ENEE - ELECTRICAL & COMPUTER ENGINEERING

ENEE101 Introduction to Electrical & Computer Engineering (3 Credits)
An exploration of topics within Electrical & Computer Engineering (ECE). Students will be introduced to key elements of both the Electrical Engineering and Computer Engineering curriculum, including: circuits, computing systems and software, communications and controls, electrodynamics and waves, microelectronics, signal processing, and power systems.
Corequisite: MATH140. And corequisite: ENEE140 or CMSC131; or a score of 5 on the A Java AP exam; or a score of 4 or 5 on the AB Java AP exam; or satisfactory performance on the department's placement exam.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer) ; and students cannot enroll in ENEE101 and ENES100 in the same semester.
Credit Only Granted for: ENEE101 or ENEE301.

ENEE131 Technology Choices (3 Credits)
An exploration of the positive and negative effects of technology on society, via diverse criteria to assess the relative well being of individuals and society; an examination of how society can help shape the future of technology and the tools that can be used to make wise technology choices.

ENEE140 Introduction to Programming Concepts for Engineers (2 Credits)
Introduction to the programming environment: editing, compiling, UNIX, data types and variable scope; program selection, formatted/unformatted input/output, repetition, functions, arrays and strings.
Prerequisite: Permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in Engineering: Electrical program; or must be in Engineering: Materials Science program.

ENEE150 Intermediate Programming Concepts for Engineers (3 Credits)
Advanced programming concepts: coding conventions and style; pointers; dynamic memory allocation and data structures; linked lists; graphs; abstract data types; object-oriented design. There will be team-based software projects and group presentations.
Prerequisite: Permission of ENGR-Electrical & Computer Engineering department. And ENEE140 or CMSC131; or score of 5 on the A Java AP exam; or score of 4 or 5 on the AB Java AP exam; or satisfactory performance on the department's placement exam.
Corequisite: MATH140.
Restriction: Must be in Engineering: Electrical program.

ENEE200 Technology and Consequences: Engineering, Ethics, and Humanity (3 Credits)
What makes a technology socially responsible? At UMD, the Fearless Ideas campaign asks us to aim our enthusiasm for technology at big real problems. At the same time, we are coming to appreciate the increasingly complex nature of technological systems as they become integrated into all forms of infrastructure, we realize they may be unpredictable, interdependent on social and biological systems, and have unintended consequences. In this midst of this complexity, people make decisions with far reaching impacts. How then do we follow our passion for technology and innovation but also stay skeptical in a way that allows us to consider the potential and shortcomings of technology? Designed for both engineering and non-engineering students wishing to explore and assess the impact of engineering technology on society and the role of society in generating that technology.
Credit Only Granted for: ENEE200 or ENES200.

ENEE205 Electric Circuits (4 Credits)
Design, analysis, simulation, construction and evaluation of electric circuits. Terminal Relationships. Kirchoff's laws. DC and AC steady state analysis. Node and mesh methods. Thevenin and Norton equivalent circuits. Transient behavior of first- and second-order circuits. Frequency response and transfer functions. Ideal op-amp circuits. Diode and transistor circuits.
Prerequisite: Minimum grade of C- in PHYS260; and minimum grade of C- in PHYS261; and permission of ENGR-Electrical & Computer Engineering department.
Corequisite: MATH246 or ENEE290.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).

ENEE222 Elements of Discrete Signal Analysis (4 Credits)
Discrete- and continuous-time signals, sampling of sinusoids. Discrete Fourier transform: properties and applications. Periodic signals and Fourier series. Discrete-time linear filters in time and frequency domains. Numerical applications and implementation of algorithms (using MATLAB).
Prerequisite: Minimum grade of C- in ENEE140; or minimum grade of C- in CMSC131; and permission of ENGR- Electrical & Computer Engineering department.
Corequisite: ENEE290; or coursework approved by the department.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer).

ENEE244 Digital Logic Design (3 Credits)
The design and analysis of combinational and synchronous sequential systems comprising digital logic gates and flip-flop memory devices; underlying tools such as switching and Boolean algebras and Karnaugh map simplification of gate networks; design and use of decoders, multiplexers, encoders, adders, registers, counters, sequence recognizers, programmable logic arrays (PLAs), read-only memories (ROMS, PROMS), and similar devices. Arbitrary radix conversion.
Prerequisite: Must have completed or be concurrently enrolled in CMSC132 or ENEE150; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Sophomore standing or higher; and must be in one of the following programs (Engineering: Computer; Engineering: Electrical).

ENEE245 Digital Circuits and Systems Laboratory (2 Credits)
Introduction to basic measurement techniques and electrical laboratory equipment (power supplies, oscilloscopes, voltmeters, etc.). Design, construction, and characterization of digital circuits containing logic gates, sequential elements, oscillators, and digital integrated circuits. Introduction to digital design and simulation with the Verilog Hardware Description Language (HDL).
Prerequisite: Minimum grade of C- in ENEE244. And minimum grade of C- in ENEE150; or minimum grade of C- in CMSC132. And permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer).

ENEE290 Introduction to Differential Equations and Linear Algebra for Engineers (4 Credits)
First-order differential equations, matrices and systems of linear equations, finite-dimensional vector spaces, inner product spaces, eigenvalues and eigenvectors, linear differential equations of higher order, and systems of differential equations. This course covers important topics in mathematics for Electrical and Computer Engineers. Specifically, several topics are covered, including first-order differential equations, matrices and systems of linear equations, finite-dimensional vector spaces, inner product spaces, eigenvalues and eigenvectors, linear differential equations of higher order, and systems of differential equations. Theoretical topics presented in the lectures will be reinforced by laboratory exercises.
Prerequisite: Minimum grade of C- in MATH141; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer).
Credit Only Granted for: ENEE290, MATH240, MATH246, or MATH461.

ENEE301 Current Trends in Electrical and Computer Engineering (3 Credits)
A survey course on the current trends in Electrical and Computer Engineering (ECE). Students will be introduced to foundational knowledge of key technologies, providing them with technical information and a broad principled understanding of the relevance of these technologies to society. Students will acquire these knowledge bases through high-level lectures and hands-on experiential learning involving key technologies, including: energy generation and utilization, communication, advanced computing, information processing and machine intelligence, and autonomy.
Prerequisite: Minimum grade of C- in MATH140; and must have completed or be concurrently enrolled in ENEE140 or CMSC131; or a score of 5 on the A Java AP exam; or a score of 4 or 5 on the AB Java AP exam; or satisfactory performance on the department's placement exam.
Restriction: Junior standing or higher; and must be in Electrical Engineering or Computer Engineering; or permission of instructor.
Credit Only Granted for: ENEE101 or ENEE301.

ENEE304 Introduction to Micro and Nanoelectronics (3 Credits)
Introduction to semiconductor device physics: drift-diffusion model, pn junction properties, BJTs and FETs. Electronic circuits: diode circuits, BJT and MOSFET amplifiers, logic gates and multi-transistor circuits (such as differential amplifiers and current mirrors).
Prerequisite: Minimum grade of C- in ENEE205; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer).
Credit Only Granted for: ENEE304 or ENEE303; ENEE304 or ENEE313.

ENEE305 Introduction to Micro and Nanoelectronics Lab (2 Credits)
Introductory laboratory in semiconductors and electronics. Characterization of diodes followed by design and testing of analog and digital circuits at the transistor (FET and BJT) level.
Prerequisite: Minimum grade of C- in ENEE304; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in the following program (Engineering: Electrical).
Credit Only Granted for: ENEE305 or ENEE307.

ENEE322 Signal and System Theory (3 Credits)
This is a course on signals and systems. The course lectures cover concepts in linear systems, and time and frequency domain analysis of signals and linear systems. Signal analysis topics: discrete- and continuous-time Fourier transforms, Laplace and z-transforms. Dynamical system properties: linearity, time-invariance, stability and invertibility. Analysis of linear time-invariant systems in the time domain (impulse response and convolution) and transform domain (transfer function and frequency response). Applications in signal processing, communications and control.
Prerequisite: Minimum grade of C- in MATH246 or ENEE290; and minimum grade of C- in ENEE222.
Restriction: Permission of ENGR-Electrical & Computer Engineering department. Must be in the following program (Engineering: Computer).
Credit Only Granted for: ENEE322 or ENEE323.

ENEE323 Signals and Systems: Theory and Applications (4 Credits)
This is a course and laboratory on signals and systems. The course lectures cover concepts in linear systems, and time and frequency domain analysis of signals and linear systems. Signal analysis topics: discrete- and continuous-time Fourier transforms, Laplace and z-transforms. Dynamical system properties: linearity, time-invariance, stability and invertibility. Analysis of linear time-invariant systems in the time domain (impulse response and convolution) and transform domain (transfer function and frequency response). Applications in signal processing, communications and control.
Prerequisite: Minimum grade of C- in MATH246 or ENEE290; and minimum grade of C- in ENEE222; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in the following program (Engineering: Electrical).
Credit Only Granted for: ENEE322 or ENEE323.

ENEE324 Engineering Probability (3 Credits)
Axioms of probability; conditional probability and Bayes' rules; random variables, probability distribution and densities: functions of random variables: weak law of large numbers and central limit theorem. Introduction to random processes; correlation functions, spectral densities, and linear systems. Applications to noise in electrical systems, filtering of signals from noise, estimation, and digital communications.
Prerequisite: Minimum grade of C- in ENEE290 or MATH246; and minimum grade of C- in ENEE222; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer).
Credit Only Granted for: DATA400, STAT400 or ENEE324.
Additional Information: Electrical Engineering majors may NOT substitute STAT400 for ENEE324.

ENEE350 Computer Organization (3 Credits)
Structure and organization of digital computers. Registers, memory, control and I/O. Data and instruction formats, addressing modes, assembly language programming. Elements of system software, subroutines and their linkages.
Prerequisite: Minimum grade of C- in ENEE244; and 1 course with a minimum grade of C- from (ENEE150, CMSC132); and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).

ENEE351 Algorithms and Data Structures (4 Credits)
Introduction to fundamental concepts in computer engineering, including topics in discrete math, data structures and algorithms. The course will also include a hands-on programming component. This course will provide students with the tools to design modular, time and space-efficient algorithms for real-world problems.
Prerequisite: Minimum grade of C- in ENEE150 and ENEE244.
Restriction: Permission of ENGR-Electrical & Computer Engineering department; and must be in the Computer Engineering Minor or the Academy of Machine Learning.
Credit Only Granted for: ENEE351 or CMSC351.

ENEE359 Intermediate Topics in Computer Engineering (1-3 Credits)
Selected intermediate level topics in computer engineering.
Prerequisite: Must have earned a minimum grade of regular (letter) C- in all required 100- and 200-level ENEE courses; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer).
Repeatable to: 6 credits if content differs.

ENEE382 Electromagnetics (4 Credits)
Theory and tools needed to solve electromagnetic problems and understand how electromagnetic waves propagate and interact with materials. Fields and potentials. Maxwell's equations and wave propagation. Reflection and transmission. Transmission lines. Antennas and radiation.
Prerequisite: Minimum of C- or better in ENEE205, MATH241, PHYS270, and PHYS271; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in the Electrical Engineering program.
Credit Only Granted for: ENEE380 or ENEE382; ENEE381 or ENEE382.

ENEE396 Leadership, Creativity and Service Learning (3 Credits)
Introduction to engineering creativity and innovation in engineering. Application of creativity methods to topics in communication, service learning, teaching, research, and leadership. Discussions of leadership style, professional communication, and the handling of ethical dilemmas. Investigation of how experiential learning can enhance leadership and teamwork skills, connect to classroom learning and provide opportunities to gain practical experience.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).

ENEE408 Capstone Design Project (3 Credits)
Culmination of prior course work in electrical and computer engineering. Utilization of modern design tools and methodologies for the design of components or systems under realistic constraints, with particular emphasis on teamwork and oral/written communication. Areas in which projects are currently offered include: microprocessor-based systems, digital systems, VLSI design (both digital and mixed-signal), and optical systems.
Prerequisite: Must have earned a minimum grade of regular (letter) C- in all required 200-level ENEE courses; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).
Repeatable to: 6 credits if content differs.

ENEE411 Advanced Analog and Digital Electronics (3 Credits)
Examination of analog and digital device models for analysis, design, and simulation of transistor level electronic circuits, emphasizing Metal Oxide Silicon Field Effect Transistors (MOSFETs); fundamental single transistor configurations; frequency response, feedback, and stability of multi-transistor circuits, such as current mirrors, differential amplifiers, voltage references, operational amplifiers and data converters; complementary Metal Oxide Silicon (CMOS) implementations of static and clocked digital as well as mixed signal circuits.
Prerequisite: Minimum grade of C- in ENEE303 or ENEE304.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer) ; and must have permission of the department.

ENEE413 Advanced Electronic Devices (3 Credits)
Advanced devices and their physical operation, providing a thorough description of those parts not usually covered in introductory electronics courses. These include Schottky and tunnel junctions, negative resistance devices used in wireless communication, homo-structure compound semiconductor transistors, hetero-structure (quantum effect) transistors, non-volatile memory devices, photonic devices such as LEDs and solid-state lasers, solar cells, photo-detectors and camera imagers, as well as bio-related components. Special consideration will be given to achieve an understanding of noise processes that limit electronic device performance. In all cases, system-level applications will be illustrated.
Prerequisite: Minimum grade of C- in ENEE313 or ENEE304.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical) ; and permission of ENGR-Electrical & Computer Engineering department.

ENEE415 Advanced Manufacturing Laboratory (3 Credits)
An interdisciplinary course designed to provide students with an overview of key processes, technology, and manufacturing techniques involved in fabricating advanced devices and systems. Students will be exposed to state-of-the-art fabrication technologies, including soft lithography, 3D printing, hybrid manufacturing, material functionalization, and systems integration. In addition to developing a theoretical understanding in the classroom, students will gain hands-on fabrication and characterization experience of systems that can interface with complex environments.
Prerequisite: ENEE313 or ENEE304.
Restriction: Must be in the Department of Electrical and Computer Engineering.
Credit Only Granted for: ENEE415, ENEE419M, ENMA489M, or BIOE489J..
Formerly: ENEE419M.

ENEE416 Integrated Circuit Fabrication Laboratory (3 Credits)
Characterization of wafers and fabrication steps. Oxide growth, lithography, dopant diffusion, and metal deposition and patterning will be discussed in the lectures and carried out in the lab in fabricating NMOS transistor circuits. The transistor characteristics will be measured and related to the fabrication parameters.
Prerequisite: Minimum grade of C- in ENEE303 or ENEE304; and must have earned a minimum grade of regular (letter) C- in all required 200-level ENEE courses.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical), and permission of ENGR-Electrical & Computer Engineering department.

ENEE419 Topics in Microelectronics (1-3 Credits)
Selected topics of current importance in microelectronics.
Prerequisite: Permission of ENGR-Electrical & Computer Engineering department; and completion of all lower-division technical courses in the EE curriculum.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer).
Repeatable to: 99 credits if content differs.

ENEE420 Communication Systems (3 Credits)
Fourier series, Fourier transforms and linear system analysis; random signals, autocorrelation functions and power spectral densities; analog communication systems: amplitude modulation, single-sideband modulation, frequency and phase modulation, sampling theorem and pulse-amplitude modulation; digital communication systems pulse-code modulation, phase-shift keying, differential phase shift keying, frequency shift keying; performance of analog and digital communication systems in the presence of noise.
Prerequisite: Minimum grade of C- in ENEE322 or ENEE323; and minimum grade of C- in ENEE324; and completion of all lower-division technical courses in the Electrical Engineering curriculum.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical), and permission of ENGR-Electrical & Computer Engineering department.

ENEE425 Digital Signal Processing (3 Credits)
Sampling as a modulation process; aliasing; the sampling theorem; the Z-transform and discrete-time system analysis; direct and computer-aided design of recursive and nonrecursive digital filters; the Discrete Fourier Transform (DFT) and Fast Fourier Transform (FFT); digital filtering using the FFT; analog-to-digital and digital-to analog conversion; effects of quantization and finite-word-length arithmetic.
Prerequisite: Minimum grade of C- in ENEE322 or ENEE323.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical), and permission of ENGR-Electrical & Computer Engineering department.

ENEE426 Communication Networks (3 Credits)
The main design issues associated with computer networks, satellite systems, radio nets, and general communication networks. Application of analytical tools of queuing theory to design problems in such networks. Review of proposed architectures and protocols.
Prerequisite: ENEE324 or STAT400; and completion of all lower-division technical courses in the EE curriculum.
Restriction: Must be in Engineering: Computer or Engineering: Electrical program.
Credit Only Granted for: CMSC417 or ENEE426.

ENEE427 Communications Design Laboratory (3 Credits)
Advanced Laboratory course exploring signal processing and communication systems theoretical concepts and implementing them on actual DSP based hardware in real time.
Prerequisite: Minimum grade of C- in ENEE322 or ENEE323; and minimum grade of C- in ENEE324 or STAT400; and completion of all lower-division technical courses in the EE curriculum.
Recommended: ENEE420 and ENEE425.
Restriction: Must be in Engineering: Electrical or Engineering: Computer program; and permission of Electrical and Computing Engineering Department.
Credit Only Granted for: ENEE427 or ENEE428.
Formerly: ENEE428.

ENEE428 Communications Design Laboratory (3 Credits)
Advanced Laboratory course exploring signal processing and communication systems theoretical concepts and implementing them on actual DSP based hardware in real time.
Prerequisite: Minimum grade of C- in ENEE322 or ENEE323; and minimum grade of C- in ENEE324 or STAT400; and completion of all lower-division technical courses in the EE curriculum.
Recommended: ENEE420 and ENEE425.
Restriction: Must be in Engineering: Electrical or Engineering: Computer program; and permission of Electrical and Computing Engineering Department.
Credit Only Granted for: ENEE427 or ENEE428.
Formerly: ENEE428.

ENEE429 Topics in Communications (1-3 Credits)
Selected topics of current importance in communications.
Prerequisite: Permission of ENGR-Electrical & Computer Engineering department; and completion of all lower-division technical courses in the EE curriculum.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer).
Repeatable to: 99 credits if content differs.

ENEE435 Quantum Information Processing (3 Credits)
Basics of linear algebra and probability theory used in quantum information processing. Quantum gates and their applications. Quantum computations and algorithms. Quantum cryptography, covering the Bennett-Brassard and Eckert key distribution protocols. Quantum error correction, examples of stabilizer codes.
Prerequisite: Minimum grade of B- in MATH240, MATH461, ENEE290, or PHYS 274; and minimum grade of C- in ENEE491 or equivalent .
Recommended: ENEE324 or STAT400.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer); and must be in the Quantum Science and Engineering minor.
Additional Information: ECE students not in the minor should contact their ECE advisor or email eceadvise@umd.edu for assistance.

ENEE436 Foundations of Machine Learning (3 Credits)
A broad introduction to the foundations of Machine Learning (ML), as well as hands-on experience in applying ML algorithms to real-world data sets. Topics include various techniques in supervised and unsupervised learning, as well as applications to computer vision, data mining, and speech recognition.
Prerequisite: 1 course with a minimum grade of C- from (ENEE324, STAT400); and 1 course with a minimum grade of C- from (ENEE150, CMSC216); and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Permission of ENGR-Electrical & Computer Engineering department. And must be in one of the following programs (Engineering: Electrical; Engineering: Computer) ; or must be in the ECE Department's Machine Learning notation program.
Credit Only Granted for: ENEE436, ENEE439M, or CMSC422.
Formerly: ENEE439M.

ENEE439 Topics in Signal Processing (1-3 Credits)
Selected topics of current importance in signal processing.
Prerequisite: Permission of ENGR-Electrical & Computer Engineering department; and completion of all lower division technical courses in the EE curriculum.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).
Repeatable to: 99 credits if content differs.

ENEE440 Microprocessors (3 Credits)
Microprocessor architectures, instruction sets, and applications. Bus structures, memory, I/O interfacing. Assembly language programming, LSI device configuration, and the embedding of microprocessors in systems.
Prerequisite: ENEE350; and completion of all lower division technical courses in the EE curriculum.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).

ENEE445 Computer Laboratory (2 Credits)
This laboratory course focuses on the hardware/software interface in computer systems. Hands-on experiments are used to teach design, construction, analysis, and measurement of both hardware and software for embedded systems. Projects emphasize using microcontrollers for control, sensing, and communication through various I/O devices.
Prerequisite: Minimum grade of C- in ENEE205 and ENEE350.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical); and permission of ENGR-Electrical & Computer Engineering department.

ENEE446 Digital Computer Design (3 Credits)
Hardware design of digital computers. Arithmetic and logic units, adders, multipliers and dividers. Floating-point arithmetic units. Bus and register structures. Control units, both hardwired and microprogrammed. Index registers, stacks, and other addressing schemes. Interrupts, DMA and interfacing.
Prerequisite: ENEE350; and completion of all lower-division technical courses in the EE curriculum.
Restriction: Permission of ENGR-Electrical & Computer Engineering department.
Credit Only Granted for: ENEE446 or CMSC411.

ENEE447 Operating Systems (4 Credits)
The course will present the theory, design, implementation and analysis of computer operating systems. Through classroom lectures, homework, and projects, students learn the fundamentals of concurrency, process management, interprocess communication and synchronization, job scheduling algorithms, memory management, input-output devices, file systems, and protection and security in operating systems. Optional topics may include communications protocols, computer security, and real-time operating systems. The lectures will be complemented with a significant level of programming, bringing up a simple operating system from scratch, concurrently as the topics are discussed in lecture. A weekly recitation section will provide TA support and an informal laboratory atmosphere. Each student will have their own board, so development will be done largely outside the classroom at each student's pace.
Prerequisite: 1 course with a minimum grade of C- from (CMSC414, CMSC417, CMSC420, CMSC430, CMSC433, CMSC435, ENEE440, ENEE457); and permission of ENGR-Electrical & Computer Engineering department; and (ENEE350, CMSC330, and CMSC351).
Restriction: Must be in Engineering: Computer program; and permission of ENGR-Electrical & Computer Engineering department.
Credit Only Granted for: ENEE447 or CMSC412.

ENEE452 Embedded Systems (3 Credits)
Embedded systems are part of most of the modern technological systems such as Industrial machines, consumer electronics, agricultural and process industry devices, automobiles, medical equipment, cameras, household appliances, airplanes, vending machines and toys, as well as mobile devices. Embedded systems are comprised of hardware, software and firmware. Design Methodologies and platforms for real time modern embedded digital systems have been evolving over time. In order to meet the system specifications, many models, tools, and operating systems exist to automate the design space exploration phase. In this course, students will be introduced to microcontroller-based embedded system design, fundamental concepts of a Real Time Operating System (RTOS), and the design of solutions for the Internet of Things (IOT). Using hands-on experience developed through practical designs, exercises, and projects, we will discuss in detail how to analyze, implement, and synthesize these systems.
Prerequisite: Minimum grade of C- in ENEE350 and ENEE244; and minimum grade of C- in ENEE150 or CMSC216.
Restriction: Permission of the Electrical and Computer Engineering Department; and must be in one of the following programs (Engineering: Computer; Engineering: Electrical).
Credit Only Granted for: ENEE452 or ENEE459V.
Formerly: ENEE459V.

ENEE456 Cryptography (3 Credits)
The theory, application, and implementation of mathematical techniques used to secure modern communications. Topics include symmetric and public-key encryption, message integrity, hash functions, block-cipher design and analysis, number theory, and digital signatures.
Prerequisite: (CMSC106, CMSC131, or ENEE150; or equivalent programming experience); and (2 courses from (CMSC330, CMSC351, ENEE324, or ENEE382); or any one of these courses and a 400-level MATH course, or two 400-level MATH courses); and Permission of CMNS-Mathematics department or permission of instructor.
Cross-listed with: MATH456, CMSC456.
Credit Only Granted for: MATH456, CMSC456 or ENEE456.

ENEE457 Computer Systems Security (3 Credits)
Theoretical and practical aspects of computer systems security. Topics covered include symmetric/asymmetric encryption, message authentication, digital signatures, access control, as well as network security, web security and cloud security. Students acquire tools necessary for designing secure computer systems and programs and for defending against malicious threats (e.g., viruses, worms, denial of service).
Prerequisite: Minimum grade of C- in ENEE350; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer) ; and permission of ENGR-Electrical & Computer Engineering department.
Credit Only Granted for: CMSC414 or ENEE457.

ENEE459 Topics in Computer Engineering (1-3 Credits)
Selected topics of current importance in computer engineering.
Prerequisite: Permission of ENGR-Electrical & Computer Engineering department; and completion of all lower-division technical courses in the EE curriculum.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).
Repeatable to: 99 credits if content differs.

ENEE460 Control Systems (3 Credits)
Mathematical models for control system components. Transform and time domain methods for linear control systems. Introductory stability theory. Root locus, bode diagrams and Nyquist plots. Design specifications in the time and frequency domains. Compensation design in the time and frequency domain. Introduction to sampled data systems.
Prerequisite: Minimum grade of C- in ENEE205, ENEE222, ENEE245, and (ENEE322 or ENEE323); and (ENEE290, MATH240, or MATH461).
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).

ENEE461 Control Systems Laboratory (3 Credits)
Students will design, implement, and test controllers for a variety of systems. This will enhance their understanding of feedback control and familiarize them with the characteristics and limitations of real control devices. They will also complete a small project. This will entail writing a proposal, purchasing parts for their controller, building the system, testing it, and writing a final report describing what they have done.
Prerequisite: Minimum grade of C- in ENEE205; and minimum grade of C- in ENEE322 or ENEE323.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical); and permission of ENGR-Electrical & Computer Engineering department.
Credit Only Granted for: ENEE461, ENME461, or ENME489N.

ENEE463 Digital Control Systems (3 Credits)
Introduction to techniques for the analysis and design of linear control systems and implementation of control systems using digital technology. Topics include linearization, solution of linear equations, z-transforms and Laplace transforms, design of linear controllers, optimal control, and digital implementation of control designs. Students will use MATLAB for the solution of problems and the design of control systems.
Prerequisite: Minimum grade of C- in ENEE322 or ENEE323.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical), and permission of ENGR-Electrical & Computer Engineering department.

ENEE464 Introduction to Optimization (3 Credits)
Students will be introduced to linear, nonlinear, unconstrained, constrained optimization. Convex optimization will be highlighted. Applications will be considered, in particular in the area of machine learning. Some optimization algorithms may be discussed, time permitting.
Prerequisite: One of the following: ENEE290, MATH240, MATH341, or MATH461; and must have completed or be concurrently enrolled in ENEE324 or STAT400.
Recommended: Experience in Matlab or Python.
Restriction: Must be in the Department of Electrical and Computer Engineering; and must have permission of ENGR-Electrical & Computer Engineering department.
Credit Only Granted for: ENEE464 or ENEE469O.
Formerly: ENEE469O.

ENEE467 Robotics Project Laboratory (3 Credits)
Teaches practical skills to build, control, and deploy robotic systems. Interdisciplinary groups of students develop real-world robotic systems, with emphasis on making a real robot do what one wants it to do.
Prerequisite: Minimum grade of C- in ENAE450.
Restriction: Must be in the Robotics and Autonomous Systems minor; and permission of Department of Electrical and Computer Engineering.

ENEE469 Topics in Controls (1-3 Credits)
Selected topics of current importance in controls.
Prerequisite: Permission of ENGR-Electrical & Computer Engineering department; and completion of all lower-division technical courses in the EE curriculum.
Repeatable to: 99 credits if content differs.

ENEE473 Electrical Machines Laboratory (3 Credits)
Students will learn theory and measurement methods of passive power components, multi-phase AC power, single and three-phase transformers, single and three-phase induction machines, three-phase synchronous machines, and DC machines. Each of these topics is addressed in one or more laboratory exercises.
Prerequisite: Minimum grade of C- in ENEE205; and must have earned a minimum grade of regular (letter) C- in all required 200-level ENEE courses.
Recommended: ENEE322 or ENEE323.
Restriction: Permission of the Electrical and Computer Engineering Department.

ENEE474 Power Systems (3 Credits)
Interconnected power systems, transmission lines, load flow studies, unit commitment and economic dispatch. Three phase networks, machine models. Symmetrical components, fault analysis and unbalanced operation. Power system transients, stability and numerical methods in power system analysis.
Prerequisite: Minimum grade of C- in ENEE322 or ENEE323.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical), and permission of ENGR-Electrical & Computer Engineering department.

ENEE475 Power Electronics (3 Credits)
This course is suitable for undergraduate and graduate students who want to learn the basic principles of power electronics and its applications. Special emphasis is placed on the interdisciplinary nature of power electronics. Strong and intimate connections between power electronics and circuit theory, electronic circuits, semiconductor devices, electric power, magnetic, motor drives and control are stressed.
Prerequisite: Minimum grade of C- in ENEE303 or ENEE304.
Restriction: Must be in one of the following programs (Engineering: Electrical; Engineering: Computer); and permission of ENGR-Electrical & Computer Engineering department.

ENEE476 Renewable Energy (3 Credits)
Solar Energy Conversion Systems: History of Photovoltaic (PV) Systems, PV Cell, Module and Array Models and Equivalent Circuits, Characteristic Resistance, Fill Factor, Effects of Parasitic Resistances, Mismatch Effects, Shading, Bypass Diodes, Sun Tracking Systems, Maximum Power Point Tracking (MPPT) Techniques, Isolated and Non-isolated Switch-mode DC/DC for PV Systems, Inverter Design and Control, Sizing the PV Panel and Battery Pack in PV Applications. Wind Energy Conversion Systems: Introduction to Wind Energy Harvesting, Horizontal and Vertical Wind Systems, Fundamentals of Wind Energy Harvesting Systems, Variable Speed and Fixed Speed Wind Energy Conversion Systems (WECS), Wind Turbines and Different Electrical Machines in Wind Applications, Induction Machine and Dynamic Model of Induction Machines, Synchronous Generators and Dynamic Model of SG, Control of Wind Energy Conversion Systems.
Prerequisite: Minimum grade of C- in ENEE303 or ENEE304.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical), and permission of ENGR-Electrical & Computer Engineering department.

ENEE484 Optoelectronic Devices (3 Credits)
Explores the fundamental physics of optoelectronic devices including lasers, solar cells, LEDs, and photodetectors. We aim at an understanding of the fundamental principles on device physics, material considerations, and significant components of optoelectronic devices. State-of-the-art device configurations and material choices in industry and academia will be discussed.
Recommended: A background in semiconductors and P-N junctions.
Restriction: Permission of the Electrical and Computer Engineering Department.
Credit Only Granted for: ENEE484 or ENEE489I.
Formerly: ENEE489I.

ENEE486 Optoelectronics Lab (2 Credits)
Hands-on experience in performing measurements in optics and electro-optics. Basics of optics, light detectors, Fourier optics, gratings and spectrometers, pulsed dye lasers, fiber optics, electro-optics, and acousto-optics.
Prerequisite: Minimum grade of C- in ENEE205; or minimum grade of C- in ENEE206. And minimum grade of C- in PHYS271 and PHYS270; and must have earned a minimum grade of regular (letter) C- in all required 200-level ENEE courses; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).

ENEE488 Independent Study in Electrical and Computer Engineering (1-3 Credits)
The purpose is to provide students with an opportunity for independent study projects on advanced electrical and computer engineering topics. These projects typically involve academic investigations of technical themes that are not addressed in the established elective and special topics courses taught by the department on a regular basis. Study plans are tailored to students educational goals but are approved and supervised by faculty.
Prerequisite: Must have completed and earned a minimum grade of regular (letter) C- in all lower-division EE or CP tech electives; and permission of ENGR-Electrical & Computer Engineering department.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).
Repeatable to: 9 credits if content differs.
Additional Information: A total of 5 credits combined of ENEE488 and ENEE499 can count towards a degree in electrical and computer engineering.

ENEE489 Topics in Electrophysics (1-3 Credits)
Selected topics of current importance in electrophysics.
Prerequisite: Permission of ENGR-Electrical & Computer Engineering department; and completion of all lower-division technical courses in the EE curriculum.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).
Repeatable to: 99 credits if content differs.

ENEE490 Physical Principles of Wireless Communications (3 Credits)
This course is intended to give students an overall understanding of the physical phenomena involved in wireless communications and to allow them to make first-cut designs. Major topics covered include antennas, antenna arrays, radiowave scattering and propagation, noise sources in communications systems, cell phone systems and satcom.
Prerequisite: ENEE381.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical).

ENEE491 Quantum Phenomena in Electrical Engineering (3 Credits)
Wave phenomena, wave-particle duality and laws of quantum mechanics. States, observables, operators and measurement, as applied to simple quantum circuits, information transmission and quantum key distribution. Also, covered: Schrodinger's equation, bound states, tunneling, scattering, periodic potentials, superconductivity and Josephson junctions.
Prerequisite: Minimum grade of C- in PHYS270, ENEE205 and (ENEE290 or MATH461).
Restriction: Permission of Electrical and Computer Engineering Department.
Credit Only Granted for: ENEE491 or ENEE489Q.
Formerly: ENEE489Q.

ENEE492 Introduction to Quantum Technology (3 Credits)
Investigates the basic concepts/building blocks of quantum computers, quantum key distribution, quantum networks, and quantum sensors. Examines what is needed to form a working qubit and different hardware platforms that implement them (for example, trapped ions, superconducting microwave circuits, color centers, and neutral atoms.) Conceptual and computational familiarity with complex numbers, vector spaces, bases, matrices, eigenvectors, and eigenvalues will be assumed, as well as quantum states/wave functions, and quantum measurement. Familiarity with spin-1/2 systems, and Pauli matrices is highly recommended.
Prerequisite: MATH141 and MATH240 or equivalent; and one of the following: PHYS360, PHYS401, PHYS457, CMSC457, or ENEE491; or permission of instructor.
Cross-listed with: PHYS467.
Credit Only Granted for: PHYS467 or ENEE492.

ENEE493 Quantum Hardware Laboratory (3 Credits)
The purpose of this lab course is to provide hands on experience for the students in working with experimental hardware and techniques which are used in research in the field of quantum computing, quantum communications and quantum sensors.
Prerequisite: Minimum grade of C- in one of the following courses: ENEE491, ENMA434, PHYS360, or PHYS401.
Restriction: Must be in the Quantum Science and Engineering minor; or have permission from the ECE department; and permission of Department of Electrical and Computer Engineering.

ENEE496 Lasers and Electro-optic Devices (3 Credits)
Modern physical optics: Gaussian beams, optical resonators, optical waveguides; theory of laser oscillation, rate equations; common laser systems. Selected modern optoelectronic devices like detectors and modulators. Role of lasers and optoelectronics in modern technology.
Prerequisite: ENEE381; and completion of all lower-division technical courses in the EE curriculum.
Restriction: Must be in one of the following programs (Engineering: Computer; Engineering: Electrical); and permission of ENGR-Electrical & Computer Engineering department.

ENEE498 Topics in Electrical Engineering (1-3 Credits)
Selected topics of current importance in electrical engineering.
Prerequisite: Permission of ENGR-Electrical & Computer Engineering department; and completion of all lower-division technical courses in the EE curriculum.
Restriction: Must be in Engineering: Electrical program.
Repeatable to: 12 credits if content differs.

ENEE499 Senior Projects in Electrical and Computer Engineering (1-6 Credits)
The purpose is to provide students with an opportunity to engage in independent research projects on advanced electrical and computer engineering topics. Projects are selected by students and supervised by faculty and other qualified mentors. While students may be required to acquire new skills or information in the course of completing a 499 project, the focus is to conduct an independent investigation of a technical theme by the student. The project may be used to satisfy the advanced lab requirement if it is approved as a primarily experimental research project. In that case, the student will enroll in ENEE499L.
Prerequisite: Completion of all lower-division technical courses in the electrical or computer engineering curriculum.
Restriction: Permission of ENGR-Electrical & Computer Engineering department.
Repeatable to: 6 credits if content differs.
Additional Information: For students in the ECE Honors Program, a total of 6 credits combined of ENEE488 and ENEE499/499L can count toward a degree in electrical or computer engineering. For non-honors ECE students, a total of 5 credits combined of ENEE488 and ENEE499/499L can count toward a degree in electrical or computer engineering.