, we will develop the theory of Markov processes, renewal processes, and basic queueing, diffusion models, epidemics and rumor spreading in networks.

Course usually offered in spring term

Prerequisite: ESE 530 or equivalent

Activity: Lecture

1 Course Unit

ESE 502 Introduction to Spatial Analysis

The course is designed to introduce students to modern statistical methods for analyzing spatial data. These methods include nearest-neighbor analyses of spatial point patterns, variogram and kriging analyses of continuous spatial data, and autoregression analyses of area data. The underlying statistical theory of each method is developed and illustrated in terms of selected GIS applications. Students are also given some experience with ARCMAP, JMPIN, and MATLAB software.

Course usually offered in spring term

Prerequisite: ESE 302 or equivalent

Activity: Lecture

1 Course Unit

ESE 503 Sim Modling & Analysis

Course usually offered in spring term

Activity: Lecture

1 Course Unit

ESE 504 Introduction to Optimization Theory

The course provides a detailed introduction to linear and nonlinear optimization analysis as well as integer optimization analysis. It discusses methods for the mathematical formulation of linear programming (LP) integer programming (IP) and nonlinear programming (NLP) problems, as well as methods of computational tools used for their solutions. In discussions surrounding the solutions to LP problems, the Simplex method and the Revised Simplex methods are covered in a fairly rigorous fashion along with the LINDO computational computer package. Sensitivity analysis associated with the optimal solutions to LP problems is also discussed in detail using both geometric and algebraic methods. In discussions surrounding the solutions to IP problems, the course covers: (a) branch and bound, (b) enumeration and (c) cutting-plane methods, and these are applied to numerous classic problems in IP. In discussions surrounding the solutions to NLP problems, the course covers methods involving: (a) differential Calculus, (b) steepest ascent and decent and (c) Lagrange Multipliers. The Kuhn-Tucker Conditions are also presented and applied to problems in Quadratic Programming. Many examples are selected from a broad range of engineering and business problems.

Course usually offered in fall term

Also Offered As: OIDD 910

Prerequisites: ESE 304 and EAS 205 or MATH 313

Activity: Lecture

1 Course Unit

ESE 505 Control of Systems

Basic methods for analysis and design of feedback control in systems. Applications to practical systems. Methods presented include time response analysis, frequency response analysis, root locus, Nyquist and Bode plots, and the state-space approach.

Course usually offered in spring term

Also Offered As: MEAM 513

Prerequisites: ESE 224 or equivalent, ESE 210 recommended

Activity: Lecture

1 Course Unit

ESE 507 Introduction to Networks and Protocols

This is an introductory course on packet networks and associated protocols, with a particular emphasis on IP-based networks such as the Internet. The course introduces design and implementation choices that underlie the development of modern networks, and emphasizes basic analytical understanding of the concepts. Topics are covered in a mostly "bottom-up" approach starting with a brief review of physical layer issues such as digital transmission, error correction and error recovery strategies. This is followed by a discussion of link layer aspects, including multiple access strategies, local area networks (Ethernet and 802.11 wireless LANs), and general store-and-forward packet switching. Network layer solutions, including IP addressing, naming, and routing are covered next, before exploring transport layer and congestion control protocols (UDP and TCP). Finally, basic approaches for quality-of-service and network security are examined. Specific applications and aspects of data compression and streaming may also be covered.

One-term course offered either term

Also Offered As: ESE 407

Activity: Lecture

1 Course Unit

Notes: Course open to Graduate Students in SEAS and Wharton

ESE 510 Electromagnetic and Optical Theory

This course reviews electrostatics, magnetostatics, electric and magnetic materials, induction, Maxwell's equations, potentials and boundary-value problems. Topics selected from the areas of wave propagation, wave guidance, antennas, and diffraction will be explored with the goal of equipping students to read current research literature in electromagnetics, microwaves, and optics.

Course usually offered in fall term

Activity: Lecture

1 Course Unit

ESE 512 Dynamical Systems for Engineering and Biological Applications

This midlevel course in nonlinear dynamics focuses on the analysis of low dimensional, continuous time models for describing and understanding complex behavior in physical, biological and engineered systems. We assume some background knowledge of ordinary differential equations, and develop at an engineering applications level the concepts and tools of qualitative dynamical systems theory with major focus on analysis and some on synthesis.

Course usually offered in fall term

Prerequisites: MATH 240, PHYS 150, ESE 210 and a sound background in computational modeling

Activity: Lecture

1 Course Unit

ESE 516 IoT Edge Computing

This course was developed to bring lessons learned from the product design industry into the classroom - specifically focusing on Internet of Things (IoT) device development and deployment. To achieve the highest level of knowledge transfer, the course will incorporate device design theory with discussions of real-world product failures and successes - as well as a heavy hands-on component to build a device from end to end. Students will learn to use industry standard tools, such as Altium, Atmel Studio, and IBM Watson - allowing them the same level of power and customization at the disposable of startups and Fortune 500 companies alike.

One-term course offered either term

Prerequisite: ESE 519 or permission of the instructor

Activity: Lecture

1 Course Unit

ESE 518 Battery and Super-Capacitor Systems

This is a senior / graduate course on scientific and technological fundamentals as they apply to electrochemical batteries and super-capacitors. The perspective utilized will be a combination of materials and systems science. The course will introduce the student to the different categories of electrochemical cells and batteries, and their related chemistry, kinds of super-capacitors, charging and discharging profiles, equivalent series resistance (ESR), power capacities, and lifetimes. For super-capacitors, the student will be introduced to double layer capacitance (DLC) and pseudo-capacitance types of energy storage, super-capacitor fundamentals through Faradaic and non-Faradaic processes, pseudo-capacitance of metal oxides and electro-active polymers (EAPs), non-ideal polarizable electrodes, energetics and kinetics of electrode processes, theories of dielectric polarization, inorganic and organic electro carbonaceous materials, effective surface area (ESA) and functionalizations, as well as the AC impedance behavior of batteries and super-capacitors including the self-discharge characteristics of both. The fundamental electrochemical relations will be discussed, as well as battery / super-caps system modeling, and batteries management systems.

One-term course offered either term

Prerequisites: CHEM 101 (General Chemistry) and MATH 104 (Calculus 1)

Activity: Lecture

1 Course Unit

ESE 519 Real-Time Embedded Systems

The use of distributed wireless sensor networks has surged in popularity in recent years with applications ranging from environmental monitoring, to people- and object-tracking in both cooperative and hostile environments. This course is targeted at understanding and obtaining hands-on experience with the state-of-the-art in such wireless sensor networks which are often composed using relatively inexpensive sensor nodes that have low power consumption, low processing power and bandwidth. The course will span a variety of topics ranging from radio communications, network stack, systems infrastructure including QoS support and energy management, programming paradigms, distributed algorithms and example applications. Some guest lectures may be given. One-term course offered either term

Also Offered As: IPD 519

Prerequisites: CIS 120, ESE 350 or equivalent, one course in computer networks and Senior or Graduate standing

Activity: Lecture

1 Course Unit

ESE 520 Agent-Based Modeling and Simulation

Agents are a new technique for trying to model, simulate, and understand systems that are ill-structured and whose mathematics is initially unknown and possibly unknowable. This approach allows the analyst to assemble models of agents and components where micro-decision rules may be understood; to bring the agents and components together as a system where macro-behavior then emerges; and to use that to empirically probe and improve understanding of the whole, the interrelations of the components, and synergies. This approach helps one explore parametrics, causality, and what-ifs about socio-technical systems (technologies that must support people, groups, crowds, organizations, and societies). It is applicable when trying to model and understand human behavior - consumers, investors, passengers, plant operators, patients, voters, political leaders, terrorists, and so on. This course will allow students to investigate and compare increasingly complex agent based paradigms along three lines - math foundations, heuristic algorithms/knowledge representations, and empirical science. The student will gain a toolbox and methodology for attempting to represent and study complex socio-technical systems. Students taking this for graduate credit will also learn how to design agent-based tools. Course usually offered in fall term

Also Offered As: ESE 420

Activity: Lecture

1 Course Unit

ESE 521 The Physics of Solid State Energy Devices

An advanced undergraduate course or graduate level course on the fundamental physical principles underlying the operation of traditional semiconducting electronic and optoelectronic devices and extends these concepts to novel nanoscale electronic and optoelectronic devices. The course assumes an undergraduate level understanding of semiconductors physics, as found in ESE 218 or PHYS 240. The course builds on the physics of solid state semiconductor devices to develop the operation and application of semiconductors and their devices in energy conversion devices such as solar photovoltaics, thermophotovoltaics, and thermoelectrics, to supply energy. The course also considers the importance of the design of modern semiconductor transistor technology to operate at low-power in CMOS.

Course usually offered in spring term

Prerequisites: ESE 218 or PHYS 240 or equivalent, or by permission of the instructor.

Activity: Lecture

1 Course Unit

ESE 523 Quantum Engineering

Quantum engineering - the design, fabrication, and control of quantum coherent devices - has emerged as a multidisciplinary field spanning physics, electrical engineering, materials science, chemistry, and biology, with the potential for transformational advances in computation, secure communication, and nanoscale sensing. This course surveys the state of the art in quantum hardware, beginning with an overview of the physical implementation requirements for a quantum computer and proceeding to a synopsis of the leading contenders for quantum building blocks, including spins in semiconductors, superconducting circuits, photons, and atoms. The course combines background material on the fundamental physics and engineering principles required to build and control these devices with readings drawn from the current literature, including promising architectures for scaling physical qubits into larger devices and secure communication networks, and for nanoscale sensing applications impacting biology, chemistry, and materials science.

Course usually offered in spring term

Prerequisites: One semester of quantum mechanics, e.g. PHYS 411, MSE 570, CHEM 523, or by permission of the instructor

Activity: Lecture

1 Course Unit

ESE 525 Nanoscale Science and Engineering

Overview of existing device and manufacturing technologies in microelectronics, optoelectronics, magnetic storage, Microsystems, and biotechnology. Overview of near- and long-term challenges facing those fields. Near- and long-term prospects of nanoscience and related technologies for the evolutionary sustention of current approaches, and for the development of revolutionary designs and applications.

Course usually offered in fall term

Also Offered As: MSE 525

Prerequisites: ESE 218 or PHYS 240 or MSE 220 or equivalent, or by permission.

Activity: Lecture

1 Course Unit

ESE 526 Photovoltaic Systems Engineering

This course will present the engineering basis for photovoltaic (PV) system design. The overall aim is for engineering students to understand the what, why, and how associated with the electrical, mechanical, economic, and aesthetic aspects of PV system. The course will introduce additional practical design considerations, added to the theoretical background, associated with pertinent electro-mechanical design.

Course usually offered in spring term

Prerequisite: Permission of the Instructor

Activity: Lecture

1 Course Unit

ESE 527 Design of Smart Systems

Smart systems are materials, structures, devices and/or networks that seek to autonomously emulate human capabilities (sensing, nervous system, deliberating, acting) for adapting and continued functioning in potentially adverse conditions. Smart systems are a highly trans-disciplinary field that utilize microsystems technology with other disciplines like biology, information science, nanoscience, or cognitive science to control networks of components. Smart systems are causing a sea-change in hybrid cyber-physical-social systems leading to such breakthroughs as: the internet of Everything, smart cars, smart cities, the next industrial revolution, solutions to reduce global warming, and personalized e-healthcare, among many others. In this course students explore state-of-the-art smart system components, learn a design methodology to integrate the components, and apply the methodology to design and simulate a smart system prototype. The course will also cover life-long coping skills for human-centered design and for modeling the security, privacy and reliability hazards of the smart systems approach. Course usually offered in spring term

Prerequisites: Junior or Senior standing, course or experience in a course with high level language

Activity: Lecture

1 Course Unit

ESE 528 Estimation and Detection Theory

Statistical decision making constitutes the core of multiple engineering systems like communication, networking, signal processing, control, market dynamics, biological systems, data processing, etc. We strive to introduce mathematical theories that formulate statistical decision and obtain decision making algorithms with application to one or more of the above domains. This course will be offered every other year.

One-term course offered either term

Prerequisite: ESE 530 or equivalent

Activity: Lecture

1 Course Unit

ESE 530 Elements of Probability Theory

This rapidly moving course provides a rigorous development of fundamental ideas in probability theory and random processes. The course is suitable for students seeking a rigorous graduate level exposure to probabilistic ideas and principles with applications in diverse settings. The topics covered are drawn from: abstract probability spaces; combinatorial probabilities; conditional probability; Bayes's rule and the theorem of total probability; independence; connections with the theory of numbers, Borel's normal law; rare events, Poisson laws, and the Lovasz local lemma; arithmetic and lattice distributions arising from the Bernoulli scheme; limit laws and characterizations of the binomial and Poisson distributions; continuous distributions in one and more dimensions; the uniform, exponential, normal, and related distributions; random variables, distribution functions; orthogonal and stationary random processes; the Gaussian process, Brownian motion; random number generation and statistical tests of randomness; mathematical expectation and the Lebesgue theory; expectations of functions, moments, convolutions; operator methods and distributional convergence, the central limit theorem, selection principles; conditional expectation; tail inequalities, concentration convergence in probability and almost surely, the law of large numbers, the law of the iterated logarithm; Poisson approximation, Janson's inequality, the Stein-Chen method; moment generating functions, renewal theory; characteristic functions.

Course usually offered in fall term

Prerequisites: A solid foundation in undergraduate probability at the level of ESE 301 or STAT 430 at Penn. Students are expected to have a sound calculus background in the first two years of a typical undergraduate engineering curriculum. Undergraduates are warned that the course is very mathematical in nature with an emphasis on rigor; upperclassmen who wish to take the course will need to see the instructor for permission to register.

Activity: Lecture

1 Course Unit

ESE 531 Digital Signal Processing

This course covers the fundamentals of discrete-time signals and systems and digital filters. Specific topics covered include: review of discrete-time signal and linear system representations in the time and frequency domain, and convolution; discrete-time Fourier transform (DTFT); Z-transforms; frequency response of linear discrete-time systems; sampling of continuous-time signals, analog to digital conversion, sampling-rate conversion; basic discrete-time filter structures and types; finite impulse response (FIR) and infinite impulse response (IIR) filters; design of FIR and IIR filters; discrete Fourier transform (DFT), the fast Fourier transform (FFT) algorithm and its applications in filtering and spectrum estimation.

Course usually offered in fall term

Prerequisites: ESE 224, ESE 325 or equivalent

Activity: Lecture

1 Course Unit

ESE 532 System-on-a-Chip Architecture

Motivation, design, programming, optimization, and use of modern System-on-a-Chip (SoC) architectures. Hands-on coverage of the breadth of computer engineering within the context of SoC platforms from gates to application software, including on-chip memories and communication networks, I/O interfacing, RTL design of accelerators, processors, concurrency, firmware and OS/infrastructure software. Formulating parallel decompositions, hardware and software solutions, hardware/software tradeoffs, and hardware/software codesign. Attention to real-time requirements.

Course usually offered in fall term

Prerequisites: Undergraduates: CIS 240, ESE 350; Graduate: Working knowledge of C

Activity: Lecture

1 Course Unit

ESE 534 Computer Organization

Organization and design of physical computational systems, basic building block for computations, understanding and exploiting structure in computational problems, design space, costs, and tradeoffs in computer organization, common machine abstractions, and implementation/optimization techniques. The course will develop fundamental issues and tradeoffs which define computer organizational and architectural styles including RISC, VLIW, Super Scalar, EPIC, SIMD, Vector, MIMD, reconfigurable FPGA, PIM, and SoC. Basic topics in the design of computational units, instruction organization, memory systems, control and data flow, and interconnect will also be covered.

Course not offered every year

Prerequisites: Basic computability and basic digital circuits, VLSI exposure helpful but not required. CIS 371 adequate.

Activity: Lecture

1 Course Unit

ESE 535 Electronic Design Automation

Formulation, automation, and analysis of design mapping problems with emphasis on VLSI and computational realizations. Major themes include: formulating and abstracting problems, figures of merit (e.g. Energy, Delay, Throughput, Area, Mapping Time), representation, traditional decomposition of flow (logic optimization, covering, scheduling, retiming, assignment, partitioning, placement, routing), and techniques for solving problems (e.g., greedy, dynamic programming, search, (integer) linear programming, graph algorithms, randomization, satisfiability).

Course not offered every year

Prerequisites: Digital logic, Programming (need to be comfortable writing ~1-3K lines of code and working with a large, existing base code).

Activity: Lecture

1 Course Unit

ESE 536 Nanofabrication and Nanocharacterization

This course is intended for first year graduate students interested in the experimental practice of nanotechnology. In the context of a hands-on laboratory experience, students will gain familiarity with both top-down and bottom-up fabrication and characterization technologies. This will be achieved through the realization of a variety of micro- and nanoscale structures and devices that can exhibit either classical or quantum effects at the small scale. Although concepts relevant to the laboratories will be emphasized in lecture, it is expected that students will already have been exposed to many of the underlying theoretical concepts of nanotechnology in previous courses.

Course usually offered in fall term

Prerequisite: ESE 525 or MSE 525 or permission of the instructor

Activity: Lecture

1 Course Unit

ESE 540 Engineering Economics

This course is cross-listed with an advanced-level undergraduate course (ESE 400). Topics include: money-time relationships, discrete and continuous compounding, equivalence of cash flows, internal and external rate of return, design and production economics, life cycle cost analysis, depreciation, after-tax cash flow analysis, cost of capital, capital financing and allocation, parametric cost estimating models, pricing, foreign exchange rates, stochastic risk analysis, replacement analysis, benefit-cost analysis, and analysis of financial statements. Case studies apply these topics to engineering systems. Students are not required to do additional work compared to ESE 400 students. The work-load is identical.

One-term course offered either term

Also Offered As: ESE 400

Activity: Lecture

1 Course Unit

ESE 543 Human Systems Engineering

This course is an introduction to human systems engineering, examining the various human factors that influence the spectrum of human performance and human systems integration. We will examine both theoretical and practical applications, emphasizing fundamental human cognitive and performance issues. Specific topics include: human performance characteristics related to perception, attention, comprehension, memory, decision making, and the role of automation in human systems integration.

Course usually offered in fall term

Activity: Lecture

1 Course Unit

ESE 544 Project Management

The course emphasizes a systems engineering approach to project management including the cycle costing and analysis, project scheduling, project organization and control, contract management, project monitoring and negotiations. In addition, the course will also examine management issues in large infrastructure projects like non-recourse or limited recourse project financing. Examples from the logistics planning process and global software project management will be used to highlight the course topics.

One-term course offered either term

Also Offered As: ESE 444

Prerequisite: ESE 304 or equivalent

Activity: Lecture

1 Course Unit

ESE 545 Data Mining: Learning from Massive Datasets

Many scientific and commercial applications require us to obtain insights from massive, high-dimensional data sets. In this graduate-level course, students will learn to apply, analyze and evaluate principled, state-of-the-art techniques from statistics, algorithms and discrete and convex optimization for learning from such large data sets. The course both covers theoretical foundations and practical applications.

Course usually offered in fall term

Prerequisites: ESE 530, ENM 503, or equivalent

Activity: Lecture

1 Course Unit

ESE 548 Transportation Planning Methods

This course introduces students to the development and uses of the 4-step urban transportation model (trip generation-trip distribution-mode choice-traffic assignment) for community and metropolitan mobility planning. Using the VISUM transportation desktop planning package, students will learn how to build and test their own models, apply them to real projects, and critique the results.

One-term course offered either term

Also Offered As: CPLN 650

Prerequisite: CPLN 505 or another planning statistics course

Activity: Lecture

1 Course Unit

ESE 550 Advance Transportation Seminar, Air Transportation Planning

Air transportation is a fascinating multi-disciplinary area of transportation bringing together business, planning, engineering, and policy. In this course, we explore the air transportation system from multiple perspectives through a series of lessons and case studies. Topics will include airport and intercity multimodal environmental planning, network design and reliability, air traffic management and recovery from irregular operations, airline operations, economics, and fuel, air transportation sustainability, and land use issues related to air transportation systems. This course will introduce concepts in economics and behavioral modeling, operations research, statistics, environmental planning, and human factors that are used in aviation and are applicable to other transportation systems. The course will emphasize learning through lessons, guest lecturers, case studies of airport development and an individual group and research project.

Course usually offered in spring term

Also Offered As: CPLN 750

Prerequisite: CPLN 550 or equivalent

Activity: Seminar

1 Course Unit

1 Course Unit

ESE 566 Networked Neuroscience

The human brain produces complex functions using a range of system components over varying temporal and spatial scales. These components are couples together by heterogeneous interactions, forming an intricate information-processing network. In this course, we will cover the use of network science in understanding such large-scale and neuronal-level brain circuitry.

One-term course offered either term

Also Offered As: BE 566

Prerequisites: Graduate standing or permission of the instructor.

Experience with Linear Algebra and MATLAB.

Activity: Lecture

1 Course Unit

ESE 567 Risk Analysis and Environmental Management

This course is designed to introduce students to the complexities of making decisions about threats to human health and the environment when people's perceptions of risks and their decision-making processes differ from expert views. Recognizing the limitations of individuals in processing information the course explores the role of techniques such as decision analysis, cost-benefit analysis, risk assessment and risk perception in structuring risk-management decisions. We will also examine policy tools such as risk communication, incentive systems, third party inspection, insurance and regulation in different problem contexts. The problem contexts for studying the interactions between analysis, perceptions, and communication will include risk-induced stigmatization of products (e.g. alar, British beef), places (e.g. Love Canal), and technologies (e.g. nuclear power); the siting of noxious facilities, radon, managing catastrophic risks including those from terrorism. A course project will enable students to apply the concepts discussed in the course to a concrete problem.

Course usually offered in spring term

Also Offered As: OIDD 261

Activity: Lecture

1 Course Unit

ESE 568 Mixed Signal Design and Modeling

This course will introduce design and analysis of mixed-signal integrated circuits. Topics include: Sampling and quantization, Sampling circuits, Switched capacitor circuits and filters, Comparators, Offset compensation, DACs/ADCs (flash, delta-sigma, pipeline, SAR), Oversampling, INL/DNL, FOM. The course will end with a final design project using analysis and design techniques learned in the course. Students must provide a written report with explanations to their design choices either with equations or simulation analysis/insight along with performance results.

One-term course offered either term

Prerequisites: ESE 319, 419 or permission of the instructor

Activity: Lecture

1 Course Unit

ESE 570 Digital Integrated Circuits and VLSI-Fundamentals

Explores the design aspects involved in the realization of an integrated circuit from device up to the register/subsystem level. It addresses major design methodologies with emphasis placed on the structured design. The course includes the study of MOS device characteristics, the critical interconnect and gate characteristics which determine the performance of VLSI circuits, and NMOS and CMOS logic design. Students will use state-of-the-art CAD tools to verify designs and develop efficient circuit layouts.

Course usually offered in spring term

Prerequisite: ESE 319 (for undergraduates) or permission of the instructor

Activity: Lecture

1 Course Unit

ESE 572 Analog Integrated Circuits

Design of analog circuits and subsystems using bipolar and MOS technologies at the transistor and higher levels. Transistor level design of building block circuits such as op amps, comparators, sample and hold circuits, voltage and current references, capacitors and resistor arrays, and class AB output stages. The course will include a design project of an analog circuit. The course will use the Cadence Design System for schematic capture and simulation with Spectre circuit simulator. This course is similar to ESE 570, except that it will not require the use of the physical layout tools associated with VLSI design and implementation. Course usually offered in fall term

Also Offered As: ESE 419

Prerequisite: ESE 319 (for undergraduates) or permission of the instructor
Activity: Lecture

1 Course Unit

ESE 574 The Principles and Practice of Microfabrication Technology

A laboratory-based course on fabricating microelectronic and micromechanical devices using photolithographic processing and related fabrication technologies. Lectures discuss: clean room procedures; microelectronic and microstructural materials; photolithography; diffusion, oxidation; materials deposition; etching and plasma processes. Basic laboratory processes are covered for the first two thirds of the course with students completing structures appropriate to their major in the final third. Students registering for ESE 574 will be expected to do extra work (including term paper and additional project).

Course usually offered in fall term

Also Offered As: ESE 460, MEAM 564

Prerequisites: Any of the following courses: ESE 218, MSE 321, MEAM 333, CBE 351, PHYS 250 or permission of the instructor
Activity: Lecture

1 Course Unit

ESE 576 Digital Communication Systems

Sampling, source coding, and channel capacity. Quantization and coding of speech and video. Baseband data transmission: bandwidth, intersymbol interference, adaptive equalization, performance analysis. Digital modulation schemes, spectral efficiency, and performance. Error control coding; block and convolutional codes.

Course usually offered in spring term

Prerequisites: Undergraduate linear systems, probability, random processes.

Activity: Lecture

1 Course Unit

ESE 578 RFIC (Radio Frequency Integrated Circuit) Design

Introduction to RF (Radio Frequency) and Microwave Theory, Components, and Systems. The course aims at providing knowledge in RF transceiver design at both microwave and millimeter-wave frequencies. Both system and circuit level perspective will be addressed, supported by modeling and simulation using professional tools (including Agilent ADS, Sonnet, and Cadence Design Systems). Topics include: Transmission Line Theory, S-parameters, Smith Chart for matching network design, stability, noise, and mixed signal design. RF devices covered will include: hybrid/Wilkinson/Lange 3dB couplers, Small Signal Amplifiers (SSA), Low Noise Amps (LNA), and Power Amps (PA). CMOS technology will be largely used to design the devices mentioned.

Course usually offered in spring term

Prerequisite: ESE 572

Activity: Lecture

1 Course Unit

ESE 590 Systems Methodology

This course covers the methodologies and techniques important to designing large complex, purposeful systems and to discovering policies that influence them throughout the stages of their lifecycle. The course focuses on hands-on synthetic thinking, where students assemble the big picture from modeling the individual actors, organizations, and artifacts in a socio-technical system of interest. This is the study of emergence of macro-behavior from the micro-decision making of the actors involved - to inquire into the design of a purposeful system, and to examine alternative futures that are ideal, yet affordable, sustainable, and workable. Specifically, the student learns systems theory, systems methodologies (design inquiry/learning systems, idealized design/interactive planning, and soft systems methodology/knowledge management), bottom up modeling (decision science, multi-attribute utility theory, affective reasoning, agent based modeling, simulated societies), and how to further research and apply the synthetic paradigm. Course usually offered in spring term

Activity: Lecture

1 Course Unit

ESE 597 Master's Thesis

One-term course offered either term

Activity: Masters Thesis

1 Course Unit

ESE 599 Independent Study for Master's credit

One-term course offered either term

Activity: Independent Study

1 Course Unit

ESE 605 Modern Convex Optimization

This course concentrates on recognizing and solving convex optimization problems that arise in engineering. Topics include: convex sets, functions, and optimization problems. Basis of convex analysis. Linear, quadratic, geometric, and semidefinite programming. Optimality conditions, duality theory, theorems of alternative, and applications. Interior-point methods, ellipsoid algorithm and barrier methods, self-concordance. Applications to signal processing, control, digital and analog circuit design, computation geometry, statistics, and mechanical engineering. Course usually offered in spring term

Prerequisites: Knowledge of linear algebra and willingness to do programming. Exposure to numerical computing, optimization, and application fields is helpful but not required.

Activity: Lecture

1 Course Unit

ESE 610 Electromagnetic and Optical Theory II

This course covers exact, approximate and numerical methods of wave propagation, radiation, diffraction and scattering with an emphasis on bringing students to a point of contributing to the current research literature. Topics are chosen from a list including analytical and numerical techniques, waves in complex media and metamaterials, photonic bandgap structures, imaging, miniaturized antennas, high-impedance ground plans, and fractal electrodynamics.

Course not offered every year

Activity: Lecture

1 Course Unit

ESE 611 Nanophotonics: Light at the Nanoscale

This course is intended for first and second year graduate students interested in nanoscale optics and photonics. Building on prior coursework in electromagnetism, this course provides a theoretical foundation and up-to-date survey of the key principles and phenomena relevant to the field of nanophotonics. Topics discussed include light-matter interaction through Maxwell's equations, photonic band theory and photonic crystals, plasmonic structures and devices, metamaterials and metasurfaces, PT-symmetric & topological photonic systems.

Applications of nanophotonic devices and principles to a wide range of scenarios will also be explored in depth, including for renewable energy, information processing, imaging and sensing. Experimental techniques used in nanophotonics will be concurrently introduced and discussed.

One-term course offered either term

Prerequisite: ESE 510 recommended or permission of the instructor

Activity: Lecture

1 Course Unit

ESE 617 Non-Linear Control Theory

The course studies issues in nonlinear control theory, with a particular emphasis on the use of geometric principles. Topics include: controllability, accessibility, and observability, for nonlinear systems; Forbenius' theorem; feedback and input/output linearization for SISO and MIMO systems; dynamic extension; zero dynamics; output tracking and regulation; model matching disturbance decoupling; examples will be taken from mechanical systems, robotic systems, including those involving nonholonomic constraints, and active control of vibrations.

Course not offered every year

Also Offered As: CBE 617, CIS 613, MEAM 613

Prerequisite: ESE 500 or equivalent

Activity: Lecture

1 Course Unit

ESE 619 Model Predictive Control

Increased system complexity and more demanding performance requirements have rendered traditional control laws inadequate regardless if simple PID loops are considered or robust feedback controllers designed according to some H2/infinity criterion. Applications ranging from the process industries to the automotive and the communications sector are making increased use of Model Predictive Control (MPC) where a fixed control law is replaced by on-line optimization performed over a receding horizon. The advantage is that MPC can deal with almost any time-varying process and specifications, limited only by the availability of real-time computer power. In the last few years we have seen tremendous progress in this interdisciplinary area where fundamentals of systems theory, computation and optimization interact. For example, methods have emerged to handle hybrid systems, i.e. systems comprising both continuous and discrete components. Also, it is now possible to perform most of the computations off-line thus reducing the control law to a simple look-up table.

Course usually offered in fall term

Prerequisites: Linear Algebra (ESE 500), Optimization (ESE 504 or ESE 605)

Activity: Lecture

1 Course Unit

ESE 621 Nanoelectronics

This is a graduate level course on fundamental operating principles and physics of semiconductor devices in reduced or highly scaled dimensions. The course will include topics and concepts covering basic quantum mechanics and solid state physics of nanostructures as well as device transport and characterization, materials and fabrication. A basic knowledge of semiconductor physics and devices is assumed. The course will build upon basic quantum mechanics and solid state physics concepts to understand the operation of nanoscale semiconductor devices and physics of electrons in confined dimensions. The course will also provide a historical perspective on micro and nanoelectronics, discuss the future of semiconductor computing technologies, cutting edge research in nanomaterials, device fabrication as well as provide a perspective on materials and technology challenges.

One-term course offered either term

Prerequisite: ESE 521 or permission of the instructor

Activity: Lecture

1 Course Unit

ESE 635 Distributed Systems

This research seminar deals with tools, methods, and algorithms for analysis and design of distributed dynamical systems. These are large collections of dynamical systems that are spatially interconnected to form a collective task or achieve a global behavior using local interactions. Over the past decade such systems have been studied in disciplines as diverse as statistical physics, computer graphics, robotics, and control theory. The purpose of this course is to build a mathematical foundation for study of such systems by exploring the interplay of control theory, distributed optimization, dynamical systems, graph theory, and algebraic topology. Assignments will consist of reading and researching the recent literature in this area. Topics covered in distributed coordination and consensus algorithms over networks, coverage problems, effects of delay in large scale networks. Power law graphs, gossip and consensus algorithms, synchronization phenomena in natural and engineered systems, etc.

Course not offered every year

Prerequisites: Basic knowledge of linear systems (ESE 500), linear algebra (MATH 312 or equivalent), and optimization (ESE 504 or equivalent) and some familiarity with basics of nonlinear systems (ESE 617 or equivalent). Students without this background should consult with the instructor before registering.

Activity: Lecture

1 Course Unit

ESE 650 Learning in Robotics

This course will cover the mathematical fundamentals and applications of machine learning algorithms to mobile robotics. Possible topics that will be discussed include probabilistic generative models for sensory feature learning. Bayesian filtering for localization and mapping, dimensionality reduction techniques for motor control, and reinforcement learning of behaviors. Students are expected to have a solid mathematical background in machine learning and signal processing, and will be expected to implement algorithms on a mobile robot platform for their course projects. Grading will be based upon course project assignments as well as class participation.

Course usually offered in fall term

Prerequisites: Students will need permission from the instructor. They will be expected to have a good mathematical background with knowledge of machine learning techniques at the level of CIS 520, signal processing techniques at the level of ESE 531, as well as have some robotics experience

Activity: Lecture

1 Course Unit

ESE 672 Integrated Communication Systems

This is an advanced radio frequency (RF) circuit design course that includes analysis and design of high-frequency and high-speed integrated communication circuits at both transistor and system levels. Students gradually design and simulate different blocks of an RF receiver and combine these blocks to form the receiver as their final project. We assume some background knowledge of device physics, electromagnetics, circuit theory, control theory, and stochastic processes. One-term course offered either term

Prerequisite: ESE 419 or ESE 572

Activity: Lecture

1 Course Unit

ESE 674 Information Theory

Deterministic and probabilistic information. The pigeon-hole principle. Entropy, relative entropy, and mutual information. Random processes and entropy rate. The asymptotic equipartition property. Optimal codes and data compression. Channel capacity. Source channel coding. The ubiquitous nature of the theory will be illustrated with a selection of applications drawn from among: universal source coding, vector quantization, network communication, the stock market, hypothesis testing, algorithmic computation and kolmogorov complexity, and thermodynamics.

Course not offered every year

Prerequisite: ESE 530 or equivalent exposure to probability theory

Activity: Lecture

1 Course Unit

ESE 676 Coding Theory

Coding theory for telecommunications with emphasis on the algebraic theory of cyclic codes using finite field arithmetic, decoding of BCH and Reed-Solomon codes, finite field Fourier transform and algebraic geometry codes, convolutional codes and trellis decoding algorithms, graph based codes, Berrou codes and Gallager codes, turbo decoding, iterative decoding. And belief propagation.

One-term course offered either term

Prerequisites: ESE 224, MATH 240, PHYS 150, Mathematical aptitude.

Activity: Lecture

1 Course Unit

ESE 680 Special Topics in Electrical and Systems Engineering

Advanced and specialized topics in both theory and application areas. Students should check Graduate Group office for offerings during each registration period.

Course not offered every year

Activity: Lecture

1 Course Unit

ESE 895 Teaching Practicum

Participation of graduate students in the teaching mission of the department will help to develop teaching, presentation, leadership, and interpersonal skills while assisting the department in discharging its teaching responsibilities. All doctoral students are required to participate under faculty guidance in the teaching mission of the department.

This requirement will be satisfied by completing two 0.5 course units of teaching practicum (ESE 895). Each 0.5 course unit of teaching practicum will consist of the equivalent of 10 hours of effort per week for one semester.

As a part of the preparation for and fulfillment of the teaching practicum requirement, the student will attend seminars emphasizing teaching and communication skills, lead recitations, lead tutorials, supervise laboratory experiments, develop instructional laboratories, develop instructional material and grade homeworks, laboratory reports, and exams. A teacher training seminar will be conducted the day before the first day of classes of the Fall semester.

Attendance is mandatory for all second-year students. As much as possible, the grading aspect of the teaching practicum course will be such as not to exceed 50% of the usual teaching assistant commitment time. Some of the recitations will be supervised and feedback and comments will be provided to the student by the faculty member responsible for the course. At the completion of every 0.5 course unit of teach, the student will receive a Satisfactory/Unsatisfactory grade and a written evaluation signed by the faculty member responsible for the course. The evaluation will be based on comments of the students taking the course and the impressions of the faculty

One-term course offered either term

Activity: Lecture

0.5 Course Units

ESE 899 Independent Study for PhD credit

For students who are studying a specific advanced subject area in electrical engineering. Students must submit a proposal outlining and detailing the study area, along with the faculty supervisor's consent, to the graduate group chair for approval. A maximum of 1 c.u. of ESE 899 may be applied toward the MSE degree requirements. A maximum of 2 c.u.'s of ESE 899 may be applied toward the Ph.D. degree requirements.

One-term course offered either term

Activity: Independent Study

1 Course Unit

ESE 995 Dissertation

Register for this after completing four years of full-time study including two course units each Summer Session (and usually equal to 40 course units).

One-term course offered either term

Activity: Dissertation

1 Course Unit

ESE 999 Thesis/Dissertation Research

For students working on an advanced research program leading to the completion of master's thesis or Ph.D. dissertation requirements.

One-term course offered either term

Activity: Independent Study

1 Course Unit