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. 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. Perform simple parameter estimation, such as finding sample mean and variance, and relate to confidence intervals. Describe random processes in the context of signal processing and communications systems problems. 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 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.
Learning Outcomes

1. Formulate and implement test procedures for validation of requirements. Evaluate alternative design solutions. Document test procedures and design solutions. Implement design to include a printed-circuit board, electronics and coding.
2. Communicate the design and validation both orally and in writing to a wide range of target audiences. 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. Understanding of solid-state devices. Biasing and small-signal analysis of MOS and BJT single transistor amplifiers. Using computer tools to simulate electronic circuits. Testing electronic circuits using power supplies, function generators, digital
2. multi-meters, and oscilloscopes. 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 E E 200 and ENGR 230.
Prerequisite/Corequisite: MATH 392.
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. Understand systems representations (e.g., impulse responses), implementations (e.g., convolution and difference/differential equations), and properties (e.g., linearity). Gain insight into transform-domain analysis for signals and systems. 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 320 and MATH 392.
Learning Outcomes

1. To model, analyze, simulate, and perform calculations with continuous- and discrete-time systems. To develop an understanding of basic modulations in communication systems. To gain insight into the basics of control systems. To develop insight into filtering and analysis of digital signals. 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. To develop an understanding of components in a power system and to understand the basic electromagnetic and electromechanical principles involved in these components. To develop an understanding of the physical-principles —to-electric-equivalent circuit approach to the analysis and design of components and systems. To develop skills in equivalent circuit based analysis techniques building upon competencies developed in prior coursework. To explore analysis and design principles for the complete power system 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. Students will analyze and solve electromagnetic-related problems by applying fundamental principles, theories, and equations (such as Maxwell's equations). Students will demonstrate effective team work. 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 MATH 1250G.
Prerequisite/Corequisite: ENGR 140.
Learning Outcomes
1. Be conversant with fundamental concepts of computer organization. Compare and contrast organizational features of different computer. 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.
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. Formulate and solve problems related to complex, hyperbolic, and dual numbers as well as quaternions. 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 333 and E E 431.
Learning Outcomes
1. Understand basic microeconomic principles, basics of market power, Cournot equilibrium Understand basics of linear programming, the primal dual problems, economic interpretation of dual variables, basics of mixed integer programming Understand dispatch optimization problems in the electric energy markets including economic dispatch, unit commitment 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 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.
Prerequisite: C- or better in ENGR 140 and ENGR 130 and E E 362.
Learning Outcomes

1. Formulate and solve problems related to basic concepts and methodologies in hardware/software co-design. Analyze concurrent specification of an algorithm to be partitioned into software (C code) and hardware (HDL) components. Design and implement both the software and hardware components integration as a solution to real-world problems to achieve optimal performance, power and cost. Descrbe various types of system architectures regarding their attributes including speed, energy, design complexity, design cost, etc. Experience working with commercially available Computer-Aided Design (CAD) development tools such as Xilinx Vivado 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. Crosslisted with: E E 512.
Prerequisite(s)/Corequisite(s): E E 480.

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. Crosslisted with: E E 542.
Prerequisite(s): C- or better in E E 333.

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.
Prerequisite(s)/Corequisite(s): E E 325. Prerequisite(s): C- or better in E E 317 and E E 333.

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. Crosslisted with: E E 540.
Prerequisite(s): C- or better in E E 317.
Learning Outcomes

1. Name at least three different types of photovoltaic materials and cells; Derive equations governing operation of photovoltaic cells; Design and create electrical engineering drawings for photovoltaic systems of different nameplate capacity; 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. Crosslisted with: E E 593.
Prerequisite(s): 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.

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. Crosslisted with: E E 588.
Prerequisite(s): C- or better in E E 446.

E E 446. Digital Image Processing
3 Credits (3)
Two-dimensional transform theory, color images, image enhancement, restoration, segmentation, compression and understanding. Same as 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 Formulate and analyze problems that utilize the mathematics behind multidimensional image processing Formulate and analyze problems involving multidimensional transformation transform-domain processing Formulate and analyze problems related to color image acquisition, processing, and display 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. Crosslisted with: E E 597.
Prerequisite(s): C- or better in E E 325.

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.
Prerequisite: E E 200.
Learning Outcomes
1. Formulate and analyze problems related to rate-distortion tradeoffs in compression Formulate and analyze problems related to scalar and vector quantization Formulate and analyze problems related to transform coding Formulate and analyze problems related to entropy coding (Huffman arithmetic) Formulate and analyze problems related to standardized codecs, including MPEG, JPEG, MP3 Formulate and analyze problems related to compressive sensing/sampling

E E 449. 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. Crosslisted with: E E 549.
Prerequisite(s): C- or better in E E 325 and E E 340.

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. Crosslisted with: E E 548.
Prerequisite(s): C- or better in E E 325 and E E 340.

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. Crosslisted with: E E 521.
Prerequisite(s): C- or better in E E 340.

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. Crosslisted with: E E 541.
Prerequisite(s): C- or better in E E 340.

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. Same as E E 558.
Prerequisite: C- or better in E E 362.
Learning Outcomes
1. Understand the security goals of information security Understand cryptography basics and their applications Formulate and analyze problems related to security threats in integrated circuits, electronic devices and semiconductor supply chain Formulate and analyze problems related to security countermeasures to the threats of integrated circuits and electronic devices Use metrics to measure and assess the security level of security mechanisms or primitives in hardware security applications Analyze and assess potential security vulnerabilities in hardware and embedded systems 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. Experience the “system engineering” of satellite design through the design of a space mission. Understand the professional and ethical responsibilities related to satellite design. Understand the impact of satellite related engineering solutions in a global, economic, environmental, and societal context. 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. Crosslisted 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 Reason about the issues that influence the architectures of processors, memory systems, interconnects, and input/output systems Evaluate and improve computer system performance through analysis and computer simulation 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. Crosslisted 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. Gain an understanding of machine learning algorithms/methods by solving problems using software. Gain experience doing independent study and research. Formulate and solve problems related to the basics of regression, classification, and unsupervised learning. 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. Crosslisted 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 Capture the design of ARM-based SoCs in a standard hardware description
2. language Conduct low-level software design for ARM-based SoCs and high-level application development Demonstrate the ability to use and choose between different techniques for digital system design and capture; Evaluate implementation results (e.g. speed, area, power) and correlate
3. them with the corresponding high level design and capture; 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. Automatic Control Systems
3 Credits (3)
Mathematical modeling of physical control systems in form of differential equations, transfer functions, and state-variables. System performance indices of feedback control systems via classical frequency-domain techniques and time-domain methods. Computer-aided solution of real-world design problems.
Prerequisite(s): C- or better in E E 325.

E E 476. Computer Control Systems
3 Credits (3)
Representation, analysis and design of discrete-time systems using time-domain and z-domain techniques. Microprocessor control systems.
Prerequisite(s): C- or better in E E 325.

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. Taught with E E 528. Recommended foundation: E E 473 /PHYS 473.
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. Develop the ability to perform calculations for the different theories (e.g., ray tracing, wave interference, polarization calculus, photon detection) to determine the propagation characteristics and describe the manipulation of light. Gain insight and experience with materials and devices for manipulating and detecting light (e.g., glass, mirrors, lenses, fiber optics, polarization elements, liquid crystals, semiconductors, and photodiodes). Apply the theoretical, mathematical, and practical understanding of optics to describe real-world applications of light technology with supporting analysis and calculations.

E E 479. Lasers and Applications
4 Credits (3+3P)
Laser operating principles, characteristics, construction and applications. Beam propagation in free space and fibers. Laser diode construction and characteristics. Hands-on laboratory. Taught with E E 529. Crosslisted with: PHYS 479.
Prerequisite(s): C- or better in E E 340 or in PHYS 461.

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. Crosslisted 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 Formulate and solve problems related to pseudo ideal operation of MOS transistors as switches and implementation with transistors of basic and complex Boolean functions Use modern software tools to simulate integrated circuits Formulate and solve problems related to operation and design of basic analog building blocks Formulate and solve problems related to operation and design of basic digital building blocks
2. 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 482. Electronics II
3 Credits (3)
Feedback analysis, application of operational amplifiers, introduction to data converters, analog filters, and oscillator circuits.
Prerequisite(s): C- or better in E E 317.

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. Crosslisted with: E E 523.
Prerequisite(s): C- or better in E E 320 and E E 480.

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(s)/Corequisite(s): E E 431. Prerequisite(s): C- or better in E E 333 or E E 391.

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. Crosslisted with: E E 581.
Prerequisite(s): C- or better in E E 200 and E E 325.

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 333 and E E 431. Taught with: E E 405.

Learning Outcomes

1. Understand basic microeconomic principles, basics of market power, Cournot equilibrium Understand basics of linear programming, the primal dual problems, economic interpretation of dual variables, basics of mixed integer programming Understand dispatch optimization problems in the electric energy markets including economic dispatch, unit commitment 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 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 212 and E E 317 Crosslisted with: E E 480.

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. Crosslisted with: E E 412.

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 516. Electromagnetic Theory II
3 Credits (3)
Continuation of E E 515.

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. Crosslisted 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. Crosslisted with: E E 485.

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. Taught with E E 478 with differentiated assignments for graduate students. Recommended foundation: Crosslisted with: PHYS 528.
Prerequisite(s): (PHYS 1320G or PHYS 2120) and E E 473/PHYS 473.

E E 529. Lasers and Applications
4 Credits (3+3P)
Laser operating principles, characteristics, construction and applications. Beam propagation in free space and fibers. Laser diode construction and characteristics. Hands-on laboratory. Recommended foundation: E E 351 or PHYS 461. Taught with: E E 479 with differentiated assignments for graduate students. Crosslisted with: PHYS 529

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 325, E E 317, and E E 333. Crosslisted with: E E 432.

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. Crosslisted with: E E 440.

Learning Outcomes

1. Name at least three different types of photovoltaic materials and cells; Derive equations governing operation of photovoltaic cells; Design and create electrical engineering drawings for photovoltaic systems of different nameplate capacity; 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. Crosslisted with: E E 454.

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. Crosslisted with: E E 431.

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. Crosslisted with: E E 493.

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 200, E E 340 and E E 496. Crosslisted with: E E 452.

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 System Synthesis I
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.

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.

Learning Outcomes

1. Formulate and solve problems related to basic concepts and methodologies in hardware/software co-design. Analyze concurrent specification of an algorithm to be partitioned into software (C code) and hardware (HDL) components. Design and implement both the software and hardware components integration as a solution to real-world problems to achieve optimal performance, power and cost. Descrbe various types of system architectures regarding their attributes including speed, energy, design complexity, design cost, etc. Experience working with commercially available Computer-Aided Design (CAD) development tools such as Xilinx Vivado 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 212. Crosslisted with: E E 458.

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 212. Crosslisted with: E E 462.

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 564. Architectural Concepts II
3 Credits (3)
Advanced topics related to computer architecture, guided by the current literature. Students are expected to have knowledge of computer architectures equivalent to C S 473 and of operating systems equivalent to C S 474. Crosslisted with: C S 573.

Learning Outcomes

1. Be able to explain the features in a modern multicore CPU architecture Be able to utilize hardware counter features of a CPU in performance evaluation Be able to explain the architecture of GPUs and their capabilities and drawbacks Be able to evaluate novel cutting-edge architectural features and designs Be able to present a research paper to an advanced audience

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 571 and MATH 480. Crosslisted with: E E 465.

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 is E E 212 and E E 317. Crosslisted with: E E 467.

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.

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.

Learning Outcomes

1. Formulate and analyze problems related to rate-distortion tradeoffs in compression Formulate and analyze problems related to scalar and vector quantization Formulate and analyze problems related to transform coding Formulate and analyze problems related to entropy coding (Huffman arithmetic) Formulate and analyze problems related to standardized codecs, including MPEG, JPEG, MP3 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.

Learning Outcomes

1. Formulate and solve problems related to multivectors and the geometric product while building geometric intuition. Formulate and solve problems related to complex, hyperbolic, and dual numbers as well as quaternions. 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 585. Telemetering Systems
3 Credits (3)
Covers the integration of components into a command and telemetry system. Topics include analog and digital modulation formats, synchronization, link effects, and applicable standards. Recommended foundation: E E 395, E E 496, and E E 497.

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 588. Advanced Image Processing
3 Credits (3)
Advanced topics in image processing including segmentation, feature extraction, object recognition, image understanding, big data, and applications. Crosslisted with: E E 444.
Prerequisite(s): 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 451 or C S 452. Crosslisted with: E E 443.

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

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. Crosslisted with: E E 447.

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.