ELECTRICAL AND COMPUTER ENGINEERING

Undergraduate Program Information

Overview

The undergraduate electrical engineering program of the Klipsch School is accredited by the Engineering Accreditation Commission of ABET, Inc., and stresses the development of analytical tools and physical concepts required to prepare students for immediate employment or graduate study. The program is flexible, allowing students to choose elective coursework towards concentrations in:

- artificial intelligence, machine learning, and data science,
- communications and signal processing,
- computers and microelectronics,
- controls and robotics,
- electromagnetics and photonics, or
- power,
- space systems.

Alternatively, students can select "no concentration" for the greatest flexibility in course selection.

Undergraduate Electrical Engineering Program Educational Objectives

The Klipsch School is dedicated to providing a quality, hands-on, educational experience for our students. Below are the program educational objectives (PEOs) that describe the expected accomplishments of graduates during their first few years after graduation.

1. Our graduates will obtain relevant, productive employment in the private sector, government and/or pursue an advanced degree.
2. Our graduates will be using their engineering foundation to innovate solutions to the problems of the real world.

Related Areas of Study

Electrical and computer engineering students wishing to broaden their educational experience may elect to earn additional bachelor's degrees in

- Engineering Physics
- Computer Science
- Mathematics
- Physics

Klipsch School students may also choose to earn a minor in one or more of the following fields:

- Computer Engineering
- Computer Science
- Mathematics
- Physics

Students must consult with an academic advisor in the offering department for specific requirements related to additional degrees and minors.

Transfer Credit

Credit earned at other institutions is generally accepted; however the following restrictions apply to transfer credits:

- Engineering credit must be earned at an ABET accredited school.
- Physics must be calculus based.
- If the NMSU requirement includes a lab, the transfer credit must include a lab.
- A grade of C-, or better, must have been earned.
- E E Courses numbered 300 or higher, Cornerstone and Capstone courses may not be transferred.
- Transfer credits for courses above 300 level are NOT ACCEPTED.

Master's Accelerated (BS/MS) Program (MAP)

Undergraduate students may apply for acceptance to the Master's Accelerated Program (MAP) after completing 60 semester hours of undergraduate coursework of which a minimum of 25 credit hours must be completed at NMSU. The GPA must be 2.75 or above for admission to the MAP program. The students must meet all other requirements as specified by the BSEE and MSEE programs. The MAP program allows up to 12 credits of NMSU coursework (450 level or higher) taken during the undergraduate years to be counted toward the master's program of study. Students must receive a grade of B or higher in the courses to be counted for the graduate degree. The courses must logically fit into the master's program. EE courses that are approved for the MAP are those EE electives with a corresponding graduate version:

Prefix	Title	Credits
E E 502	Electricity Markets	3
E E 503	Numerical Computational Methods for Smart Grid	3
E E 504	Smart Grid Technologies	3
E E 506	Quantum Computing	3
E E 510	Introduction to Analog and Digital VLSI	3
E E 512	ASIC Design	3
E E 521	Microwave Engineering	3
E E 523	Analog VLSI Design	3
E E 528	Fundamentals of Photonics	4
E E 533	Power System Operation	3
E E 537	Power Electronics	3
E E 540	Photovoltaic Devices and Systems	3
E E 541	Antennas and Radiation	4
E E 542	Power Systems II	3
E E 543	Power Systems III	3
E E 548	Introduction to Radar	3
E E 549	Smart Antennas	3
E E 551	Control Systems Synthesis	3
E E 553	Noncooperative Game Theory	3
E E 556	Hardware & Software Codesign	3
E E 558	Hardware Security and Trust	3
E E 562	Computer Systems Architecture	3
E E 565	Machine Learning I	3
E E 567	ARM SOC Design	3
E E 573	Signal Compression	3
E E 576	Geometric Algebra	3
E E 581	Digital Communication Systems I	3
E E 588	Advanced Image Processing	3

E E 596	Digital Image Processing	3
E E 597	Neural Signal Processing	3

For the most up to date listing of elective courses, please see the course listing in the most recent catalog. More information and the application for the MAP program can be found at: https://gradschool.nmsu.edu/current-students/masters-accelerated-program.html.

Graduate Program Information

Overview

The Klipsch School of Electrical and Computer Engineering offers graduate work leading to the Master of Science and Doctor of Philosophy degrees. Areas of emphasis for masters and doctoral students are:

- communications,
- computer engineering,
- controls,
- digital signal processing,
- electromagnetics,
- electric energy systems,
- photonics, and
- microelectronics/VLSI.

Research in the above areas currently being conducted by the faculty ensures that doctoral candidates will work on the frontier of knowledge in these areas. The graduate programs are intended to provide broad graduate-level training in electrical engineering. In addition, appropriate courses in computer science, industrial engineering, mathematics, physics, business management, and other areas may be integrated into a graduate student's program of study (see the list of permitted course prefixes in program description for EE graduate degrees).

Students desiring to work toward an advanced degree in electrical engineering must have completed undergraduate preparation substantially equivalent to that required for the Bachelor of Science in Electrical Engineering degree at this institution. For students with undergraduate degrees in other disciplines, see below. For further information on the Klipsch School of Electrical and Computer Engineering, please consult the web page http://www.ece.nmsu.edu/ (http://ece.nmsu.edu).

Faculty Research Interests

- **Communications**: Wireless and Digital Communications, Optical Communications, Error Control Coding, Data Compression, Information Theory, Physical Layer Security, Localization and Navigation.
- **Computer Architecture, Performance, And Security**: Performance Modeling and Simulation, Micro-Architecture Power Optimization, Performance Analysis and Optimization Of Large-Scale Scientific Applications, Heterogeneous HPC Computing for Field-Deployable Systems, Hardware Security and Trust, Hardware Software Co-Design, Embedded System Security, Machine Learning and Artificial Intelligence Security.
- **Digital Signal Processing**: Processing and Analysis Of EEG Signals, Time-Frequency Analysis, and Speech Processing.
- **Electromagnetics**: Propagation Through Dispersive Media (Soil, Seawater, Foliage, Biological Tissues), UWB and Synthetic Aperture Radar Systems, Antennas, Digital Beamforming, Microwave Engineering, Electromagnetic Interference and Compatibility, and Nondestructive Evaluation.
- **Electric Energy Systems**: Renewable Energy Integration, Protection, Advanced Control and Optimization, and Customer Driven Microgrids, Public Utilities Regulation and Management.
- **Machine Learning**: Image Processing and Application Of Machine Learning and Deep Learning To Image Analysis, Focusing on Astronomy And Biomedical Image Analysis, Health Care, and Defense.
- **Microelectronics And VLSI**: Micro Integrated Circuits, Sensors, Wireless Communication With IOT Devices, Signal Processing, Robotics, Analog and Mixed-Signal VLSI Design, Integrated Power Management Circuits, and Micro-Controller Sensor Systems.
- **Photonics**: Optical Wave Propagation through Atmospheric Turbulence, Free Space Optical Communications, Optical Remote Sensing involving Spectral and Polarization Sensing Techniques, and Astronomical Instrumentation Development.
- **Space Systems**: Research in Space Weather, High-Energy Astrophysics, Autonomous Proximity Operations, and Docking Of Small Satellites.

Support for Graduate Students

A number of teaching assistantships, research assistantships and fellowships are available. Teaching assistants are recommended by individual faculty for selection by the ECE Department's Graduate Studies Committee. International students must pass university screening prior to being eligible for selection as a TA. Nominations for new TAs are made by the advisor after a student is admitted. Research assistants are hired directly by the faculty member who has received a contract or grant for research.

The College of Engineering awards graduate scholarships and fellowships on behalf of Electrical and Computer Engineering. These include:

- the MIT/Lincoln Laboratory Fellowship,
- the Paul and Valerie Klipsch Grad Scholarship,
- the Admiral Paul Arthur Grad Scholarship, and
- the Barry Neil Rappaport Grad Scholarship.

Applications can be completed on-line at https://scholarships.nmsu.edu/. The priority deadline for the Scholar Dollar$ is March 1^{st}. The Electrical Utility Management Program has a limited number of fellowships for students interested in pursuing master's degrees in electrical energy systems.

Admission

Prospective graduate students for the Master of Science or Doctor of Philosophy in Electrical Engineering must first meet the entrance requirements of the Graduate School. The prospective US graduate student should make formal application to the Graduate Student Services office (http://gradschool.nmsu.edu (http://gradschool.nmsu.edu/)). International graduate students must start with the Admissions Office (https://isss.nmsu.edu/#admissions). Official transcripts from all undergraduate and graduate institutions must be sent directly to the Graduate School. International students must also submit their TOEFL (Test of English as a Foreign Language) scores. If the applicant meets the Graduate School's minimum requirements, the application is sent to the Klipsch School's Graduate Studies Committee for review. U.S. residents are given every chance of being successful in the pursuit of a graduate degree. If they do not meet the requirements of the Klipsch School, they can enter the Graduate School as "undeclared" where they must demonstrate competence in two or more graduate-level E E courses before they re-apply.

Requirements for Students Without BSEE Degree or Equivalent

Students without a BSEE degree or equivalent preparation will be expected to take classes covering the core knowledge required in our BSEE program. This includes mathematics through differential equations and basic engineering physics. The student's graduate advisor will prepare an individualized deficiency schedule, based on the student's academic background and work experience.

The following courses from our undergraduate program will be considered deficiencies for students without a BSEE

Prefix	Title	Credits
ENGR 120	DC Circuit Analysis	4
ENGR 130	Digital Logic	4
ENGR 140	Introduction to Programming and Embedded Systems	4
ENGR 230	AC Circuit Analysis	4
E E 200	Linear Algebra, Probability and Statistics Applications	4
E E 240	Multivariate and Vector Calculus Applications	3
E E 317	Semiconductor Devices and Electronics I	4
E E 320	Signals and Systems I	3
E E 325	Signals and Systems II	4
E E 340	Fields and Waves	4
E E 362	Introduction to Computer Organization	4

Degrees for the Department

Bachelor Degree(s)

- Computer Engineering - Bachelor of Science in Computer Engineering (https://catalogs.nmsu.edu/nmsu/engineering/electrical-computer-engineering/computer-engineering-bachelor-science-computer-engineering/)
- Electrical Engineering (Artificial Intelligence, Machine Learning, & Data Science) - Bachelor of Science in Electrical Engineering (https://catalogs.nmsu.edu/nmsu/engineering/electrical-computer-engineering/electrical-engineering-artificial-intelligence-machine-learning-data-science-bachelor-science-electrical-engineering/)
- Electrical Engineering (Communications and Signal Processing) - Bachelor of Science in Electrical Engineering (https://catalogs.nmsu.edu/nmsu/engineering/electrical-computer-engineering/electrical-engineering-comm-signal-process-bachelor-science-electrical-engineering/)
- Electrical Engineering (Computers and Microelectronics) - Bachelor of Science in Electrical Engineering (https://catalogs.nmsu.edu/nmsu/engineering/electrical-computer-engineering/electrical-engineering-computers-microelectro-bachelor-science-electrical-engineering/)
- Electrical Engineering (Controls & Robotics) - Bachelor of Science in Electrical Engineering (https://catalogs.nmsu.edu/nmsu/engineering/electrical-computer-engineering/electrical-engineering-controls-robotics-bsee/)
- Electrical Engineering (Electromagnetics and Photonics) - Bachelor of Science in Electrical Engineering (https://catalogs.nmsu.edu/nmsu/engineering/electrical-computer-engineering/electrical-engineering-electromag-photonics-bachelor-science-electrical-engineering/)
- Electrical Engineering (Power) - Bachelor of Science in Electrical Engineering (https://catalogs.nmsu.edu/nmsu/engineering/electrical-computer-engineering/electrical-engineering-power-bachelor-science-electrical-engineering/)
- Electrical Engineering (Space Systems Engineering) - Bachelor of Science in Electrical Engineering (https://catalogs.nmsu.edu/nmsu/engineering/electrical-computer-engineering/electrical-engineering-space-systems-bachelor-science-electrical-engineering/)
- Electrical Engineering - Bachelor of Science in Electrical Engineering (https://catalogs.nmsu.edu/nmsu/engineering/electrical-computer-engineering/electrical-engineering-bachelor-science-electrical-engineering/)

Master Degree(s)

- Electrical Engineering - Master of Engineering in Electrical Engineering (https://catalogs.nmsu.edu/nmsu/graduate-school/electrical-engineering-master-engineering-electrical-engineering/)
- Electrical Engineering - Master of Engineering in Electrical Engineering (Online) (https://catalogs.nmsu.edu/global/nmsu-global/electrical-engineering-meee-online/)
- Electrical Engineering - Master of Science in Electrical Engineering (https://catalogs.nmsu.edu/nmsu/graduate-school/electrical-engineering-master-science-electrical-engineering/)
- Electrical Engineering - Master of Science in Electrical Engineering (Online) (https://catalogs.nmsu.edu/global/nmsu-global/electrical-engineering-msee-online/)

Doctoral Degree(s)

- Engineering (Electrical Engineering) - Doctor of Philosophy (https://catalogs.nmsu.edu/nmsu/graduate-school/engineering-electrical-engineering-doctor-philosophy/)

Minors for the Department

- Computer Engineering - Undergraduate Minor (https://catalogs.nmsu.edu/nmsu/engineering/electrical-computer-engineering/computer-engineering-undergraduate-minor/)
- Electrical Engineering - Undergraduate Minor (https://catalogs.nmsu.edu/nmsu/engineering/electrical-computer-engineering/electrical-engineering-undergraduate-minor/)

Graduate Certificates in the Department

- Digital Communications - Graduate Certificate (https://catalogs.nmsu.edu/nmsu/graduate-school/digital-communications-graduate-certificate/)
- Digital Communications - Graduate Certificate (Online) (https://catalogs.nmsu.edu/global/nmsu-global/digital-communications-graduate-certificate-online/)
- Digital Signal Processing - Graduate Certificate (https://catalogs.nmsu.edu/nmsu/graduate-school/digital-signal-processing-graduate-certificate/)
- Digital Signal Processing - Graduate Certificate (Online) (https://catalogs.nmsu.edu/global/nmsu-global/digital-signal-processing-graduate-certificate-online/)
- Electric Energy Systems - Graduate Certificate (https://catalogs.nmsu.edu/nmsu/graduate-school/electric-energy-systems-graduate-certificate/)
- Electric Energy Systems - Graduate Certificate (Online) (https://catalogs.nmsu.edu/global/nmsu-global/electric-energy-systems-graduate-certificate-online/)

- Teaching English to Speakers of Other Languages - Graduate Certificate (https://catalogs.nmsu.edu/nmsu/graduate-school/teaching-english-speakers-other-languages-graduate-certificate/)
- Teaching Spanish for Heritage Language Learners - Graduate Certificate (https://catalogs.nmsu.edu/nmsu/graduate-school/teaching-spanish-heritage-language-learners-graduate-certificate/)
- Telemetry - Graduate Certificate (https://catalogs.nmsu.edu/nmsu/graduate-school/telemetry-graduate-certificate/)
- Telemetry - Graduate Certificate (Online) (https://catalogs.nmsu.edu/global/nmsu-global/telemetry-graduate-certificate-online/)

Department Head Steve Stochaj

Professors Borah, Boucheron, Creusere, Dawood, Stochaj, Tang

Associate Professors Badawy, Garcia Carrillo, Lavrova, Mitchell, Sandoval, Shi

Assistant Professors Renteria Piñon, van Iersel, Wang

Professors of Practice

Emeritus Professors Carden, Castillo, Giles, Sheila Horan, Stephen Horan, Johnson[1], Jordan, Kersting, Ludeman, Merrill, Petersen, Ranade, Reinfelds, Smolleck[1], Steelman[1], Taylor, Voelz

[1] Registered Professional Engineer (NM)

Electrical Engineering Courses

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.
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 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 434. Numerical Computational Methods for Smart Grid
3 Credits (3)
This course reviews modeling of power system and provides a comprehensive study of the various computational methods and software packages that form the basis of many analytical studies of power systems. It presents the analytical background of the algorithms used in many commercially available software packages, thereby enabling the student to make more informed decisions in their use of the software and correctly interpret their results. The course provides a balanced discussion of the theory and applications of the algorithms. Taught with EE 503.
Prerequisite: C- or better in E E 493.
Learning Outcomes
1. Review models of power system components and formulate popular problems for the applications of computational tools to be studied.
2. Acquaint students with various computational tools used in solving many advanced problems in power systems and other research areas.
3. Demonstrate knowledge in the strengths and weaknesses of the various computational tools by selecting and using the appropriate method to solve a given problem.
4. Demonstrate problem-solving skills in successfully addressing a complicated numerical problem relating to the student’s research area.

E E 435. Smart Grid Technologies
3 Credits (3)
Technical concepts of smart grid and microgrid devices, operation principles and methodologies. Taught with EE 504.
Prerequisite: C- or better in E E 493.

Learning Outcomes

1. Review models of power system components and formulate problems and challenges of transitioning of a traditional power grid to a smart grid concept.
2. Be familiar with various current research topics and problems in modern power systems and other research areas.
3. Demonstrate knowledge in the strengths and weaknesses of the various technologies in modern power systems.
4. Demonstrate problem-solving skills in successfully addressing a complicated numerical problem relating to the student's research area, as applicable to power systems.

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 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 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. Taught with E E 549.
Prerequisite: C- or better in E E 325 and E E 340.
Learning Outcomes

1. Antenna and Array fundamentals.
2. Smart Antenna and Adaptive Array concepts: Uniform and Planar Arrays; Array steering; Array performance criteria; Error effects on beamforming.
3. 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.

4. Applications: Angle of arrival estimation; Diversity combining; Nulling for jammer suppression and clutter cancellation, etc.

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 495. 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.
Prerequisite: C- or better in E E 325.
Learning Outcomes
1. The student should be comfortable with the theory and practice of digital signal processing including sampling and reconstruction and quantization effects.
2. The student should be comfortable with the theory and practice of digital signal processing including discrete-time systems, digital filtering, and digital filter realizations.
3. The student should be comfortable with the theory and practice of digital signal processing including z-transform analysis.
4. The student should be comfortable with the theory and practice of digital signal processing including discrete Fourier transform (DFT) and fast Fourier transform (FFT).
5. The student should be comfortable with the theory and practice of digital signal processing including finite impulse response (FIR) and infinite impulse response (IIR) filter design.

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: C- or better in E E 325.
Learning Outcomes
1. To analyze signals in time and frequency domains.
2. To mathematically describe analog modulation and demodulation techniques and relate these through electronic subsystems to form communications transmitters and receivers.
3. To apply basic digital communication operations and solve numerical problems on introductory digital communications principles.
4. To identify and explain the roles of basic communication blocks in a few practical systems, and to discuss contemporary issues, impact of the solutions and professional and ethical aspects.

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 503. Numerical Computational Methods for Smart Grid
3 Credits

This course reviews modeling of power system and provides a comprehensive study of the various computational methods and software packages that form the basis of many analytical studies of power systems. It presents the analytical background of the algorithms used in many commercially available software packages, thereby enabling the student to make more informed decisions in their use of the software and correctly interpret their results. The course provides a balanced discussion of the theory and applications of the algorithms. Taught with EE434.

Prerequisite: C- or better in EE493 or EE543 or equivalent.

Learning Outcomes

1. Review models of power system components and formulate popular problems for the applications of computational tools to be studied.
2. Acquaint students with various computational tools used in solving many advanced problems in power systems and other research areas.
3. Demonstrate knowledge in the strengths and weaknesses of the various computational tools by selecting and using the appropriate method to solve a given problem.
4. Demonstrate problem-solving skills in successfully addressing a complicated numerical problem relating to the student's research area.

E E 504. Smart Grid Technologies
3 Credits

Technical concepts of smart grid and microgrid devices, operation principles and methodologies. Taught with EE 435.

Prerequisite: C- or better in E E 493 or E E 543 or equivalent.

Learning Outcomes

1. Review models of power system components and formulate problems and challenges of transitioning of a traditional power grid to a smart grid concept.
2. Be familiar with various current research topics and problems in modern power systems and other research areas.
3. Demonstrate knowledge in the strengths and weaknesses of the various technologies in modern power systems.
4. Demonstrate problem-solving skills in successfully addressing a complicated numerical problem relating to the student's research area, as applicable to power systems.

E E 505. Application of Optimization Techniques in Power Systems
3 Credits

This course explores the dynamic intersection of optimization methods and the real-world application in power systems. will gain an in-depth understanding of how to formulate and solve complex optimization challenges in power generation, transmission, and distribution. This course covers primal and dual problems, mixed integer programming, and solving techniques such as branch and bound. Students. Additionally, the course covers decomposition algorithms, such as Benders decomposition and Lagrangian relaxation, facet defining valid inequalities, resolution theorems, certificates of unboundedness and infeasibility, as well as the application of stochastic programming and robust optimization to navigate the uncertainties inherent in the energy sector. By the end of this course, students will be equipped to address pressing issues in power system operation, planning, and decision-making using advanced optimization techniques.

Prerequisite: C- or better in E E 431 or E E 542 or equivalent.

Learning Outcomes

1. Understand basics of linear programming and can use software to solve simple linear programming problems.
2. Understand stochastic programming and can use Benders decomposition techniques to solve stochastic programming problems in parallel.
3. Understand robust optimization and can use robust optimization in unit commitment and planning.

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 507. Data Analytics and AI for the Smart Grid
3 Credits

This course explores the application of data analytics and artificial intelligence in enhancing smart grid operations. This course equips students with the skills to analyze smart grid data, implement AI strategies for grid optimization, and innovate solutions for real-world challenges. Through a mix of theoretical understanding and practical exercises, students will learn to make effective decisions, forecast loads, and integrate renewable energy resources. Recommended foundation: C S 453 or equivalent or proficiency in python programming.

Prerequisite: C- or better in E E 431 or E E 542 or equivalent.

Learning Outcomes

1. Grasp the core principles of smart grid technology, data analytics, and AI, and how these technologies can help enhance power grid operation and control.
2. Gain proficiency in applying various data analytics methods to real-world smart grid data, enabling effective decision-making and problem-solving in grid management.
3. Develop the capability to design and implement AI algorithms and machine learning models that optimize smart grid operations, including load forecasting and renewable energy integration.

4. Cultivate the skills to critically analyze and interpret complex datasets, drawing meaningful insights pertinent to smart grid operations and maintenance.
5. Encourage innovation and application of learned concepts to address real-world challenges in the smart grid sector, fostering a mindset of continuous improvement and adaptation to emerging technologies.
6. Enhance teamwork and communication skills, essential for collaborative problem-solving in multi-disciplinary environments typical of the smart grid ecosystem.
7. Stay abreast of the latest trends and developments in the field of smart grids, data analytics, and AI, preparing students for a future of ongoing learning and adaptation in a rapidly evolving sector.

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 533. 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. Taught concurrently with E E 406.
Prerequisite: C- or better in E E 431 or E E 542 or equivalent.
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-1 criteria, contingency analysis, and security constraints.

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.
Learning Outcomes
1. Identify and explain the function of commonly used relay elements and relaying schemes.
2. Set up and use Fault, Powerflow and Stability studies to synthesize data for relay schemes and settings for typical problems.
3. Apply analysis and design principles to design protection systems.

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 or E E 542 or equivalent. 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.

Learning Outcomes

1. Describe how distribution systems evolve as a function of load growth; identify traditional and modern distribution components and architectures.
2. Develop proper models and analytical methods to study distribution.
3. Use standard tools for distribution system analysis and design.
4. Assess issues in Resource integration and identify engineering solutions.

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.

Learning Outcomes

1. The student should be comfortable with the theory and practice of data compressing including quantization: Scalar, differential, and vector.
2. The student should be comfortable with the theory and practice of data compressing including transform coding: DCT, Wavelet.
3. The student should be comfortable with the theory and practice of data compressing including entropy Coding (Huffman Arithmetic).
4. The student should be comfortable with the theory and practice of data compressing including standardized codecs, including MPEG, JPEG, MP3s.

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. Taught with E E 475.

Learning Outcomes

1. Understand the concepts of Model Identification and Parameter Estimation (least-square identification of an 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.

Learning Outcomes

1. Specify performance requirements for computing systems.
2. Evaluate design alternatives for computing systems.
3. Compare two or more computing systems.
4. Determine the optimal value of a parameter (tuning) for computing systems.
5. Find performance bottlenecks in computing systems.
6. Characterize the load on the system (workload characterization).
7. Predict the performance at future workloads (forecasting).

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.

Learning Outcomes

1. Describe components of a digital communications/storage system. Characterize different modulation schemes and channel models.
2. Construct linear codes and describe them by generator and parity-check matrices, determine important code parameters such as minimum distance and rate, and prove code properties using basic algebra.
3. Describe and characterize important classical linear block and convolutional codes, including their encoding and decoding algorithms.
4. Derive and compute analytical performance bounds for coded systems.
5. Explain the characteristics and properties of modern turbo and LDPC codes. Analyze and implement their iterative decoding algorithms for various channel models.

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.
Learning Outcomes
1. Describe the mathematical properties of the two-dimensional Fourier transform and apply the transform to the analysis of linear optical systems.
2. Explain the basic concepts of scalar diffraction theory.
3. Apply the Fresnel and Fraunhofer approximations to calculate optical propagation characteristics and diffraction patterns for common optical applications.
4. Apply Fourier methods to model and analyze the performance of basic optical imaging systems.
5. Discuss ethical, societal, and professional issues related to photonics and optics.

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 telescopes. Recommended foundation: E E/PHYS 473, E E/PHYS 528 and E E/PHYS 577. Taught with: PHYS 578.
Learning Outcomes
1. Apply basic geometrical optics design concepts for lenses, mirrors and simple optical systems.
2. Model sequential optical systems in Zemax OpticStudio.
3. Apply merit functions to optimize optical system performance.
4. Discuss ethical, societal, and professional issues related to optics and photonics.

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 Communications
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.
Learning Outcomes
1. Analyze mobile radio propagation.
2. Evaluate various modulations, multiple access and fading channel mitigation techniques.
3. Discuss concepts and issues related to cellular systems.
4. Discuss wireless standards and current topics.

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.
Learning Outcomes
1. Quantify information using random variables and solve problems regarding entropy, mutual information, and relative entropy.
2. Characterize source coding techniques for a single random variable: employ standard techniques such as Shannon, Fano, and Huffman coding; describe universal source coding and Lempel-Ziv coding.
3. Describe coding for sources with memory and compare lossy and lossless source coding.
4. Describe the problem of channel coding. Use Fano's inequality, define and determine channel capacity, compute error exponents.
5. Characterize the Gaussian channel. Explain the characteristics and properties of channel codes, including convolutional and polar codes.

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: C- or better in E E 446 or E E 596 or equivalent.
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 590. Selected Topics
1-9 Credits
May be repeated for a maximum of 18 credits.

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.

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