ECE - Electrical and Computer Engineering

Electrical and Computer Engineering: ECE

Lower-Division Courses

ECE 302 (TCCN: ENGR 2305). Introduction to Electrical Engineering.

Examine the scope and nature of professional activities of electrical engineers, including problem-solving techniques; analysis and design methods; engineering professional ethics; analysis of analog resistive circuits, including Thevenin/Norton equivalents, mesh analysis, and nodal analysis; and operational amplifiers (DC response). Three lecture hours and two laboratory hours a week for one semester Only one of the following may be counted: Electrical and Computer Engineering 302, 302H, Electrical Engineering 302, 302H. Prerequisite: Credit with a grade of at least C- or registration for Mathematics 408C or 408K.

ECE 302H. Introduction to Electrical Engineering: Honors.

Restricted to students in the electrical and computer engineering honors program. Examine the scope and nature of professional activities of electrical engineers, including problem-solving techniques; analysis and design methods; engineering professional ethics; analysis of linear and non-linear analog circuits, including Thevenin/Norton equivalents, two-port networks, frequency domain analysis, mesh analysis, and nodal analysis; and operational amplifiers (DC response). Three lecture hours and two laboratory hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 302, 302H, Electrical Engineering 302, 302H. Prerequisite: Credit with a grade of at least C- or registration for Mathematics 408D.

ECE 306. Introduction to Computing.

Introduction to computing including bits and operations on bits, number formats, arithmetic and logic operations, and digital logic. Explore the Von Neumann model of processing including memory, arithmetic logic unit, registers, and instruction decoding and execution. Examine structured programming and debugging, machine and assembly language programming, the structure of an assembler, physical input/output through device registers, subroutine call/return; trap instruction, stacks and applications of stacks. Three lecture hours and one recitation hour a week for one semester. Only one of the following may be counted: Biomedical Engineering 306, Electrical and Computer Engineering 306, 306H, Electrical Engineering 306, 306H. Prerequisite: Credit with a grade of at least a C- or registration for Mathematics 408C or 408K.

ECE 306H. Introduction to Computing: Honors.

Introduction to computing including bits and operations on bits, number formats, arithmetic and logic operations, and digital logic. Explore the Von Neumann model of processing including memory, arithmetic logic unit, registers, and instruction decoding and execution. Examine structured programming and debugging, machine and assembly language programming, the structure of an assembler, physical input/output through device registers, subroutine call/return; trap instruction, stacks and applications of stacks. Three lecture hours and one recitation hour a week for one semester. Only one of the following may be counted: Biomedical Engineering 306, Electrical and Computer Engineering 306, 306H, Electrical Engineering 306, 306H. Prerequisite: Credit with a grade of at least a C- or registration for Mathematics 408C or 408K.

ECE 307E. Elements of Electrical and Computer Engineering.

Introduction to electrical engineering: direct current circuit analysis, resistors, LEDs, switches, current and voltage measurements. Introduction to computer engineering: number systems, digital logic, storage, finite state machines, programming basics, microcontrollers. Three lecture hours and one laboratory hour a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 307E, Electrical Engineering 307E, 307S (Topic: Elements of Elec/Comp Engr). Prerequisite: Consent of instructor.

ECE 107H. Engineering Leadership: Honors.

Explore different research areas in electrical and computer engineering and participate in community service projects within the discipline. One lecture hour a week for one semester. Offered on the letter-grade basis only.

ECE 108S. Topics in Technical Skills.

Explore the development of a specific technical skill. The equivalent of one lecture and one laboratory hour a week for one semester. May be repeated for credit when the topics vary. Offered on the pass/fail basis only. Prerequisite: Consent of instructor.

ECE 109K, 209K, 309K, 409K. Topics in Electrical Engineering.

For each semester hour of credit earned, one lecture hour a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Consent of instructor.

ECE 209P. Introduction to Professional Engineering.

Explore professional skills including academic success, career development, and engineering ethics. Two lecture hours a week for one semester. Prerequisite: Electrical and Computer Engineering 302 (or Electrical Engineering 302) or 302H (or Electrical Engineering 302H) with grade of at least C-.

ECE 309S. Development of a Solar-Powered Vehicle.

Analyze, design, and construct a solar-powered car for national competitions involving other universities. Study electrical, mechanical, and aerodynamic systems. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 309S and Electrical Engineering 309S may not both be counted.

ECE 411. Circuit Theory.

Examine capacitance and inductance; first- and second-order transient circuit response, including operational amplifier circuits; sinusoidal steady state analysis; Bode plots; complex power in single and balanced three-phase systems; transformers; two-port networks (Z-parameters and Y-parameters); and computer-aided analysis and design. Three lecture hours and two recitation hours a week for one semester. Only one of the following may be counted: Biomedical Engineering 311, Electrical and Computer Engineering 411, 411H, Electrical Engineering 411. Prerequisite: One of the following with a grade of at least C- Electrical and Computer Engineering 302 (or Electrical Engineering 302) or 302H (or Electrical Engineering 302H); credit with a grade of at least C- or registration for Mathematics 427J or 427K, and Physics 303L and 105N.

ECE 411H. Circuit Theory: Honors.

Examine capacitance and inductance; first- and second-order transient circuit response, including operational amplifier circuits; sinusoidal steady state analysis; Bode plots; complex power in single and balanced three-phase systems; transformers; two-port networks (Z-parameters and Y-parameters); and computer-aided analysis and design. Three lecture hours and two recitation hours a week for one semester. Only one of the following may be counted: Biomedical Engineering 311, Electrical and Computer Engineering 411, 411H, Electrical Engineering 411. Offered on the letter-grade basis only. Prerequisite: Electrical and Computer Engineering 302 (or Electrical Engineering 302) or 302H (or Electrical Engineering 302H) with a grade of at least B; credit with a grade of at

least C- or registration for Mathematics 427J or 427K, and Physics 303L and 103N

ECE 111S. Tools to Enhance Academic Success.

Explore the components necessary to enhance academic success in engineering coursework including academic self-regulation, time management, self-discipline, goal-setting, weekly and semester planning, growth mindset, self-motivation, management of anxiety and stress, learning and memory, learning strategies, retrieval practices, and exam preparation. One lecture hour a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 111S, Electrical Engineering 109K (Topic: Enhancing Academic Success), 111S.

ECE 312. Software Design and Implementation I.

Explore basic problem solving, design and implementation techniques for imperative programming; structured programming in the C/C++ language; programming idioms. Examine software design principles, including modularity, coupling and cohesion; software engineering tools; elementary data structures; and asymptotic analysis. Three lecture hours and one recitation hour a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 312, 312H, Electrical Engineering 312, 312H. Prerequisite: The following coursework with a grade of at least C-: Biomedical Engineering 306 or Electrical and Computer Engineering 306 (or Electrical Engineering 306) or 306H (or Electrical Engineering 306H), and 319K (or Electrical Engineering 319K) or 319H (or Electrical Engineering 319H).

ECE 312H. Software Design and Implementation I: Honors.

Explore basic problem solving, design and implementation techniques for imperative programming; structured programming in the C/C++ language; programming idioms. Examine software design principles, including modularity, coupling and cohesion; software engineering tools; elementary data structures; and asymptotic analysis. Three lecture hours and one recitation hour a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 312, 312H, Electrical Engineering 312, 312H. Prerequisite: The following coursework with a grade of at least B in each: Biomedical Engineering 306 or Electrical and Computer Engineering 306 (or Electrical Engineering 306) or 306H (or Electrical Engineering 306H); Electrical and Computer Engineering 319K (or Electrical Engineering 319K) or 319H (or Electrical Engineering 319H) or registration for Electrical and Computer Engineering 319H (or credit for Electrical Engineering 319H).

ECE 313. Linear Systems and Signals.

Examine representation of signals and systems; system properties; sampling; Laplace and z-transforms; transfer functions and frequency response; convolution; stability; Fourier transform; feedback; and control applications. Explore computer analysis using MATLAB or Python. Three lecture hours a week for one semester. Only one of the following may be counted: Biomedical Engineering 343, Electrical and Computer Engineering 313, 313H, Electrical Engineering 313. Prerequisite: Biomedical Engineering 311, Electrical and Computer Engineering 411 (or Electrical Engineering 411), Electrical and Computer Engineering 411H (or Electrical Engineering 411H), or 331 (or Electrical Engineering 331) with a grade of at least C-; Mathematics 427J or 427K with a grade of at least C-; and credit with a grade of at least C- or registration for Mathematics 340L.

ECE 313H. Linear Systems and Signals: Honors.

Examine representation of signals and systems; system properties; sampling; Laplace and z-transforms; transfer functions and frequency response; convolution; stability; Fourier transform; feedback; and control applications. Explore computer analysis using MATLAB or Python. Three lecture hours a week for one semester. Only one of the following may be counted: Biomedical Engineering 343, Electrical and Computer Engineering 313, 313H, Electrical Engineering 313. Offered on the letter-grade basis only. Prerequisite: Biomedical Engineering 311, Electrical and Computer Engineering 411 (or Electrical Engineering 411), 411H, or 331 (or Electrical Engineering 331) with a grade of at least B; Mathematics 427J or 427K with a grade of at least C-; and credit with a grade of at least C- or registration for Mathematics 340L.

ECE 316. Digital Logic Design.

Explore boolean algebra; analysis and design of combinational and sequential logic circuits; state machine design and state tables and graphs; simulation of combinational and sequential circuits; applications to computer design; and hardware description languages (HDLs) and field-programmable gate arrays (FPGAs). Three lecture hours and one recitation hour a week for one semester. Electrical and Computer Engineering 316 and Electrical Engineering 316 may not both be counted. Prerequisite: Biomedical Engineering 306, Computer Science 429, Electrical and Computer Engineering 306 (or Electrical Engineering 306) or 306H (or Electrical Engineering 306H) with a grade of at least C-.

ECE 319H. Introduction to Embedded Systems: Honors.

Examine embedded systems; machine language execution; assembly and C language programming; local variables and subroutines; input/output synchronization; analog to digital conversion and digital to analog conversion; debugging; and interrupts. Three lecture hours and one laboratory hour a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 319K, 319H, Electrical Engineering 319K, 319H. Prerequisite: Biomedical Engineering 306, Electrical and Computer Engineering 306 (or Electrical Engineering 306), 306H (or Electrical Engineering 306H), or Mechanical Engineering 340 and 140L with a grade of at least C-.

ECE 319K. Introduction to Embedded Systems.

Explore embedded systems; machine language execution; assembly and C language programming; local variables and subroutines; input/output synchronization; analog to digital conversion and digital to analog conversion; debugging; and interrupts. Three lecture hours and one laboratory hour a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 319K, 319H, Electrical Engineering 319K, 319H. Prerequisite: Biomedical Engineering 306, Electrical and Computer Engineering 306 (or Electrical Engineering 306), 306H (or Electrical Engineering 306H), or Mechanical Engineering 340 and 140L with a grade of at least C-.

ECE 119S, 219S, 319S, 419S, 519S, 619S, 719S, 819S, 919S. Topics in Electrical and Computer Engineering.

Used to record credit the student earns while enrolled at another institution in a program administered by the University's Study Abroad Office. Credit is recorded as assigned by the study abroad advisor in the Department of Electrical and Computer Engineering. University credit is awarded for work in an exchange program; it may be counted as coursework taken in residence. Transfer credit is awarded for work in an affiliated studies program. May be repeated for credit when the topics vary.

Upper-Division Courses

ECE 321K. Mixed Signal and Circuits Laboratory.

Explore digital and analog parametric testing of mixed-signal circuits and systems, including frequency response, harmonic and intermodulation, and noise behavior; use of system-level test equipment, including network analyzers, spectrum analyzers, and probe stations; coherent versus noncoherent measurements; and design for testability. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 321K and Electrical Engineering 321K may not both be counted. Prerequisite: Electrical and Computer Engineering 438 (or Electrical Engineering 438) with a grade of at least

C-; and credit with a grade of at least C- or registration for Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or credit with a grade of at least C- for Electrical Engineering 333T), Engineering Studies 333T, Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T.

ECE 422C. Software Design and Implementation II.

Explore methods for engineering software with a focus on abstraction; specification, design, implementation, and testing of object-oriented code using a modern development tool-set for complex systems; design and implementation of object-oriented programs in Java; abstract data types; inheritance; polymorphism; parameterized types and generic programming; the operation and application of commonly used data structures; exception handling and fault tolerance; algorithm analysis; and teamwork models. Three lecture hours and one and one-half laboratory hours a week for one semester. Electrical and Computer Engineering 422C and Electrical Engineering 422C may not both be counted. Prerequisite: Computer Science 312 or Electrical and Computer Engineering 312 (or Electrical Engineering 312) or 312H (or Electrical Engineering 312H) with a grade of at least C-.

ECE 325. Electromagnetic Engineering.

Examine electrostatics and magnetostatics; properties of conductive, dielectric, and magnetic materials; solutions of Maxwell's equations; uniform plane wave applications; and frequency- and time-domain analyses of transmission lines. Three lecture hours a week for one semester. Electrical and Computer Engineering 325 and Electrical Engineering 325 may not both be counted. Prerequisite: Electrical and Computer Engineering 411 (or Electrical Engineering 411) or 411H, Mathematics 427J or 427K, Physics 303L, and Physics 105N or 103N with a grade of at least C- in each; and credit with a grade of at least C- or registration for Mathematics 427L.

ECE 325K. Antennas and Wireless Propagation.

Explore solutions of time-varying Maxwell's equations with applications to antennas and wireless propagation; antenna theory and design, array synthesis; electromagnetic wave propagation, scattering, and diffraction; and numerical methods for solving Maxwell's equations. Three lecture hours a week for one semester. Electrical and Computer Engineering 325K and Electrical Engineering 325K may not both be counted. Prerequisite: Electrical and Computer Engineering 325 (or Electrical Engineering 325) with a grade of at least C-

ECE 125S. Internship in Electrical and Computer Engineering.

Practical work experience in industry or a research lab under the supervision of an engineer or scientist. Requires a substantial final report. At least ten hours of work a week, for a total of 150 hours a semester. May be repeated for credit. Offered on the pass/fail basis only.

ECE 129S, 229S, 329S, 429S, 529S, 629S, 729S, 829S, 929S. Topics in Electrical and Computer Engineering.

This course is used to record credit the student earns while enrolled at another institution in a program administered by the University's Study Abroad Office. Credit is recorded as assigned by the study abroad adviser in the Department of Electrical and Computer Engineering. University credit is awarded for work in an exchange program; it may be counted as coursework taken in residence. Transfer credit is awarded for work in an affiliated studies program. May be repeated for credit when the topics vary.

ECE 331. Electrical Circuits, Electronics, and Machinery.

Restricted to non-electrical engineering majors. Explore brief theory of direct and alternating current circuits; single-phase and three-phase power transmission; electronic devices and instrumentation; and electromechanics. Three lecture hours a week for one semester. Electrical and Computer Engineering 331 and Electrical Engineering 331 may not both be counted. Prerequisite: Mathematics 408D or 408M with a grade of at least C-, and Physics 303L and 103N with a grade of at least C- in each.

ECE 333T. Engineering Communication.

Restricted to electrical engineering majors. Explore advanced engineering communication skills, with emphasis on technical documents, oral reports, and graphics. Participate in collaborative work involving online communication and research. Three lecture hours a week for one semester. Only one of the following may be counted: Aerospace Engineering 333T, Biomedical Engineering 333T, Communication 333T, Civil Engineering 333T, Chemical Engineering 333T, Electrical and Computer Engineering 333T, Electrical Engineering 333T, Engineering Studies 333T, Mechanical Engineering 333T, Petroleum and Geosystems Engineering 333T. Prerequisite: Rhetoric and Writing 306, and Electrical and Computer Engineering 319K or 319H with a grade of at least C-.

ECE 334K. Quantum Theory of Electronic Materials.

Introduction to quantum mechanics; atoms and molecules; electron statistics; quantum theory of solids; electronic phenomena in semiconductors; and device applications based on these phenomena. Three lecture hours a week for one semester. Electrical and Computer Engineering 334K and Electrical Engineering 334K may not both be counted. Prerequisite: Mathematics 427J or 427K, Physics 303L, and Physics 105N OR 103N with a grade of at least C- in each.

ECE 438. Fundamentals of Electronic Circuits I Laboratory.

Explore the analysis and design of electronic circuits using semiconductor devices. Examine basic device physics and small-signal modeling for diodes, bipolar junction transistors, and metal-oxide-semiconductor transistors; operation region and biasing; basic switching circuits; single-stage and multi-stage amplifier design and analysis; input and output impedance characteristics of amplifiers; frequency response; AC and DC coupling techniques; and differential amplifiers and output stages. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 438 and Electrical Engineering 438 may not both be counted. Prerequisite: Biomedical Engineering 311, Electrical and Computer Engineering 411 (or Electrical Engineering 411), or 411H with a grade of at least C-; and credit with a grade of at least C- or registration for one of the following: Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T.

ECE 438K. Analog Electronics.

Explore the analysis and design of analog electronic circuits; transistor models; single-ended amplifiers; differential amplifiers; operational amplifiers; frequency response; feedback theory; stability analysis; circuit nonidealities; op-amp-based circuits; output stages; power amplifiers; passive and active analog filters; and relaxation oscillators Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 438K and Electrical Engineering 438K may not both be counted. Prerequisite: Electrical and Computer Engineering 438 (or Electrical Engineering 438) with a grade of at least C-.

ECE 338L. Analog Integrated Circuit Design.

Explore the analysis and design of analog integrated circuits; transistor models; simple and advanced current mirrors; single-ended amplifiers; differential amplifiers; operational amplifiers; frequency response;

feedback theory; stability analysis; circuit nonidealities and noise; output stages; and analog filters. Examine computer-aided design (CAD) tools for circuit analysis and design. Three lecture hours a week for one semester. Electrical and Computer Engineering 338L and Electrical Engineering 338L may not both be counted. Prerequisite: Electrical and Computer Engineering 438 (or Electrical Engineering 438) with a grade of at least C-.

ECE 339. Solid-State Electronic Devices.

Examine semiconductor materials; atomic orbitals to energy band structure of semiconductors; charge carrier transport, electron-hole generation and recombination; p-n junctions and Schottky barriers; bipolar and field-effect transistors; and optoelectronic devices. Three lecture hours a week for one semester. Electrical and Computer Engineering 339 and Electrical Engineering 339 may not both be counted. Prerequisite: Mathematics 427J or 427K, Physics 303L, and Physics 105N OR 103N with a grade of at least C- in each.

ECE 339S. Solar Energy Conversion Devices.

Investigate basic principles of photovoltaic devices which convert light into charge carriers (electrons and holes). Examine electrons and holes in semiconductors, generation and recombination, junctions, analysis of the p-n junction, silicon and III-V semiconductor solar cell design and optimization, thin film solar cell technologies, managing light, strategies for higher efficiency, and a brief overview of non-photovoltaic approaches to solar energy conversion. Three lecture hours a week for one semester. Electrical and Computer Engineering 339S and Electrical Engineering 339S may not both be counted. Prerequisite: Mathematics 427J or 427K, Physics 303L, and Physics 105N or 103N with a grade of at least C- in each.

ECE 440. Integrated Circuit Nanomanufacturing Techniques.

Examine integrated circuit processing; crystal growth and wafer preparation; epitaxial growth; oxidation, diffusion, and ion implantation; thin-film deposition techniques; and lithography and etching. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 440 and Electrical Engineering 440 may not both be counted. Prerequisite: Credit with a grade of at least a C- for Mathematics 427J or 427K; credit with a grade of at least a C- for Physics 303L; credit with a grade of at least a C- for Physics 103N; and credit with a grade of at least C- or registration for Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Engineering Studies 333T, Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T.

ECE 340P. High-Throughput Nanopatterning.

Explore sub-50nm fabrication using mechanical patterning techniques; overview of photolithography, mechanical nanopatterning processes, hot embossing, and UV imprint lithography; wafer-scale and roll-to-roll nanopatterning with applications in electronics, photonics, and nanomedicine; physics of nanoreplication, process limits, template (mold) fabrication, defect mechanisms, and factors affecting throughput. Three lecture hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 340P, Electrical Engineering 340P, 379K (Topic: High Throughput Nanopatterning), Mechanical Engineering 379M (Topic: High Throughput Nanopatterning). Prerequisite: Electrical and Computer Engineering 411 (or Electrical Engineering 411) or 411H, and 339 (or Electrical Engineering 339), and Mathematics 427K or 427J, with a grade of at least C- in each.

ECE 341. Electric Drives and Machines.

Explore fundamentals of electric machines. Examine electromechanical energy conversion; magnetic circuits, transformers, and energy conversion devices; and power electronics. Discuss motor drive fundamentals and applications. Three lecture hours a week for one semester. Electrical and Computer Engineering 341 and Electrical Engineering 341 may not both be counted. Prerequisite: Electrical and Computer Engineering 411 (or Electrical Engineering 411) or 411H with a grade of at least C-.

ECE 445L. Embedded Systems Design Laboratory.

Explore the design of microcontroller-based embedded systems; interfacing from both a hardware and software perspective; and applications, including audio, data acquisition, and communication systems. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 445L and Electrical Engineering 445L may not both be counted. Prerequisite: Electrical and Computer Engineering 312 (or Electrical Engineering 312) or 312H (or Electrical Engineering 312H) and 319K (or Electrical Engineering 319K) or 319H (or Electrical Engineering 319H) with a grade of at least C- in each; Electrical and Computer Engineering 411 (or Electrical Engineering 411) or 411H and 313 (or Electrical Engineering 313) or 313H, or Biomedical Engineering 311 and 343, or Mechanical Engineering 348E with a grade of at least C- in each; and credit with a grade of at least C- or registration for Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Engineering Studies 333T, Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T.

ECE 445M. Embedded and Real-Time Systems Laboratory.

Explore real-time operating systems; implementation of context switching, threads, multitasking, real-time scheduling, synchronization, communication, storage, file systems, memory management, process linking and loading, hardware interfacing, and networking; debugging and testing; operating system performance, including latency, jitter, deadlines, deadlocks, and starvation; real-time systems, including data acquisition, sensing, actuating, digital control, signal processing, and robotics. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 445M and Electrical Engineering 445M may not both be counted. Prerequisite: One of the following with a grade of at least C- Electrical and Computer Engineering 306 (or Electrical Engineering 306) or 306H (or Electrical Engineering 306H); one of the following with a grade of at least C- Electrical and Computer Engineering 312 (or Electrical Engineering 312) or 312H (or Electrical Engineering 312H); and one of the following with a grade of at least C- Electrical and Computer Engineering 319K (or Electrical Engineering 319K) or 319H (or Electrical Engineering 319H).

ECE 445S. Real-Time Digital Signal Processing Laboratory.

Explore digital signal processing algorithms; simulation and real-time implementation of audio and communication systems; filters; pulse shaping and matched filters; modulation and demodulation; adaptive filters; carrier recovery; symbol synchronization; equalization; quantization; and data conversion. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 445S and Electrical Engineering 445S may not both be counted. Prerequisite: Electrical and Computer Engineering 312 (or Electrical Engineering 312) or 312H (or Electrical Engineering 312H) and 319K (or Electrical Engineering 319K) or 319H (or Electrical Engineering 319H) with a grade of at least C- in each; Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H with a grade of at least C-; credit with a grade of at least C- or registration for Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Engineering Studies 333T, Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T; and credit with a grade of at least C-

or registration for Biomedical Engineering 335, Electrical and Computer Engineering 351K (or Electrical Engineering 351K), or 351H.

ECE 347. Modern Optics.

Explore modern optical wave phenomena with applications to imaging, holography, fiber optics, lasers, and optical information processing. Three lecture hours a week for one semester. Electrical and Computer Engineering 347 and Electrical Engineering 347 may not both be counted. Prerequisite: Electrical and Computer Engineering 313 (or Electrical Engineering 313) or 313H, and 325 (or Electrical Engineering 325) with a grade of at least C- in each; or Biomedical Engineering 343 with a grade of at least C-.

ECE 348. Laser and Optical Engineering.

Explore principles of operation and applications of lasers, optical modulators, and optical detectors. Three lecture hours a week for one semester. Electrical and Computer Engineering 348 and Electrical Engineering 348 may not both be counted. Prerequisite: Electrical and Computer Engineering 325 (or Electrical Engineering 325) with a grade of at least C-.

ECE 351H. Probability and Random Processes: Honors.

Examine probability, random variables, statistics, and random processes, including counting, independence, conditioning, expectation, density functions, distributions, law of large numbers, central limit theorem, confidence intervals, hypothesis testing, statistical estimation, stationary processes, Markov chains, and ergodicity. Three lecture hours and one laboratory hour a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 351H, 351K, Electrical Engineering 351K. Offered on the letter-grade basis only. Prerequisite: Biomedical Engineering 306, Electrical and Computer Engineering 306 (or Electrical Engineering 306), 306H (or Electrical Engineering 306H), or Mechanical Engineering 340 and 140L with a grade of at least B.

ECE 351K. Probability and Random Processes.

Examine probability, random variables, statistics, and random processes, including counting, independence, conditioning, expectation, density functions, distributions, law of large numbers, central limit theorem, confidence intervals, hypothesis testing, statistical estimation, stationary processes, Markov chains, and ergodicity. Three lecture hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 351H, 351K, Electrical Engineering 351K. Prerequisite: Mathematics 427J or 427K with a grade of at least C-.

ECE 351M. Digital Signal Processing.

Explore sampling, aliasing, truncation effects; discrete and fast Fourier transform methods; convolution and deconvolution; finite and infinite impulse response filter design methods; Wiener, Kalman, noncausal, linear phase, median, and prediction filters; and spectral estimation. Three lecture hours a week for one semester. Electrical and Computer Engineering 351M and Electrical Engineering 351M may not both be counted. Prerequisite: Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H with a grade of at least a C-, and credit with a grade of at least C- or registration for Biomedical Engineering 335, Electrical and Computer Engineering 351K (or credit with a grade of at least C- for Electrical Engineering 351K), or 351H.

ECE 155. Electrical and Computer Engineering Seminar.

Hear presentations by speakers from industry, government, academia, and professional private practice. Explore environmental and other ethical concerns, safety awareness, quality management, technical career descriptions, and professionalism with a focus on engineering communication. One lecture hour a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 155, Electrical Engineering 155, Electrical and Computer Engineering 364D, Electrical Engineering 364D. Prerequisite: One of the following with a grade of at least C-: English 316L (or 316K), 316M (or 316K), 316N (or 316K), or 316P (or 316K).

ECE 155L. Engineering Leadership Seminar.

Hear presentations by speakers from industry, government, academia, and professional private practice. Explore environmental and other ethical concerns, safety awareness, quality management, technical career descriptions, and professionalism. One lecture hour a week for one semester. Electrical and Computer Engineering 155L and Electrical Engineering 155L may not both be counted. Prerequisite: Consent of the dean and one of the following with a grade of at least C-: English 316L (or 316K), 316M (or 316K), 316N (or 316K), or 316P (or 316K).

ECE 155R. Undergraduate Research Seminar.

Restricted to students in the Department of Electrical and Computer Engineering. Explore areas of research in electrical and computer engineering. One lecture hour a week for a semester. Electrical and Computer Engineering 155R and Electrical Engineering 155R may not both be counted. Offered on the pass/fail basis only.

ECE 160, 260, 360, 460. Special Problems in Electrical and Computer Engineering.

Restricted to engineering majors. Investigate special problems as approved by the electrical and computer engineering department. For each semester hour of credit earned, the equivalent of three laboratory hours a week for one semester. May be repeated for credit. Prerequisite: Electrical and Computer Engineering 312 (or Electrical Engineering 312), 312H (or Electrical Engineering 312H), 313 (or Electrical Engineering 313), or 313H with a grade of at least C- and consent of instructor.

ECE 360C. Algorithms.

Explore advanced problem-solving methods; algorithm design principles; complexity analysis; the study of the nature, impact, and handling of intractability; and the study of common algorithmic classes and their applications. Three lecture hours a week for one semester. Electrical and Computer Engineering 360C and Electrical Engineering 360C may not both be counted. Prerequisite: Computer Science 312, Electrical and Computer Engineering 312 (or Electrical Engineering 312), or 312H (or Electrical Engineering 312H) with a grade of at least C-; and Mathematics 325K, Computer Science 311, or 311H with a grade of at least C-.

ECE 360F. Introduction to Software Engineering.

Introduction to the discipline of software engineering. Explore software system creation and evolution; fundamental concepts and principles of software product and software process systems, including requirements, architecture and design, construction, deployment, and maintenance; and documentation and document management, measurement and evaluation, software evolution, teamwork, and project management. Three lecture hours a week for one semester. Electrical and Computer Engineering 360F and Electrical Engineering 360F may not both be counted. Prerequisite: One of the following with a grade of at least C-: Computer Science 314, 314H, or Electrical and Computer Engineering 422C (or Electrical Engineering 422C) and consent of instructor.

ECE 460J. Data Science Laboratory.

Explore predictive modeling, regression and classification, data cleaning and preprocessing, feature engineering, unsupervised methods, principal component analysis, data clustering, model selection and feature selection, entropy and information theory, neural networks, deep learning, and machine learning for signals and time-series data. Three lecture hours and three laboratory hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 460J, Electrical Engineering 460J, 379K (Topic: Data Science Laboratory),

379K (Topic 24). Prerequisite: The following with a grade of at least C- in each: Biomedical Engineering 343 or Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H; and Biomedical Engineering 335, Electrical and Computer Engineering 351K (or Electrical Engineering 351K), 351H, or Mathematics 362K; and Mathematics 340L. Credit with a grade of at least C- or registration for Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Engineering Studies 333T, Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T

ECE 360K. Introduction to Digital Communications.

Examine characterization of baseband and passband communication signals and channels, digital modulation, and pulse shaping; optimum receivers in additive white Gaussian noise including matched-filtering, machine learning (ML), and mean average precision (mAP) detection and their bit error probability for M-ary modulation; inter-symbol interference channels, finite impulse response (FIR) and infinite impulse response (IIR) equalization, multicarrier modulation, orthogonal frequency-division multiplexing (OFDM) and frequency domain equalization. Introduction to information theory, channel capacity, error control codes, and ML sequence detection (Viterbi decoding). Explore applications to stationary wireless and wireline channels. Three lecture hours a week for one semester. Electrical and Computer Engineering 360K and Electrical Engineering 360K may not both be counted. Prerequisite: Biomedical Engineering 335, Electrical and Computer Engineering 351K (or Electrical Engineering 351K), or 351H with a grade of at least C-; Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H with a grade of at least C-; and Electrical and Computer Engineering 351M (or Electrical Engineering 351M) or 445S (or Electrical Engineering 445S) with a grade of at least a C-.

ECE 460M. Digital Systems Design Using Hardware Description Languages.

Explore organization, design, simulation, synthesis, and testing of digital systems; hardware description languages (HDLs); field programmable gate arrays (FPGAs); hardware implementation of arithmetic and other algorithmic processes; state machine charts; microprogramming; and microprocessor design. Three lecture hours and three laboratory hours a week for one semester. Electrical Engineering 460M and Electrical Engineering 460M may not both be counted. Prerequisite: Electrical and Computer Engineering 312 (or Electrical Engineering 312) or 312H (or Electrical Engineering 312H), 316 (or Electrical Engineering 316), and 319K (or Electrical Engineering 319K) or 319H (or Electrical Engineering 319H) with a grade of at least C- in each.

ECE 460N. Computer Architecture.

Examine characteristics of instruction set architecture and microarchitecture; physical and virtual memory; caches and cache design; interrupts and exceptions; integer and floating-point arithmetic; I/O processing; buses; pipelining, out-of-order execution, branch prediction, and other performance enhancements; design trade-offs; and case studies of commercial microprocessors. Explore behavioral-level design of a microarchitecture in a laboratory setting. Three lecture hours and one-and-one-half laboratory/recitation hours a week for one semester. Electrical and Computer Engineering 460N and Electrical Engineering 460N may not both be counted. Prerequisite: Computer Science 312 or 312H, and 429 or 429H with a grade of at least C- in each; or Electrical and Computer Engineering 306 (or Electrical Engineering 306) or 306H (or Electrical Engineering 306H), 312 (or Electrical Engineering 312) or 312H (or Electrical Engineering 312H), and 319K (or Electrical Engineering 319K) or 319H (or Electrical Engineering 319H) with a grade of at least C- in each.

ECE 360P. Concurrent and Distributed Systems.

Investigate concurrency, lock-based and lock-free synchronization, resource allocation, multi-threaded programming, distributed systems programming, mutual exclusion, global snapshots, global property evaluation, message ordering, consensus, Byzantine agreement, and commit protocols. Three lecture hours a week for one semester. Electrical and Computer Engineering 360P and Electrical Engineering 360P may not both be counted. Prerequisite: Electrical and Computer Engineering 422C (or Electrical Engineering 422C) and 360C (or Electrical Engineering 360C) with a grade of at least C-.

ECE 460R. Introduction to VLSI Design.

Explore theory and practice of very-large-scale integration (VLSI) circuit design. Examine metal-oxide-semiconductor (MOS) transistors; static and dynamic complementary metal-oxide-semiconductor (CMOS) combinational and sequential circuits; design of adders, multipliers, and shifters; performance, power consumption and testing. Use computer-aided design (CAD) tools for layout, timing analysis, synthesis, physical design, and verification. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 460R and Electrical Engineering 460R may not both be counted. Prerequisite: Electrical and Computer Engineering 316 (or Electrical Engineering 316) and 438 (or Electrical Engineering 438) with a grade of at least C- in each.

ECE 360S. Digital Integrated Circuit Design.

Examine circuit-level aspects of metal oxide silicon (MOS) and bipolar integrated circuit technologies. Explore logic gates and latches; propagation delays; and circuit simulation models. Three lecture hours a week for one semester. Electrical and Computer Engineering 360S and Electrical Engineering 360S may not both be counted.

ECE 360T. Software Testing.

Explore basic concepts and techniques used in testing software and finding bugs. Examine process, unit, integration, and system testing; manual and automatic techniques for generation of test inputs and validation of test outputs; and coverage criteria. Focus on functional testing. Three lecture hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 360T, Electrical Engineering 360T, 379K (Topic: Software Testing). Prerequisite: One of the following with a grade of at least C-: Computer Science 314 or 314H, or Electrical and Computer Engineering 422C (or Electrical Engineering 422C).

ECE 361C. Multicore Computing.

Explore theoretical and practical aspects of designing multicore software systems; programming constructs for concurrent computation; openMP; sequential consistency; linearizability; lock-based synchronization; lock-free synchronization; wait-free synchronization; consensus number; software transactional memory; testing and debugging parallel programs; race detection; concurrent data structures such as stacks, queues, linked lists, hash tables, and skiplists; formal models; temporal logic; reachability analysis; and parallel graph algorithms. Three lecture hours a week for one semester. Electrical and Computer Engineering 361C and Electrical Engineering 361C may not both be counted. Prerequisite: Electrical and Computer Engineering 422C (or Electrical Engineering 422C) and Electrical and Computer Engineering 360C (or Electrical Engineering 360C) with a grade of at least C-.

ECE 361D. System Design Metrics.

Examine engineering design, manufacturing, and lifetime support issues; implications of customer perceptions of quality on design; economics of design; and legal implications of design decisions. The equivalent of three lecture hours a week for one semester. Electrical and Computer Engineering 361D and Electrical Engineering 361D may not both be

counted. Prerequisite: Electrical and Computer Engineering 364D (or Electrical Engineering 364D) with a grade of at least C-.

ECE 361E. Machine Learning and Data Analytics for Edge Artificial Intelligence.

Examine edge computing; Internet-of-Things (IoT); cyber-physical systems; energy-aware machine learning (ML); deep learning; model compression; knowledge distillation; federated learning; ML security; system optimization; model-architecture co-design; object detection; and social sensing. Three lecture hours a week for one semester. Electrical and Computer Engineering 361E and Electrical Engineering 379K (Topic: ML/Data Analytc for EDGE AI) may not both be counted. Prerequisite: Electrical and Computer Engineering 460J (or Electrical Engineering 460J) or Computer Science 342 with a grade of at least C-.

ECE 361G. Engineering Program Analysis.

Explore program analysis; compilers; interpreters; code instrumentation; control-flow analysis; data-flow analysis; static single assignment form; dependency analysis; incremental analysis; autotuning; and just-in-time compilation. The equivalent of three lecture hours for one semester. Electrical and Computer Engineering 361G and Electrical Engineering 379K (Topic: Engineering Dynmc Prgrm Anly) may not both be counted. Prerequisite: Electrical and Computer Engineering 422C (or Electrical Engineering 422C) and Electrical and Computer Engineering 360C (or Electrical Engineering 360C) with a grade of at least C- in each.

ECE 461L. Software Engineering and Design Laboratory.

Examine generation of concrete software engineering artifacts at all stages of the software life-cycle processes; stakeholder needs to system requirements mapping; object-oriented design and analysis; and test driven development. Study design principles and methods; design and modeling tools; collaborative development environment; design patterns and refactoring; integration and testing tools. Examine emerging concepts in cloud native devops, including microservices, containers, and application programming interfaces (APIs). Explore design and development of at-scale software system using modern software development techniques, including re-usable front-end and back-end components, and cloud deployment. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 461L and Electrical Engineering 461L may not both be counted. Prerequisite: Computer Science 314, 314H, or Electrical and Computer Engineering 422C (or Electrical Engineering 422C) with a grade of at least C-; Mathematics 325K with a grade of at least C-; and credit or registration with a grade of at least C- for Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Engineering Studies 333T, Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T.

ECE 361M. Software Architectures.

Explore the definitions, motivations, and utility of software system architectures from a technical and business perspective; derivation, specification, and analysis of architectural views in support of different phases in the system engineering lifecycle; methods to judge architectural quality; and communication of architectural views to a wide range of system stakeholders. Three lecture hours a week for one semester. Electrical and Computer Engineering 361M and Electrical Engineering 379K (Topic: Software Architectures) may not both be counted. Offered on the letter-grade basis only. Prerequisite: Upper-division standing; and Electrical and Computer Engineering 422C (or Electrical Engineering 422C) or 360C (or Electrical Engineering 360C) with a grade of at least C-.

ECE 361N. Information Security and Privacy.

Explore information valuation; information classification; information confidentiality, integrity and availability; access control models; trusted identity, trust frameworks. Examine cryptology, designing information system security and privacy, threats and vulnerabilities. Introduction to network, software, and web security; risk assessments; data breach incident response; privacy laws and regulations. The equivalent of three lecture hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 361N, Electrical Engineering 361N, 379K (Topic: Information Security & Privacy). Prerequisite: Computer Science 312 or 312H, or Electrical and Computer Engineering 312 (or Electrical Engineering 312) or 312H (or Electrical Engineering 312H) with a grade of at least C-.

ECE 461P. Data Science Principles.

Examine principles of unsupervised and supervised learning; exploratory data analysis; feature engineering; predictive modeling for regression and classification; clustering algorithms; neural networks and stochastic gradient descent methods; scalable models for Big Data sets; case studies; and programming predictive models in Python and R. Four lecture hours a week for one semester. Only one of following may be counted: Electrical and Computer Engineering 461P, Electrical Engineering 361M, 461P. Prerequisite: The following with a grade of at least C- in each: Mathematics 340L; and Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H; and Biomedical Engineering 335 or Electrical and Computer Engineering 351K (or Electrical Engineering 351K), 351H, or Mathematics 362K.

ECE 361Q. Requirements Engineering.

Explore the methods and technology for acquiring, representing, documenting, verifying, validating, and maintaining requirements; text-based, graphic-based, and computational requirements model representations; requirements analysis to synthesize and resolve conflicts among disparate stakeholder viewpoints; requirements traceability and evolution; and change management. The equivalent of three lecture hours a week for one semester. Electrical and Computer Engineering 361Q and Electrical Engineering 361Q may not both be counted. Prerequisite: Computer Science 312, 312H, Electrical and Computer Engineering 312 (or Electrical Engineering 312) or 312H (or Electrical Engineering 312H) with a grade of at least C-.

ECE 361R. Radio-Frequency Electronics.

Examine modeling of active and passive devices and transmission line structures at high frequencies. Explore analysis and design of radio-frequency electronic circuits including amplifiers, mixers, multipliers, detectors, and oscillators; transistor-, circuit-, and system-level design methods, challenges, and topologies; noise and distortion analysis; and evaluation of modern radio systems. The equivalent of three lecture hours a week for one semester. Electrical and Computer Engineering 361R and Electrical Engineering 361R may not both be counted. Prerequisite: Electrical and Computer Engineering 325 (or Electrical Engineering 325) and 438 (or Electrical Engineering 438) with a grade of at least C- in each.

ECE 461S. Operating Systems.

Introduction to operating system design and implementation; the shell; process management and system calls; memory management; thread management, scheduling, synchronization and concurrency; file systems; input/output systems; virtual machines; and networking and security. Three lecture hours and one-and-one-half laboratory hour a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 461S, Electrical Engineering 461S, Electrical Engineering 379K (Topic: Operating Systems). Prerequisite: The following with a grade of at least C-: Electrical and Computer Engineering

312 (or Electrical Engineering 312) or 312H (or Electrical Engineering 312H), 319K (or Electrical Engineering 319K) or 319H (or Electrical Engineering 319H) and Mathematics 325K.

ECE 362G. Smart Grids.

Explore the fundamentals of smart electric power grids; smart grid architecture, communications, measurement, sensing, design, performance, standards and cyber security; distributed energy, renewable sources, and energy storage; and interoperability. Three lecture hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 362G, Electrical Engineering 362G, Electrical Engineering 379K (Topic: Smart Grids). Prerequisite: Electrical and Computer Engineering 468L (or Electrical Engineering 368L) or 369 (or Electrical Engineering 369) with a grade of at least C-.

ECE 362K. Introduction to Automatic Control.

Restricted to engineering majors. Explore analysis of linear automatic control systems in time and frequency domains; stability analysis; state variable analysis of continuous-time and discrete-time systems; root locus; Nyquist diagrams; Bode plots; sensitivity; and lead and lag compensation. Three lecture hours a week for one semester. Electrical and Computer Engineering 362K and Electrical Engineering 362K may not both be counted. Prerequisite: Upper-division standing, Electrical and Computer Engineering 313 (or Electrical Engineering 313) or 313H, and Mathematics 340L with a grade of at least C- in each.

ECE 462L. Power Electronics Laboratory.

Explore the analysis, design, and operation of power electronic circuits; power conversion from AC to DC, DC to DC, and DC to AC; rectifiers, inverters, and pulse width modulated motor drives. Examine the use of energy from renewable sources such as photovoltaics and wind in a laboratory setting. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 462L and Electrical Engineering 462L may not both be counted. Prerequisite: Electrical and Computer Engineering 411 (or Electrical Engineering 411) or 411H with a grade of at least C-; and credit with a grade of at least C- or registration for one of the following: Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Engineering Studies 333T, Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T.

ECE 362M. Power Electronics II.

Examine pulse-width-modulated power converters, rigorous physical design and device selection, gate driving, thermal design, magnetics design, small-signal modeling and control, and EMI filtering. Explore design and prototyping. Three lecture hours a week for one semester. Electrical and Computer Engineering 362M and Electrical Engineering 379K (Topic: Fundmntls of Power Electronics) may not both be counted. Prerequisite: Upper-division standing, Electrical and Computer Engineering 462L (or Electrical Engineering 462L), and consent of instructor.

ECE 362Q. Power Quality and Harmonics.

Examine and analyze power quality and harmonic phenomena in electric power systems, including characteristics and definitions, voltage sags, electrical transients, harmonics, mitigation techniques, and standards of power quality and harmonics. The equivalent of three lecture hours a week for one semester. Electrical and Computer Engineering 362Q and Electrical Engineering 362Q may not both be counted. Prerequisite: Electrical and Computer Engineering 368L (or Electrical Engineering 368L) or 468L with a grade of at least C-.

ECE 362R. Renewable Energy and Power Systems.

Examine renewable energy sources and their integration into power systems. Explore wind energy: resources, turbines, blades, rotor power characteristics, generators, active and reactive power, variability, and voltage regulation; solar energy: resources, solar radiation measurements, photovoltaic materials and properties, photovoltaic electrical characteristics, and system integration; and demonstrations with commercial-grade solar panels and laboratory-scale wind turbines. Three lecture hours a week for one semester. Electrical and Computer Engineering 362R and Electrical Engineering 362R may not both be counted. Prerequisite: Electrical and Computer Engineering 411 (or Electrical Engineering 411) or 411H with a grade of at least C-.

ECE 362S. Development of a Solar-Powered Vehicle.

Analyze, design, and construct a solar-powered car for national competitions involving other universities. Study electrical, mechanical, and aerodynamic systems. Three lecture hours and three laboratory hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 362S, Electrical Engineering 362S, Mechanical Engineering 362S. Prerequisite: One of the following with a grade of at least C-: Electrical and Computer Engineering 312 (or Electrical Engineering 312), 312H (or Electrical Engineering 312H), 313 (or Electrical Engineering 313), or 313H.

ECE 363M. Microwave and Radio Frequency Engineering.

Examine design principles in microwave and radio frequency systems; transmission lines and waveguides; S-parameter representation; impedance matching; microwave network analysis; microwave devices and components; and electromagnetic effects in high-speed and high-frequency applications. Three lecture hours a week for one semester. Electrical and Computer Engineering 363M and Electrical Engineering 363M may not both be counted. Prerequisite: Electrical and Computer Engineering 325 (or Electrical Engineering 325) with a grade of at least C-.

ECE 363N. Engineering Acoustics.

Same as Mechanical Engineering 379N. Principles of acoustics, with applications drawn from audio engineering, biomedical ultrasound, industrial acoustics, noise control, room acoustics, and underwater sound. Three lecture hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 363N, Electrical Engineering 363N, Mechanical Engineering 379N. Prerequisite: Mathematics 427J or 427K with a grade of at least C-.

ECE 464C. Corporate Senior Design Project.

Undertake design and experimental projects in the laboratories of local companies. Examine the ethics of design for safety and reliability. Designed for electrical engineering students working full-time in the industry. Three lecture hours and one-and-one-half laboratory hours a week for one semester. Electrical and Computer Engineering 464C and Electrical Engineering 464C may not both be counted. Prerequisite: Electrical and Computer Engineering 364D (or Electrical Engineering 364D) with a grade of at least C-, and one of the following with a grade of at least C-: Electrical and Computer Engineering 438 (or Electrical Engineering 438), 440 (or Electrical Engineering 440), 445L (or Electrical Engineering 445L), 445S (or Electrical Engineering 445S), 460J (or Electrical Engineering 460J), 461L (or Electrical Engineering 461L), 462L (or Electrical Engineering 462L), 468L, 471C (or Electrical Engineering 471C).

ECE 364D. Introduction to Engineering Design.

Introduction to the engineering design process. Explore the assessment and documentation of engineering problems and customer needs, such as acquiring, documenting, and verifying requirements; high-level system design principles; effects of economic, environmental, ethical, safety,

and social issues in design; writing and presenting design specifications; and effective teamwork. Two lecture hours and three laboratory hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 155, Electrical Engineering 155, Electrical and Computer Engineering 364D, Electrical Engineering 364D. Only one of the following may be counted: Electrical and Computer Engineering 364E, 364D, Electrical Engineering 364D, 364E. Prerequisite: Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Engineering Studies 333T, Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T with a grade of at least C-; and credit with a grade of at least C- or registration for Electrical and Computer Engineering 438 (or Electrical Engineering 438), 440 (or Electrical Engineering 440), 445L (or Electrical Engineering 445L), 445S (or Electrical Engineering 445S), 460J (or Electrical Engineering 460J), 461L (or Electrical Engineering 461L), 462L (or Electrical Engineering 462L), 468L, or 471C (or Electrical Engineering 471C).

ECE 364E. Interdisciplinary Entrepreneurship.

Start a company with a team. Explore skill development and mentoring in start-up formation, technology development, market validation, marketing, sales, operations, human resources, program management, and finance. Discuss the role of intellectual property and the social issues in design, as well as ethical and safety considerations. The equivalent of three lecture hours a week for one semester, with additional hours to be arranged. Only one of the following may be counted: Electrical and Computer Engineering 364D, 364E, Electrical Engineering 364D, 364E. Prerequisite: Credit with a grade of at least C- in Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T; credit with a grade of at least C- or registration for Electrical and Computer Engineering 438 (or Electrical Engineering 438), 440 (or Electrical Engineering 440), 445L (or Electrical Engineering 445L), 445S (or Electrical Engineering 445S), 460J (or Electrical Engineering 460J), 461L (or Electrical Engineering 461L), 462L (or Electrical Engineering 462L), or 471C (or Electrical Engineering 471C); and consent of instructor.

ECE 464G. Multidisciplinary Senior Design Project.

Undertake design and experimental projects with teams from multiple engineering disciplines. Examine the ethics of design for safety and reliability. Three lecture hours and one-and-one-half laboratory hours a week for one semester. Electrical and Computer Engineering 464G and Electrical Engineering 464G may not both be counted. Prerequisite: Electrical and Computer Engineering 364D (or Electrical Engineering 364D) with a grade of at least C-, and one of the following with a grade of at least C-: Electrical and Computer Engineering 438 (or Electrical Engineering 438), 440 (or Electrical Engineering 440), 445L (or EE445L), 445S (or Electrical Engineering 445S), 460J (or Electrical Engineering 460J), 461L (or Electrical Engineering 461L), 462L (or Electrical Engineering 462L), 468L, 471C (or Electrical Engineering 471C).

ECE 464H. Honors Senior Design Project.

Implement the previously developed engineering system design, including design review, prototyping, project testing and any subsequent design modifications; addressing economic, environmental, ethical, safety, and social issues; documentation of each of the preceding and publicly presenting design results; and working effectively in teams. Three lecture hours and six laboratory hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 464H, 464K, 464R, 464S, Electrical Engineering 464H, 464K, 464R, 464S. Prerequisite: Electrical and Computer Engineering 364D (or Electrical Engineering 364D) with a grade of at least C-, and one of the following with a grade of at least C-: Electrical and Computer Engineering 438 (or Electrical Engineering 438), 440 (or Electrical Engineering 440), 445L (or Electrical Engineering 445L), 445S (or Electrical Engineering 445S), 460J (or Electrical Engineering 460J), 461L (or Electrical Engineering 461L), 462L (or Electrical Engineering 462L), 468L, 471C (or Electrical Engineering 471C).

ECE 464K. Senior Design Project.

Implement the previously developed engineering system design, including design review, prototyping, project testing and any subsequent design modifications; addressing economic, environmental, ethical, safety, and social issues; documentation of each of the preceding and publicly presenting design results; and working effectively in teams. Three lecture hours and six laboratory hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 464H, 464K, 464R, 464S, Electrical Engineering 464H, 464K, 464R, 464S. Prerequisite: Electrical and Computer Engineering 364D (or Electrical Engineering 364D) with a grade of at least C-, and one of the following with a grade of at least C-: Electrical and Computer Engineering 438 (or Electrical Engineering 438), 440 (or Electrical Engineering 440), 445L (or Electrical Engineering 445L), 445S (or Electrical Engineering 445S), 460J (or Electrical Engineering 460J), 461L (or Electrical Engineering 461L), 462L (or Electrical Engineering 462L), 468L, 471C (or Electrical Engineering 471C).

ECE 464R. Research Senior Design Project.

Implement the previously developed engineering system design, including design review, prototyping, project testing and any subsequent design modifications; addressing economic, environmental, ethical, safety, and social issues; documentation of each of the preceding and publicly presenting design results; and working effectively in teams. Three lecture hours and six laboratory hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 464H, 464K, 464R, 464S, Electrical Engineering 464H, 464K, 464R, 464S. Prerequisite: Electrical and Computer Engineering 364D (or Electrical Engineering 364D) with a grade of at least C-, and one of the following with a grade of at least C-: Electrical and Computer Engineering 438 (or Electrical Engineering 438), 440 (or Electrical Engineering 440), 445L (or Electrical Engineering 445L), 445S (or Electrical Engineering 445S), 460J (or Electrical Engineering 460J), 461L (or Electrical Engineering 461L), 462L (or Electrical Engineering 462L), 468L, 471C (or Electrical Engineering 471C).

ECE 464S. Start-Up Senior Design Project.

Complete a practical engineering product design; validate the design through prototype construction and testing, modeling and simulation, and manufacturability analysis. Develop a completed company prospectus and seek venture funding for the project. Three lecture hours and six laboratory hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 464H, 464K, 464R, 464S, Electrical Engineering 464H, 464K, 464R, 464S. Prerequisite: Electrical and Computer Engineering 364D (or Electrical Engineering 364D) with a grade of at least C-, and one of the following with a grade of at least C-: Electrical and Computer Engineering 438 (or Electrical Engineering 438), 440 (or Electrical Engineering 440), 445L (or Electrical Engineering 445L), 445S (or Electrical Engineering 445S), 460J (or Electrical Engineering 460J), 461L (or Electrical Engineering 461L), 462L (or Electrical Engineering 462L), 468L, or 471C (or Electrical Engineering 471C).

ECE 366. Engineering Economics I.

Explore business organization; discounted cash flow calculations, including present-worth and rate-of-return calculations; replacement analyses; financial analyses; accounting and depreciation; income taxes; inflation; risk analysis, utility theory, decision models, sequential

decision making; and value of information. Three lecture hours a week for one semester. Electrical and Computer Engineering 366 and Electrical Engineering 366 may not both be counted. Prerequisite: The following with a grade of at least C-: Biomedical Engineering 335, Electrical and Computer Engineering 351K (or Electrical Engineering 351K), or 351H; and Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H.

ECE 366K. Engineering Economics II.

Explore the fundamentals of risk management, including portfolio theory, capital asset pricing theory, and optimal project mix; hedging financial risk; advanced economic analysis of alternative energy systems; and advanced mathematical modeling techniques for economic analysis. Three lecture hours a week for one semester. Electrical and Computer Engineering 366K and Electrical Engineering 366K may not both be counted. Prerequisite: Electrical and Computer Engineering 366 (or Electrical Engineering 366) with a grade of at least C-.

ECE 366L. Statistics for Manufacturing.

Explore statistical analysis applied to the development and control of manufacturing operations. Examine quality control, statistical process control, and design of experiments. Three lecture hours a week for one semester. Electrical and Computer Engineering 366L and Electrical Engineering 366L may not both be counted. Prerequisite: The following with a grade of at least C-: Biomedical Engineering 335, Electrical and Computer Engineering 351K (or Electrical Engineering 351K), or 351H; and Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H.

ECE 368L, 468L. Power Systems Apparatus and Laboratory.

Explore fundamentals of power systems emphasized through laboratory experiments; complex power, three-phase circuits, per-unit system, transformers, synchronous machines, transmission line models, steady-state analysis, induction machines, capacitor banks, protective relaying, surge arrestors, and instrumentation. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 368L and Electrical Engineering 368L may not both be counted. Prerequisite: Electrical and Computer Engineering 411 (or Electrical Engineering 411) with a grade of at least C-; and credit with a grade of at least C- or registration for Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T.

ECE 369. Power Systems Engineering.

Examine power systems engineering. Explore complex power, phasors, balanced three phase power systems, transformers and per-unit systems, transmission line parameters, steady state operation of transmission lines, the power flow problem, symmetrical faults, power system controls, economic operation of power systems, optimal power flow, and deregulation and restructuring of electricity markets. Three lecture hours a week for one semester. Electrical and Computer Engineering 369 and Electrical Engineering 369 may not both be counted. Prerequisite: Electrical and Computer Engineering 411 (or Electrical Engineering 411) or 411H with a grade of at least C-.

ECE 369L. Relay Protection of Power Systems.

Examine the theory, principles, and practices for protecting medium-voltage industrial power systems and high-voltage transmission grids, including symmetrical components; fault calculations and grounding; protection of motors, generators, cables, and transmission lines; and relay settings, fusing, and coordination of multiple protection devices. Two lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 369L and Electrical Engineering 369L may not both be counted. Prerequisite: Electrical and Computer Engineering 313 (or Electrical Engineering 313) or 313H with a grade of at least C-.

ECE 370. Automatic Control II.

Introduction to modern control theory, nonlinear and optimal control systems; controllability, observability, stability; state feedback, observers, eigenvalue assignment. Three lecture hours a week for one semester. Electrical and Computer Engineering 370 and Electrical Engineering 370 may not both be counted. Prerequisite: Credit with a grade of at least C- or registration for Electrical and Computer Engineering 362K (or credit with a grade of at least C- for Electrical Engineering 362K).

ECE 370K. Computer Control Systems.

Explore the analysis and design of linear discrete time control systems; z-transform theory; modified z-transforms; stability; multirate systems; digital simulation of discrete time systems; and synthesis of algorithms for computer controllers. Three lecture hours a week for one semester. Electrical and Computer Engineering 370K and Electrical Engineering 370K may not both be counted. Prerequisite: Credit with a grade of at least C- or registration for Electrical and Computer Engineering 362K (or Electrical Engineering 362K).

ECE 370L. Introduction to Manufacturing Systems Automation.

Explore applications of automation techniques to manufacturing systems, robotics, and computer vision. Three lecture hours a week for one semester. Electrical and Computer Engineering 370L and Electrical Engineering 370L may not both be counted. Prerequisite: Electrical and Computer Engineering 362K (or Electrical Engineering 362K) with a grade of at least C-.

ECE 370N. Introduction to Robotics and Mechatronics.

Examine structures for industrial robots; geometry and transformation; direct and inverse kinematics; differential kinematics; dynamics; trajectory planning; actuators and sensors; adaptive control and learning compliance; vision and pattern recognition; and expert systems. Three lecture hours a week for one semester. Electrical and Computer Engineering 370N and Electrical Engineering 370N may not both be counted. Prerequisite: Electrical and Computer Engineering 362K (or Electrical Engineering 362K) with a grade of at least C-.

ECE 471C. Wireless Communications Laboratory.

Examine the fundamentals of wireless communication from a digital signal processing perspective; linear modulation, demodulation, and orthogonal frequency division multiplexing; synchronization, channel estimation, and equalization; communication in fading channels; and wireless standards. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 371C and Electrical Engineering 371C may not both be counted. Prerequisite: Electrical and Computer Engineering 445S (or Electrical Engineering 445S), 351M (or Electrical Engineering 351M), or 360K (or Electrical Engineering 360K) with a grade of at least C-; and credit with a grade of at least C- or registration for Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Engineering Studies 333T, Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T.

ECE 371D. Introduction to Neural Networks.

Explore characteristics of artificial neural networks, feedforward networks, and recurrent networks; learning algorithms; self-organization; biological links; and data mining and other applications. Three lecture hours a week for one semester. Electrical and Computer Engineering 371D and Electrical Engineering 371D may not both be

counted. Prerequisite: The following with a grade of at least C- in each: Mathematics 340L; and Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H; and Biomedical Engineering 335, Electrical and Computer Engineering 351K (or Electrical Engineering 351K), 351H, or Mathematics 362K.

ECE 371M. Communication Systems.

Explore analog and digital modulation; noise in communication systems; signal-to-noise ratio; coding; optimal receiver design; phase-locked loops; and performance analysis. Three lecture hours a week for one semester. Electrical and Computer Engineering 371M and Electrical Engineering 371M may not both be counted. Prerequisite: The following with a grade of at least C- in each: Mathematics 340L; and Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H; and Biomedical Engineering 335, Electrical and Computer Engineering 351K, (or Electrical Engineering 351K), 351H, or Mathematics 362K.

ECE 371Q. Digital Image Processing.

Examine digital image acquisition, processing, and analysis; two dimensional Fourier analysis; 2D wavelets; image filtering; image denoising; image compression; machine learning for image processing and analysis; deep learning of images; picture quality prediction; image analysis; 3D stereoscopic ranging. Three lecture hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 371Q, Electrical Engineering 371Q, 371R. Prerequisite: The following with a grade of at least C- in each: Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H; and Biomedical Engineering 335, Electrical and Computer Engineering 351K (or Electrical Engineering 351K), 351H, or Mathematics 362K.

ECE 472L. Network Engineering Laboratory.

Explore local, metropolitan, and wide-area operations; telecommunication common carrier organizations and services; administrative and political considerations; premise distribution systems; name resolution, address assignment, and mail; datagra,s, packets, frames, and cells; addressing and network-level interconnection; internetwork architecture; TCP/IP protocol suite (v. 4 and 6); Ethernet and IEEE 802.3 standards; IEEE 802.11 standards and wireless access points; repeaters, hubs, bridges, routers; local area network emulation; public switched network access through POTS and ISDN; intradomain and interdomain routing; routing protocols, including RIP, OSPF, and BGP; multicast; media testing; and local- and wide-area diagnostic tools. Three lecture hours and three laboratory hours a week for one semester. Electrical and Computer Engineering 472L and Electrical Engineering 372L may not both be counted. Prerequisite: Electrical and Computer Engineering 372N (or Electrical Engineering 372N) with a grade of at least C-; and credit with a grade of at least C- or registration for Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or Electrical Engineering 333T), Engineering Studies 333T, Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T.

ECE 372N. Telecommunication Networks.

Examine circuit and packet-switched networks; local area networks; protocol stacks; asynchronous transfer mode (ATM) and broadband integrated services digital network (ISDN); Internet; routing, congestion control, and performance evaluation; and multimedia applications. Three lecture hours a week for one semester. Electrical and Computer Engineering 372N and Electrical Engineering 372N may not both be counted. Prerequisite: The following with a grade of at least C- in each: Mathematics 340L; and Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H; and Biomedical Engineering 335, Electrical and Computer Engineering 351K (or Electrical Engineering 351K), 351H, or Mathematics 362K.

ECE 372S. Cryptography and Network Security.

Explore distributed information system security, cryptographic tools, authentication, message security, and system management. The equivalent of three lecture hours a week for one semester. Electrical and Computer Engineering 372S and Electrical Engineering 372S may not both be counted. Prerequisite: Mathematics 325K or 340L with a grade of at least C-.

ECE 374K. Biomedical Electronic Instrument Design.

Explore the application of electrical engineering principles in the design of electronic instrumentation at the circuit-board level for the measurement of pressure, temperature, flow, and impedance. Examine the study of light intensity, bioelectric potentials, and stimulation devices such as pacemakers and defibrillators. Focus on design considerations specific to electro-medical environments, safety and efficacy, and public policy issues. Three lecture hours a week for one semester. Electrical and Computer Engineering 374K and Electrical Engineering 374K may not both be counted. Prerequisite: Electrical and Computer Engineering 438 (or Electrical Engineering 438) with a grade of at least C-.

ECE 374L. Applications of Biomedical Engineering.

Examine areas of biomedical engineering, such as optical and thermal properties of laser interaction with tissue; measurement of perfusion in the microvascular system; diagnostic imaging; interaction of living systems with electromagnetic fields; robotic surgical tools; ophthalmic instrumentation; and noninvasive cardiovascular measurements. Three lecture hours and six laboratory hours a week for one semester. Electrical and Computer Engineering 374L and Electrical Engineering 374L may not both be counted. Prerequisite: Electrical and Computer Engineering 374K (or Electrical Engineering 374K) with a grade of at least C-; and credit with a grade of at least C- or registration for Aerospace Engineering 333T, Biomedical Engineering 333T, Chemical Engineering 333T, Civil Engineering 333T, Electrical and Computer Engineering 333T (or credit with a grade of at least C- for Electrical Engineering 333T), Engineering Studies 333T, Mechanical Engineering 333T, or Petroleum and Geosystems Engineering 333T.

ECE 374N. Neural Engineering.

Examine a variety of clinical conditions and their associated neurological basis, and then analyze the engineering solutions to cope with the neurological deficits, with an emphasis on electrical and computer engineering components. Study approaches to design motor neuroprosthetics and sensory neuroprosthetics that restore lost functions. Learn principles of deep brain stimulation, neuromodulation, and brain plasticity. Explore the concepts behind technological approaches for neurorehabilitation, in particular robotics and brain-computer interfaces. Three lecture hours a week for one semester. Electrical and Computer Engineering 374N and Electrical Engineering 379K (Topic: Neural Engineering) may not both be counted. Prerequisite: Upper-division standing; Electrical and Computer Engineering 351M (or Electrical Engineering 351M) or 445S (or Electrical Engineering 351M); Electrical and Computer Engineering 461P (or Electrical Engineering 461P) or 460J (or Electrical Engineering 460J); and consent of the instructor.

ECE 679H. Undergraduate Honors Thesis.

Restricted to students in the Engineering Honors Program. Undertake research across two consecutive semesters under the supervision of an engineering faculty member. Investigate a research area, selected with a faculty member with approval by the director of the Honors Program. Deliver an oral presentation and write a thesis. Individual instruction for two semesters. Electrical and Computer Engineering 679H and Electrical

Engineering 679H may not both be counted. Prerequisite: For 679HB, Electrical and Computer Engineering 679HA (or Electrical Engineering 679HA) with a grade of at least C-.

ECE 179K, 279K, 379K, 479K. Topics in Electrical Engineering.

For each semester hour of credit earned, one lecture hour a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Upper-division standing, Electrical and Computer Engineering 312 (or Electrical Engineering 312), 312H (or Electrical Engineering 312H), 313 (or Electrical Engineering 313), or 313H with a grade of at least C-, and consent of instructor.

Topic 1: Conference Course. Electrical and Computer Engineering 179K (Topic 1) and Electrical Engineering 179K (Topic 1) may not both be counted.
Topic 15: Information Theory. Examine measures of information; noiseless coding and data compression; discrete memoryless channels and channel capacity; broadcast channels; and error-correcting codes. Electrical and Computer Engineering 179K (Topic 15) and Electrical Engineering 179K (Topic 15) may not both be counted. Additional prerequisite: The following with a grade of at least C- in each: Mathematics 340L; and Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H; and Biomedical Engineering 335, Electrical and Computer Engineering 351K (or Electrical Engineering 351K), 351H, or Mathematics 362K.
Topic 20: Computer Architecture: Personal Computer Design. Explore commercial general-purpose processors, memory architecture, buses, storage devices, graphics subsystems, I/O devices and peripherals, audio subsystems, operating systems, benchmarking, manufacturing, and testing of personal computer systems. Electrical and Computer Engineering 179K (Topic 20) and Electrical Engineering 179K (Topic 20) may not both be counted. Additional prerequisite: Electrical and Computer Engineering 460N (or Electrical Engineering 460N) with a grade of at least C-.
Topic 21: Information and Cryptography. Explore information theory; construction of codes; cryptography, including security and randomized encryption; Kolmogorov complexity; statistics, including large deviations, nonparametrics, and information inequalities; Vapnik-Cervonenkis methods for learning theory. Electrical and Computer Engineering 179K (Topic 21) and Electrical Engineering 179K (Topic 21) may not both be counted. Additional prerequisite: The following with a grade of at least C- in each: Mathematics 340L; and Biomedical Engineering 343, Electrical and Computer Engineering 313 (or Electrical Engineering 313), or 313H; and Biomedical Engineering 335, Electrical and Computer Engineering 351K (or Electrical Engineering 351K), 351H, or Mathematics 362K.
Topic 23: Software Evolution. Explore software design principles; program differencing techniques; program transformation languages and tools; and analysis, testing, debugging and visualization methods for evolving software. Only one of the following may be counted: Electrical and Computer Engineering 379K (Topic 23), Electrical Engineering 379K (Topic: Software Evolution), 379K (Topic 23). Additional prerequisite: Electrical and Computer Engineering 461L (or Electrical Engineering 461L) with a grade of at least C-, or an equivalent computer science course with a grade of at least C-.

Graduate Courses

ECE 380C. Introduction to Optimization.

Three lecture hours a week for one semester. Electrical and Computer Engineering 380C and Electrical Engineering 380C may not both be counted. Prerequisite: Graduate standing.

ECE 380K. Introduction to System Theory.

Introduction to linear dynamical systems and differential equations, state space analysis and applications to feedback control, functional analytic methods, realization theory, stability theory, and elements of optimal control. Three lecture hours a week for one semester. Electrical and Computer Engineering 380K and Electrical Engineering 380K may not both be counted. Prerequisite: Graduate standing and knowledge in real analysis.

ECE 380L. Topics in Computer Systems in Engineering.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

Topic 5: Engineering Programming Languages. Explore higher-level languages for engineering design and problem solving; object-oriented programming in C++ and Unix systems programming. Electrical and Computer Engineering 380L (Topic 5) and Electrical Engineering 380L (Topic 5) may not both be counted.
Topic 7: Introduction to Pattern Recognition and Computer Vision. Explore pattern recognition, including Bayesian decision theory, maximum likelihood and estimation, nonparametric techniques, and linear discriminant functions. Examine computer vision, including geometric camera models and calibration, geometry of multiple views and stereopsis, structure from motion, and tracking. Electrical and Computer Engineering 380L (Topic 7) and Electrical Engineering 380L (Topic 7) may not both be counted.
Topic 8: Computer Vision Systems. Discuss current research results and explore new directions in computer vision systems, including linear discriminant functions, nonmetric methods, unsupervised learning and clustering, model-based vision, segmentation using probabilistic methods, and content-based image and video analysis. Apply the techniques to real-world vision systems. Electrical and Computer Engineering 380L (Topic 8) and Electrical Engineering 380L (Topic 8) may not both be counted.
Topic 9: Artificial Neural Systems. Examine feed-forward networks, distributed associative memory, recurrent networks, self-organization, parallel implementation, and applications. Electrical and Computer Engineering 380L (Topic 9) and Electrical Engineering 380L (Topic 9) may not both be counted.
Topic 11: Mining the Web. Analyze data and information available from the World Wide Web. Explore the exploitation of the hyperlink structure of the Web for developing better search engines. Examine content analysis; information retrieval, clustering, and hierarchical categorization of Web documents; web usage mining; and collaborative filtering and personalizing the Web. Electrical and Computer Engineering 380L (Topic 11) and Electrical Engineering 380L (Topic 11) may not both be counted. Additional prerequisite: Electrical and Computer Engineering 380L (Topic 10) (or Electrical Engineering 380L (Topic 10)) or Computer Science 391L.
Topic 12: Real-Time Operating Systems Laboratory. Explore real-time operating systems; implementation of context switching, threads, multitasking, real-time scheduling, synchronization, communication, storage, file systems, memory management, process linking and loading, hardware interfacing, and networking; debugging and testing; operating system performance, including latency, jitter, deadlines, deadlocks, and starvation; real-time systems, including data acquisition, sensing, actuating, digital control, signal processing, and robotics. Only one of the following may be counted: Electrical and Computer Engineering 380L (Topic 12), Electrical Engineering 380L (Topic 6), 380L (Topic 12). Additional prerequisite: General understanding of assembly and C programming, computer architecture, embedded systems, and hardware/software interfacing.

ECE 380N. Topics in System Theory.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing and Electrical and Computer Engineering 380K (or Electrical Engineering 380K).

Topic 1: Nonlinear Systems: Input-Output Properties. Electrical and Computer Engineering 380N (Topic 1) and Electrical Engineering 380N (Topic 1) may not both be counted.
Topic 2: Nonlinear Systems: Geometric Theory. Electrical and Computer Engineering 380N (Topic 2) and Electrical Engineering 380N (Topic 2) may not both be counted.
Topic 3: Adaptive Control Systems. Electrical and Computer Engineering 380N (Topic 3) and Electrical Engineering 380N (Topic 3) may not both be counted.
Topic 4: Learning Systems and Cybernetic Machines. Electrical and Computer Engineering 380N (Topic 4) and Electrical Engineering 380N (Topic 4) may not both be counted.
Topic 5: Stochastic Control Theory. Examine dynamic programming in finite and infinite horizon, models with imperfect state information, ergodic control problems, and adaptive and risk-sensitive control. Electrical and Computer Engineering 380N (Topic 5) and Electrical Engineering 380N (Topic 5) may not both be counted. Additional prerequisite: Electrical and Computer Engineering 381J (or Electrical Engineering 381J).
Topic 7: Design of Computer-Controlled Systems. Electrical and Computer Engineering 380N (Topic 7) and Electrical Engineering 380N (Topic 7) may not both be counted.
Topic 8: Algorithms for Parallel and Distributed Computation. Electrical and Computer Engineering 380N (Topic 8) and Electrical Engineering 380N (Topic 8) may not both be counted.
Topic 9: Fundamentals of Robotics and Mechatronics. Explore the theory of robotics and mechatronics, with emphasis on control, sensing, actuation, low- and high-level vision. Examine manipulator geometry, kinematics, dynamics, and planning of trajectories. Electrical Engineering 380N (Topic 9) and Electrical Engineering 380N (Topic 9) may not both be counted.
Topic 10: Robotics II. Electrical and Computer Engineering 380N (Topic 10) and Electrical Engineering 380N (Topic 10) may not both be counted.
Topic 11: Optimization in Engineering Systems. Same as Operations Research and Industrial Engineering 391Q (Topic 16). Formulation and solution of continuous optimization problems in engineering design and operations. Only one of the following may be counted: Electrical and Computer Engineering 380N (Topic 11), Electrical Engineering 380N (Topic 11), Operations Research and Industrial Engineering 391Q (Topic 16).

ECE 381C. Verification and Validation.

Three lecture hours a week for one semester. Electrical and Computer Engineering 381C and Electrical Engineering 381C may not both be counted. Prerequisite: Graduate standing.

ECE 381J. Probability and Stochastic Processes I.

Examine probability spaces, random variables, expectation, conditional expectation, stochastic convergence, characteristic functions, and limit theorems. Explore Markov and Gaussian processes, stationary processes, spectral representation, ergodicity, renewal processes, martingales, and applications to estimation, prediction, and queueing theory. Three lecture hours a week for one semester. Electrical and Computer Engineering 381J and Electrical Engineering 381J may not both be counted. Prerequisite: Graduate standing, and an undergraduate course in probability, statistics, and random processes.

ECE 381K. Topics in Decision, Information, and Communications Engineering.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing; additional prerequisites vary with topic.

Topic 1: Detection Theory. Electrical and Computer Engineering 381K (Topic 1) and Electrical Engineering 381K (Topic 1) may not both be counted.
Topic 2: Digital Communications. Explore characterization of baseband and passband communication signals and channels, digital modulation, and pulse shaping; optimum receivers in additive white Gaussian noise including matched-filtering, ML, and MAP detection and their bit error probability for M-ary modulation; inter-symbol interference channels, FIR and IIR equalization, multicarrier modulation, OFDM and frequency domain equalization. Introduction to information theory, channel capacity, error control codes, and ML sequence detection (Viterbi decoding). Examine applications to stationary wireless and wireline channels. Electrical and Computer Engineering 381K (Topic 2) and Electrical Engineering 381K (Topic 2) may not both be counted. Additional prerequisite: Knowledge in probability and random processes, digital signal processing, and digital communications.
Topic 3: Applied Machine Learning. Examine approaches to extracting valid and useful insights from data using statistically oriented approaches, with emphasis on predictive models learned from large-scale data sets. Code machine learning algorithms in Python and use various data visualization techniques. Only one of the following may counted: Electrical and Computer Engineering 380L (Topic 10), 381K (Topic 3), Electrical Engineering 380L (Topic 10).
Topic 5: Advanced Telecommunication Networks. Explore methods and research issues in the performance evaluation and management of high-speed and mobile communication networks. Electrical and Computer Engineering 381K (Topic 5) and Electrical Engineering 381K (Topic 5) may not both be counted. Additional prerequisite: Electrical and Computer Engineering 380N (Topic 11) (or Electrical Engineering 380N (Topic 11)), 381J (or Electrical Engineering 381J), and 381K (Topic 13) (or Electrical Engineering 381K (Topic 13)).
Topic 6: Estimation Theory. Electrical and Computer Engineering 381K (Topic 6) and Electrical Engineering 381K (Topic 6) may not both be counted.
Topic 7: Information Theory. Explore source and channel coding theorems, Kolmogorov complexity, network information theory, and connections with large deviations. Electrical and Computer Engineering 381K (Topic 7) and Electrical Engineering 381K (Topic 7) may not both be counted. Additional prerequisite: Knowledge in communications systems.
Topic 8: Digital Signal Processing. Examine signals and systems; generalized functions; z-transforms; Fourier series and transforms; fast Fourier transform; sampling, quantization, and aliasing; digital filter design; discrete-time random processes; multirate processing; filter banks and subband decomposition; nonlinear digital filters. Electrical and Computer Engineering 381K (Topic 8) and Electrical Engineering 381K (Topic 8) may not both be counted. Additional prerequisite: Knowledge in probability and random processes, and digital signal processing.
Topic 9: Advanced Signal Processing. Explore signal modeling; optimum filtering; spectral estimation; fast algorithms; and applications in array signal processing, speech coding, and digital communication. Electrical and Computer Engineering 381K (Topic 9) and Electrical Engineering 381K (Topic 9) may not both be counted. Additional prerequisite: Knowledge in probability and random processes, digital signal processing, and matrices and matrix calculations.

Topic 11: Wireless Communications. Introduction to fundamental aspects of wireless communication systems including channel modeling, diversity, multiple antenna transmission and reception, beamforming, adaptive modulation. Explore multiuser communication concepts including OFDMA and SC-FDMA, spread spectrum and CDMA, and broadcast and MAC channels. Examine system-level modeling including network information theory, stochastic geometry, and network interference models. Electrical and Computer Engineering 381K (Topic 11) and Electrical Engineering 381K (Topic 11) may not both be counted. Additional prerequisite: Electrical and Computer Engineering 381K (Topic 2) (or Electrical Engineering 381K (Topic 2)), Electrical and Computer Engineering 471C (or Electrical Engineering 471C) or Electrical and Computer Engineering 381K (Topic 17) (or Electrical Engineering 381K (Topic 17)) or consent of instructor.

Topic 13: Analysis and Design of Communication Networks. Examine stochastic and deterministic traffic and queueing models. Explore techniques for call admission, routing, flow control, network optimization, estimation, and decision making in uncertain environments. Electrical and Computer Engineering 381K (Topic 13) and Electrical Engineering 381K (Topic 13) may not both be counted. Additional prerequisite: Electrical and Computer Engineering 381J (or Electrical Engineering 381J) and 381K (Topic 15) (or Electrical Engineering 381K (Topic 15) or 382N (Topic 5)).

Topic 14: Multidimensional Digital Signal Processing. Explore multidimensional signals and systems, multidimensional discrete Fourier analysis, discrete cosine transform, two-dimensional filters, beamforming, seismic processing, tomography, multidimensional multirate systems, image halftoning, and video processing. Electrical and Computer Engineering 381K (Topic 14) and Electrical Engineering 381K (Topic 14) may not both be counted. Additional prerequisite: Electrical and Computer Engineering 380K (or Electrical Engineering 380K), 381K (Topic 8) (or Electrical Engineering 381K (Topic 8)), or 383P (Topic 1) (or Electrical Engineering 383P (Topic 1)).

Topic 15: Communication Networks: Technology, Architectures, and Protocols. Explore network services and techniques, layered architectures, circuit and packet-switching networks, internetworking, switch architectures, control mechanisms, and economic issues. Only one of the following may be counted: Electrical and Computer Engineering 381K (Topic 15), Electrical Engineering 381K (Topic 15), 382N (Topic 5). Additional prerequisite: Consent of instructor.

Topic 16: Digital Video. Same as Biomedical Engineering 381J (Topic 14). Examine video sampling and transform; video (retinal and cortical) filters; motion detection and estimation; statistical models of videos; neuroscience of video perception; natural video statistics; modern video compression standards; video quality prediction; video denoising; active contour models; and video saliency. Only one of the following may be counted: Biomedical Engineering 381J (Topic: Digital Video), 381J (Topic 14), Electrical and Computer Engineering 381K (Topic 16), Electrical Engineering 381K (Topic 16), 381V (Topic: Digital Video).

Topic 17: Wireless Communications Laboratory. Explore the fundamentals of wireless communication from a digital signal processing perspective; linear modulation, demodulation, and orthogonal frequency division multiplexing; synchronization, channel estimation, and equalization; communication in fading channels; principles of multiple-input, multiple-output (MIMO) communication; and wireless standards. Only one of the following may be counted: Electrical and Computer Engineering 381K (Topic 17), Electrical Engineering 381K (Topic 17), 381V (Topic: Wireless Communications Lab). Additional prerequisite: Consent of instructor.

Topic 18: Convex Optimization. Same as Operations Research and Industrial Engineering 391Q (Topic 15). The fundamentals of convex optimization with a focus on modeling, computation and scale: convex sets and functions, unconstrained optimization via first and second-order methods, duality, constrained optimization, SDPs, stochastic and sub-gradient descent methods, ADMMs, and applications. Only one of the following may be counted: Electrical and Computer Engineering 381K (Topic 18), Electrical Engineering 381K (Topic 18), 381V (Topic: Large Scale Optimization), Operations Research and Industrial Engineering 391Q (Topic 15). Additional prerequisite: Consent of instructor.

Topic 19: Wireless Network Modeling and Performance Evaluation. Explore modeling of large wireless networks, random graphs, stochastic geometry, point processes, space and time averages, connectivity, stability, capacity, and network design optimization, with applications for cellular network, mobile ad hoc networks, device to device networks, and vehicular networks. Electrical and Computer Engineering 381K (Topic 19) and Electrical Engineering 381K (Topic 19) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 20: Machine Learning on Real World Networks. Explore networks in natural and socio-technological systems. Examine network structure and dynamics, machine learning on real networks, clustering; network models, small worlds, scale free networks, preferential attachment, community structure, network-on-chip optimization and control, epidemics and rumors, human mobility, network embedding, deep learning on graphs, graph neural networks, and other networks. Electrical and Computer Engineering 381K (Topic 20) and Electrical Engineering 381K (Topic 20) may not both be counted.

ECE 381L. Digital Time Series Analysis and Applications.

Examine digital implementation of higher-order spectra and other techniques useful in analyzing, interpreting, and modeling random time series data from linear and nonlinear physical systems. Three lecture hours a week for one semester. Electrical and Computer Engineering 381L and Electrical Engineering 381L may not both be counted. Prerequisite: Graduate standing in engineering or natural sciences.

ECE 381M. Probability and Stochastic Processes II.

Examine random walk and Brownian motion; renewal and regenerative processes; Markov processes; ergodic theory; continuous parameter martingales; stochastic differential equations; diffusions; stochastic control; and multidimensional stochastic models. Three lecture hours a week for one semester. Electrical and Computer Engineering 381M and Electrical Engineering 381M may not both be counted. Prerequisite: Graduate standing and Electrical and Computer Engineering 381J (or Electrical Engineering 381J).

ECE 381S. Space-Time Communication.

Explore multiple-input multiple-output (MIMO) wireless communication, including discrete-time signal models, equalization, and channel estimation; channel models; channel capacity; average probability of error in fading channels; channel coding; transmit and receive diversity; space-time codes; spatial multiplexing; precoding and limited feedback; space-time adaptation; multiuser communication; multiuser information theory; practical multiuser algorithms; and applications in recent standards. Three lecture hours a week for one semester. Electrical and Computer Engineering 381S and Electrical Engineering 381S may not both be counted. Prerequisite: Graduate standing and Electrical and Computer Engineering 381J (or Electrical Engineering 381J) and 381K (Topic 2) (or Electrical Engineering 381K (Topic 2)).

ECE 381V. Topics in Communications, Networks, and Systems.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

ECE 382C. Topics in Software Engineering and Systems.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

Topic 1: Engineering Design of Software and Software Systems. Explore the software development process; selection and application of software design methods; and evaluation of software designs. Electrical and Computer Engineering 382C (Topic 1) and Electrical Engineering 382C (Topic 1) may not both be counted.

Topic 2: Creation and Maintenance of Distributed Software Systems. Examine the creation of large distributed software applications, with emphasis on specification, failure models, correctness, and security. Electrical and Computer Engineering 382C (Topic 2) and Electrical Engineering 382C (Topic 2) may not both be counted.

Topic 3: Verification and Validation of Software. Evaluate software for correctness, efficiency, performance, and reliability. Electrical and Computer Engineering 382C (Topic 3) and Electrical Engineering 382C (Topic 3) may not both be counted.

Topic 4: Software and Hardware Engineering Project Management. Examine the requirements for a project management plan; role of the manager of the software development life cycle; economic and customer-driven factors. Electrical and Computer Engineering 382C (Topic 4) and Electrical Engineering 382C (Topic 4) may not both be counted.

Topic 5: Large Software, Hardware, and Communications Systems Engineering. Explore the techniques used to specify and design systems of software, hardware, and communications components. Create a requirements document and system specification. Electrical and Computer Engineering 382C (Topic 5) and Electrical Engineering 382C (Topic 5) may not both be counted.

Topic 6: Software for Highly-Available Distributed Applications. Electrical and Computer Engineering 382C (Topic 6) and Electrical Engineering 382C (Topic 6) may not both be counted.

Topic 7: Software Architectures. Explore the definitions, motivations, and utility of software system architectures from a technical and business perspective; derivation, specification, and analysis of architectural views in support of different phases in the system engineering lifecycle; methods to judge architectural quality; and communication of architectural views to a wide range of system stakeholders. Electrical and Computer Engineering 382C (Topic 7) and Electrical Engineering 382C (Topic 7) may not both be counted.

Topic 8: Theory Blockchains and Smart Contracts. Explore blockchains and smart contracts, including but not limited to distributed consensus; layer 1 protocol architecture; associated cryptosystems; decentralized peer to peer networks; properties of blockchains; design of blockchain protocols and associated cryptosystems; security and privacy; scalability; liveness of such networks; proof of work; stake and other consensus mechanisms; and incentive design for participation in decentralized systems. Examine decentralized finance and decentralized applications. Only one of the following may be counted: Electrical and Computer Engineering 382C (Topic 8), Electrical and Computer Engineering 382V (Topic: Blockchains & Smart Contracts), Electrical Engineering 382V (Topic: Intro BlckChn/Smart Cntrcts).

Topic 9: Embedded Software Systems. Examine dataflow models, uniprocessor and multiprocessor scheduling, hardware/software codesign, hierarchical finite state machines, synchronous languages, reactive systems, synchronous reactive languages, and heterogeneous systems. Electrical and Computer Engineering 382C (Topic 9) and Electrical Engineering 382C (Topic 9) may not both be counted.

Topic 11: Requirements Engineering. Electrical and Computer Engineering 382C (Topic 11) and Electrical Engineering 382C (Topic 11) may not both be counted.

Topic 12: Multicore Computing. Examine theoretical and practical aspects of designing multicore software systems; programming constructs for concurrent computation, openMP, sequential consistency, linearizability, lock-based synchronization, lock-free synchronization, wait-free synchronization, consensus number, software transactional memory, testing and debugging parallel programs, race detection, concurrent data structures such as stacks, queues, linked lists, hash tables and skiplists, formal models, temporal logic, reachability analysis, and parallel graph algorithms. Only one of the following may be counted: Electrical and Computer Engineering 382C (Topic 12), Electrical Engineering 382C (Topic 12), 382V (Topic: Multicore Computing).

Topic 13: Mobile Computing. Explore an overview of emerging research areas in mobile computing with a specific focus on the software engineering ramifications of mobile and pervasive computing technologies. Develop a solid foundation to support future discourse and research in the areas of mobile and pervasive computing, and skills to critically read research papers, assimilate information, find additional resources, and draw connections. Only one of the following may be counted: Electrical and Computer Engineering 382C (Topic 13), Electrical Engineering 382C (Topic 13), 382V (Topic: Mobile Computing).

Topic 14: Software Evolution Principles. Review program analysis techniques for evolving software; incremental testing, debugging, and verification; static and dynamic dependency analysis; program transformations; and software visualization. Only one of the following may be counted: Electrical and Computer Engineering 382C (Topic 14), Electrical Engineering 382V (Topic: Software Evolution), 382V (Topic 1), 382C (Topic 14). Additional prerequisite: Knowledge in algorithms, concurrent and distributed systems, software testing, or consent of instructor.

Topic 15: Middleware Architecture and Design. Introduction to the design of distributed computing middleware, with a focus on architectural principles. Explore an overview of required functions of emerging middleware and how middleware is designed to support these functions. Examine particular domains such as middleware for mobile computing, middleware for embedded systems, and middleware for sensor networks. Electrical and Computer Engineering 382C (Topic 15) and Electrical Engineering 382C (Topic 15) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 16: Software Testing. Examine basic concepts and techniques for testing software and finding bugs. Explore the testing process; unit, integration and system testing; manual and automatic techniques for generation of test inputs and validation of test outputs; and coverage criteria. Focus on functional testing. Only one of the following may be counted: Electrical and Computer Engineering 382C (Topic 16), Electrical Engineering 382C (Topic 16), 382V (Topic: Software Testing). Additional prerequisite: Consent of instructor.

Topic 17: Algorithmic Foundations for Software Systems. Examine complex data structures and algorithms, graph algorithms, performance analysis, correctness analysis, engineering effective techniques, and domain-specific methods, such as systematic or heuristic search. Only one of the following may be counted: Electrical and Computer Engineering 382C (Topic 17), Electrical and Computer Engineering 382C (Topic 17), 382V (Topic: Algor Fndtn Software Sys). Additional prerequisite: Consent of instructor.

Topic 18: Computer Graphics. Examine computer graphics, including in-depth treatments of techniques for realistic image synthesis, advanced geometric modeling methods, animation and dynamic simulation, scientific visualization, and high-performance graphics architectures. Only one of the following may be counted: Electrical and Computer Engineering 382C (Topic 18), Electrical Engineering 382C (Topic 18), 382V (Topic: Computer Graphics). Additional prerequisite: Consent of instructor.

ECE 382L. Topics in Theory of Digital Systems.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

Topic 1: Switching Theory. Explore general theory and realization algorithms for combinational, sequential, and array logic. Electrical and Computer Engineering 382L (Topic 1) and Electrical Engineering 382L (Topic 1) may not both be counted.
Topic 2: Graph Theory and Applications. Examine elementary graph theory concepts; graph theory algorithms and applications in multicomputer architecture, switching and coding theory, data structures, computer networks, programming, algorithm analysis, diagnosis and fault tolerance. Electrical and Computer Engineering 382L (Topic 2) and Electrical Engineering 382L (Topic 2) may not both be counted.

ECE 382M. Topics in Integrated Circuits and Systems.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

Topic 1: VLSI Testing. Examine hardware and software reliability analysis of digital systems; testing, design for testability, self-diagnosis, fault-tolerant logic design, error-detecting and error-correcting codes. Electrical and Computer Engineering 382M (Topic 1) and Electrical Engineering 382M (Topic 1) may not both be counted.
Topic 2: Dependable Computing. Examine design techniques for reliable, fault-tolerant, fail-safe and fail-soft systems; fault diagnosis and fault avoidance methods at program and system levels; experimental and commercial fault-tolerant computer systems. Electrical and Computer Engineering 382M (Topic 2) and Electrical Engineering 382M (Topic 2) may not both be counted.
Topic 7: VLSI I. Examine very-large scale integration (VLSI) circuit design. Explore complementary metal oxide semiconductor (CMOS) technology; static and dynamic CMOS combinational and sequential circuits; design of datapath elements; performance, power consumption, and testing. Use computer-aided design (CAD) tools for layout, timing analysis, synthesis, physical design, and verification. Electrical and Computer Engineering 382M (Topic 7) and Electrical Engineering 382M (Topic 7) may not both be counted.
Topic 8: VLSI II. Examine microelectronic systems architecture; VLSI circuit testing methods; integration of heterogeneous computer-aided design tools; wafer scale integration; advanced high-speed circuit design and integration. Electrical and Computer Engineering 382M (Topic 8) and Electrical Engineering 382M (Topic 8) may not both be counted.
Topic 9: Simulation Methods in CAD and VLSI. Examine techniques and algorithms for simulating large-scale digital and analog circuits. Electrical and Computer Engineering 382M (Topic 9) and Electrical Engineering 382M (Topic 9) may not both be counted.
Topic 10: Synthesis of Digital Systems. Explore automatic generation of gate-level implementations from hardware description language (HDL) specifications; optimization of two-level, multilevel, and sequential circuits for area, speed, and testability. Electrical and Computer Engineering 382M (Topic 10) and Electrical Engineering 382M (Topic 10) may not both be counted.
Topic 11: Verification of Digital Systems. Examine automatic verification of digital systems; formal models and specifications, equivalence checking, design verification, temporal logic, binary decision diagrams (BDDs), logical foundations, automata theory, recent developments. Electrical and Computer Engineering 382M (Topic 11) and Electrical Engineering 382M (Topic 11) may not both be counted.
Topic 12: Semiconductor Memory Design. Examine semiconductor memory design in depth. Explore volatile memory circuit designs with static random access memory (SRAM), dynamic RAMs (DRAM), multi-ported RAMs, and content addressable memories (CAMs). Explore non-volatile semiconductor memory designs such as read-only-memories, resistive RAM, magnetic RAM, FLASH, and 3D memories. Discuss in-memory and near-memory computing circuit techniques for machine learning and artificial intelligence applications. Electrical and Computer Engineering 382M (Topic 12) and Electrical Engineering 382V (Topic: Semiconductor Memories) may not both be counted.
Topic 13: Analysis and Design of Digital Integrated Circuits. Examine device and circuit-level aspects of metal oxide semiconductors (MOS) digital integrated circuit design. Electrical and Computer Engineering 382M (Topic 13) and Electrical Engineering 382M (Topic 13) may not both be counted.
Topic 14: Analog Integrated Circuit Design. Explore the analysis and design of analog integrated circuits; transistor models and integrated circuit technologies; layout techniques; noise; mismatches; current mirrors; differential amplifiers; frequency response and compensation; feedback and stability; nonlinear circuits; voltage references; and operational amplifiers using state-of-the-art computer-aided design (CAD) tools for design, simulation, and layout. Electrical and Computer Engineering 382M (Topic 14) and Electrical Engineering 382M (Topic 14) may not both be counted.
Topic 16: Application-Specific Processing. Examine techniques for the design and analysis of application-specific processors, including special purpose systems, embedded processors, and systems-on-chip. Electrical and Computer Engineering 382M (Topic 16) and Electrical Engineering 382M (Topic 16) may not both be counted.
Topic 17: High-Level Synthesis of Digital Systems. Examine the synthesis from high-level languages (C) to RTL; allocation, scheduling and binding algorithms, and optimizations under area and performance objectives and constraints. Electrical and Computer Engineering 382M (Topic 17) and Electrical Engineering 382M (Topic 17) may not both be counted.
Topic 19: Mixed-Signal System Design and Modeling. Explore architecture development for mixed-signal integrated circuits. Model analog and digital filters, data converters, and digital data receivers. Electrical and Computer Engineering 382M (Topic 19) and Electrical Engineering 382M (Topic 19) may not both be counted.
Topic 20: System-on-Chip Design. Examine the methodologies and tools for System-on-Chip (SoC) design, hardware/software co-design and co-verification; partitioning; real-time scheduling; hardware acceleration; high-level C-to-RTL synthesis; allocation, scheduling and binding algorithms for hardware synthesis; SoC integration, communication architectures and hardware/software interfacing; virtual prototyping and hardware/software co-simulation; FPGA prototyping of hardware/software systems. Electrical and Computer Engineering 382M (Topic 20) and Electrical Engineering 382M (Topic 20) may not both be counted.
Topic 22: VLSI Physical Design Automation. Examine algorithms and methodologies in circuit partitioning, floorplanning, global placement, detailed placement, global routing, detailed routing, clock tree routing, and power and ground routing. Explore new trends in physical design. Only one of the following may be counted: Electrical and Computer Engineering 382M (Topic 22), Electrical Engineering 382M (Topic 22), 382V (Topic: VLSI Physical Design Automatn). Additional prerequisite: Consent of instructor.
Topic 23: Low-Power and Robustness Design. Examine nanometer transistors and models; design-time and runtime techniques for dynamic and standby power minimization; power minimization at circuit and architecture levels; power minimization for logic, memory, and interconnect; sources of variability; statistical data collection and analysis of variance; statistical circuit simulation and timing analysis; manufacturability and resolution enhancement techniques. Electrical and Computer Engineering 382M (Topic 23) and Electrical Engineering 382M (Topic 23) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 24: Analog-Digital Data Conversion Circuits. Explore the analysis and design of analog-digital data conversion circuits including both architectural-level and transistor-level design considerations; design trade-offs among power, noise, linearity, and speed; sample-and-hold circuits and voltage comparators; noise analysis for mixed-signal circuits; flash, pipelined, successive approximation, and delta-sigma oversampling analog-to-digital-converters (ADCs); resistor-string, R-2R, current-steering, and delta-sigma oversampling digital-to-analog-converters (DACs); and the use of state-of-the-art computer-aided design (CAD) tools for analysis, design, and validation. Only one of the following may be counted: Electrical and Computer Engineering 382M (Topic 24), Electrical Engineering 382M (Topic 24), 382V (Topic: Data Converters). Additional prerequisite: Consent of instructor.

Topic 25: Radio Frequency Integrated Circuit Design. Examine noise and distortion in devices and circuits; amplifier design techniques for low noise, variable gain, high output power, and high dynamic range; analysis and design of integrated mixers and other frequency converters; voltage and current mode mixers; rectifiers; integrated oscillators for generating fixed and variable frequencies; relevant performance metrics and trade-offs; noise in linear and non-linear time varying circuits; circuit techniques for linearity enhancement; design optimization in bipolar and complementary metal-oxide-semiconductor (CMOS) technologies. Explore transceiver architectures. Only one of the following may be counted: Electrical and Computer Engineering 382M (Topic 25), Electrical Engineering 382M (Topic 25), 382V (Topic: Radio Freq Integ Circuit Dsgn). Additional prerequisite: Consent of instructor.

Topic 26: VLSI CAD and Optimization. Explore interconnect and gate modeling; timing analysis; interconnect topology optimization; gate sizing; buffer insertion and sizing; wire sizing and planning; crosstalk analysis and mitigation; clock network synthesis; interconnect planning; modern placement techniques; congestion mitigation; low power optimization; design for manufacturability and reliability; design and computer-aided design (CAD) for emerging technologies. Only one of the following may be counted: Electrical and Computer Engineering 382M (Topic 26), Electrical Engineering 382M (Topic 21), 382M (Topic 26). Additional prerequisite: Consent of instructor.

ECE 382N. Topics in Architecture, Computer Systems, and Embedded Systems.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

Topic 1: Computer Architecture. Examine characteristics of instruction set architecture and microarchitecture; physical and virtual memory; caches and cache design; interrupts and exceptions; integer and floating-point arithmetic; I/O processing; buses; pipelining, out-of-order execution, branch prediction, and other performance enhancements; design trade-offs; and case studies of commercial microprocessors. Participate in an individual laboratory. Electrical and Computer Engineering 382N (Topic 1) and Electrical Engineering 382N (Topic 1) may not both be counted.

Topic 3: Interconnection Networks. Explore topologies, routing algorithms, permutations, resource allocations, performance evaluation, fault tolerance, VLSI design, parallel and distributed algorithms, languages for specifying protocols, and distributed operating systems. Electrical and Computer Engineering 382N (Topic 3) and Electrical Engineering 382N (Topic 3) may not both be counted.

Topic 4: Advanced Embedded Microcontroller Systems. Examine hardware and software design of advanced microcontroller systems; embedded applications, Linux drivers, handlers, and kernel modules, file systems, debugging; hardware acceleration, intelligent sensors and I/O subsystems, embedded field-programmable gate array (FPGAs), and networking-on-chip. Electrical and Computer Engineering 382N (Topic 4) and Electrical Engineering 382N (Topic 4) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 10: Parallel Computer Architecture. Study parallel computing, including models, algorithms, languages, compilers, interconnection networks, and architectures. Electrical and Computer Engineering 382N (Topic 10) and Electrical Engineering 382N (Topic 10) may not both be counted.

Topic 11: Distributed Systems. Examine tracking dependency, mutex algorithms, snapshot algorithms, leader election, spanning tree, distributed algorithms, Map-Reduce, slicer, termination detection, message order, synchronizers, self-stabilization, knowledge, consensus, Byzantine agreement, fault-tolerance. Electrical and Computer Engineering 382N (Topic 11) and Electrical Engineering 382N (Topic 11) may not both be counted.

Topic 14: High-Speed Computer Arithmetic I. Explore the design of computer arithmetic units: fast adders, fast multipliers, dividers, and floating-point arithmetic units. Electrical and Computer Engineering 382N (Topic 14) and Electrical Engineering 382N (Topic 14) may not both be counted.

Topic 15: High-Speed Computer Arithmetic II. Explore advanced computer arithmetic, including error correcting coding, residue number systems, CORDIC arithmetic, and VLSI implementation. Electrical and Computer Engineering 382N (Topic 15) and Electrical Engineering 382N (Topic 15) may not both be counted. Additional prerequisite: Electrical and Computer Engineering 382N (Topic 14) (or Electrical Engineering 382N (Topic 14)).

Topic 16: Distributed Information System Security. Electrical and Computer Engineering 382N (Topic 16) and Electrical Engineering 382N (Topic 16) may not both be counted.

Topic 17: Superscalar Microprocessor Architectures. Examine superscalar processor architectures; instruction level parallelism; machine level parallelism; superscalar organization; instruction windows; reservation station; register data flow; register renaming; reorder buffers; memory disambiguation; branch prediction; value prediction; instruction reuse techniques; comparison with very long instruction word (VLIW), single instruction-multiple data (SIMD), and multiple instruction-multiple data (MIMD) approaches; memory systems for superscalar processors; design for performance and power efficiency; performance evaluation of superscalar processors; and case studies. Electrical and Computer Engineering 382N (Topic 17) and Electrical Engineering 382N (Topic 17) may not both be counted.

Topic 18: Distributed Systems II. Electrical and Computer Engineering 382N (Topic 18) and Electrical Engineering 382N (Topic 18) may not both be counted.

Topic 19: Microarchitecture. Explore concepts in architecture and microarchitecture. Examine critical path, bread-and-butter design, partitioning, timing, and pipelining; data path, state machine, microsequencer, microinstruction, microcode, microprogramming, and CAD tools; pipelining, branch prediction, and out-of-order execution; trace cache, block-structured ISA, simultaneous multithreading, and clustering; single instruction-multiple data (SIMD), very long instruction word (VLIW), decoupled access/execute (DAE), high performance switch (HPS), and data flow. survey the impact of compiler technology, reduced instruction set computing (RISC), and predicated execution; multiprocessor issues, cache coherency, memory consistency, and graphics processing units (GPUs); IEEE Floating Point, and example state-of-the-art microarchitectures. Electrical Engineering 382N (Topic 19) and Electrical Engineering 382N (Topic 19) may not both be counted.

Topic 20: Computer Architecture: Parallelism and Locality. Examine hardware and software parallelism and locality mechanisms, and their impact on processor performance, bandwidth, and power requirements; architectures and microarchitectures of throughput-

oriented processors that rely on parallelism, locality, and hierarchical control; parallel memory systems; and streaming and bulk execution and programming models. Explore programming and measuring performance on massively parallel processors. Electrical and Computer Engineering 382N (Topic 20) and Electrical Engineering 382N (Topic 20) may not both be counted.

Topic 21: Computer Performance Evaluation and Benchmarking. Examine performance analysis of microprocessors and computer architectures; impact of performance analysis on microprocessor design; techniques for analysis of architectural trade-offs; performance and power modeling; performance metrics; benchmarks, measurement tools, and techniques; simulation, challenges in full-system simulation; instruction profiling; trace generation; sampling; simulation points; analytical modeling; calibration of microprocessor performance models; workload characterization; benchmarks for emerging programming paradigms; synthetic benchmarks; statistical methods to compare alternatives; linear regression; and design of experiments. Only one of the following may be counted: Electrical and Computer Engineering 382N (Topic 21), Electrical Engineering 382M (Topic 15), 382N (Topic 21). Additional prerequisite: Consent of instructor.

Topic 22: Computer Architecture: User System Interplay. Explore fundamental principles in computer architecture focusing on the hardware and the compiler, as well as developing an understanding of their interplay with each other and with usage and programming models. Examine the development of several system families and follow common threads of identifying the intended users, system properties, and evaluation methodology. Review case studies including PCs and workstations with general-purpose processors, large parallel systems, graphics processors, and more experimental architectures such as stream processing and transactional memory. Electrical and Computer Engineering 382N (Topic 22) and Electrical Engineering 382N (Topic 22) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 23: Embedded System Design and Modeling. Examine the methods and techniques for formal specification, modeling, and system-level design of embedded systems; models of computation (MoCs), concurrency and time including finite state machines (FSMs), process networks and dataflow; system-level design languages (SLDLs) and methodologies; system-level synthesis algorithms for partitioning, scheduling and design space exploration; system refinement and implementation models; virtual platform prototyping, system simulation and transaction-level modeling (TLM); hardware and software synthesis; system-level design tools and case studies. Electrical and Computer Engineering 382N (Topic 23) and Electrical Engineering 382N (Topic 23) may not both be counted.

Topic 24: Code Generation and Optimization. Generate executable machine code understood by machines from program source code understood by programmers. Explore program optimization for performance, energy efficiency and reliability; code generation and optimization for different types of hardware; and runtime systems and just-in-time compilation. Only one of the following may be counted: Electrical and Computer Engineering 382N (Topic 24), Electrical Engineering 382N (Topic 24), 382V (Topic: Code Generation & Optimization). Additional prerequisite: Consent of instructor.

Topic 25: Runtime Systems. Examine fundamentals of runtime systems; design, implementation, and optimization of emulation engines; interpreters; binary translators; dynamic binary optimization; high-level language virtual machines; co-designed virtual machines; system-level virtual machines; and processor virtualization. Only one of the following may be counted: Electrical and Computer Engineering 382N (Topic 25), Electrical Engineering 382N (Topic 25), 382V (Topic: Dynamic Compilation). Additional prerequisite: Basic knowledge of computer architecture and operating systems; and consent of instructor.

Topic 26: Machine Learning Hardware-Algorithm Codesign. Explore co-design of machine learning (ML) algorithms and hardware; foundations of ML, compute-intensive ML architectures, high-performance matrix multiplication, spatial computing, roofline modeling, and scheduling and dataflows; ML-specific numerics, compression, quantization, and architectures for edge and mobile; codesign for scaling and system considerations; and circuit-level techniques for ultra-low-power ML, analog, and processing-in-memory techniques. Only one of the following may be counted: Electrical and Computer Engineering 382N (Topic 26), Electrical and Computer Engineering 382V (Topic: Crss-Lyr ML Algo/Hw Co-Dsgn), Electrical Engineering 382V (Topic: Crss-Lyr ML Algo/Hw Co-Dsgn).

ECE 382V. Topics in Computer Engineering.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

ECE 383L. Electromagnetic Field Theory.

Examine vector space, Green's function; equivalence theorem; vector potentials; plane, cylindrical, and spherical waves; and radiation and scattering. Three lecture hours a week for one semester. Electrical and Computer Engineering 383L and Electrical Engineering 383L may not both be counted. Prerequisite: Graduate standing in electrical engineering.

ECE 383M. Microwave Field Theory.

Examine guided waves in cylindrical waveguides, microstrip lines, dielectric and optical waveguides; integrated circuits; and periodic structures. Three lecture hours a week for one semester. Electrical and Computer Engineering 383M and Electrical Engineering 383M may not both be counted. Prerequisite: Graduate standing in electrical engineering.

ECE 383N. Theory of Electromagnetic Fields: Electrodynamics.

Explore intermediate electromagnetic field theory, with emphasis on the interaction of fields and material media, including anisotropic media. Three lecture hours a week for one semester. Electrical and Computer Engineering 383N and Electrical Engineering 383N may not both be counted. Prerequisite: Graduate standing.

ECE 383P. Topics in Optical Processing and Laser Communications.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing in engineering, mathematics, chemistry, or physics.

Topic 1: Fourier Optics. Examine Fourier transforming properties of lenses, frequency analysis of optical imaging systems, and spatial filtering. Explore optical information processing and holography. Electrical and Computer Engineering 382P (Topic 1) and Electrical Engineering 382P (Topic 1) may not both be counted.

Topic 3: Techniques of Laser Communications. Examine optical propagation in crystalline media, harmonic generation, frequency conversion, and modulation systems. Electrical and Computer Engineering 383P (Topic 3) and Electrical Engineering 383P (Topic 3) may not both be counted.

Topic 4: Fiber and Integrated Optics I. Examine waveguiding in slabs, cylinders, and fibers; optical fiber communications principles; mode coupling; guided-wave optical sources, modulators, and detectors. Electrical and Computer Engineering 383P (Topic 4) and Electrical Engineering 383P (Topic 4) may not both be counted.

Topic 5: Fiber and Integrated Optics II. Examine principles and practices of guided-wave optical sensor technology. Explore nonlinear optical effects in fibers, including amplification and fiber lasers.

Electrical and Computer Engineering 383P (Topic 5) and Electrical Engineering 383P (Topic 5) may not both be counted.
Topic 6: Semiconductor Optoelectronic Devices. Examine semiconductor materials and nanomaterials growth. Review light-matter interaction in bulk and nanostructures, including both band-to-band and intersubband transitions. Discuss band structure in real-space and k-space. Explore photonic devices and their design: light-emitting diodes (LEDs), photodetectors, modulators, solar cells, and semiconductor lasers (diode and quantum cascade). Electrical and Computer Engineering 382P (Topic 6) and Electrical Engineering 382P (Topic 6) may not both be counted. Additional prerequisite: Knowledge in electromagnetic engineering, quantum theory of electronic materials, and solid-state electronic devices.
Topic 8: Optical Communications. Explore the concepts behind research and development in optical communications and optical interconnects. Examine device physics and system applications. Discuss advanced technology solutions and innovative manufacturing processes to deliver optical passive and active micro- and nanodevices that enable the deployment of short-haul and metropolitan area all-optical networks for communications and for sensing networks. Electrical and Computer Engineering 382P (Topic 8) and Electrical Engineering 382P (Topic 8) may not both be counted. Additional prerequisite: Knowledge in electromagnetic engineering and quantum theory of electronic materials.

ECE 383V. Topics in Electromagnetics.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

ECE 384N. Topics in Acoustics.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing and consent of instructor.

Topic 1: Acoustics I. Same as Mechanical Engineering 384N (Topic 1). Plane waves in fluids; transient and steady-state reflection and transmission; lumped elements; refraction; strings, membranes, and rooms; horns; ray acoustics; absorption and dispersion. Only one of the following may be counted: Electrical and Computer Engineering 384N (Topic 1), Electrical Engineering 384N (Topic 1), Mechanical Engineering 384N (Topic 1).
Topic 2: Acoustics II. Same as Mechanical Engineering 384N (Topic 2). Spherical and cylindrical waves, radiation and scattering, multipole expansions, Green's functions, waveguides, sound beams, Fourier acoustics, Kirchhoff theory of diffraction, and arrays. Only one of the following may be counted: Electrical and Computer Engineering 384N (Topic 2), Electrical Engineering 384N (Topic 2), Mechanical Engineering 384N (Topic 2).
Topic 3: Electromechanical Transducers. Same as Mechanical Engineering 384N (Topic 3). Modeling, analysis, and design of transducers for reception and transmission of acoustic and vibration signals; dynamics of coupled electrical, mechanical, and acoustical systems; and the effects of transducer characteristics on fidelity and efficiency of transduction. Only one of the following may be counted: Electrical and Computer Engineering 384N (Topic 3), Electrical Engineering 384N (Topic 3), Mechanical Engineering 384N (Topic 3).
Topic 4: Nonlinear Acoustics. Same as Mechanical Engineering 384N (Topic 4). Waveform distortion and shock formation, harmonic generation and spectral interactions, effects of absorption and dispersion, parametric arrays, Rankine-Hugoniot relations, weak shock theory, numerical modeling, radiation pressure, and acoustic streaming. Only one of the following may be counted: Electrical and Computer Engineering 384N (Topic 4), Electrical Engineering 384N (Topic 4), Mechanical Engineering 384N (Topic 4).
Topic 5: Underwater Acoustics. Same as Mechanical Engineering 384N (Topic 5). Acoustic properties of the ocean; acoustic propagation, reflection, reverberation, scattering and target strength; ocean noise; introduction to array and signal processing; basics of sonar design. Only one of the following may be counted: Electrical and Computer Engineering 384N (Topic 5), Electrical Engineering 384N (Topic 5), Mechanical Engineering 384N (Topic 5).
Topic 6: Architectural Acoustics. Same as Mechanical Engineering 384N (Topic 6). Human perception of sound, principles of room acoustics, sound-absorptive materials, transmission between rooms, and acoustical design of enclosed spaces. Only one of the following may be counted: Electrical and Computer Engineering 384N (Topic 6), Electrical Engineering 384N (Topic 6), Mechanical Engineering 384N (Topic 6).
Topic 7: Ultrasonics. Same as Mechanical Engineering 384N (Topic 7). Acoustic wave propagation in fluids, elastic solids, and tissue; transducers, arrays, and beamforming; nondestructive evaluation; and acoustical imaging. Only one of the following may be counted: Electrical and Computer Engineering 384N (Topic 7), Electrical Engineering 384N (Topic 7), Mechanical Engineering 384N (Topic 7).
Topic 8: Wave Phenomena. Same as Mechanical Engineering 384N (Topic 8). Fourier acoustics and angular spectra; nearfield acoustical holography; Fraunhofer, Fresnel, and parabolic approximations; sound beams; Green's functions; Born approximation; propagation and scattering in moving, periodic, and random media. Only one of the following may be counted Electrical and Computer Engineering 384N (Topic 8), Electrical Engineering 384N (Topic 8), Mechanical Engineering 384N (Topic 8), 397 (Topic: Wave Phenomena).
Topic 9: Acoustic Metamaterials. Same as Mechanical Engineering 384N (Topic 9). Examine wave propagation in heterogeneous media displaying nonclassical effective properties. Introduction to effective medium theories including fundamental limits on effective properties, transmission and scattering matrices, waves in periodic media, localized resonance, and transformation acoustics. Only one of the following may be counted: Mechanical Engineering 384N (Topic 9), 397 (Topic: Acoustic Metamaterials), Electrical and Computer Engineering 384N (Topic 9).

ECE 385J. Topics in Biomedical Engineering.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing in engineering and consent of instructor.

Topic 1: Neural Engineering. Examine a variety of clinical conditions and their associated neurological basis, and then analyze the engineering solutions to cope with the neurological deficits, with an emphasis on electrical and computer engineering components. Study approaches to design motor neuroprosthetics and sensory neuroprosthetics that restore lost functions. Learn principles of deep brain stimulation, neuromodulation, and brain plasticity. Explore the concepts behind technological approaches for neurorehabilitation, in particular robotics and brain-computer interfaces. Electrical and Computer Engineering 385J (Topic: Neural Engineering) and 385J (Topic 1) may not both be counted. Additional prerequisite: Course in Data Mining or Data Science Principles and course in Digital Signal Processing or equivalent; or consent of instructor.
Topic 3: Bioelectric Phenomena. Same as Biomedical Engineering 384J (Topic 4). Examines the physiological bases of bioelectricity and the techniques required to record bioelectric phenomena both intracellularly and extracellularly; the representation of bioelectric activity by equivalent dipoles and the volume conductor fields produced. Only one of the following may be counted: Biomedical Engineering 384J (Topic 4), Electrical and Computer Engineering 385J (Topic 3), Electrical Engineering 385J (Topic 3).

Topic 9: Laser-Tissue Interaction: Thermal. Same as Biomedical Engineering 381J (Topic 1). The thermal response of random media in interaction with laser irradiation. Calculation of the rate of heat production caused by direct absorption of the laser light, thermal damage, and ablation. Only one of the following may be counted: Biomedical Engineering 381J (Topic 1), Electrical and Computer Engineering 385J (Topic 9), Electrical Engineering 385J (Topic 9).
Topic 15: Biosignal Analysis. Same as Biomedical Engineering 384J (Topic 3). Theory and classification of biological signals such as EEG, EKG, and EMG. Data acquisition and analysis procedures for biological signals, including computer applications. Only one of the following may be counted: Biomedical Engineering 384J (Topic 3), Electrical and Computer Engineering 385J (Topic 15), Electrical Engineering 385J (Topic 15).
Topic 16: Laser-Tissue Interaction: Optical. Same as Biomedical Engineering 381J (Topic 2). The optical behavior of random media such as tissue in interaction with laser irradiation. Approximate transport equation methods to predict the absorption and scattering parameters of laser light inside tissue. Port-wine stain treatment; cancer treatment by photochemotherapy; and cardiovascular applications. Only one of the following may be counted: Biomedical Engineering 381J (Topic 2), Electrical and Computer Engineering 385J (Topic 16), Electrical Engineering 385J (Topic 16).
Topic 17: Biomedical Instrumentation II: Real-Time Computer-Based Systems. Same as Biomedical Engineering 384J (Topic 2). Design, testing, patient safety, electrical noise, biomedical measurement transducers, therapeutics, instrumentation electronics, microcomputer interfaces, and embedded systems. Participate in an individual laboratory. Only one of the following may be counted: Biomedical Engineering 384J (Topic 2), Electrical and Computer Engineering 385J (Topic 17), Electrical Engineering 385J (Topic 17).
Topic 18: Imaging Signals and Systems. Same as Biomedical Engineering 381J (Topic 3). Physical principles and signal processing techniques used in thermographic, ultrasonic, and radiographic imaging, including image reconstruction from projections such as CT scanning, MRI, and millimeter wave determination of temperature profiles. Only one of the following may be counted: Biomedical Engineering 381J (Topic 3), Electrical and Computer Engineering 385J (Topic 18), Electrical Engineering 385J (Topic 18).
Topic 23: Optical Spectroscopy. Same as Biomedical Engineering 381J (Topic 4). Measurement and interpretation of spectra: steady-state and time-resolved absorption, fluorescence, phosphorescence, and Raman spectroscopy in the ultraviolet, visible, and infrared portions of the spectrum. Only one of the following may be counted: Biomedical Engineering 381J (Topic 4), Electrical and Computer Engineering 385J (Topic 23), Electrical Engineering 385J (Topic 23).
Topic 26: Therapeutic Heating. Same as Biomedical Engineering 381J (Topic 5). Engineering aspects of electromagnetic fields that have therapeutic applications: diathermy (short wave, microwave, and ultrasound), electrosurgery (thermal damage processes), stimulation of excitable tissue, and electrical safety. Only one of the following may be counted: Biomedical Engineering 381J (Topic 5), Electrical and Computer Engineering 385J (Topic 26), Electrical Engineering 385J (Topic 26).
Topic 28: Noninvasive Optical Tomography. Same as Biomedical Engineering 381J (Topic 6). Basic principles of optical tomographic imaging of biological materials for diagnostic or therapeutic applications. Optical-based tomographic imaging techniques including photothermal, photoacoustic, and coherent methodologies. Only one of the following may be counted: Biomedical Engineering 381J (Topic 6), Electrical and Computer Engineering 385J (Topic 28), Electrical Engineering 385J (Topic 28).
Topic 31: Biomedical Instrumentation I. Same as Biomedical Engineering 384J (Topic 1). Application of electrical engineering techniques to analysis and instrumentation in biological sciences: pressure, flow, temperature measurement; bioelectrical signals; pacemakers; ultrasonics; electrical safety; electrotherapeutics. Only one of the following may be counted: Biomedical Engineering 384J (Topic 1), Electrical and Computer Engineering 385J (Topic 31), Electrical Engineering 385J (Topic 31).
Topic 32: Projects in Biomedical Engineering. Same as Biomedical Engineering 384J (Topic 5). An in-depth examination of selected topics, such as optical and thermal properties of laser interaction with tissue; measurement of perfusion in the microvascular system; diagnostic imaging; interaction of living systems with electromagnetic fields; robotic surgical tools; ophthalmic instrumentation; noninvasive cardiovascular measurements. Only one of the following may be counted: Biomedical Engineering 384J (Topic 5), Electrical and Computer Engineering 385J (Topic 32), Electrical Engineering 385J (Topic 32). Additional prerequisite: Biomedical Engineering 384J (Topic 1) or Electrical and Computer Engineering 385J (Topic 31) (or Electrical Engineering 385J (Topic 31)).
Topic 33: Neurophysiology/Prosthesis Design. Same as Biomedical Engineering 384J (Topic 6). The structure and function of the human brain. Discussion of selected neurological diseases in conjunction with normal neurophysiology. Study of neuroprosthesis treatments and design philosophy, functional neural stimulation, and functional muscular stimulation. Only one of the following may be counted: Biomedical Engineering 385J (Topic 6), Electrical and Computer Engineering 385J (Topic 33), Electrical Engineering 385J (Topic 33).
Topic 35: Brain-Computer Interaction. Examine the architecture of a brain-computer interface (BCI), the brain signals that can be recorded as input to a BCI, and the interaction paradigms where these signals can be decoded and exploited. Study the design principles of complex brain-controlled devices, with an emphasis on electroencephalogram (EEG) signals, the most common signal for BCI. Explore how to enhance EEG signal-to-noise ratio, and techniques to decode subjects' intents and cognitive states. Apply those techniques EEG signals acquired during closed-loop BCI experiments. Electrical and Computer Engineering 385J (Topic 35) and Electrical Engineering 385V (Topic: Brain Computer Interaction) may not both be counted. Additional prerequisite: Course in Data Mining or Data Science Principles and course in Digital Signal Processing or equivalent; or consent of instructor.

ECE 386C. Software Architecture.

Three lecture hours a week for one semester. Electrical and Computer Engineering 386C and Electrical Engineering 386C may not both be counted. Prerequisite: Graduate standing.

ECE 390C. Statistical Methods in Engineering and Quality Assurance.

Examine the interpretation of data from designed experiments and production processes. Explore subjects including probability distributions, confidence intervals, analysis of variance, hypothesis testing, factorial designs, and quality control data. Three lecture hours a week for one semester. Electrical and Computer Engineering 390C and Electrical Engineering 390C may not both be counted. Prerequisite: Graduate standing in engineering and a course in probability and statistics.

ECE 390V. Topics in Manufacturing Systems Engineering.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

ECE 391C. Technical Entrepreneurship.

Examine the technology-based company: entrepreneurship, intrapreneurship, strategic planning, finance, marketing, sales, operations, research and development, manufacturing, and management. Form hypothetical companies in a team and simulate their ventures

over an extended period. Three lecture hours a week for one semester. Electrical and Computer Engineering 391C and Electrical Engineering 391C may not both be counted. Prerequisite: Graduate standing.

ECE 392C. Software Testing.

Three lecture hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 392C, Electrical Engineering 382V (Topic: Software Testing), 392C. Prerequisite: Graduate standing.

ECE 392K. Antenna Theory and Practice.

Explore modern antenna systems for receiving and transmitting, including driven and parasitic arrays, horns, parabolic and other antennas. Three lecture hours a week for one semester. Electrical and Computer Engineering 392K and Electrical Engineering 392K may not both be counted. Prerequisite: Graduate standing in electrical engineering and knowledge in electromagnetic engineering.

ECE 392L. Computational Electromagnetics.

Explore fundamental computational modeling and analysis techniques for applications in antennas, microwave circuits, biomedical engineering, and geophysics. Focus on boundary-value problem formulation, numerical methods, computer implementation, and error quantification. Examine differential and integral equation-based methods for solving Maxwell's equations in frequency and time domains. Three lecture hours a week for one semester. Electrical and Computer Engineering 392L and Electrical Engineering 392L may not both be counted. Prerequisite: Graduate standing.

ECE 392N. Principles of Radar.

Explore the fundamentals of radar, with an emphasis on electromagnetics and signal processing. Examine radar range equation, antennas, propagation and target scattering, matched filter, ambiguity function, waveform design, pulse compression, microwave imaging, synthetic aperture radar, and inverse synthetic aperture radar (ISAR). Three lecture hours a week for one semester. Electrical and Computer Engineering 392N and Electrical Engineering 392N may not both be counted. Prerequisite: Graduate standing.

ECE 393C. Topics in Plasma Dynamics.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing in engineering, physics, chemistry, or mathematics.

Topic 1: Introduction to Plasma Dynamics. Examine plasma properties, including collective effects, Debye shielding, quasineutrality, the plasma frequency, and collisions. Explore single particle motions in electric and magnetic fields. Study particle drifts, adiabatic invariants, and cyclotron resonance. Electrical and Computer Engineering 393C (Topic 1) and Electrical Engineering 393C (Topic 1) may not both be counted.

ECE 394. Topics in Power System Engineering.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing in electrical engineering, or graduate standing and consent of instructor.

Topic 7: Power Electronic Devices and Systems. Explore power electronic components and circuits; high-voltage, direct current (HVDC) converters; electronic drives for machines; AC/DC converters. Electrical and Computer Engineering 394 (Topic 7) and Electrical Engineering 394 (Topic 7) may not both be counted.
Topic 9: Power Quality. Examine electrical transients, switching surges, lightning, and other phenomena that cause deviations in 60-hertz sinusoidal voltages and currents. Electrical and Computer Engineering 394 (Topic 9) and Electrical Engineering 394 (Topic 9) may not both be counted.
Topic 14: Electrical Transients in Power Systems. Explore analysis and modeling of electrical transient phenomena in power systems, traveling wave, insulation coordination, and overvoltage protection. Electrical and Computer Engineering 394 (Topic 14) and Electrical Engineering 394 (Topic 14) may not both be counted.
Topic 15: Power System Operations and Control. Only one of the following may be counted: Electrical and Computer Engineering 394 (Topic 15), Electrical Engineering 394 (Topic 15), 394V (Topic: Power Sys Operatns/Control).
Topic 16: Restructured Electricity Markets: Locational Marginal Pricing. Examine locational marginal pricing (LMP) model of electricity markets. Explore market dispatch formulated as an optimization problem, unit commitment issues, and pricing rules and incentives in markets; energy- price and transmission-price risk hedging and energy network models; and revenue adequacy of financial transmission rights, a mixed-integer programming approach to unit commitment, the representation of voltage constraints into market models, and the design of electricity markets to mitigate market power. Only one of the following may be counted: Electrical and Computer Engineering 394 (Topic 16), Electrical Engineering 394 (Topic 16), 394V (Topic: Res Elect Mrkts: Loc Marg Pric).
Topic 17: Restructured Electricity Markets: Market Power. Explore the definition and analysis of market power, especially as an issue in the design and functioning of electricity markets. Focus on transmission constraints and offer-based markets that involve locational marginal pricing. Electrical and Computer Engineering 394 (Topic 17) and Electrical Engineering 394 (Topic 17) may not both be counted.
Topic 18: Electric Machinery and Drive Systems. Explore electric drives and machines used in commercial and industrial applications. Examine magnetic circuits and magnetic materials; electromechanical energy conversion principles; rotating and linear machine concepts, including synchronous, induction, DC, and variable reluctance; and control strategies. Only one of the following may be counted: Electrical and Computer Engineering 394 (Topic 18), Electrical Engineering 394 (Topic 13), 394 (Topic 18).

ECE 394J. Topics in Energy Systems.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

Topic 1: Power System Engineering I. Examine physical features, operational characteristics, and analytical models for major electric power systems and components. Electrical and Computer Engineering 394J (Topic 1) and Electrical Engineering 394J (Topic 1) may not both be counted.
Topic 2: Power System Engineering II. Explore advanced techniques for solving large power networks; load flow, symmetrical components, and short circuit analysis. Electrical and Computer Engineering 394J (Topic 2) and Electrical Engineering 394J (Topic 2) may not both be counted.
Topic 9: Wind Energy Systems. Examine wind resource characteristics and assessments; wind turbine technologies (fixed and variable-speed turbines); wind power transmission; integration and interconnection issues; and reliability impacts. Electrical and Computer Engineering 394J (Topic 9) and Electrical Engineering 394J (Topic 9) may not both be counted.
Topic 10: Distributed Generation Technologies. Examine distributed generation and microgrids elements; microsources; energy storage; power electronics interfaces; DC and AC architectures; economics, operation, stabilization, and control; reliability and availability aspects; interaction between microgrids and bulk power grids; and smart grids. Electrical and Computer Engineering 394J (Topic 10) and Electrical Engineering 394J (Topic 10) may not both be counted. Additional

prerequisite: Knowledge of fundamentals of power electronics and power systems, familiarity with modeling and simulation techniques, and knowledge of how to use professional publications.

Topic 11: Advanced Power Electronics. Explore resonant converters, switched-capacitor converters, the dual active bridge converter, high-frequency magnetics, high-frequency inverters and rectifiers, power factor correction, and other areas of current interest. Undertake projects with intensive design, prototyping, and/or simulation components. Electrical and Computer Engineering 394J (Topic 11) and Electrical Engineering 394J (Topic 11) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 12: Modeling and Simulation of Wind Power Plants. Explore the analysis, modeling, and simulation of wind turbines and wind farms; fundamentals of wind turbines and technologies, reference-frame theory, dynamic models of induction and synchronous machines, fixed-speed direct-connect, wide-slip, doubly-fed, full-converter wind turbines, operation and control, and interconnection issues. Electrical and Computer Engineering 394J (Topic 12) and Electrical Engineering 394J (Topic 12) may not both be counted. Additional prerequisite: Consent of instructor.

ECE 394L. Power Systems Apparatus and Laboratory.

Examine the fundamentals of power systems emphasized through laboratory experiments. Explore complex power, three-phase circuits, per-unit system, transformers, synchronous machines, transmission line models, steady-state analysis, induction machines, capacitor banks, protective relaying, surge arrestors, and instrumentation. Three lecture hours and three laboratory hours a week for one semester. Only one of the following may be counted: Electrical and Computer Engineering 394L, Electrical Engineering 394L, 394V (Topic: Power Systems Apparatus and Laboratory). Prerequisite: Graduate standing.

ECE 396K. Topics in Solid-State Device Theory.

Explore the theory of electron, magnetic, and electro-optic devices. Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing and consent of instructor.

Topic 1: Metal Oxide Semiconductor Devices: Physics and Technology. Electrical and Computer Engineering 396K (Topic 1) and Electrical Engineering 396K (Topic 1) may not both be counted.

Topic 2: Semiconductor Physics. Introduction to the fundamental physics of charge carrier states in semiconductors, charge carrier interactions among themselves and with the environment, and charge transport in semiconductors and their heterostructures. Electrical and Computer Engineering 396K (Topic 2) and Electrical Engineering 396K (Topic 2) may not both be counted. Additional prerequisite: An undergraduate-level introduction to solid-state devices and quantum mechanics.

Topic 4: Synthesis, Growth, and Analysis of Electronic Materials. Electrical and Computer Engineering 396K (Topic 4) and Electrical Engineering 396K (Topic 4) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 5: Superconducting Electronic Devices. Electrical and Computer Engineering 396K (Topic 5) and Electrical Engineering 396K (Topic 5) may not both be counted.

Topic 6: Magnetic Phenomena in Materials. Electrical and Computer Engineering 396K (Topic 6) and Electrical Engineering 396K (Topic 6) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 7: Metal Oxide Semiconductor Integrated Circuit Process Integration. Electrical and Computer Engineering 396K (Topic 7) and Electrical Engineering 396K (Topic 7) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 8: Ultra-Large-Scale Integration Techniques. Examine integrated circuit processing; crystal growth and wafer preparation; epitaxial growth; oxidation, diffusion, and ion implantation; thin-film deposition techniques; and lithography and etching. Participate in an individual laboratory. Electrical and Computer Engineering 396K (Topic 8) and Electrical Engineering 396K (Topic 8) may not both be counted. Additional prerequisite: Knowledge in solid-state electronic devices.

Topic 9: Localized versus Itinerant Electrons in Solids. Same as Mechanical Engineering 386R (Topic 1). Description of electrons, from free atoms to crystals; band theory contrasted with crystal-field theory; evolution of electronic properties on passing from magnetic insulators to normal metals, from ionic to covalent solids, from single-valent compounds to mixed-valent systems; electron-lattice interactions and phase transitions; many examples. Only one of the following may be counted: Electrical and Computer Engineering 396K (Topic 9), Electrical Engineering 396K (Topic 9), Mechanical Engineering 386R (Topic 1). Additional prerequisite: A semester of quantum mechanics and a semester of solid-state science or technology.

Topic 10: Ionic Conductors. Same as Mechanical Engineering 386T (Topic 1). Only one of the following may be counted: Mechanical Engineering 386T (Topic 1), Electrical Engineering 396K (Topic 10), Electrical and Computer Engineering 396K (Topic 10).

Topic 11: High-Temperature Superconductors. Same as Mechanical Engineering 386T (Topic 2). Only one of the following may be counted: Mechanical Engineering 386T (Topic 2), Electrical Engineering 396K (Topic 11), Electrical and Computer Engineering 396K (Topic 11).

Topic 12: Catalytic Electrodes. Same as Mechanical Engineering 386T (Topic 3). Only one of the following may be counted: Mechanical Engineering 386T (Topic 3), Electrical and Computer Engineering 396K (Topic 12), Electrical Engineering 396K (Topic 12).

Topic 13: Magnetic Materials. Same as Mechanical Engineering 386T (Topic 4). Only one of the following may be counted: Electrical and Computer Engineering 396K (Topic 13), Electrical Engineering 396K (Topic 13), Mechanical Engineering 386T (Topic 4).

Topic 14: Optical Interconnects. Electrical and Computer Engineering 396K (Topic 14) and Electrical Engineering 396K (Topic 14) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 15: Optoelectronics Integrated Circuits. Electrical and Computer Engineering 396K (Topic 15) and Electrical Engineering 396K (Topic 15) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 16: Semiconductor Lasers. Examine the principles of compound semiconductor lasers and LEDs; bulk and quantum-well laser structures; radiative and nonradiative recombination processes; optical, electrical, and thermal properties of lasers; dynamic rate equations and modulation characteristics; lasing spectra, chirp, modal noise and linewidth; and edge-emitting and surface-emitting lasers. Electrical and Computer Engineering 396K (Topic 16) and Electrical Engineering 396K (Topic 16) may not both be counted. Additional prerequisite: Knowledge in electromagnetic engineering, quantum theory of electronic materials, and solid-state electronic devices; and consent of instructor.

Topic 17: Localized-Electron Phenomena. Same as Mechanical Engineering 386R (Topic 2). Analysis of the variation in physical properties versus chemical composition of several groups of isostructural transition-metal compounds. Only one of the following may be counted: Electrical and Computer Engineering 396K (Topic 17), Electrical Engineering 396K (Topic 17), Mechanical Engineering 386R (Topic 2). Additional prerequisite: A semester of solid-state science and/or quantum mechanics.

Topic 19: Plasma Processing of Semiconductors I. Explore plasma analysis using Boltzmann and fluid equations; plasma properties, including Debye length, quasineutrality, and sheaths; basic collisional properties, including Coulomb and polarization scattering; analysis

of capacitive and wave-heated plasma processing reactors. Electrical and Computer Engineering 396K (Topic 19) and Electrical Engineering 396K (Topic 19) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 20: Plasma Processing of Semiconductors II. Explore plasma chemistry and equilibrium; analysis of molecular collisions; chemical kinetics and surface processes; plasma discharge particle and energy balance; analysis of inductive and DC plasma processing reactors; plasma etching, deposition, and implantation. Electrical and Computer Engineering 396K (Topic 20) and Electrical Engineering 396K (Topic 20) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 21: Nanoscale Device Physics and Technologies. Examine physical principles and operational characteristics of semiconductor devices. Explore the physics of metal-oxide-semiconductor field-effect transistors (MOSFET) and bipolar junction transistors (BJT). Discuss short-channel effects, ultra-thin oxide, and high-K gate dielectrics; semiconductor interface characterization; hot-electron effects; lightly-doped drain devices (LDD); subthreshold characteristics; complementary-symmetry metal-oxide- semiconductor (CMOS) latchup; gate-induced leakage current of MOSFETs; poly-depletion and quantum mechanical effects; silicon on insulator (SOI) devices; strained-Si; advanced 3-D devices and bandgap narrowing effect; Webster effect; Kirk effect; punchthrough and avalanche breakdown; base transit time for bipolar transistors; and scaling issues of both BJT and MOSFETs. Electrical and Computer Engineering 396K (Topic 21) and Electrical Engineering 396K (Topic 21) may not both be counted. Additional prerequisite: Knowledge in solid-state electronic devices.

Topic 22: Semiconductor Microlithography. Electrical and Computer Engineering 396K (Topic 22) and Electrical Engineering 396K (Topic 22) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 23: Semiconductor Heterostructures. Electrical and Computer Engineering 396K (Topic 23) and Electrical Engineering 396K (Topic 23) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 24: Microwave Devices. Electrical and Computer Engineering 396K (Topic 24) and Electrical Engineering 396K (Topic 24) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 25: Organic and Polymer Semiconductor Devices. Electrical and Computer Engineering 396K (Topic 25) and Electrical Engineering 396K (Topic 25) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 26: Microelectromechanical Systems. Electrical and Computer Engineering 396K (Topic 26) and Electrical Engineering 396K (Topic 26) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 27: Charge Transport in Organic Semiconductors. Electrical and Computer Engineering 396K (Topic 27) and Electrical Engineering 396K (Topic 27) may not both be counted. Additional prerequisite: Consent of instructor.

Topic 28: Magnetic Materials and Devices. Explore the fundamentals and applications of magnetic materials, in particular to nano-devices. Examine the origin of magnetism in oxides and metals, magnetic switching mechanisms, and how spin structures arise such as domain walls and topologically-protected spin states. Discuss applications to future computing nano-devices. Only one of the following may be counted: Electrical and Computer Engineering 396K (Topic 28), Electrical Engineering 396K (Topic 28), 396V (Topic: Magnetic Material/Devices). Additional prerequisite: Undergraduate-level course or background in electricity and magnetism strongly recommended; undergraduate-level course or background in quantum mechanics also recommended.

Topic 29: Thin Film Transistors. Explore device physics of thin-film and 2D transistors, charge transport phenomena, and materials aspects. Discuss organic polymer and amorphous inorganic semiconductors (oxides and silicon). Study organic polymer and amorphous inorganic semiconductors (oxides and silicon), and field effect transistors with 2D semiconductors such as transition metal dicalcogenides (TMDs). Review change of properties with layer thickness, device physics and transport, contacts, and performance characteristics and discuss unusual properties of thin film transistors (TFTs) such as light emission and ambipolar charge transport, lateral junctions, and ionic gating. Electrical and Computer Engineering 396K (Topic 29) and Electrical Engineering 396V (Topic: Thin Film Transistors) may not both be counted. Additional prerequisite: Undergraduate course in semiconductor devices or the equivalent, or consent of instructor.

Topic 30: Solar Energy Conversion Devices. Study radiation from the Sun and the solar energy flux on Earth, and discuss the principles of semiconductors and semiconductor device physics relevant to diodes under various bias conditions. Examine the physics of pn junction under solar illumination and with various recombination mechanisms. Review the most important materials families of solar cells including single crystal silicon; polysilicon; amorphous silicon; solar cells based on CdTe and copper indium diselenide and related compounds; and III-V compound semiconductor heterojunction solar cells including tandem cells and space-grade solar cells. Discuss new materials technologies including organic and perovskite-based solar cells. Electrical and Computer Engineering 396K (Topic 30) and Electrical Engineering 396V (Topic: Solar Energy Conversn Devices) may not both be counted.

ECE 396M. Topics in Quantum Electronics.

Examine quantum mechanical principles as applied to electron devices, lasers, and electro-optics; material properties and interaction of radiation and material. Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing in electrical engineering or physics.

Topic 1: Introductory Quantum Electronics. Examine basic quantum mechanics and applications to solid-state phenomena and lasers. Electrical and Computer Engineering 396M (Topic 1) and Electrical Engineering 396M (Topic 1) may not both be counted.

Topic 2: Quantum Information Hardware. Explore various hardware platforms used for quantum information processing from an applied physics perspective. Examine the physical requirements for a hardware platform to process quantum information. Review characteristics of current hardware platforms such as superconducting quantum circuits, atomic systems, solid-state spins and optical photons. Electrical and Computer Engineering 396M (Topic 2) and Electrical Engineering 396V (Topic: Quantum Information Hardware) may not both be counted.

ECE 396N. Topics in Nanotechnology.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

Topic 1: Semiconductor Nanostructures. Examine the theoretical framework for the understanding of electronic properties and electron transport in quantum confined devices; two-dimensional electron systems in semiconductor heterostructures; quantum wires; quantum dots; spintronic devices; and growth and fabrication techniques. Electrical and Computer Engineering 396N (Topic 1) and Electrical Engineering 396N (Topic 1) may not both be counted. Additional prerequisite: Knowledge in quantum theory of electronic materials and solid-state electronic devices.

Topic 2: Carbon and 2D Devices. Introduction to the material properties and device physics of carbon nanotubes, graphene and

related 2D materials; science and technology of carbon nanomaterials and their electronic, optical, and sensor properties; and a basic review of quantum mechanics and elementary theory of solids. Examine carbon synthesis, sensor devices, energy devices, interconnects, transistors, and circuit applications of carbon nanomaterials. Explore 2D materials beyond graphene including transitional metal dichalcogenides. Electrical and Computer Engineering 396N (Topic 2) and 396V (Topic: Carbon and 2D Devices) may not both be counted.

ECE 396V. Topics in Solid-State Electronics.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing.

Topic 5: Introduction to Solid-State Properties of Materials. Same as Materials Science and Engineering 386P (Topic 4) and Mechanical Engineering 386P (Topic 4). Introduction to the electronic, magnetic, and optical properties of materials. Solid-state properties of metals, semiconductors, and ceramics; fundamental concepts needed for the description of these properties, using an introductory-level description of the electronic structure of solids. Only one of the following may be counted: Electrical Engineering 396V (Topic 5), Electrical and Computer Engineering 396V (Topic 5), Mechanical Engineering 386P (Topic 4), Materials Science and Engineering 386P (Topic 4). Additional prerequisite: Graduate standing and consent of instructor.
Topic 6: Advanced Semiconductor Lasers. Examine dynamic properties of semiconductor lasers; intensity, phase, and frequency noise; dynamic lasing spectra, chirp, and mode partition noise; injection locking and optical feedback; short pulse generation by mode-locking and gain switching; single-mode distributed feedback, distributed Bragg reflector (DBR), and coupled-cavity lasers; wavelength-tunable single-mode lasers; externally modulated lasers; coherent high-power laser arrays; quantum-dot lasers and amplifiers; vertical-cavity surface-emitting lasers; and integrated wavelength-division multiplexing (WDM) laser arrays and photonic integrated circuits. Electrical and Computer Engineering 396V (Topic 6) and Electrical Engineering 396V (Topic 6) may not both be counted. Additional prerequisite: Electrical and Computer Engineering 396K (Topic 16) or the equivalent.
Topic 7: Optoelectronics for Optical Networking. Examine advanced optical communication systems and optoelectronics technologies, including dense and coarse wavelength division multiplexing, soliton transmission, coherent detection, subcarrier multiplexing, nonregenerative erbium-doped fiber amplifier (EDFA) networks, and Raman amplification. Explore photonic switching system architectures and optical switching technologies, including both passive and active components. Electrical and Computer Engineering 396V (Topic 7) and Electrical Engineering 396V (Topic 7) may not both be counted. Additional prerequisite: Electrical and Computer Engineering 383P (Topic 6) and 396K (Topic 16), or their equivalents, are recommended.

ECE 197C, 297C, 397C, 697C, 997C. Research Problems.

Select and research a problem with approval of the department. For each semester hour of credit earned, the equivalent of one lecture hour a week for one semester. Electrical and Computer Engineering 197C and Electrical Engineering 197C may not both be counted. Offered on the credit/no credit basis only. Prerequisite: Graduate standing in electrical engineering and consent of the graduate advisor.

ECE 197G, 297G, 397G, 697G, 997G. Research Problems.

Problem selected by the student with approval of the department. For each semester hour of credit earned, the equivalent of one lecture hour a week for one semester. Electrical and Computer Engineering 197G and Electrical Engineering 197G may not both be counted. Offered on the letter-grade basis only. Prerequisite: Graduate standing in electrical engineering and consent of instructor and the graduate advisor.

ECE 397K. Advanced Topics in Electrical Engineering.

Three lecture hours a week for one semester. May be repeated for credit when the topics vary. Prerequisite: Graduate standing in electrical engineering and consent of instructor.

ECE 197M, 297M, 397M. Graduate Research Internship.

Engage in research associated with enrollment in the Graduate Research Internship Program (GRIP). For every hour of credit earned, the equivalent of one lecture hour a week for one semester. Electrical and Computer Engineering 197M and Electrical Engineering 197M may not both be counted. Offered on the credit/no credit basis only. Prerequisite: Graduate standing in electrical engineering and consent of instructor.

ECE 397N. Conference Course.

The equivalent of three lecture hours a week for one semester. May be repeated for credit. Prerequisite: Graduate standing in electrical and computer engineering and consent of instructor.

ECE 197S, 297S, 397S. Graduate Seminar in Electrical Engineering.

For each semester hour of credit earned, one lecture hour a week for one semester. May be repeated for credit. Prerequisite: Graduate standing.

ECE 698. Thesis.

The equivalent of three lecture hours a week for two semesters. Electrical and Computer Engineering 698 and Electrical Engineering 698 may not both be counted. Offered on the credit/no credit basis only. Prerequisite: For 698A, graduate standing in electrical and computer engineering and consent of the graduate advisor; for 698B, Electrical and Computer Engineering 698A (or Electrical Engineering 698A).

ECE 398R. Master's Report.

Prepare a report to fulfill the requirement for the Master's degree under the report option. The equivalent of three lecture hours a week for one semester. Electrical and Computer Engineering 398R and Electrical Engineering 398R may not both be counted. Offered on the credit/no credit basis only. Prerequisite: Graduate standing in electrical and computer engineering and consent of the graduate advisor.

ECE 398T. Supervised Teaching in Electrical Engineering.

Teach under close supervision for one semester. Attend group meetings or individual consultations, and submit reports as required. The equivalent of three lecture hours a week for one semester. Electrical and Computer Engineering 398T and Electrical Engineering 398T may not both be counted. Offered on the credit/no credit basis only. Prerequisite: Graduate standing and appointment as a teaching assistant.

ECE 399W, 499W, 599W, 699W, 799W, 899W, 999W. Dissertation.

May be repeated for credit. Offered on the credit/no credit basis only. Prerequisite: Admission to candidacy for the doctoral degree.

Professional Courses