ENEE - ELECTRICAL & COMPUTER ENGINEERING

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.

ENEE600 Solid State Electronics (3 Credits)
Properties of crystals; energy bands: electron transport theory; conductivity and hall effect; statistical distributions; fermi level: impurities; non-equilibrium carrier distributions; normal modes of lattice vibration and thermal properties of crystals; tunneling phenomena; surface properties.
Prerequisite: ENEE413; and must have background in elementary quantum mechanics.
Credit Only Granted for: ENEE600 or ENEE793.
Formerly: ENEE793.

ENEE601 Semiconductor Devices and Technology (3 Credits)
The principles, structures and characteristics of semiconductor devices. Technology and fabrication of semiconductor devices.
Recommended: ENEE413 and ENEE600.
Credit Only Granted for: ENEE601 or ENEE697.
Formerly: ENEE697.

ENEE605 Design and Fabrication of Micro-Electro-Mechanical Systems (MEMS) (3 Credits)
The goals are to explore the world of Micro-Electro-Mechanical Systems (MEMS) by understanding its design and fabrication aspects.
Credit Only Granted for: ENEE605 or ENEE719R.
Formerly: ENEE719R.

ENEE610 Electrical Network Theory (3 Credits)
Matrix algebra, network elements, ports, passivity and activity, geometrical and analytical descriptions of networks, state variable characterizations, scattering matrices, signal flow graphs, sensitivity.
Prerequisite: Must have completed undergraduate-level Circuit Theory; or permission of instructor.

ENEE611 Integrated Circuit Design and Analysis (3 Credits)
Active and passive elements used in semiconductor structures. Design application of linear and digital integrated circuits.
Recommended: ENEE610.
Credit Only Granted for: ENEE611 or ENEE696.
Formerly: ENEE696.

ENEE612 Advanced Power Electronics (3 Credits)
Advanced power electronic converters, techniques to model and control switching circuits, pulse width modulation, resonant switch converters, resonant DC-link converters, series and parallel loaded resonant (SLR, PLR) DC-DC converters, zero voltage switching clamped-voltage (ZVS-CV) converters, ZVS resonant-switch DC-DC converters are explained. In addition, this course deals with small-signal and large-signal modeling and control of switched mode power converters, sliding-mode operation, state space models, generalized state-space averaging, and feedback linearization techniques. Multiple-input converters and their operational principles are explained. Furthermore, practical design procedures for type II and type III compensators with voltage-mode error-amplifier for DC/DC converters are explained.
Prerequisite: ENEE303, ENEE475, or ENEE476; or students who have taken courses with comparable content may contact the department.
Credit Only Granted for: ENEE719B or ENEE612.
Formerly: ENEE719B.

ENEE614 Radio Frequency VLSI Circuit Design (3 Credits)
This course will give students the knowledge required to analyze, design and lay-out discrete and integrated circuits used in modern radio frequency communications. The course will focus on advanced amplifier concepts, frequency conversion, tuning, and low-noise techniques. Implementation of AM, FM and digital modulation techniques will be covered. Emphasis will be given to CMOS technology as applied to analog VLSI. Advanced applications of SPICE and VLSI design layout tools will be covered.
Recommended: ENEE611.

ENEE620 Random Processes in Communication and Control (3 Credits)
Introduction to random processes: characterization, classification, representation; Gaussian and other examples. Linear operations on random processes, stationary processes: covariance function and spectral density. Linear least square waveform estimating Wiener-Kolmogroff filtering, Kalman-Bucy recursive filtering: function space characterization, non-linear operations on random processes.
Prerequisite: ENEE324; or students who have taken courses with comparable content may contact the department.

ENEE621 Estimation and Detection Theory (3 Credits)
Estimation of unknown parameters, Cramer-Rao lower bound; optimum (map) demodulation; filtering, amplitude and angle modulation, comparison with conventional systems; statistical decision theory Bayes, minimax, Neyman/Pearson, Criteria-68 simple and composite hypotheses; application to coherent and incoherent signal detection; M-ary hypotheses; application to uncoded and coded digital communication systems.
Prerequisite: ENEE620; or students who have taken courses with comparable content may contact the department.

ENEE623 Digital Communications (3 Credits)
Review of sampling and quantization, functional characterization of digital signals and transmission facilities, band-limited signals and systems. Digital modulation/demodulation techniques, error probability, intersymbol interference and its effects, adaptive equalization. Signaling with coded waveforms, fading and satellite channels, multiple access problems and protocols. Introduction to spread-spectrum Communications.
Recommended: ENEE420.

ENEE625 Multi-user Communication (3 Credits)
Basic queueing models. Store-and forward communications networks; switching modes; delay-throughput measures; capacity assignment; routing; topological design; computational aspects; flow control; error control; protocols; specification and validation; local networks; satellite and packet radio systems; multiple access schemes; stability and performance; multi-user information theory; and large scale system theory.
Prerequisite: ENEE620.

ENEE626 Error Correcting Codes (3 Credits)
Introduction to linear codes; bounds on the error correction capabilities of codes; convolutional codes with threshold, sequential and viterbi decoding; cyclic random error correcting codes; P-N sequences; cyclic and convolutional burst error correcting codes.
Prerequisite: ENEE420; or students who have taken courses with comparable content may contact the department.
Credit Only Granted for: ENEE626 or ENEE722.
Formerly: ENEE722.

ENEE627 Information Theory (3 Credits)
Information measures and their properties; entropy, relative entropy and mutual information. Information source models. Lossless data compression: the Kraft inequality, Shannon-Fano and Huffman codes. Typical sequences, asymptotic equipartition property, lossy source coding. Discrete memoryless channels: capacity, channel coding theorem. The additive Gaussian channel. Source coding under a fidelity constraint: rate distortion function and rate distortion theorem.
Prerequisite: ENEE620.
Credit Only Granted for: ENEE627 or ENEE721.
Formerly: ENEE721.

ENEE630 Advanced Digital Signal Processing (3 Credits)
This is the first-year graduate course in signal processing. The objective is to establish fundamental concepts of signal processing on multirate processing, parametric modeling, linear prediction theory, modern spectral estimation, and high-resolution techniques.
Prerequisite: ENEE425.
Corequisite: ENEE620.
Credit Only Granted for: ENEE624 or ENEE630.
Formerly: ENEE624.

ENEE631 Digital Image and Video Processing (3 Credits)
Foundations of digital image and video processing. Topics covered: 2-D systems and transforms; image acquisition and perception; multi-dimensional sampling; quantization; linear and non-linear techniques for image enhancement and restoration; basics on image analysis; lossless and lossy image compression; motion estimation and compensation; still image and video coding standards; applications of image and video processing.
Prerequisite: ENEE620 and ENEE630; or students who have taken courses with comparable content may contact the department.

ENEE632 Speech and Audio Processing (3 Credits)
The objective is to apply digital signal processing techniques to speech and music signals. Topics covered include acoustic theory of speech production leading to the source-filter model; acoustic and digital vocal-tract models of speech production; speech analysis-synthesis based on the short-time Fourier transform, linear prediction, and homomorphic representations; extensions to other multiresolution analysis; time-domain models for speech processing; auditory perception and speech perception; waveform and model-based speech coding using scalar and vector quantization; time-scale modification; pitch and formant estimation; application of techniques to music analysis-synthesis.
Prerequisite: ENEE620 and ENEE630.
Credit Only Granted for: ENEE739A or ENEE632.
Formerly: ENEE739A.

ENEE633 Statistical Pattern Recognition (3 Credits)
The goal is to introduce mathematical pattern analysis and recognition. Emphasis is given to parametric and non-parametric statistical pattern recognition methods and clustering with applications to speech, image and video recognition.
Prerequisite: MATH461; or students who have taken courses with comparable content may contact the department; or permission of instructor.
Corequisite: ENEE620; or permission of instructor.
Credit Only Granted for: ENEE633 or ENEE739Q.
Formerly: ENEE739Q.

ENEE634 Learning and Statistical Signal Processing (3 Credits)
Adaptive learning and statistical signal processing, including: numerical analysis; principal component analysis and support vector machines; adaptive signal processing (supervised learning); blind equalization and identification (unsupervised learning); antenna array and MIMO signal processing; space-time and space-time-frequency coding; neural networks (nonlinear adaptive learning); advanced topics on machine learning, such as online and deep learning.
Prerequisite: ENEE620 and ENEE630.

ENEE640 Digital CMOS VLSI Design (3 Credits)
Review of MOS transistors: fabrication, layout, characterization; CMOS circuit and logic design: circuit and logic simulation, fully complementary CMOS logic, pseudo-nMOS logic, dynamic CMOS logic, pass-transistor logic, clocking strategies; sub system design: ALUs, multipliers, memories, PLAs; architecture design: datapath, floorplanning, iterative cellular arrays, systolic arrays; VLSI algorithms; chip design and test: full custom design of chips, possible chip fabrication by MOSIS and subsequent chip testing.
Prerequisite: ENEE303 and ENEE350; or students who have taken courses with comparable content may contact the department; or permission of instructor.

ENEE641 Mathematical Foundations for Computer Engineering (3 Credits)
Mathematical modeling, design, analysis and proof techniques related to computer engineering. Probability, logic, combinatorics, set theory, and graph theory, as they pertain to the design and performance of computer engineering systems. Techniques for the design and analysis of efficient computational methods from graph theory and networks. Understanding of the limits on the efficiency of such computational methods. Translation from mathematical theory to actual programming. The course emphasizes mathematical rigor.
Credit Only Granted for: ENEE641 or ENEE759F.
Formerly: ENEE759F.

ENEE644 Computer-Aided Design of Digital Systems (3 Credits)
Design methodologies for digital systems using a modern hardware description language. Algorithmic, architectural and implementation aspects of arithmetic processing elements. Design of Complex Instruction Set (CISC), Reduced Instruction Set (RISC), and floating point processors. Synthesis, simulation and testing of processors with computer-aided design tools. Students in some sections may, on permission, fabricate VLSI chips via MOSIS.

ENEE645 Compilers and Optimization (3 Credits)
The compilation, linking and loading process. Using lexical analyzers and parsers. Intermediate forms. Global, stack and heap objects, and their addressing modes. Stack implementation. Control flow analysis and optimization. Dataflow analysis and optimization including Static, single assignment. Alias analysis.
Prerequisite: ENEE350 or CMSC216; or students who have taken courses with comparable content may contact the department.
Credit Only Granted for: ENPM808T, ENEE645, or ENPM617.

ENEE646 Digital Computer Design (3 Credits)
Concepts and techniques for design of computer systems with improved performance. Advanced I/O systems, memory organization, pipeland and parallel processors, bus bandwidth, processor/memory interconnections, cache memory, virtual memory, multiprocessors, performance evaluation.
Prerequisite: ENEE446; or students who have taken courses with comparable content may contact the department.

ENEE648 Advanced Topics in Electrical Engineering (3 Credits)
Every semester courses intended for a high degree of specialization are offered by visiting or regular electrical engineering faculty members in two or more of the areas listed in 488. The student should check with the electrical engineering office of graduate studies for a list and the description of the topics offered currently.
Repeatable to: 99 credits if content differs.

ENEE651 Parallel Algorithms (3 Credits)
A presentation of the theory of parallel computers and parallel processing. Models of parallel processing and the relationships between these models. Techniques for the design and analysis of efficient parallel algorithms including parallel prefix, searching, sorting, graph problems, and algebraic problems. Theoretical limits of parallelism.
Prerequisite: CMSC451; or ENEE641; or students who have taken courses with comparable content may contact the department.
Cross-listed with: CMSC751.
Credit Only Granted for: ENEE459P, ENEE651, ENEE759K or CMSC751.
Formerly: ENEE759K.

ENEE657 Computer Security (3 Credits)
An introduction to the principles of building secure systems. Topics include operating system (OS) security, secure network communications, software security, real-world attacks, applied cryptography, and hardware security. Within these topics, the course emphasizes the cross-cutting concerns of attacks, defenses and measurement.
Prerequisite: ENEE457 or CMSC414; or students who have taken courses with comparable content may contact the department.

ENEE660 System Theory (3 Credits)
General systems models. State variables and state space. Linearity and its implications. Controllability and observability. State space structure and representation. Realization theory and algorithmic solutions. Parameterizations of linear systems; canonical forms. Basic results from stability theory. Stabilizability. Fine structure of linear multivariable systems; minimal indices and polynomial matrices. Interplay between frequency domain and state space.
Prerequisite: ENEE460 and MATH463; or students who have taken courses with comparable content may contact the department.

ENEE661 Nonlinear Control Systems (3 Credits)
State space methods of stability analysis including second order systems and the phase plane, linearization and stability in the small, stability in the large and Lyapunov's second method. Frequency domain methods including the describing function. Popov's method and functional analytic methods. Introduction to Volterra series representations of nonlinear systems. Applications to conrol system design.
Prerequisite: ENEE660; and (MATH410 or MATH411; or students who have taken courses with comparable content may contact the department). Or permission of instructor.

ENEE662 Convex Optimization (3 Credits)
Focuses on recognizing, solving, and analyzing convex optimization problems. Convex sets, convex functions, convex and quasi-convex optimization problems. Duality theory and optimality conditions. Specific classes of problems including linear optimization (LP), semi-definite optimization (SDP), geometric programming. Algorithms for unconstrained and constrained optimization; interior-point methods. Applications in controls, communications, signal processing, statistics, and other areas.
Recommended: MATH410.
Credit Only Granted for: ENEE759F or ENEE662.

ENEE664 Optimal Control (3 Credits)
General optimization and control problems. Conditions of optimality for unconstrained and constrained optimization problems; sensitivity; duality. Introduction to linear and nonlinear programming methods. Dynamic optimization. Discrete time maximum principle and applications. Pontryagin maximum principle in continuous time. Dynamic programming. Feedback realization of optimal control.
Prerequisite: ENEE660 and MATH410; or students who have taken courses with comparable content may contact the department; or permission of instructor.
Corequisite: MATH411; or permission of instructor.

ENEE680 Fundamentals of Electromagnetics (3 Credits)
Theoretical analysis and engineering applications of Maxwell's equations: boundary value problems of electrostatics and magnetostatics, dielectric and magnetic properties of matter, energy and momentum content of fields, introduction to EM wave propagation.
Prerequisite: ENEE381; or students who have taken courses with comparable content may contact the department.

ENEE681 Electromagnetic Waves and Applications (3 Credits)
Review of Maxwell's equations: potentials, EM energy and momentum, EM plane waves. Properties of waves: dispersion, group velocity, diffraction, the ray optic limit. Waves in media: left-handed media, anisotropic media, wave guides, fibers, cavities. Radiation: antennas, Cherenkov radiation, radiation by accelerated charges, scattering. Additional topics: Wave chaos, Special Relativity.
Prerequisite: ENEE381; or students who have taken courses with comparable content may contact the department.

ENEE686 Charged Particle Dynamics, Electron and Ion Beams (3 Credits)
General principles of single-particle dynamics; mapping of the electric and magnetic fields; equation of motion and methods of solution; production and control of charge particle beams; electron optics; Liouville's theorem; space charge effects in high current beams; design principles of special electron and ion beam devices.

ENEE690 Introduction to Quantum Mechanics (3 Credits)
Introduction to the Schroedinger equation, matrix formulations of quantum mechanics, identical particles, entanglement, approximation methods, symmetries. Applications to solid-state, atomic, and quantum information science.
Prerequisite: ENEE381; or students who have taken courses with comparable content may contact the department.

ENEE691 Optical Communication Systems (3 Credits)
Optical components and systems. Measures of performance of optical communication systems. Topics include: single and multi-mode optical fibers, DFB and DBR lasers, transmitters and receivers, pin and APD detectors, noise analysis, receiver sensitivity modulation formats, system performance, bit-error-rate, power budget, TDM and WDM systems, network architecture.

ENEE692 Introduction to Photonics (3 Credits)
Introduction to photonic concepts and applications. In particular, high quality factor optical resonators, photonic crystals, microresonators, statistical and photon optics, spontaneous and stimulated emission, semiconductor lasers and detectors, modulators and optical switches are discussed. Finally, the concept of photons and the quantum states of light are presented.
Prerequisite: ENEE380 and ENEE381; or students who have taken courses with comparable content may contact the department.

ENEE698 Graduate Seminar (1-3 Credits)
Every semester regular seminars are held in electrical science and in the six areas of specialization offered by the electrical engineering department. They may be taken, by arrangement with the student's advisor, for repeated credit.
Restriction: Permission of instructor.

ENEE699 Independent Studies in Electrical Engineering (1-3 Credits)
Supervised individual study or project, or supervised group study or project, at an advanced level, in electrical engineering.
Repeatable to: 99 credits if content differs.
Formerly: ENEE609.

ENEE704 Physics and Simulation of Semiconductor Devices (3 Credits)
The physics of electron transport in semiconductor devices will be covered. Numerical methods for attaining solutions to transport equations will be explored. Students will also learn how to use CAD tools fro semiconductor device design. Nano-electronic devices will be introduced.
Recommended: ENEE601 and ENEE600; and exposure to quantum mechanics.
Credit Only Granted for: ENEE694 and ENEE704.
Formerly: ENEE694.

ENEE719 Advanced Topics in Microelectronics (3 Credits)
Repeatable to: 99 credits if content differs.
Formerly: ENEE718.

ENEE729 Advanced Topics in Communication (3 Credits)
Repeatable to: 99 credits if content differs.
Formerly: ENEE728.

ENEE731 Image Understanding (3 Credits)
An advanced graduate level course on image understanding. Mathematical and statistical approaches to solving image understanding problems will be discussed. Topics to be covered include: optimal edge and shape detection; image understanding using Markov random field models; Monte Carlo Markov Chain techniques for image understanding; shape from shading, stereo, texture and contour; structure from motion and object recognition. Existence, uniqueness and convergence issues for many of these problems will be discussed.
Prerequisite: ENEE631 and ENEE633.
Credit Only Granted for: ENEE739J or ENEE731.
Formerly: ENEE739J.

ENEE739 Advanced Topics in Signal Processing (3 Credits)
Repeatable to: 99 credits if content differs.
Formerly: ENEE738.

ENEE749 Advanced Digital Systems Design (3 Credits)
VLSI architecture and algorithms; design strategies; design methodologies; system-level design; area/delay/power trade-offs; high performance systems; multi-chip modules; low-power design; hardware/software co-design; design for testability, design for manufacturability; algorithm, architecture, and component design for adaptive computing systems; prototype system development and test, possible chip fabrication by MOSIS and subsequent chip testing.
Prerequisite: ENEE640 or ENEE644.
Restriction: Permission of instructor.
Repeatable to: 6 credits if content differs.

ENEE757 Security in Distributed Systems and Networks (3 Credits)
Threats and countermeasures in centralized and distributed systems; communication security techniques based on encryption; symmetric and asymmetric encryption; encryption modes, including stream and block encryption, and cipher block chaining; message origin and mutual authentication; third-party and inter-realm authentication, authentication of mobile users; data confidentiality and integrity protocols; formal analysis of authentication protocols and message integrity; access control in distributed systems and networks; firewall design; case studies of security mechanisms and policies.
Prerequisite: ENEE647; or permission of instructor.

ENEE759 Advanced Topics in Computer Engineering (3 Credits)
Topics, as announced every semester, from the field of computer engineering and its applications.
Repeatable to: 99 credits if content differs.

ENEE762 Stochastic Control (3 Credits)
Stochastic control systems, numerical methods for the Ricatti equation, the separation principle, control of linear systems with Gaussian signals and quadratic cost, non-linear stochastic control, stochastic stability, introduction to stochastic games.
Prerequisite: ENEE620 and ENEE660; or students who have taken courses with comparable content may contact the department.

ENEE763 Advanced Nonlinear Control Systems (3 Credits)
General introduction to the geometric theory of nonlinear control systems. Theory of decoupling, disturbance rejection, feedback linearization, stability, stabilization, etc.
Prerequisite: ENEE661; or permission of instructor.

ENEE765 Adaptive Control (3 Credits)
General principles of adaptive control. Self-tuning regulators and model reference adaptive systems. Theoretical issues: stability, convergence, and robustness. Practical issues: implementation, computation, auto-tuning, and other successful application. Alternatives to adaptive control.
Prerequisite: ENEE660 and ENEE664; or students who have taken courses with comparable content may contact the department.

ENEE769 Advanced Topics in Controls (3 Credits)
Topics selected, as announced every semester, from the field of controls and its applications.
Repeatable to: 99 credits if content differs.

ENEE789 Advanced Topics in Electrophysics (3 Credits)
Topics selected, as announced every semester, from the field of electrophysics and its applications.
Repeatable to: 99 credits if content differs.
Formerly: ENEE788.

ENEE790 Quantum Electronics I (3 Credits)
Spontaneous emission, interaction of radiation and matter, masers, optical resonators, the gas, solid and semi-conductor lasers, electro-optical effect, propagation in anisotropic media and light modulation.
Prerequisite: Must have knowledge of quantum mechanics; or permission of instructor.

ENEE791 Quantum Electronics II (3 Credits)
Nonlinear optical effects and devices, tunable coherent light sources: optical parametric oscillator; frequency conversion and dye laser. Ultrashort pulse generation and measurement, stimulated raman effect, and applications. Interaction of acoustic and optical waves, and holography.

ENEE798 Advanced Topics in Electrical Engineering (3 Credits)
Topics selected, as announced every semester.
Formerly: ENEE648.

ENEE799 Master's Thesis Research (1-6 Credits)

ENEE889 Teaching Workshop (1 Credit)
Provide training in education for senior PhD students who contemplate an academic career, and give them the opportunity to gain some teaching experience. Emphasis is on issues that are of special importance in electrical and computer engineering education.
Restriction: Must be in ENGR: MS/PhD-Electrical Engineering (Doctoral) program; and permission of ENGR-Electrical & Computer Engineering department.
Repeatable to: 4 credits if content differs.

ENEE898 Pre-Candidacy Research (1-8 Credits)
Provide training in education for senior PhD students who contemplate an academic career, and give them the opportunity to gain some teaching experience. Emphasis is on issues that are of special importance in electrical and computer engineering education.
Restriction: Must be in ENGR: MS/PhD-Electrical Engineering (Doctoral) program; and permission of ENGR-Electrical & Computer Engineering department.
Repeatable to: 4 credits if content differs.

ENEE899 Doctoral Dissertation Research (1-8 Credits)