E E-ELECTRICAL ENGINEERING

E E 200. Linear Algebra, Probability and Statistics Applications
4 Credits (3+3P)
The theory of linear algebra (vectors and matrices) and probability (random variables and random processes) with application to electrical engineering. Computer programming to solve problems in linear algebra and probability.
Prerequisite: C- or better in ENGR 140 and (MATH 1521G or MATH 1521H or ENGR 190).
Learning Outcomes
1. Perform vector and matrix operations, including matrix inversion, eigen analysis, finding basis and dimension of vector spaces and rank of a matrix, and solving a set of linear equations.
2. Calculate probabilities using probability mass, density, and cumulative distribution functions for single and multiple, discrete and continuous random variables, and relate them to electrical engineering applications.
3. Perform simple parameter estimation, such as finding sample mean and variance, and relate to confidence intervals.
4. Describe random processes in the context of signal processing and communications systems problems.
5. Use MATLAB to solve problems involving linear algebra and probability, including designing and performing simple numerical experiments.

E E 240. Multivariate and Vector Calculus Applications
3 Credits (3)
Vector algebra, cylindrical and spherical coordinates, partial derivatives, multiple integrals. Calculus of vector functions through electrostatic applications. Divergence, gradient, curl, divergence theorem, Stokes's theorem, Coulomb's Law, Gauss's Law, electric field, electric potential. Applications in Matlab.
Prerequisite: C- or better in (MATH 1521G or MATH 1521H or ENGR 190) and ENGR 140.
Learning Outcomes
1. Students will demonstrate conceptual understanding of the fundamental principles and theories in vector calculus
2. Students will analyze and solve problems using vector calculus in three coordinate systems

E E 300. Cornerstone Design
2 Credits (1+3P)
Application and realization of engineering principles to a guided team-based design project. Formulation and implementation of test procedures, evaluation of alternate solutions and oral and written communication of the design and test results. Restricted to: E E majors. Restricted to Las Cruces campus only.
Prerequisite: C- or better in ENGR 140 and ENGR 230 and E E 200.
Learning Outcomes
1. Formulate and implement test procedures for validation of requirements.
2. Evaluate alternative design solutions.
3. Document test procedures and design solutions.
4. Implement design to include a printed-circuit board, electronics and coding.
5. Communicate the design and validation both orally and in writing to a wide range of target audiences.
6. Work in teams.

E E 317. Semiconductor Devices and Electronics I
4 Credits (3+3P)
Analysis and design of opamp circuits, diode circuits and single-transistor MOS and BJT amplifiers. Introduction to solid-slate semiconductor devices.
Prerequisite: C- or better in ENGR 230 and CHEM 1215G.
Learning Outcomes
1. Analysis and design of single time-constant circuits, op-amp circuits, and linear power supplies.
2. Understanding of solid-state devices.
3. Biasing and small-signal analysis of MOS and BJT single transistor amplifiers.
4. Using computer tools to simulate electronic circuits.
5. Testing electronic circuits using power supplies, function generators, digital multi-meters, and oscilloscopes.
6. Writing and documenting laboratory results.

E E 320. Signals and Systems I
3 Credits (3)
Introduction to the modeling and analysis of continuous- and discrete-time signals and systems using time- and frequency-domain methods suitable for both mathematical approaches and computer-aided simulations.
Prerequisite: C- or better in ENGR 190.
Learning Outcomes
1. Understand different types of signals (continuous-time, discrete-time, periodic, etc.) and how these signals are represented mathematically and in a computer.
2. Understand systems representations (e.g., impulse responses), implementations (e.g., convolution and difference/differential equations), and properties (e.g., linearity).
3. Gain insight into transform-domain analysis for signals and systems.
4. Develop the ability to apply transform domain and LTI analysis to simple applications in signal processing, communications, and controls using Matlab.

E E 325. Signals and Systems II
4 Credits (3+3P)
Introduction to communication systems including amplitude and frequency modulation. Introduction to control systems including linear feedback systems, root-locus analysis, and graphical representations. Introduction to digital signal processing including sampling, digital filtering, and spectral analysis.
Prerequisite: C- or better in E E 200 and E E 320.
Learning Outcomes
1. To model, analyze, simulate, and perform calculations with continuous- and discrete-time systems.
2. To develop an understanding of basic modulations in communication systems.
3. To gain insight into the basics of control systems.
4. To develop insight into filtering and analysis of digital signals.
5. To learn how to use MATLAB and SIMULINK to perform analysis, design, and simulation of communication, control, and signal processing systems.

E E 333. AC Circuit Analysis and Introduction to Power Systems
3 Credits (2+3P)
Steady-state analysis of AC circuits, three-phase circuits, and an introduction to power systems.
Prerequisite: C- or better in ENGR 230.
Learning Outcomes
1. To introduce students to the basic structure and requirements of any electric power supply system and the nature of power systems engineering and the profession which will establish background for further studies in power systems.
2. To develop an understanding of components in a power system and to understand the basic electromagnetic and electromechanical principles involved in these components.
3. To develop an understanding of the physical-principles—to-electric-equivalent circuit approach to the analysis and design of components and systems.
4. To develop skills in equivalent circuit based analysis techniques building upon competencies developed in prior coursework.
5. To explore analysis and design principles for the complete power system
6. To understand measurement, analysis, simulation and design techniques, through laboratory exercises involving hardware and software.

E E 340. Fields and Waves
4 Credits (3+3P)
Static electromagnetic field. Maxwell's equation and time-varying electromagnetic fields. Generalized plane wave propagation, reflection, transmission, superposition and polarization. Transmission line theory. Extensions to optical wave propagation. Applications including Time Domain Reflectrometry (TDR) and fiber optic transmission. Laboratory experience with RF/microwave test equipment and optical apparatus.
Prerequisite: C- or better in ENGR 230 and E E 240.
Learning Outcomes
1. Students will demonstrate an understanding of the fundamental principles, theories, and equations (such as Maxwell's) governing transmission lines, static and time-varying fields, propagation, reflection and transmission of plane waves, waveguides, and antennas.
2. Students will analyze and solve electromagnetic-related problems by applying fundamental principles, theories, and equations (such as Maxwell's equations).
3. Students will demonstrate effective team work.
4. Students will demonstrate the use of RF/microwave test equipment to perform basic RF circuit measurements.

E E 362. Introduction to Computer Organization
4 Credits (3+3P)
Concepts of modern computer organization, CPU control, pipelining, memory hierarchies, memory mapping, hardware-software interface, and operating systems.
Prerequisite: C- or better in ENGR 120 and ENGR130 and ENGR140 and MATH 1250G.
Learning Outcomes
1. Be conversant with fundamental concepts of computer organization.
2. Compare and contrast organizational features of different computer.
3. Understand the use of microprocessors and peripheral devices in practical applications.

E E 395. Introduction to Digital Signal Processing
3 Credits (3)
Undergraduate treatment of sampling/reconstruction, quantization, discrete-time systems, digital filtering, z-transforms, transfer functions, digital filter realizations, discrete Fourier transform (DFT) and fast Fourier transform (FFT), finite impulse response (FIR) and infinite impulse response (IIR) filter design, and digital signal processing (DSP) applications. Laboratory will emphasize practical implementation of signal processing including real-time signal processing.
Prerequisite(s): C- or better in E E 325.

E E 400. Undergraduate Research
1-3 Credits
Directed undergraduate research. May be repeated for a maximum of 9 credits.
Prerequisite: consent of the department head.

E E 403. Geometric Algebra
3 Credits (3)
Geometric algebra provides a common mathematical language for many areas of physics (classical and quantum mechanics, electrodynamics, special and general relativity), computer science (graphics, robotics, computer vision), engineering, and other fields. Topics include: the geometric product and multivectors; Euclidean, Lorentzian, Galilean, and Projective Geometries; Complex, Hyperbolic, and Dual Numbers; Quaternions and Rotations. Taught with E E 576.
Prerequisite: C- or better in E E 320.
Learning Outcomes
1. Formulate and solve problems related to multivectors and the geometric product while building geometric intuition.
2. Formulate and solve problems related to complex, hyperbolic, and dual numbers as well as quaternions.
3. Formulate and solve problems related to non-Euclidean spaces including Lorentzian, Galilean, and projective geometries.

E E 405. Electricity Markets
3 Credits (3)
Power systems operation in regulated and competitive environments. Topics include: basics of microeconomics; linear programming, duality; electricity market pricing and settlement; RTO operation. Taught with E E 502.
Prerequisite: C- or better in E E 431.
Learning Outcomes
1. Understand basic microeconomic principles, basics of market power, Cournot equilibrium
2. Understand basics of linear programming, the primal dual problems, economic interpretation of dual variables, basics of mixed integer programming
3. Understand dispatch optimization problems in the electric energy markets including economic dispatch, unit commitment
4. Understand motivation and objectives of market design, including uniform vs. pay-as-bid pricing, locational marginal prices (LMPs), dual of the DCOPF and the various terms (load payment, congestion rent, etc.), pricing issues in non-convex markets, financial transmission rights, ancillary services market

E E 406. Quantum Computing
3 Credits (3)
This course is an introduction to quantum computing (QC), emphasizing the underlying theory. Topics covered include single and multiple qubit systems, state transformations, algorithms, subsystems, and error correction. The course is intended to be accessible to a wide audience

of engineers, mathematicians, and scientists; no previous exposure to quantum physics is required. It is highly recommended that students have completed a college-level linear algebra course. Taught concurrently with E E 506.

Learning Outcomes

1. Explain the quantum computing paradigm.
2. Apply the principles of quantum mechanics for computation.
3. Analyze quantum algorithms and evaluate possible quantum speedups.
4. Describe the framework of quantum error correction codes.

E E 407. Introduction to Control Systems
3 Credits (3)

This course provides an introduction to the analysis of control systems. The main focus will be on techniques in classical control theory. System dynamics and modeling techniques in both the frequency domain and the time domain will be covered. Students will learn how to transform linear dynamical systems between state-space and frequency domains, and evaluate conditions for stability in each domain. Students will analyze and characterize both the transient and steady-state response, and examine root locus, Bode, and Nyquist plots. Concepts of robust control, including tradeoffs between sensitivity and performance, will be emphasized throughout. Applications will range across electrical, mechanical, chemical, biomedical, and biological systems. Laboratory activities include modeling, analysis and simulation of physical processes.

Prerequisite: C- or better in E E 325 and MATH 392.

Learning Outcomes

1. Obtain mathematical models of electrical and mechanical systems from their idealized elements.
2. Derive the transfer function of a control system.
3. Apply their mathematical knowledge to determine the response of a linear system to various types of inputs.
4. Develop familiarity and confidence with analyzing transient and steady state responses of a linear system.
5. Apply their mathematical knowledge to understand the concept of stability.
6. Develop familiarity and confidence with controller design based on Routh-Hurwitz, Root locus and P, PI, PID modes of control.
7. Develop proficiency in systems simulation using MATLAB and SIMULINK.

E E 408. Noncooperative Game Theory
3 Credits (3)

The purpose of this course is to teach students to formulate problems as mathematical games and provide the basic tools to solve them. The course covers: Static games, starting with two-player zero-sum games and eventually building up to n-player non-zero sum games. Saddle-points and Nash equilibria will be covered. Dynamic optimization (dynamic programming) for discrete and continuous time. Dynamic games, both open and closed-loop policies. The intended audience includes (but is not restricted to) students in engineering and computer science. The class is heavily project-oriented and the students are strongly encouraged to choose a project that is relevant to their own area of research. Taught with E E 553.

Prerequisite: C- or better in E E 200 or ((MATH 2415 or MATH 480) and (STAT 371 or STAT470) and (C S 172 or C S 271)) or equivalent.

Learning Outcomes

1. Comprehend the key principles of noncooperative game theory.
2. Apply the Minimax Theorem and evaluating mixed saddle-point equilibria.
3. Analyze stochastic policies for games in extensive form, and apply them to the existence and computation of saddle-point equilibria.
4. Comprehend games with N-players.
5. Analyze potential games and evaluate Nash equilibria for potential games.
6. Analyze dynamic games: the optimal control of a dynamical system.
7. Evaluate the saddle-point equilibria of zero-sum discrete-time and continuous-time dynamic games in state-feedback policies.

E E 409. Hardware & Software Codesign
3 Credits (3)

This course introduces the concept and techniques of designing electronic systems that integrates both hardware and software components. Topics include nature of hardware and software, dataflow modeling, software and hardware implementations of dataflows, analysis of control flows and dataflows, FSM with Datapath, microprogramming, embedded cores, and trade-offs between hardware and software components, etc. Students gain experience in implementing hardware and software co-design solutions for solving real-world problems through hands-on laboratory/project on a programmable System-on-Chip (SoC) platform that integrates a dual-core ARM Cortex-A9 processor and FPGA fabrics. Students develop a fundamental understanding of state-of-the-art practices in developing codesign solutions to problems that prepare them well for industrial and academic careers in this field. Taught with E E 556.

Prerequisite: C- or better in ENGR 140 and ENGR 130 and (E E 362 or C S 473).

Learning Outcomes

1. Formulate and solve problems related to basic concepts and methodologies in hardware/software co-design.
2. Analyze concurrent specification of an algorithm to be partitioned into software (C code) and hardware (HDL) components.
3. Design and implement both the software and hardware components integration as a solution to real-world problems to achieve optimal performance, power and cost.
4. Descrbe various types of system architectures regarding their attributes including speed, energy, design complexity, design cost, etc.
5. Experience working with commercially available Computer-Aided Design (CAD) development tools such as Xilinx Vivado
6. Experience working in translation between C code and HDL of practical problems and verify/test the solution on FPGA SoC architecture

E E 412. ASIC Design
3 Credits (3)

This course provides students with experiential knowledge of modern application specific integrated circuits. Topics include ASIC packaging and testing, I/O pads and ESD, Verilog programming and simulation, FPGA verification, Register-transfer level synthesis, timing and area optimization, floorplanning and routing, digital interfaces, full custom and standard cell design, post-layout simulation, and PCB schematics and layout. Taught with E E 512.

Prerequisite: C - or better in E E 480.

Learning Outcomes

1. Cadence ASIC design tools and design flow
2. Verilog programming, simulation, and FPGA verification

3. Padring, I/O, and ESD for ASIC
4. CMOS standard cell library for large scale digital circuit
5. MOSIS Tapeout options and ASIC package selections
6. Typical digital interfaces
7. Allegro PCB schematic and layout, ASIC testing
8. Digital Signal Processing Circuits implementation in ASIC

E E 431. Power Systems II
3 Credits (3)
Analysis of a power system in the steady-state. Includes the development of models and analysis procedures for major power system components and for power networks. Taught with E E 542.
Prerequisite: C- or better in E E 333.
Learning Outcomes

1. To introduce students to the basic structure and requirements of any electric power supply system and the nature of power systems engineering and the profession. To establish background for further studies in power systems
2. To develop an understanding of components in a power system and to understand the basic electromagnetic and electromechanical principles involved in these components.
3. To develop an understanding of the physical-principles—to-electric-equivalent circuit approach to the analysis and design of components and systems.
4. To develop skills in equivalent circuit based analysis techniques building upon competencies developed in prior coursework.
5. To explore analysis and design principles for the complete power system
6. To convey to the student a thorough understanding of both the theory and the mechanics involved in the modeling and analysis of power system components and networks
7. To study how such modeling and analysis is used in the design/planning of power systems

E E 432. Power Electronics
3 Credits (2+3P)
Basic principles of power electronics and its applications to power supplies, electric machine control, and power systems. Taught with E E 537.
Prerequisite: C- or better in E E 317 and E E 333.
Learning Outcomes

1. To introduce students to the basic structure and requirements of any electric power supply system and the nature of power systems engineering and the profession. To establish background for further studies in power systems
2. To develop an understanding of components in a power system and to understand the basic electromagnetic and electromechanical principles involved in these components.
3. To develop an understanding of the physical-principles—to-electric-equivalent circuit approach to the analysis and design of components and systems.
4. To develop skills in equivalent circuit based analysis techniques building upon competencies developed in prior coursework.
5. To explore analysis and design principles for the complete power system
6. To convey to the student a thorough understanding of both the theory and the mechanics involved in the modeling and analysis of power system components and networks
7. To study how such modeling and analysis is used in the design/planning of power systems

E E 433. Power System Operation
3 Credits (3)
Basics of power system operation; linear programming, economic dispatch, mixed integer programing, power system security and contingency analysis; RTO operation; generation control; renewable integration.
Prerequisite: C- or better in E E 431.
Learning Outcomes

1. Understand basic microeconomic principles, basics of market power, Cournot equilibrium.
2. Understand basics of linear programming and can use software to solve simple linear programming problems.
3. Understand the different between AC and DC power flow. Understand dispatch optimization problems in the electric energy markets including economic dispatch, unit commitment.
4. Understand the control schemes in power system, including governor repose, automatic generation control.
5. Understand the power system security including N-I criteria, contingency analysis, and security constraints.

E E 440. Photovoltaic Devices and Systems
3 Credits (3)
Technical concepts of photovoltaics, with primary focus on solar cell technology. Solar cell device level operation, packaging, and manufacturing. Design of photovoltaic systems for stand-alone or grid-tied operation. Business-case analysis using real-life scenarios of photovoltaic system solutions. Taught with E E 540.
Prerequisite: C- or better in E E 317.
Learning Outcomes

1. Name at least three different types of photovoltaic materials and cells;
2. Derive equations governing operation of photovoltaic cells;
3. Design and create electrical engineering drawings for photovoltaic systems of different nameplate capacity;
4. Describe principles of operation of the “balance of the system” (BOS) components of the photovoltaic system.

E E 443. Mobile Application Development
3 Credits (3)
Introduction to mobile application development. Students will develop applications for iOS devices including iPhone and iPad. Topics include object-oriented programming using Swift, model-view-controller (MVC) pattern, view controllers including tables and navigation, graphical user interface (GUI) design, data persistence, GPS and mapping, camera, and cloud and web services. Taught with E E 593.
Prerequisite: C- or better in C S 151 or C S 152 or C S 172 or C S 271 or C S 451 or C S 452.
Learning Outcomes

1. The objective of this course is to gain an understanding of mobile application development, including Swift, Model-View-Controller (MVC) pattern, Memory management, View controllers, Frameworks: Foundation, CoreGraphics, CoreLocation, MapKit, UIKit, WebKit

E E 444. Advanced Image Processing
3 Credits (3)
Advanced topics in image processing including segmentation, feature extraction, object recognition, image understanding, big data, and applications. Taught with E E 588.

Prerequisite: C- or better in E E 446.

Learning Outcomes

1. Implement and analyze segmentation of color and grayscale images.
2. Implement and analyze morphological analysis of binary images
3. Implement and analyze compression of images
4. Implement and analyze feature extraction and classification of images
5. Implement and analyze convolutional neural networks (CNNs) for classification of images

E E 446. Digital Image Processing

3 Credits (3)

Two-dimensional transform theory, color images, image enhancement, restoration, segmentation, compression and understanding. Taught with E E 596.

Prerequisite: C- or better in E E 325.

Learning Outcomes

1. Analyze human visual perception and the implications to science and society
2. Formulate and analyze problems that utilize the mathematics behind multidimensional image processing
3. Formulate and analyze problems involving multidimensional transformation transform-domain processing
4. Formulate and analyze problems related to color image acquisition, processing, and display
5. Implementing image processing algorithms on computers in Matlab or python

E E 447. Neural Signal Processing

3 Credits (3)

Cross-disciplinary course focused on the acquisition and processing of neural signals. Students in this class will be learn about basic brain structure, different brain signal acquisition techniques (fMRI, EEG, MEG, etc.), neural modeling, and EEG signal processing. To perform EEG signal processing, students will learn and use Matlab along with an EEG analysis package. Taught with E E 597.

Prerequisite: C- or better in E E 325.

Learning Outcomes

1. Demonstrate understanding and skill in the Structure and basic operation of the human brain
2. Demonstrate understanding and skill in processing of EEG brain signals using Matlab and EEGLAB
3. Demonstrate understanding and skill in EEG-related neural modeling
4. Demonstrate understanding and skill in brain signal types and acquisition

E E 448. Signal Compression

3 Credits (3)

Fundamentals of information source encoding and decoding. Includes information theory bounds on source coding, lossless coding algorithms, scalar quantizing and vector quantizing. Taught with E E 573.

Prerequisite: C- or better in E E 200.

Learning Outcomes

1. Formulate and analyze problems related to rate-distortion tradeoffs in compression
2. Formulate and analyze problems related to scalar and vector quantization
3. Formulate and analyze problems related to transform coding
4. Formulate and analyze problems related to entropy coding (Huffman arithmetic)
5. Formulate and analyze problems related to standardized codecs, including MPEG, JPEG, MP3
6. Formulate and analyze problems related to compressive sensing/ sampling

E E 452. Introduction to Radar

3 Credits (3)

Basic concepts of radar. Radar equation; detection theory. AM, FM, and CW radars. Analysis of tracking, search, MTI, and imaging radar. Recommended foundation: E E 496. Taught with E E 548.

Prerequisite: C- or better in E E 325 and E E 340.

Learning Outcomes

1. Students will demonstrate an understanding of fundamental principles of various types of radar systems and their applications,
2. Students will learn to analyze a given radar system,
3. Students will learn to use simulation techniques to design a radar system that will yield desired characteristics,
4. Students will experience working in groups/teams

E E 453. Microwave Engineering

3 Credits (3)

Techniques for microwave measurements and communication system design, including transmissions lines, waveguides, and components. Microwave network analysis and active device design. Taught with E E 521.

Prerequisite: C- or better in E E 340.

Learning Outcomes

1. Students will demonstrate an understanding of fundamental principles and theories related to microwave systems, components, and devices
2. Students will analyze and solve microwave engineering-related problems using the fundamental microwave engineering theories and principles
3. Students will demonstrate the use of microwave engineering design tools
4. Students will demonstrate effective team work
5. Students will demonstrate an understanding the impact of engineering solutions in a global, economic, environmental, and societal context
6. Students will demonstrate an understanding of the knowledge of contemporary professional, societal and global issues

E E 454. Antennas and Radiation

4 Credits (3+3P)

Basic antenna analysis and design. Fundamental antenna concepts and radiation integrals. Study of wire antennas, aperture antennas, arrays, reflectors, and broadband antennas. Taught with E E 541.

Prerequisite: C- or better in E E 340.

Learning Outcomes

1. Students will demonstrate an understanding of the fundamental principles, theories, and equations governing antenna radiation, antenna arrays, and matching, etc.
2. Students will analyze and solve the antenna-related radiation problems, antenna structures.
3. Students will demonstrate the use of antenna synthesis techniques and simulation software to solve antenna related problems
4. Students will demonstrate effective team work
5. Students will demonstrate an understanding the impact of engineering solutions in a global, economic, environmental, and societal context

6. Students will demonstrate an understanding of the knowledge of contemporary professional, societal and global issues

E E 458. Hardware Security and Trust
3 Credits (3)
This course introduces and investigates recent technology development for the design and evaluation of secure and trustworthy hardware and embedded systems. Topics include IoT security, cryptography, hardware security primitives, authentication and key generation, invasive and non-invasive attacks and countermeasures, IC piracy and intellectual property protection, hardware trojans, and secure boot. Taught with E E 558.
Prerequisite: C- or better in E E 362.
Learning Outcomes
1. Understand the security goals of information security
2. Understand cryptography basics and their applications
3. Formulate and analyze problems related to security threats in integrated circuits, electronic devices and semiconductor supply chain
4. Formulate and analyze problems related to security countermeasures to the threats of integrated circuits and electronic devices
5. Use metrics to measure and assess the security level of security mechanisms or primitives in hardware security applications
6. Analyze and assess potential security vulnerabilities in hardware and embedded systems
7. Learn state-of-art security mechanisms and research topics in the hardware and embedded security area

E E 460. Space System Mission Design and Analysis
3 Credits (3)
Satellite system design, including development, fabrication, launch, and operations. A systems engineering approach to concepts, methodologies, models, and tools for space systems. Students must be in junior standing to enroll.
Learning Outcomes
1. Apply knowledge from science, math and engineering to satellite design.
2. Experience the “system engineering” of satellite design through the design of a space mission.
3. Understand the professional and ethical responsibilities related to satellite design.
4. Understand the impact of satellite related engineering solutions in a global, economic, environmental, and societal context.
5. Maintain a knowledge of contemporary professional, societal and global issues as they relate to satellites.

E E 462. Computer Systems Architecture
3 Credits (3)
The course covers uniprocessors, caches, memory systems, virtual memory, storage systems, with introduction to multiprocessor and distributed computer architectures; models of parallel computation; processing element and interconnection network structures, and nontraditional architectures. Taught with E E 562.
Prerequisite: C- or better in E E 362.
Learning Outcomes
1. Recognize the basic principles and current practices of computer architectures of processors, memory systems, interconnects, and input/output systems
2. Reason about the issues that influence the architectures of processors, memory systems, interconnects, and input/output systems
3. Evaluate and improve computer system performance through analysis and computer simulation
4. Solve and implement a small research problem in computer architecture.

E E 465. Machine Learning I
3 Credits (3)
An undergraduate-level introduction to machine learning algorithms, including supervised and unsupervised learning methods. Topics covered include clustering, linear regression models, linear discriminant functions, feed-forward neural networks, statistical pattern classification and regression, maximum likelihood, naive Bayes, non-parametric density estimation, mixture models, decision trees, and ensemble learning. Taught with E E 565.
Prerequisite: C- or better in E E 200.
Learning Outcomes
1. Formulate and solve problems related to the basic concepts and mathematical techniques of machine learning.
2. Gain an understanding of machine learning algorithms/methods by solving problems using software.
3. Gain experience doing independent study and research.
4. Formulate and solve problems related to the basics of regression, classification, and unsupervised learning.
5. Gain practical experience through project-based assignments and technical report writing.

E E 467. ARM SOC Design
3 Credits (3)
The course aims to produce students who are capable of developing ARM-based SoCs from high level functional specifications to design, implementation and testing on real FPGA hardware using standard hardware description and software programming languages. Taught with E E 567.
Prerequisite: C- or better in E E 362 and E E 317.
Learning Outcomes
1. Formulate and solve problems requiring knowledge and understanding of ARM processor architectures and ARM-based SoCs
2. Capture the design of ARM-based SoCs in a standard hardware description language
3. Conduct low-level software design for ARM-based SoCs and high-level application development
4. Demonstrate the ability to use and choose between different techniques for digital system design and capture;
5. Evaluate implementation results (e.g. speed, area, power) and correlate them with the corresponding high level design and capture;
6. Demonstrate the ability to use a commercial tools to develop ARM-based SoCs

E E 473. Introduction to Optics
3 Credits (3)
The nature of light, geometrical optics, basic optical instruments, wave optics, aberrations, polarization, and diffraction. Elements of optical radiometry, lasers and fiber optics. Crosslisted with: PHYS 473.
Prerequisite(s): C- or better in PHYS 1320G or PHYS 2120.

E E 475. Control Systems Synthesis
3 Credits (3)
An advanced perspective of linear modern control system analysis and design, including the essential algebraic, structural, and numerical properties of linear dynamical systems. Computer-aided solution of real-world design problems. Taught with E E 551.

Prerequisite: C- or better in E E 407.

Learning Outcomes

1. Understand the concepts of Model Identification and Parameter Estimation (least-square identification of a auto-regressive model; nonparametric identification in the time domain; and nonparametric identification in the frequency domain)
2. Understand Robust Control techniques (Nyquist-plots, small-gain, and passivity)
3. Understand Optimal control techniques (LQR/LQG for state-space systems and time-optimal controller for the positioning of a mass using force actuation)
4. Understand Nonlinear control techniques (Lyapunov's stability method; feedback linearization controller for a fully actuated 2nd order mechanical system; backstepping for triangular nonlinear systems; actuator limitations)

E E 478. Fundamentals of Photonics
4 Credits (3+3P)

Ray, wave and guided optics, lasers and thermal sources, radiometry, photon detection and signal-to-noise ratio. Elements of photonic crystals, polarization, acousto-optics, electro-optics, and optical nanostructures. Recommended foundation: E E 473 /PHYS 473. Taught with E E 528.

Prerequisite: C- or better in PHYS 1320G or PHYS 2120.

Learning Outcomes

1. Understand the fundamentals of the different theories of light including ray, wave, electromagnetic (vector) and photon optics, and how these theories are represented mathematically and on a computer.
2. Develop the ability to perform calculations for the different theories (ray tracing, wave interference, polarization calculus, photon detection) to determine the propagation characteristics and describe the manipulation of light.
3. Gain insight and experience with materials and devices for manipulating and detecting light (glass, mirrors, lenses, fiber optics, polarization elements, liquid crystals, semiconductors, and photodiodes).
4. Apply the theoretical, mathematical, and practical understanding of optics to describe real-world applications of light technology with supporting analysis and calculations.

E E 480. Introduction to Analog and Digital VLSI
3 Credits (3)

Introduction to analog and digital VLSI circuits implemented in CMOS technology. Design of differential amplifiers, opamps, CMOS logic, flip-flops, and adders. Introduction to VLSI fabrication process. Taught with E E 510.

Prerequisite: C- or better in E E 362 and E E 317.

Learning Outcomes

1. Explain the basic concepts of CMOS VLSI system design
2. Formulate and solve problems related to pseudo ideal operation of MOS transistors as switches and implementation with transistors of basic and complex Boolean functions
3. Use modern software tools to simulate integrated circuits
4. Formulate and solve problems related to operation and design of basic analog building blocks
5. Formulate and solve problems related to operation and design of basic digital building blocks
6. Formulate and solve problems related to key aspects of performance characteristics (speed, power dissipation, Silicon area..) of VLSI systems and how to size transistors in order to achieve desired performance specifications.

E E 485. Analog VLSI Design
3 Credits (2+3P)

Analysis, design, simulation, layout and verification of CMOS analog building blocks, including references, opamps, switches and comparators. Teams implement a complex analog IC. Taught with E E 523.

Prerequisite: C- or better in E E 320 and E E 480.

Learning Outcomes

1. Analysis, design, simulation, and layout of current mirrors, current sources, and voltage references
2. Analysis, design, simulation, and layout of differential and operational amplifiers
3. Analysis, design, simulation, and layout of switched-capacitor circuits
4. Using VLSI CAD tools for simulating and laying out analog integrated circuits
5. Writing laboratory reports and project documentation

E E 490. Selected Topics
1-3 Credits

May be repeated for a maximum of 9 credits. Graduate students may not use credits of E E 490 toward an M.S. or Ph.D. in electrical engineering.

Prerequisite: consent of instructor.

E E 493. Power Systems III
3 Credits (3)

Analysis of a power system under abnormal operating conditions. Topics include symmetrical three-phase faults, theory of symmetrical components, unsymmetrical faults, system protection, and power system stability. Taught with E E 543.

Prerequisite: C- or better in E E 431.

Learning Outcomes

1. To introduce students to the basic structure and requirements of any electric power supply system and the nature of power systems engineering and the profession. To establish background for further studies in power systems
2. To develop an understanding of components in a power system and to understand the basic electromagnetic and electromechanical principles involved in these components.
3. To develop an understanding of the physical-principles—to-electric-equivalent circuit approach to the analysis and design of components and systems.
4. To develop skills in equivalent circuit based analysis techniques building upon competencies developed in prior coursework.
5. To explore analysis and design principles for the complete power system
6. To understand measurement, analysis, simulation and design techniques, through laboratory exercises involving hardware and software.

E E 496. Introduction to Communication Systems
3 Credits (3)

Introduction to the analysis of signals in the frequency and time domains. A study of baseband digital transmission systems and digital/analog RF transmission systems. Introduction to telecom systems as well as satellite systems.

Prerequisite(s): C- or better in E E 325.

E E 497. Digital Communication Systems I
3 Credits (3)

Techniques for transmitting digital data over commercial networks. Topics include baseband and bandpass data transmission and synchronization techniques. Recommended foundation: E E 496. Taught with: E E 581.
Prerequisite: C- or better in E E 200 and E E 325.
Learning Outcomes
1. Analyze bandwidth and error performance of baseband and bandpass signals through mathematical explanations and simulated experimental data.
2. Evaluate channel code structures and their performance.
3. Analyze communication system issues involving link budgets, synchronization and resource allocations.
4. Develop a wider perspective recognizing contemporary technologies, impact of the solutions and professional and ethical responsibilities.

E E 501. Research Topics in Electrical and Computer Engineering
1 Credit (1)
Ethics and methods of engineering research; contemporary research topics in electrical and computer engineering.

E E 502. Electricity Markets
3 Credits (3)
Power systems operation in regulated and competitive environments. Topics include: basics of microeconomics; linear programming, duality; electricity market pricing and settlement; RTO operation. Recommended foundation: E E 431. Taught with: E E 405.
Learning Outcomes
1. Understand basic microeconomic principles, basics of market power, Cournot equilibrium
2. Understand basics of linear programming, the primal dual problems, economic interpretation of dual variables, basics of mixed integer programming
3. Understand dispatch optimization problems in the electric energy markets including economic dispatch, unit commitment
4. Understand motivation and objectives of market design, including uniform vs. pay-as-bid pricing, locational marginal prices (LMPs), dual of the DCOPF and the various terms (load payment, congestion rent, etc.), pricing issues in non-convex markets, financial transmission rights, ancillary services market

E E 506. Quantum Computing
3 Credits (3)
This course is an introduction to quantum computing (QC), emphasizing the underlying theory. Topics covered include single and multiple qubit systems, state transformations, algorithms, subsystems, and error correction. The course is intended to be accessible to a wide audience of engineers, mathematicians, and scientists; no previous exposure to quantum physics is required. It is highly recommended that students have completed a college-level linear algebra course. Taught with E E 406.
Learning Outcomes
1. Explain the quantum computing paradigm.
2. Apply the principles of quantum mechanics for computation.
3. Analyze quantum algorithms and evaluate possible quantum speedups.
4. Describe the framework of quantum error correction codes.

E E 510. Introduction to Analog and Digital VLSI
3 Credits (3)
Introduction to analog and digital VLSI circuits implemented in CMOS technology. Design of differential amplifiers, opamps, CMOS logic, flip-flops, and adders. Introduction to VLSI fabrication process. Recommended foundation: E E 362 and E E 317 Taught with E E 480.
Learning Outcomes
1. Explain the basic concepts of CMOS VLSI system design
2. Formulate and solve problems related to pseudo ideal operation of MOS transistors as switches and implementation with transistors of basic and complex Boolean functions
3. Use modern software tools to simulate integrated circuits
4. Formulate and solve problems related to operation and design of basic analog building blocks
5. Formulate and solve problems related to operation and design of basic digital building blocks
6. Formulate and solve problems related to key aspects of performance characteristics (speed, power dissipation, Silicon area..) of VLSI systems and how to size transistors in order to achieve desired performance specifications.

E E 512. ASIC Design
3 Credits (3)
This course provides students with experiential knowledge of modern application specific integrated circuits. Topics include ASIC packaging and testing, I/O pads and ESD, Verilog programming and simulation, FPGA verification, Register-transfer level synthesis, timing and area optimization, floorplanning and routing, digital interfaces, full custom and standard cell design, post-layout simulation, and PCB schematics and layout. Recommended foundation: E E 480. Taught with E E 412.
Learning Outcomes
1. Cadence ASIC design tools and design flow
2. Verilog programming, simulation, and FPGA verification
3. Padring, I/O, and ESD for ASIC
4. CMOS standard cell library for large scale digital circuit
5. MOSIS Tapeout options and ASIC package selections
6. Typical digital interfaces
7. Allegro PCB schematic and layout, ASIC testing
8. Digital Signal Processing Circuits implementation in ASIC

E E 515. Electromagnetic Theory I
3 Credits (3)
Electromagnetic theory of time-harmonic fields in rectangular, cylindrical and spherical coordinates with applications to guided waves and radiated waves. Induction and equivalence theorems, perturbational and variational principles applied to engineering problems in electromagnetics. Recommended foundation: E E 340.

E E 521. Microwave Engineering
3 Credits (3)
Techniques for microwave measurements and communication system design, including transmission lines, waveguides, and components. Microwave network analysis and active device design. Recommended foundation: E E 340. Taught with: E E 453.

E E 523. Analog VLSI Design
3 Credits (2+3P)
Analysis, design, simulation, layout and verification of CMOS analog building blocks, including references, opamps, switches and comparators. Teams implement a complex analog IC. Recommended foundation: E E 320 and E E 480. Taught with: E E 485.
Learning Outcomes
1. Students completing the course with a grade of C or better will perform satisfactorily on analysis, design, simulation, and layout of current mirrors, current sources, and voltage references.

2. Students completing the course with a grade of C or better will perform satisfactorily on analysis, design, simulation, and layout of differential and operational amplifiers.
3. Students completing the course with a grade of C or better will perform satisfactorily on analysis, design, simulation, and layout of switched-capacitor circuits.
4. Students completing the course with a grade of C or better will perform satisfactorily on using VLSI CAD tools for simulating and laying out analog integrated circuits.
5. Students completing the course with a grade of C or better will perform satisfactorily on writing laboratory reports and project documentation.

E E 528. Fundamentals of Photonics
4 Credits (3+3P)
Ray, wave and guided optics, lasers and thermal sources, radiometry, photon detection and signal-to-noise ratio. Elements of photonic crystals, polarization, acousto-optics, electro-optics, and optical nanostructures. Recommended foundation (PHYS 1320G or PHYS2120) and (E E 473 or PHYS 473), Taught with E E 478. Crosslisted with PHYS 528.
Learning Outcomes
1. Describe the fundamental properties of light.
2. Formulate the concepts of ray, wave, and photon optics mathematically.
3. Represent and incorporate basic elements of an optical system.
4. Perform an analysis of a simple photonic/optical system mathematically by hand and with computer tools such as MATLAB.
5. Discuss ethical, societal, and professional issues related to photonics and optics.

E E 534. Power System Relaying
3 Credits (3)
Fundamental relay operating principles and characteristics. Current, voltage, directional, differential relays; distance relays; pilot relaying schemes. Standard protective schemes for system protection. Operating principles and overview of digital relays. Recommended foundation: E E 493.

E E 537. Power Electronics
3 Credits (2+3P)
Basic principles of power electronics and its applications to power supplies, electric machine control, and power systems. Recommended foundation: E E 317 and E E 333. Taught with: E E 432.
Learning Outcomes
1. To introduce students to the basic structure and requirements of any electric power supply system and the nature of power systems engineering and the profession. To establish background for further studies in power systems
2. To develop an understanding of components in a power system and to understand the basic electromagnetic and electromechanical principles involved in these components.
3. To develop an understanding of the physical-principles—to-electric-equivalent circuit approach to the analysis and design of components and systems.
4. To develop skills in equivalent circuit based analysis techniques building upon competencies developed in prior coursework.
5. To explore analysis and design principles for the complete power system
6. To convey to the student a thorough understanding of both the theory and the mechanics involved in the modeling and analysis of power system components and networks
7. To study how such modeling and analysis is used in the design/planning of power systems

E E 540. Photovoltaic Devices and Systems
3 Credits (3)
Technical concepts of photovoltaics, with primary focus on solar cell technology. Solar cell device level operation, packaging, and manufacturing. Design of photovoltaic systems for stand-alone or grid-tied operation. Business-case analysis using real-life scenarios of photovoltaic system solutions. Recommended foundation: E E 317. Taught with: E E 440.
Learning Outcomes
1. Name at least three different types of photovoltaic materials and cells.
2. Derive equations governing operation of photovoltaic cells.
3. Design and create electrical engineering drawings for photovoltaic systems of different nameplate capacity.
4. Describe principles of operation of the “balance of the system” (BOS) components of the photovoltaic system.

E E 541. Antennas and Radiation
4 Credits (3+3P)
Basic antenna analysis and design. Fundamental antenna concepts and radiation integrals. Study of wire antennas, aperture antennas, arrays, reflectors, and broadband antennas. Recommended foundation is E E 340. Taught with E E 454.
Learning Outcomes
1. Students will demonstrate an understanding of the fundamental principles, theories, and equations governing antenna radiation, antenna arrays, and matching, etc.
2. Students will analyze and solve the antenna-related radiation problems, antenna structures.
3. Students will demonstrate the use of antenna synthesis techniques and simulation software to solve antenna related problems
4. Students will demonstrate effective team work
5. Students will demonstrate an understanding the impact of engineering solutions in a global, economic, environmental, and societal context
6. Students will demonstrate an understanding of the knowledge of contemporary professional, societal and global issues

E E 542. Power Systems II
3 Credits (3)
Analysis of a power system in the steady-state. Includes the development of models and analysis procedures for major power system components and for power networks. Recommended foundation: E E 333. Taught with E E 431.
Learning Outcomes
1. To introduce students to the basic structure and requirements of any electric power supply system and the nature of power systems engineering and the profession. To establish background for further studies in power systems
2. To develop an understanding of components in a power system and to understand the basic electromagnetic and electromechanical principles involved in these components.

3. To develop an understanding of the physical-principles—to-electric-equivalent circuit approach to the analysis and design of components and systems.
4. To develop skills in equivalent circuit based analysis techniques building upon competencies developed in prior coursework.
5. To explore analysis and design principles for the complete power system
6. To convey to the student a thorough understanding of both the theory and the mechanics involved in the modeling and analysis of power system components and networks
7. To study how such modeling and analysis is used in the design/planning of power systems

E E 543. Power Systems III
3 Credits (3)
Analysis of a power system under abnormal operating conditions. Topics include symmetrical three-phase faults, theory of symmetrical components, unsymmetrical faults, system protection, and power system stability. Recommended foundation: E E 431. Taught with: E E 493.
Learning Outcomes
1. To introduce students to the basic structure and requirements of any electric power supply system and the nature of power systems engineering and the profession. To establish background for further studies in power systems
2. To develop an understanding of components in a power system and to understand the basic electromagnetic and electromechanical principles involved in these components.
3. To develop an understanding of the physical-principles—to-electric-equivalent circuit approach to the analysis and design of components and systems.
4. To develop skills in equivalent circuit based analysis techniques building upon competencies developed in prior coursework.
5. To explore analysis and design principles for the complete power system
6. To understand measurement, analysis, simulation and design techniques, through laboratory exercises involving hardware and software.

E E 544. Distribution Systems
3 Credits (3)
Concepts and techniques associated with the design and operation of electrical distribution systems. Recommended foundation: E E 542 and E E 543.

E E 545. Digital Signal Processing II
3 Credits (3)
Non-ideal sampling and reconstruction, oversampling and noise shaping in A/D and D/A, finite word length effects, random signals, spectral analysis, multirate filter banks and wavelets, and applications. Recommended foundation: E E 395.

E E 548. Introduction to Radar
3 Credits (3)
Basic concepts of radar. Radar equation; detection theory, AM, FM, and CW radars. Analysis of tracking, search, MTI, and image radar. Recommended foundation: E E 325, E E 340 and E E 496. Taught with: E E 452.
Learning Outcomes
1. Students will demonstrate an understanding of fundamental principles of various types of radar systems and their applications.
2. Students will learn to analyze a given radar system.
3. Students will learn to use simulation techniques to design a radar system that will yield desired characteristics.
4. Students will experience working in groups/teams.

E E 549. Smart Antennas
3 Credits (3)
Smart antenna and adaptive array concepts and fundamentals, uniform and plannar arrays, optimum array processing. Adaptive beamforming algorithms and architectures: gradient-based algorithms, sample matrix inversion, least mean square, recursive least mean square, sidelobes cancellers, direction of arrival estimations, effects of mutual coupling and its mitigation. Recommended foundation: E E 325 and E E 340. Crosslisted with: E E 449.

E E 551. Control Systems Synthesis
3 Credits (3)
An advanced perspective of linear modern control system analysis and design, including the essential algebraic, structural, and numerical properties of linear dynamical systems. Computer-aided solution of real-world design problems. Recommended foundation: E E 407 Intro to Control Systems or equivalent. Taught with E E 475.
Learning Outcomes
1. Understand the concepts of Model Identification and Parameter Estimation (least-square identification of a auto-regressive model; nonparametric identification in the time domain; and nonparametric identification in the frequency domain)
2. Understand Robust Control techniques (Nyquist-plots, small-gain, and passivity)
3. Understand Optimal control techniques (LQR/LQG for state-space systems and time-optimal controller for the positioning of a mass using force actuation)
4. Understand Nonlinear control techniques (Lyapunov's stability method; feedback linearization controller for a fully actuated 2nd order mechanical system; backstepping for triangular nonlinear systems; actuator limitations)

E E 553. Noncooperative Game Theory
3 Credits (3)
The purpose of this course is to teach students to formulate problems as mathematical games and provide the basic tools to solve them. The course covers: Static games, starting with two-player zero-sum games and eventually building up to n-player non-zero sum games. Saddle-points and Nash equilibria will be covered. Dynamic optimization (dynamic programming) for discrete and continuous time. Dynamic games, both open and closed-loop policies. The intended audience includes (but is not restricted to) students in engineering and computer science. The class is heavily project-oriented and the students are strongly encouraged to choose a project that is relevant to their own area of research. Recommended foundation: undergraduate linear algebra and probability. Taught with E E 408.
Learning Outcomes
1. Comprehend the key principles of noncooperative game theory.
2. Apply the Minimax Theorem and evaluating mixed saddle-point equilibria.
3. Analyze stochastic policies for games in extensive form, and apply them to the existence and computation of saddle-point equilibria.
4. Comprehend games with N-players.
5. Analyze potential games and evaluate Nash equilibria for potential games.
6. Analyze dynamic games: the optimal control of a dynamical system.

7. Evaluate the saddle-point equilibria of zero-sum discrete-time and continuous-time dynamic games in state-feedback policies.

E E 556. Hardware & Software Codesign
3 Credits (3)
This course introduces the concept and techniques of designing electronic systems that integrates both hardware and software components. Topics include nature of hardware and software, dataflow modeling, software and hardware implementations of dataflows, analysis of control flows and dataflows, FSM with Datapath, microprogramming, embedded cores, and trade-offs between hardware and software components, etc. Students gain experience in implementing hardware and software co-design solutions for solving real-world problems through hands-on laboratory/project on a programmable System-on-Chip (SoC) platform that integrates a dual-core ARM Cortex-A9 processor and FPGA fabrics. Students develop a fundamental understanding of state-of-the-art practices in developing codesign solutions to problems that prepare them well for industrial and academic careers in this field. Recommended foundation ENGR 140, ENGR 130, (E E 362 or C S 473). Taught with E E 409.

Learning Outcomes
1. Formulate and solve problems related to basic concepts and methodologies in hardware/software co-design.
2. Analyze concurrent specification of an algorithm to be partitioned into software (C code) and hardware (HDL) components.
3. Design and implement both the software and hardware components integration as a solution to real-world problems to achieve optimal performance, power and cost.
4. Descrbe various types of system architectures regarding their attributes including speed, energy, design complexity, design cost, etc.
5. Experience working with commercially available Computer-Aided Design (CAD) development tools such as Xilinx Vivado.
6. Experience working in translation between C code and HDL of practical problems and verify/test the solution on FPGA SoC architecture.

E E 558. Hardware Security and Trust
3 Credits (3)
This course introduces and investigates recent technology development for the design and evaluation of secure and trustworthy hardware and embedded systems. Topics include IoT security, cryptography, hardware security primitives, authentication and key generation, invasive and non-invasive attacks and countermeasures, IC piracy and intellectual property protection, hardware trojans, and secure boot. Recommended foundation: E E 362. Taught with: E E 458.

Learning Outcomes
1. Students completing the course with a grade of C or better will perform satisfactorily on understanding of security goals of information security.
2. Students completing the course with a grade of C or better will perform satisfactorily on understanding of Cryptography basics and their applications.
3. Students completing the course with a grade of C or better will perform satisfactorily on security threats in integrated circuits, electronic devices and semiconductor supply chain.
4. Students completing the course with a grade of C or better will perform satisfactorily on security countermeasures to the threats of integrated circuits and electronic devices.
5. Students completing the course with a grade of C or better will perform satisfactorily on metrics used to measure and assess the security level of security mechanisms or primitives in hardware security applications.
6. Students completing the course with a grade of C or better will perform satisfactorily on analysis and assessment of potential security vulnerabilities in hardware and embedded systems.
7. Students completing the course with a grade of C or better will perform satisfactorily on state-of-art security mechanisms and research topics in the hardware and embedded security area.

E E 562. Computer Systems Architecture
3 Credits (3)
The course covers uniprocessors, caches, memory systems, virtual memory, storage systems, with introduction to multiprocessor and distributed computer architectures; models of parallel computation; processing element and interconnection network structures, and nontraditional architectures. Recommended foundation is E E 362. Taught with: E E 462.

Learning Outcomes
1. Recognize the basic principles and current practices of computer architectures of processors, memory systems, interconnects, and input/output systems.
2. Reason about the issues that influence the architectures of processors, memory systems, interconnects, and input/output systems.
3. Evaluate and improve computer system performance through analysis and computer simulation.
4. Solve and implement a small research problem in computer architecture.

E E 563. Computer Performance Analysis I
3 Credits (3)
Issues involved and techniques used to analyze performance of a computer system. Topics covered include computer system workloads; statistical analysis techniques such as principal component analysis, confidence interval, and linear regression; design and analysis of experiments; queuing system analysis; computer system simulation; and random number generation. Recommended foundation: E E 200 and E E 462.

E E 565. Machine Learning I
3 Credits (3)
A graduate-level introduction to machine learning algorithms, including supervised and unsupervised learning methods. Topics covered include clustering, linear regression models, linear discriminant functions, feed-forward neural networks, statistical pattern classification and regression, maximum likelihood, naive Bayes, non-parametric density estimation, mixture models, decision trees, and ensemble learning. Recommended foundation: E E 200, E E 571, and MATH 480. Taught with: E E 465.

Learning Outcomes
1. Formulate and solve problems related to the basic concepts and mathematical techniques of machine learning.
2. Gain an understanding of machine learning algorithms/methods by solving problems using software.
3. Gain experience doing independent study and research.
4. Formulate and solve problems related to the basics of regression, classification, and unsupervised learning.
5. Gain practical experience through project-based assignments and technical report writing.

E E 567. ARM SOC Design
3 Credits (3)
The course aims to produce students who are capable of developing ARM-based SoCs from high level functional specifications to design, implementation and testing on real FPGA hardware using standard hardware description and software programming languages. Recommended foundation E E 362 and E E 317. Taught with: E E 467.
Learning Outcomes
1. Formulate and solve problems requiring knowledge and understanding of ARM processor architectures and ARM-based SoCs.
2. Capture the design of ARM-based SoCs in a standard hardware description language.
3. Conduct low-level software design for ARM-based SoCs and high-level application development.
4. Demonstrate the ability to use and choose between different techniques for digital system design and capture.
5. Evaluate implementation results (e.g. speed, area, power) and correlate them with the corresponding high level design and capture.
6. Demonstrate the ability to use a commercial tools to develop ARM-based SoCs.

E E 571. Random Signal Analysis
3 Credits (3)
Application of probability and random variables to problems in communication systems, analysis of random signal and noise in linear and nonlinear systems. Recommended foundation E E 200 and E E 240. May be repeated up to 3 credits.
Learning Outcomes
1. To specify sample space and solve problems requiring probability computations based on axioms of probabilities and basic properties of event probabilities.
2. To characterize discrete and continuous random variables through various functions, example distributions, and moment calculations. To describe and compute probabilities involving multiple random variables in electrical engineering problems.
3. To analyze different notions of convergence, limit theorems, and specify their significance in communication system applications.
4. To describe and characterize random processes relevant to electrical engineering in general, and communications systems in particular. To perform differentiation and integration of random processes and to analyze specific classes of random processes including random walk, Gaussian processes, and AR processes.
5. To relate the significance of random processes to problems in electrical engineering, and solve problems involving power spectral density and transfer functions.

E E 572. Modern Coding Theory
3 Credits (3)
Error control techniques for digital transmission and storage systems. Introduction to basic coding bounds, linear and cyclic block codes, Reed-Solomon codes, convolutional codes, maximum likelihood decoding, maximum a posteriori probability decoding, factor graphs, low density parity check codes, turbo codes, iterative decoding. Applications to data networks, space and satellite transmission, and data modems. Recommended foundation: E E 200 and E E 496.

E E 573. Signal Compression
3 Credits (3)
Fundamentals of information source encoding and decoding. Includes information theory bounds on source coding, lossless coding algorithms, scalar quantizing and vector quantizing. Recommended foundation E E 200. Taught with E E 448.
Learning Outcomes
1. Formulate and analyze problems related to rate-distortion tradeoffs in compression
2. Formulate and analyze problems related to scalar and vector quantization
3. Formulate and analyze problems related to transform coding
4. Formulate and analyze problems related to entropy coding (Huffman arithmetic)
5. Formulate and analyze problems related to standardized codecs, including MPEG, JPEG, MP3
6. Formulate and analyze problems related to compressive sensing/sampling

E E 576. Geometric Algebra
3 Credits (3)
Geometric algebra provides a common mathematical language for many areas of physics (classical and quantum mechanics, electrodynamics, special and general relativity), computer science (graphics, robotics, computer vision), engineering, and other fields. Topics include: the geometric product and multivectors; Euclidean, Lorentzian, Galilean, and Projective Geometries; Complex, Hyperbolic, and Dual Numbers; Quaternions and Rotations. Recommended foundation E E 320. Taught with E E 403.
Learning Outcomes
1. Formulate and solve problems related to multivectors and the geometric product while building geometric intuition.
2. Formulate and solve problems related to complex, hyperbolic, and dual numbers as well as quaternions.
3. Formulate and solve problems related to non-Euclidean spaces including Lorentzian, Galilean, and projective geometries.

E E 577. Fourier Methods in Electro-Optics
3 Credits (3)
Linear systems theory, convolution and Fourier transformation are applied to one-dimensional and two dimensional signals encountered in electro-optical systems. Applications in diffraction, coherent and incoherent imaging, and optical signal processing. Recommended foundation: E E 320 and E E 528. Crosslisted with: PHYS 577.

E E 578. Optical System Design
3 Credits (3)
Optical design software is used to study optical systems involving lenses, mirrors, windows and relay optics. Systems considered include camera lenses, microscopes and telecsopes. Recommended foundation: E E/PHYS 473, E E/PHYS 528 and E E/PHYS 577. Crosslisted with: PHYS 578.

E E 581. Digital Communication Systems I
3 Credits (3)
Techniques for transmitting digital data over commercial networks. Topics include baseband and bandpass data transmission and synchronization techniques. Recommended foundation: E E 200, E E 325, and E E 496. Crosslisted with: E E 497.

E E 583. Wireless Communication
3 Credits (3)
Cellular networks, wireless channels and channel models, modulation and demodulation, MIMO, diversity and multiplexing, OFDM, wireless standards including LTE and WiMAX. Recommended foundation: E E 571 and E E 325.

E E 586. Information Theory
3 Credits (3)
This class is a study of Shannon's measure of information and discusses mutual information, entropy, and channel capacity, the noiseless source coding theorem, the noisy channel coding theorem, channel coding and random coding bounds, rate-distortion theory, and data compression. Restricted to: Main campus only. Crosslisted with: MATH 509
Prerequisite(s): E E 571 or MATH 515.

E E 587. Deep Learning for Image Processing
3 Credits (3)
Implementation and analysis of deep learning architectures for image processing. Specific projects will be adjusted according to current state-of-the-art research, but may include such topics as networks for: segmentation of images, captioning of images, understanding of images at a human interpretable level, visualization of network behavior, incorporation of temporal information from image sequences.
Prerequisite: E E 446 or E E 596.

Learning Outcomes

1. Read, synthesize, and discuss academic research papers describing deep learning architectures for image processing.
2. Install, run, modify, and analyze results from third-party software (e.g., from github) implementing deep learning architectures for image processing.
3. Present project results orally.
4. Present project results in a written report following the conventions expected of technical writing in engineering disciplines.

E E 588. Advanced Image Processing
3 Credits (3)
Advanced topics in image processing including segmentation, feature extraction, object recognition, image understanding, big data, and applications. Taught with: E E 444.
Prerequisite: E E 446 or E E 596.

E E 590. Selected Topics
1-9 Credits
May be repeated for a maximum of 18 credits.

E E 593. Mobile Application Development
3 Credits (3)
Introduction to mobile application development. Students will develop applications for iOS devices including iPhone and iPad. Topics include object-oriented programming using Swift, model-view-controller (MVC) pattern, view controllers including tables and navigation, graphical user interface (GUI) design, data persistence, GPS and mapping, camera, and cloud and web services. Recommended foundation: C S 151 or C S 152 or C S 172 or C S 271 or C S 451 or C S 452. Taught with: E E 443.

Learning Outcomes

1. The objective of this course is to gain an understanding of mobile application development, including Swift, Model-View-Controller (MVC) pattern, Memory management, View controllers, Frameworks: Foundation, CoreGraphics, CoreLocation, MapKit, UIKit, WebKit

E E 596. Digital Image Processing
3 Credits (3)
Two-dimensional transform theory, color images, image enhancement, restoration, segmentation, compression and understanding. Recommended foundation E E 325. Taught with: E E 446.

Learning Outcomes

1. Analyze human visual perception and the implications to science and society.
2. Formulate and analyze problems that utilize the mathematics behind multidimensional image processing.
3. Formulate and analyze problems involving multidimensional transformation transform-domain processing.
4. Formulate and analyze problems related to color image acquisition, processing, and display.
5. Implementing image processing algorithms on computers in Matlab or python.

E E 597. Neural Signal Processing
3 Credits (3)
Cross-disciplinary course focused on the acquisition and processing of neural signals. Students in this class will be learn about basic brain structure, different brain signal acquisition techniques (fMRI, EEG, MEG, etc.), neural modeling, and EEG signal processing. To perform EEG signal processing, students will learn and use Matlab along with an EEG analysis package. Recommended foundation E E 325. Taught with: E E 447.

Learning Outcomes

1. Demonstrate understanding and skill in the Structure and basic operation of the human brain.
2. Demonstrate understanding and skill in processing of EEG brain signals using Matlab and EEGLAB.
3. Demonstrate understanding and skill in EEG-related neural modeling.
4. Demonstrate understanding and skill in brain signal types and acquisition.

E E 598. Master's Technical Report
1-9 Credits (1-9)
Individual investigation, either analytical or experimental, culminating in a technical report. Graded PR/S/U. May be repeated up to 18 credits. Thesis/Dissertation Grading.

E E 599. Master's Thesis
1-15 Credits (1-15)
Thesis. May be repeated up to 88 credits. Thesis/Dissertation Grading.

E E 600. Doctoral Research
1-15 Credits
Research.

E E 615. Computational Electromagnetics
3 Credits (3)
The numerical solution of electromagnetics problems. Topics include differential equation techniques, integral equation methods, hybrid techniques, algorithm development and implementation, and error analysis. Particular algorithms, including FEM, finite differences, direct solvers, and iterative solvers, are studied.

E E 690. Selected Topics
1-9 Credits
May be repeated for a maximum of 9 credits.

E E 700. Doctoral Dissertation
1-15 Credits (1-15)
Dissertation. May be repeated up to 88 credits. Thesis/Dissertation Grading.