Electrical and Computer Engineering

The department of electrical and computer engineering (ECE) offers undergraduate and graduate programs of study along with supporting research for students interested in the fields of electrical engineering and computer engineering. Graduate study leads to the degrees, master of science, master of engineering, and doctor of philosophy in electrical engineering, and the master of science and doctor of philosophy in computer engineering.

The undergraduate programs emphasize the fundamental aspects of their respective areas. Engineering design concepts are introduced early in the curriculum, and required instructional laboratories introduce design as a hands-on activity. Electives permit students to tailor their programs according to their interests and goals, whether they be in preparation for graduate study or entry into industry. Students are free to select courses offered by other departments and are encouraged to do so when appropriate. In this way they can prepare themselves for activities which straddle departmental boundaries or for entry into professional schools such as medicine or management. Students synthesize and apply their knowledge in a senior design project. Students may use the senior design project as a way to participate in the various research projects in the department.

The department maintains a number of laboratories in support of its curricular programs. These laboratories include the sophomore and junior lab, electronic circuits and systems laboratory, microcomputer laboratory, electromechanics laboratory, digital signal processing laboratory, digital systems laboratory and senior projects laboratories.

The department has research laboratories in computer architectures, wireless communications, optoelectronics, compound semiconductors, electron device physics, microelectronics fabrication, signal processing, and communications. These laboratories, among others, are available for undergraduate projects.

The graduate programs allow students to deepen their professional knowledge, understanding, and capability within their subspecialties. Each graduate student develops a program of study in consultation with his or her graduate advisor. Key research thrust areas in the department include:

1. Microelectronics and Nanotechnology.
2. Wireless Communications and Networking.
3. Optoelectronics.
4. Bio-Engineering.

Graduate research is encouraged in these and other areas.

Computers and computer usage are an essential part of the student's learning experience. The university provides a distributed network of about 75 high-performance workstations and over 300 PC-compatible microcomputers in public sites throughout the campus. The ECE department has state-of-the-art systems to augment and extend the generally available university systems. There are approximately 90 Workstations running the Microsoft and Linux platforms that are located in various ECE Teaching Labs. Additionally, there is an ECE Teaching Lab Linux Platform with over 40 servers that are used both for graduate research and to augment classroom learning. The systems provide an array of software for students and researchers, such as Cadence, Synopsys, Silvaco, Anaconda/Python, Nvidia CUDA Development Kit, Matlab, LabView, Xilinx, and many open source applications. The ECE Department workstations and servers are connected via high speed ethernet, which are in turn connected to the university's backbone network, and to the external world through the internet. 2. Students are not required by the department, nor the university, to own a personal computer, but many find such a tool a valuable asset.

A detailed description of the curricular programs follows with a listing of the required courses and with a listing of the departmental course offerings. The departmental courses carry the prefix ECE for electrical and computer engineering. Courses given by the Computer Science and Engineering department have the prefix CSE. Students are urged to search both listings for courses appropriate to their career goals.

Professors. Rick Blum, PhD (University of Pennsylvania); Miltiadis K. Hatalis, PhD (Carnegie Mellon University); Shalinee Kishore, PhD (Princeton University); Alan J. Snyder, PhD (The Pennsylvania State University); Chengshan Xiao, PhD (University of Sydney); Zhiyuan Yan, PhD (University of Illinois at Urbana-Champaign); Rosa Zheng, PhD (Carleton University)

Associate Professors. Yevgeny Berdichevsky, PhD (University of California, San Diego); Xiaochen Guo, PhD (University of Rochester); Sushil Kumar, PhD (Massachusetts Institute of Technology); Wenxin Liu, PhD (University Missouri Rolla); Karl H Norian, PhD (University of London); Parv Venkitasubramaniam, PhD (Cornell University)

Assistant Professors. Javad Khazaei, PhD (University of South Florida); Wujie Wen, PhD (University of Pittsburgh); Jieming Yin, PhD (University of Minnesota Twin Cities)

Professors Of Practice. Misha Cutitaru, PhD (Old Dominion Univ); Rudy Shankar, PhD (University of Delaware)

Emeriti. Fil Bartoli, PhD (Catholic University of America); Richard Decker, PhD (Lehigh University); Douglas R Frey, PhD (Lehigh University); Bruce D. Fritchman, PhD (Lehigh University); Bill Haller, MS (Lehigh University); Carl S. Holzinger, PhD (Lehigh University); Alastair D. McAulay, PhD (Carnegie Mellon University); Don Talhelm, MS (Lehigh University); Kenneth Kai-Ming Tzeng, PhD (University of Illinois at Urbana-Champaign); Meghanad D. Wagh, PhD (Indian Institute of Technology Bombay); George D. Watkins, PhD (Harvard University); Marvin H. White, PhD (Ohio State University)

UNDERGRADUATE PROGRAMS

Mission Statement for the Electrical Engineering and Computer Engineering Programs

The mission of the electrical engineering and computer engineering programs is to prepare engineers to meet the challenges of the future, to promote a sense of scholarship, leadership, and service among our graduates, to instill in the students the desire to create, develop, and disseminate new knowledge, and to provide international leadership to the electrical engineering and computer engineering professions.

Program Educational Objectives in Electrical Engineering and Computer Engineering

It is expected that our alumni will:

1. Be valued as dependable and technically proficient electrical engineers across a wide variety of fields, industries, non-profit organizations, national laboratories, entrepreneurial endeavors or in the pursuit of graduate education;
2. Pursue life-long learning and professional development to advance their knowledge and skills for successful and rewarding careers,
3. function and communicate effectively individually and in a team environment, contribute to multi-disciplinary projects, and attain leadership positions in their chosen profession, communities, and the global society, and
4. function as responsible members of society with an awareness of the professional responsibilities and the global, social and the ethical ramifications associated with their work.

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

The required courses for this degree contain the fundamentals of linear circuits, systems and control theory, electronic circuits, signal theory, physical electronics, electromagnetic theory, energy conversion, digital systems, and computing techniques. A strong foundation in the physical sciences and in mathematics is required. Approved electives, chosen with the advisor's consent, are selected in preparation for graduate study or entry into industry according to individual interests. The program requires a minimum of 125 credit hours. The recommended sequence of courses follows:

First Year			
First Semester	Credits	Second Semester	Credits
ENGL 001	3	ENGL 002	3
MATH 021	4	MATH 022	4

ENGR 005	2	HSS Elective or ECO 001	3-4
Select one of the following:	5-6	Select one of the following:	5-6
CHM 030 & ENGR 010[1]		CHM 030 & ENGR 010[1]	
PHY 011 & PHY 012[1]		PHY 011 & PHY 012[1]	
	14-15		**15-17**

Second Year

First Semester	Credits	Second Semester	Credits
ECE 033	4	ECE 121	2
ECE 081	4	ECE 123	3
PHY 021 & PHY 022	5	ECE 126	3
MATH 023	4	ECE 108	4
		MATH 205	3
	17		**15**

Third Year

First Semester	Credits	Second Semester	Credits
ECE 125	3	ECE 132	3
ECE 182	1	ECE 203	3
ECE 200	1	ECE 205	3
ECE 202	3	approved technical elective[2]	6
MATH 231	3	HSS ELECTIVE	3
HSS elective or ECO 001	4		
	15		**18**

Fourth Year

First Semester	Credits	Second Semester	Credits
ECE 257	3	ECE 258	2
HSS elective	4	approved technical electives[2]	6
approved technical electives[2]	6	HSS elective	4
free elective	3	free elective	3
	16		**15**

Total Credits: 125-128

1

Required natural science courses, one taken fall semester and the other taken in spring

2

Approved technical electives are subjects in the area of science and technology. Students must select a minimum of four courses (totaling at least 12 credits) from the ECE or CSE course listings, with a minimum of two courses in one of the technical areas described in the following list. Students must also choose at least one engineering elective in either materials, mechanics, thermodynamics, fluid mechanics or physical chemistry, and at least one science elective in physics, chemistry or biology. For students interested in solid-state electronics, quantum mechanics is recommended for the science elective.

Approved Technical Electives for Electrical Engineering Requirement

Minimum of 4 ECE or CSE elective courses chosen from the new areas below.

Circuits and Power		
ECE 310	Wireless Circuits	3
ECE 313	Power Electronics	3
ECE 328	Electricity Economics	3
ECE 321	Introduction to Power Systems	3
ECE 322	Introduction to Photovoltaic Energy Systems	3
ECE 332	Design of Linear Electronic Circuits	3
ECE 333	Medical Electronics	3
ECE 337	Introduction to Micro- and Nanofabrication	3
ECE 355	Mixed Signal Circuits	3
ECE 361	Introduction to VLSI Circuits	3
ECE 363	Computer-Aided Design of Digital Systems	3
ECE 366	Neural Engineering	3
Communications and Cyber Physical Systems		
ECE 212	Control Theory	3
ECE 327	Communications & Networking for Smart Grids	3
ECE 339	Graphical Signal Processing	3
ECE 341	Fundamentals of Wireless Communications	3
ECE 342	Communication Theory	3
ECE 345	Fundamentals of Data Networks	
ECE 364	Introduction to Cryptography and Network Security	3
ECE 387	Digital Control	3
ECE 389	Control Systems Laboratory	2
Semiconductor Devices and Photonics		
ECE 308	Physics and Models of Electronic Devices	3
ECE 309	Applied Quantum Engineering	3
ECE 325	Semiconductor Lasers I	3
ECE 348	Optoelectronics Physics and Lightwave Technology	3
ECE 368	Introduction to Biophotonics and Optical Biomedical Imaging	3
ECE 375	Semiconductor Optoelectronics	3
Learning and Artificial Intelligence		
ECE 303	Accelerated Computing for Deep Learning	3
ECE 306	Autonomous Driving and Robotic Racing	3
ECE 340	Introduction to Online and Reinforcement Learning	3
ECE 343	Digital Signal Processing	3
ECE 344	Statistical Signal Processing	3
Computers		
Any CSE course except CSE 002, CSE 012, CSE 015, or CSE 252		
ECE 201	Computer Architecture	3
ECE 303	Accelerated Computing for Deep Learning	3
ECE 305	Memory Systems	3
ECE 306	Autonomous Driving and Robotic Racing	3
ECE 319	Digital System Design	3
ECE/CSE 336	Embedded Systems	3
ECE 340	Introduction to Online and Reinforcement Learning	3
ECE 345	Fundamentals of Data Networks	
ECE 364	Introduction to Cryptography and Network Security	3

Note: Special Topics (3) (The area of each course must be evaluated individually)

MINOR IN ELECTRICAL ENGINEERING

The purpose of the Electrical Engineering minor is to enable students to supplement their major with knowledge and skills that increase their ability to realize their multi-disciplinary goals and/or make them more marketable upon graduation.

Required Courses		
ECE 081	Principles of Electrical Engineering [1]	4
or ECE 083 & ECE 162	Introduction to Electrical Engineering and Electrical Laboratory	
ECE 108	Signals and Systems [2]	4
ECE 121	Electronic Circuits Laboratory	2
ECE 123	Electronic Circuits	3
Select one of the following Electrical and Computer Engineering Courses or Other Approved Elective:		3-4
ECE 033	Introduction to Computer Engineering	
ECE 125	Circuits and Systems	
ECE 126	Fundamentals of Semiconductor Devices	
ECE 136	Electromechanics	
ECE 339	Graphical Signal Processing	
ECE 341	Fundamentals of Wireless Communications	
ECE 343	Digital Signal Processing	
ECE 371	Optical Information Processing	
ECE 372	Optical Networks	
Total Credits		**16-17**

1. ECE 083 and ECE 162 plus departmental approval.
2. Mechanical Engineering substitute ME 245 Engineering Vibrations for ECE 108, by petition, but must select an additional ECE elective. Because of similar course requirements between electrical and computer engineering majors, computer engineering students wishing to minor in electrical engineering can use one required course in their major and must choose four electives, excluding required courses, from the above list to satisfy the requirements of the electrical engineering minor. Computer engineering technical electives (chosen from the above list) can be used to satisfy the requirements of the minor.

Technical minors must be declared by the end of pre-registration of the student’s sixth semester. If course requirements change or a student wishes to vary the list of courses above, a revised minor declaration form must be submitted.

BACHELOR OF SCIENCE IN COMPUTER ENGINEERING

See catalog entry for Computer Engineering (http://catalog.lehigh.edu/coursesprogramsandcurricula/engineeringandappliedscience/computerengineering/).

GRADUATE PROGRAMS

Graduate programs of study provide a balance between formal classroom instruction and research and are tailored to the individual student’s professional goals. The programs appeal to individuals with backgrounds in electrical or computer engineering, mathematics, or the physical sciences. Research is an essential part of the graduate program. Major research areas include:

Microelectronics Devices, Integrated Circuits, VLSI Design

Mixed Signal design, Silicon integrated circuit technology, processing, fabrication and testing. Semiconductor device physics, nano scale devices, CMOS VLSI logic design and verification, computer-aided design (CAD), VLSI chip architectures, computer architecture including embedded systems and systems-on-a-chip. New sensors, actuators and novel microsystems, ranging from micro-electromechanical-systems (MEMS) to chemical microreactors and Biochips.

Optoelectronics and Photonics

Fiber optic communications and networks, applications of nonlinear optics, optical switching, novel devices, and optical computing. Freespace optical communication systems. Terahertz generation, amplification, detection, and applications, nanostructures and nanodevices. Biophotonics.

The Master of Science degree requires the completion of 30 credit hours of work that may include a six credit hour thesis for the EE and CompE degrees. A program of study must be submitted in compliance with the graduate school regulations. An oral presentation of the thesis is required.

The Master of Engineering degree requires the completion of 30 credit hours of work, which includes design-oriented courses and an engineering project. A program of study must be submitted in compliance with the college rules. An oral presentation of the project is required.

The Ph.D. degree in electrical engineering requires the completion of 42 credit hours of work (including the dissertation) beyond the master's degree (48 hours if the master's degree is non-Lehigh), the passing of a departmental qualifying examination appropriate to each degree within one year after entrance into the degree program, the passing of a general examination in the candidate's area of specialization, the admission into candidacy, and the writing and defense of a dissertation. Competence in a foreign language is not required.

The ECE Department has a core curriculum requirement for graduate students in each of the degree programs. The purpose of this requirement is to guarantee that all students pursuing graduate studies in the department acquire an appropriate breadth of knowledge of their discipline.

Electrical Engineering

To satisfy the core curriculum requirements in Electrical Engineering:

Select three courses from the following five different areas:		9
ECE 401	Advanced Computer Architecture	
ECE 402	Advanced Electromagnetics	
ECE 441	Fundamentals of Wireless Communications	
ECE 420	Advanced Circuits and Systems	
ECE 451	Physics of Semiconductor Devices	
Total Credits		**9**

Computer Engineering

See catalog entry for Computer Engineering (http://catalog.lehigh.edu/coursesprogramsandcurricula/engineeringandappliedscience/computerengineering/).

M.S. in Photonics

The Masters of Science degree in Photonics is an interdisciplinary degree that is designed to provide students with a broad training experience in the various aspects of photonics, including topics in Physics, Electrical Engineering and Materials Science and Engineering. It covers both theoretical and practical topics in areas such as fiber optics, integrated optics, lasers, nonlinear optics and optical materials to prepare the students to work in industry directly after graduation. The program is also designed so as to make it possible for students who wish to continue on for a Ph.D. to still satisfy the requirements of their individual departments for the more advanced degree. For details on this program, see the separate catalog section under Interdisciplinary Graduate Study and Research.

DEPARTMENTAL COURSES

Courses are listed under the prefixes ECE and CSE. Generally, electrical engineering courses carry the ECE prefix and appear in the following listing. Computer science courses carry the CSE prefix. Computer engineering courses are found under either prefix. The CSE courses are listed in the Computer Science and Engineering department section in this catalog. The reader should consult both listings.

Courses

ECE 033 Introduction to Computer Engineering 0,4 Credits
Analysis, design and implementation of small digital circuits. Boolean algebra. Minimization techniques, synchronous sequential circuit design, number systems and arithmetic. Microcomputer architecture and assembly level programming.
Prerequisites: CSE 017 or ENGR 010 or ENGR 097

ECE 081 Principles of Electrical Engineering 0,4 Credits
Circuit elements and laws. Behavior of simple linear networks, include equivalent circuits and solution techniques. Solution of DC circuits and AC circuits using phasor techniques. Introduction to operational amplifiers. Steady state and transient response of simple circuits. Includes a weekly session for review and discussion. May not be taken with ECE 083 for credit.
Prerequisites: (MATH 022 or MATH 096) and PHY 021
Can be taken Concurrently: PHY 021

ECE 083 Introduction to Electrical Engineering 3 Credits
Circuit elements and laws. Behavior of simple linear networks. Characteristics of electronic circuits and modeling. Introduction to functional circuits, such as operational amplifiers, instrumentation amplifiers, and power systems. Introduction to basic filters and data converters. May not be taken with ECE 081 for credit.
Prerequisites: MATH 022 and PHY 021
Can be taken Concurrently: PHY 021

ECE 108 Signals and Systems 0,4 Credits
Continuous and discrete signal and system descriptions using signal space and transform representations. Includes Fourier series, continuous and discrete Fourier transforms, Laplace transforms, and z-transforms. Introduction to sampling.
Prerequisites: ECE 081

ECE 121 Electronic Circuits Laboratory 0,2 Credits
One lecture and one laboratory per week. Experiments illustrating the principles of operation of electronic devices and their circuit applications. Basic electronic instrumentation and measurement techniques.
Prerequisites: ECE 081

ECE 123 Electronic Circuits 3 Credits
Methods for analyzing and designing circuits containing electronic devices. Topics include device models, basic amplifier configurations, operating point stabilization, frequency response analysis, and computer-aided analysis of active circuits.
Prerequisites: ECE 081

ECE 125 Random Signals and Learning 3 Credits
Formulation of linear circuit equations in the time and frequency domain. Complete solutions of difference and differential equations. Network theorems. Basic stability and feedback concepts. Modulation theory, sampling theory and basic digital signal processing ideas.
Prerequisites: ECE 108 and (MATH 231 or MATH 263)
Can be taken Concurrently: MATH 231, MATH 263

ECE 126 Fundamentals of Semiconductor Devices 3 Credits
Introduction to the physics of semiconductors in terms of atomic bonding and electron energy bands in solids. Charge carriers in semiconductors and carrier concentration at thermal equilibrium. Principles of electron and hole transport, drift and diffusion currents, generation and recombination processes, continuity. Treatment of semiconductor devices including p-n junctions, bipolar junction transistors and field effect transistors.
Prerequisites: ECE 081

ECE 128 FPGA Laboratory 0,3 Credits
Implementation issues and techniques for digital logic design; combinational and sequential logic design using digital ICs; hardware description languages; field programmable gate arrays (FPGAs); designs with modular building blocks; and functional simulations will be covered in this course.
Prerequisites: ECE 033

ECE 132 Microcontroller Laboratory 0,3 Credits
Basic digital logic and circuitry. Architecture of microcontrollers. Number conversion and data encoding in microcontrollers. Input and output of microcontrollers. Timers and interrupt routines. Serial communication protocols. Data acquisition, control, sensors, and actuators. Basic software techniques of programming microcontrollers.
Prerequisites: ECE 033

ECE 136 Electromechanics 0-3 Credits
Two lectures and one laboratory per week. An experimental introduction to electromechanical energy conversion. Basic concepts of magnetic fields and forces and their application to electrical apparatus including electromechanical transducers, transformers, AC and DC machines.
Prerequisites: ECE 081

ECE 138 Digital Systems Laboratory 2 Credits
Implementation issues and techniques for digital logic design. Combinational and sequential logic design using standard integrated circuits. I/O and interrupt processing. Design and implementation of real-time complex digital logic using microprocessor systems.
Prerequisites: ECE 033

ECE 162 Electrical Laboratory 1 Credit
Experiments on circuits, machines, and electronic devices. Elementary network theory. Survey laboratory for students not majoring in electrical or computer engineering.
Prerequisites: ECE 081 or ECE 083
Can be taken Concurrently: ECE 081, ECE 083

ECE 182 Junior Laboratory 1 Credit
Experiments designed to exploit the students understanding of basic circuits and filters. Experiments designed to help students understand basic signals and systems concepts such as time-frequency domain duality, power measurement, modulation, sampling and data conversion. Students are introduced to a variety of integrated circuits including multipliers, analog switches, digital electronics, S/H, A/D, and D/A converters. Computer software design aids, especially Spice and LabView, are used throughout the semester. One three-hour laboratory per week.
Prerequisites: ECE 033 and ECE 121 and ECE 123

ECE 200 Electrical and Computer Engineering Seminar 1 Credit
This course provides a comprehensive overview of the field of Electrical and Computer Engineering. Different research areas in the field will be discussed through weekly seminars. The seminars will cover relevant and cutting edge topics in signal processing and machine learning, communication and cyber physical systems, high performance computing and computing architectures, semiconductors and quantum engineering, electronic circuits and power systems, and bio-electrical engineering.

ECE 201 Computer Architecture 3 Credits
Structure and function of digital computers. Computer components and their operations. Computer interconnection structures. Memory system and cache memory. Interrupt driven input/output and direct memory access. Instruction sets and addressing modes. Instruction pipelining. Floating-point representation and arithmetic. Alternative architectures: RISC vs. CISC and introduction to parallel architectures.
Prerequisites: ECE 033

ECE 202 Introduction to Electromagnetics 3 Credits
Elements of vector analysis, Coulomb's law, Biot-Savart's and Ampere's laws, Lorentz Forces, Laplace's, and Maxwell's equations, boundary conditions, methods of solution in static electric and magnetic fields, including finite element numerical approach. Quasistationary fields, inductance.
Prerequisites: MATH 205 and PHY 021

ECE 203 Introduction to Electromagnetic Waves 3 Credits
Uniform plane waves in free space and in materials, skin effect. Waves in transmission lines and waveguides, including optical fibers. Energy and power flow, Poynting's theorem. Reflection and refraction. Resonators. Radiation and diffraction.
Prerequisites: ECE 202

ECE 205 C/C++ Programming 3 Credits
Introduction to C/C++ programming language and algorithms to solve engineering problems. Topics include data types, operators, flow control statements, loops, functions, structures, classes, and search and sort algorithm. Several programming projects are assigned throughout the course.
Prerequisites: ENGR 010

ECE 212 Control Theory 3 Credits
Introduction to feedback control. Dynamic analysis of linear feedback systems in the time and frequency domain, with emphasis on stability and steady-state accuracy. Major analytical tools: signal-flow graphs, root-locus methods. Nyquist plot, Bode analysis. Cascade compensation techniques.
Prerequisites: ECE 125

ECE 256 Honors Project 1 Credit
Open by invitation only to students who have completed ECE 257, Senior Project. Selection is based upon the quality of the senior project with regard to ingenuity, design approach and completeness. The objective of this course is to carry the successful senior projects forward to completion of a technical paper suitable for publication or submission to a technical conference. A written paper and oral presentation are required by mid-semester. Oral presentations will be made before an appropriate public forum. Enrollment limited.

ECE 257 Senior Lab I 3 Credits
With ECE 258, provides a complete design experience for Electrical and Computer Engineers. Students are expected to identify essential project aspects crucial to success and to perform in-depth engineering evaluation and testing demonstrating that desired results can be achieved with the proposed implementation. Instruction in technical writing, product development, ethics and professional engineering, and presentation of design and research. Two three hour sessions and one additional two hour lecture per week. Must have senior status.

ECE 258 Senior Lab II 2 Credits
Continuation of ECE 257. Complete design, construction, and testing of projects selected and developed in ECE 257. Present final design reviews and project presentations. Submit a final written report. Discuss development issues, including manufacturability, patents, and ethics. Two three-hour sessions per week.
Prerequisites: ECE 257

ECE 300 Apprentice Teaching 1-4 Credits

ECE 303 Accelerated Computing for Deep Learning 3 Credits
Graphics Processing Unit (GPU) versus Computer Processing Unit (CPU), hardware architecture of parallel computers, memory allocation and data parallelism, multidimensional kernel configuration, kernel-based parallel programming, principles and patterns of parallel algorithms, application of parallel computing to deep learning neural networks. Deep Learning (DL) algorithms, such as Convolutional Neural Networks (CNN), Stochastic Gradient Descent, and back propagation algorithms. Credit will not be given for both ECE 303 and ECE 403.
Prerequisites: (ECE 201 or CSE 202) and (MATH 231 or MATH 309)

ECE 305 Memory Systems 3 Credits
Cache and memory internal implementations, timing constraints, high-performance memory controllers, advanced memory interfaces, emerging memory technologies, 3D stacked memories, and processing-in-memory architectures. Reviews of state-of-the-art research topics on energy, performance, and reliability issues in cache and memory systems.
Prerequisites: ECE 201

ECE 306 Autonomous Driving and Robotic Racing 0,3 Credits
Basic framework of autonomous robots; drive train, vehicle controls, and dynamics models; perception subsystems including sensors such as sonar, Lidar, camera, or inertial measurement units (IMU); Robotic Operating Systems (ROS), racing simulators, autonomous driving methods including reactive and deliberative methods; simultaneous localization and mapping (SLAM); path planning and race-line optimization; learning and vision with image classification and obstacle detection.
Prerequisites: ECE 108 and (MATH 205 or CSE 140)

ECE 308 Physics and Models of Electronic Devices 3 Credits
Physics of metal-semiconductor junction, p-n junctions, and MOS capacitors. Models of Schottky barrier and p-n junction diodes, JFET, MOSFET, and bipolar transistors.
Prerequisites: ECE 126

ECE 310 Wireless Circuits 3 Credits
Theory and design of high-frequency circuits for wireless communications. Transmission lines and microwave networks. Types of circuits explored include filters, amplifiers, mixers, voltage controlled oscillators (VCOs), phase locked loops (PLLs), synthesizers, modulators and demodulators, and antennae. Design using scattering parameters, Smith chart and RF/microwave CAD programs for simulation. System performance analysis based on noise figure, antenna gain and the Friis equation will be developed. Modulation techniques of AM, FM, PM, and QPSK systems will be compared based on bit error rates (BER) calculated from system parameters.
Prerequisites: ECE 203

ECE 313 Power Electronics 3 Credits
Introduction to power semiconductor devices, circuits, and applications. Diodes, thyristors, bipolar and MOS transistors, IGBTs, and other emerging types, and their use in typical power conversion circuits such as rectifiers, buck and boost converters, and dc-dc, dc-ac, and ac-ac inverters and converters. Application examples in motor drives, power supplies and HVDC transmission.
Prerequisites: ECE 081

ECE 319 Digital System Design 3 Credits
Design techniques at the register transfer level. Control strategies for hardware architectures. Implementation of microprogramming, intersystem communication and peripheral interfacing. Hardware design languages and their use in design specification, verification and simulation.
Prerequisites: ECE 138

ECE 321 Introduction to Power Systems 3 Credits
Power systems engineering relating to generation, transmission, distribution and utilization of electric power. This course introduces basic yet critical concepts of large-scale power systems. Topics include power system modeling, power flow, symmetrical faults, unsymmetrical faults, transient stability, and optimal power flow. Subject material is useful to students who pursue careers or research in electric power systems.
Prerequisites: ECE 123

ECE 322 Introduction to Photovoltaic Energy Systems 3 Credits
Basic principles for design, installation, and operation of photovoltaic energy systems. Properties of sunlight and physics of photovoltaic cells. Photovoltaic cells, modules, and arrays. Inverters and other system components. Site assessment. Design and installation of grid-connected and stand-alone PV systems. Systems operation. Maintenance, performance, and economic analysis. Relevant design and simulation tools are introduced.
Prerequisites: ECE 081

ECE 325 Semiconductor Lasers I 3 Credits
Review of elementary solid-state physics. Relationships between Fermi energy and carrier density and leakage. Introduction to optical waveguiding in simple double-heterostructures. Density of optical modes, Blackbody radiation and the spontaneous emission factor. Modal gain, modal loss, and confinement factors. Einstein's approach to gain and spontaneous emission. Periodic structures and the transmission matrix. Ingredients. A phenomenological approach to diode lasers. Mirrors and resonators for diode lasers. Gain and current relations. Credit will not be given for both ECE 325 and ECE 425.
Prerequisites: ECE 203

ECE 326 Semiconductor Lasers II 3 Credits
Continuation of Semiconductor Lasers I. Topics covered include: Gain and current relations; dynamic effects; perturbation and coupled-mode theory; dielectric waveguides; and photonic integrated circuits. Credit will not be given for both ECE 326 and ECE 426.
Prerequisites: ECE 325

ECE 327 Communications & Networking for Smart Grids 3 Credits
Overview of smart grid electricity systems. Concepts covered include power system background and operations, electricity markets, legacy grid communications, and the smart grid vision and objectives. Additional focus on relevant communications and networking technologies that enable smart grid applications, such as real-time grid monitoring, automated control, demand response, distributed energy systems, microgrids, vehicle-to-grid integration, and smart homes and buildings. Credit will not be given for both ECE 327 and ECE 427.
Prerequisites: ECE 105

ECE 328 (ECO 328) Electricity Economics 3 Credits
The course is intended primarily for students who are interested in an exploration of electricity markets around the world, risk management, operation, and the main considerations in the wake of a smart grid implementation as well as in the transition to a low carbon economy.
Repeat Status: Course may be repeated.
Prerequisites: ECO 001 and (MATH 023 or ECO 146)
Attribute/Distribution: SS

ECE 329 Power System Modeling and Computation 3 Credits
A comprehensive study of various computational methods that form the basis of many analytical studies of power systems. Topics include power system modeling, solution of linear systems, systems of nonlinear equations, sparse matrix solution techniques, numerical integration, optimization, and their applications in power system analysis. Students are enabled to make informed decisions in their use of commercial software packages and correctly interpret the results. Matlab is used extensively. ECE 329 and ECE 429 may not both be taken for credit.
Prerequisites: ECE 136 or ECE 321 or ECE 421

ECE 332 Design of Linear Electronic Circuits 3 Credits
Introduction to a variety of linear design concepts and topologies, with audio networks providing many of the concrete examples. Topics include preamplifiers, equalizers and filters, multipliers, voltage-controlled amplifiers, level detectors, and power amplifiers.
Prerequisites: ECE 123 and ECE 125
Can be taken Concurrently: ECE 125

ECE 333 Medical Electronics 3 Credits
Bioelectric events and electrical methods used to study and influence them in medicine, electrically excitable membranes, action potentials, electrical activity of muscle, the heart and brain, bioamplifiers, pulse circuits and their applications.
Prerequisites: ECE 123

ECE 336 (CSE 336) Embedded Systems 3 Credits
Use of small computers embedded as part of other machines. Limited-resource microcontrollers and state machines from high level description language. Embedded hardware: RAM, ROM, flash, timers, UARTs, PWM, A/D, multiplexing, debouncing. Development and debugging tools running on host computers. Real-Time Operating System (RTOS) semaphores, mailboxes, queues. Task priorities and rate monotonic scheduling. Software architectures for embedded systems.
Prerequisites: CSE 017

ECE 337 Introduction to Micro- and Nanofabrication 3 Credits
Survey of the standard IC fabrication processes, such as photolithography, dry and wet etching, oxidation, thin-film deposition and chemical mechanical polishing. In-depth analysis of MEMS-specific processes such as wafer bonding, wet anisotropic etching, photolithography using thick photoresist, and deep reactive ion etching of silicon. The basics of nanofabrication techniques. The fundamentals of MEMS design will be outlined. A wide variety of MEMS and NEMS devices will be discussed.
Prerequisites: (MAT 033 and MATH 231) or ECE 351

ECE 338 Quantum Electronics 3 Credits
Electromagnetic fields and their quantization. propagation of optical beams in homogeneous and lens-like media. Modulation of optical radiation. Coherent interactions of radiation fields and atomic systems. Introduction to nonlinear optics-second-harmonic generation. Parametric amplification, oscillation, and fluorescence. Third-order optical nonlinearities. Credit will not be given for both ECE 338 and ECE 438.
Prerequisites: ECE 203

ECE 339 Graphical Signal Processing 3 Credits
Application of graphical programming to mathematical principles in data analysis and signal processing. Review of digital signal processing, use of structures, arrays, charts, building virtual instruments, graphical programming for linear algebra, curve fitting, solving differential and difference equations, signal generation, DFT and FFT analysis, windowing and filtering.
Prerequisites: ECE 108

ECE 340 Introduction to Online and Reinforcement Learning 3 Credits
Review of probability and random processes, basic reinforcement learning framework, learning from streaming data, actions in response to changing environment through Markov Decision Processes, elements of artificial intelligence. Exploration-Exploitation tradeoffs through bandit problems, and different methods for reinforcement learning including dynamic programming, Monte Carlo methods, temporal difference and Q-learning. Approximate solutions for very large state space systems, policy iteration and actor critic methods, introduction of deep reinforcement learning. Credit will not be given for both ECE 340 and ECE 440.
Prerequisites: MATH 231 or MATH 309

ECE 341 Fundamentals of Wireless Communications 3 Credits
Overview of wireless communication systems basics. Cellular concept and other wireless systems. System design fundamentals. Mobile Radio Propagation Modeling: Flat, Frequency Selective, Fast, Slow fading channels, Path Loss Models. Multiple access. Modulation Techniques for wireless. Introduction to wireless networking. Wireless systems and standards. Future wireless systems.
Prerequisites: ECE 108

ECE 342 Communication Theory 3 Credits
Theory and application of analog and digital modulation. Sampling theory with application to analog-to-digital and digital-to-analog conversion techniques. Time and frequency division multiplexing. Introduction to random processes including filtering and noise problems. Introduction to statistical communication theory with primary emphasis on optimum receiver principles.
Prerequisites: ECE 125 and (MATH 309 or MATH 231)

ECE 343 Digital Signal Processing 3 Credits
Study of orthogonal signal expansions and their discrete representations, including the Discrete Fourier Transform and Walsh-Hadamard Transform. Development of fast algorithms to compute these, with applications to speech processing and communication. Introduction to the z-transform representation of numerical sequences with applications to input/output analysis of discrete systems and the design of digital filters. Analysis of the internal behavior of discrete systems using state variables for the study of stability, observability and controllability.
Prerequisites: ECE 108

ECE 344 Statistical Signal Processing 3 Credits
Introduction to random processes, covariance and spectral density, time average, stationarity, and ergodicity. Response of systems to random inputs. Sampling and quantization of random signals. Optimum filtering, estimation, and hypothesis testing.
Prerequisites: (ECE 108) and (MATH 231 or MATH 309)

ECE 345 Fundamentals of Data Networks 3 Credits
Analytical foundations in the design and evaluation of data communication networks. Fundamental mathematical models underlying network design with their applications in practical network algorithms. Layered network architecture, queuing models with applications in network delay analysis, Markov chain theory with applications in packet radio networks and dynamic programming with applications to network routing algorithms. Background on stochastic processes and dynamic programming will be reviewed. Prereq: MATH 231 and ECE125.
Prerequisites: MATH 231 and ECE 125

ECE 347 Introduction to Integrated Optics 3 Credits
Theory of dielectric waveguides (ray and wave approach). Modes in planar slab optical guides and in waveguides with graded index profiles. Coupled-mode formalism and periodic structures. Coupling of optical beams to planar structures. Switching and modulation of light in dielectric guides: phase, frequency and polarization modulators; electro-optic, acousto-optic and magneto-optic modulators. Semiconductor lasers. Fabrication of semiconductor components. Recent advances.
Prerequisites: (ECE 202 and ECE 203)

ECE 348 Fundamentals of Photonics 3 Credits
Concepts of signal generation, modulation, transmission, isolation, detection, and switching in current optical fiber networks. Classical and quantum properties of radiation and matter in optoelectronic devices. Physics of light propagation in optical waveguides, and of light generation and detection in optoelectronic devices. Fundamentals of operation of common types of discrete and integrated optical components such as light-emitting diodes and lasers, photodetectors, modulators, and optical couplers. Credit will not also be given for ECE 448. Prereq: ECE 203.
Prerequisites: ECE 203

ECE 350 Special Topics 3 Credits
Selected topics in the field of electrical and computer engineering not included in other courses.
Repeat Status: Course may be repeated.

ECE 355 Mixed Signal Circuits 3 Credits
Analysis and design of contemporary mixed signal electronic circuits, including phase-locked loops, A/D and D/A converters, sigma-delta converters, and switching power supplies. Continuous and discrete time simulation of mixed signal systems starting with operational amplifiers as a prototype feedback system using Spice and Matlab.
Prerequisites: ECE 108 and ECE 123

ECE 361 Introduction to VLSI Circuits 3 Credits
The design of Very Large Scale Integrated (VLSI) Circuits, with emphasis on CMOS Standard Cell design. Topics include MOS transistor physics, device behavior and device modeling, MOS technology and physical layout, design of combinational and sequential circuits, static and dynamic memories, and VLSI chip organization. The course includes a design project using CAE tools for layout, design rule checking, parameter extraction, and SPICE simulations for performance prediction. Two one-hour lectures and three hours of laboratory per week.
Prerequisites: ECE 123

ECE 363 Computer-Aided Design of Digital Systems 0,3 Credits
Modern digital chip design, with emphasis on key design concepts, methodology and flow using state-of-the-art electronic design automation (EDA) tools and standard cell libraries from the semiconductor industry. Topics include CMOS transistor operations, interconnect, dynamic/leakage power, delay, RTL coding, logic synthesis, static timing analysis, formal verification, RTL/gate level simulation and physical design. The course consists of a set of labs and a project built upon multiple Synopsys EDA tools, including Design Compiler, PrimeTime, Formality, VCS etc.
Prerequisites: ECE 033

ECE 364 Introduction to Cryptography and Network Security 3 Credits
Introduction to cryptography, classical cipher systems, cryptanalysis, perfect secrecy and the one time pad, DES and AES, public key cryptography covering systems based on discrete logarithms, the RSA and the knapsack systems, and various applications of cryptography. May not be taken with ECE 464 for credit. Must have junior or senior standing.

ECE 366 (BIOE 366) Neural Engineering 3 Credits
Neural system interfaces for scientific and health applications. Basic properties of neurons, signal detection and stimulation, instrumentation and microfabricated electrode arrays. Fundamentals of peripheral and central neural signals and EEG, and applications such as neural prostheses, implants and brain-computer interfaces. Closed to students who have taken BIOE 366, BIOE 466, and ECE 466.
Prerequisites: ECE 081

ECE 368 (BIOE 368) Introduction to Biophotonics and Optical Biomedical Imaging 3 Credits
Optical principles, techniques, and instruments used in biomedical research and clinical medicine. Fundamental concepts of optical imaging and spectroscopy systems, and details of light-tissue interaction. Commercial devices and instruments, as well as novel optical imaging technologies in development. Closed to students who have taken ECE 468, BIOE 368, or BIOE 468.
Prerequisites: ECE 202 or PHY 212

ECE 371 Optical Information Processing 3 Credits
Introduction to optical information processing and applications. Interference and diffraction of optical waves. 2D optical matched filters that use lenses for Fourier transforms. Methods and devices for modulating light beams for information processing, communications, and optical computing. Construction and application of holograms for optical memory and interconnections.
Prerequisites: (ECE 108 and ECE 202)

ECE 372 Optical Networks 3 Credits
Study the design of optical fiber local, metropolitan, and wide area networks. Topics include: passive and active photonic components for optical switching, tuning, modulation and amplification; optical interconnection switches and buffering; hardware and software architectures for packet switching and wavelength division multiaccess systems. The class is supported with a laboratory.
Prerequisites: (ECE 081 and ECE 202)

ECE 375 Semiconductor Optoelectronics 3 Credits
Theory and practical implementation of semiconductor optoelectronic devices. Broad coverage of the fundamentals of the propagation, modulation, generation, and detection of light. Topics include the energy transfer between photons and electron-hole pairs, light emission and absorption, radiative and non-radiative processes, electrical and optical characteristics, carrier diffusion and mobility, light extraction and trapping. Specific devices include laser diodes, light-emitting diodes, electroabsorption modulators, photodetectors, and solar cells. Credit will not be given for both ECE 375 and ECE 475.
Prerequisites: ECE 126 and ECE 202

ECE 387 (CHE 387, ME 387) Digital Control 3 Credits
Sampled-data systems; z-transforms; pulse transfer functions; stability in the z-plane; root locus and frequency response design methods; minimal prototype design; digital control hardware; discrete state variables; state transition matrix; Liapunov stability; state feedback control.
Prerequisites: CHE 386 or ECE 212 or ME 343

ECE 389 (CHE 389, ME 389) Control Systems Laboratory 2 Credits
Experiments on a variety of mechanical, electrical and chemical dynamic control systems. Exposure to state of the art control instrumentation: sensors, transmitters, control valves, analog and digital controllers. Emphasis on comparison of theoretical computer simulation predictions with actual experimental data. Lab teams will be interdisciplinary.
Prerequisites: CHE 386 or ECE 212 or ME 343

ECE 392 Independent Study 1-3 Credits
An intensive study, with report of a topic in electrical and computer engineering which is not treated in other courses. Consent of instructor required.
Repeat Status: Course may be repeated.

ECE 401 (CSE 401) Advanced Computer Architecture 3 Credits
Design, analysis and performance of computer architectures; high-speed memory systems; cache design and analysis; modeling cache performance; principle of pipeline processing, performance of pipelined computers; scheduling and control of a pipeline; classification of parallel architectures; systolic and data flow architectures; multiprocessor performance; multiprocessor interconnections and cache coherence.
Prerequisites: ECE 201

ECE 402 Advanced Electromagnetics 3 Credits
Maxwell's equations for various media and boundary geometries. Electromagnetic wave propagation through anisotropic and nonlinear media. Guided waves, layered media and resonators. Radiation, antennas, strong and weak scattering. Scalar and vector diffraction, and periodic structures. Numerical solutions for boundary value problems.
Prerequisites: (ECE 202 and ECE 203)

ECE 403 Accelerated Computing for Deep Learning 3 Credits
Graphics Processing Unit (GPU) versus Computer Processing Unit (CPU), hardware architecture of parallel computers, memory allocation and data parallelism, multidimensional kernel configuration, kernel-based parallel programming, principles and patterns of parallel algorithms, application of parallel computing to deep learning neural networks. Deep Learning (DL) algorithms, such as Convolutional Neural Networks (CNN), Stochastic Gradient Descent, and back propagation algorithms. Credit will not be given for both ECE 303 and ECE 403.
Prerequisites: (ECE 201 or CSE 202) and (MATH 231 or MATH 309)

ECE 404 (CSE 404) Computer Networks 3 Credits
Study of architecture and protocols of computer networks. The ISO model; network topology; data-communication principles, including circuit switching, packet switching and error control techniques; sliding window protocols, protocol analysis and verification; routing and flow control; local area networks; network interconnection; topics in security and privacy.

ECE 405 Memory Systems 3 Credits
Cache and memory internal implementations, timing constraints, high-performance memory controllers, advanced memory interfaces, emerging memory technologies, 3D stacked memories, and processing-in-memory architectures. Reviews of state-of-the-art research topics on energy, performance, and reliability issues in cache and memory systems. Credit may not be given for both ECE 305 and ECE 405.
Prerequisites: ECE 201

ECE 406 Autonomous Driving and Robotic Racing 0,3 Credits
Basic framework of autonomous robots; drive train, vehicle controls, and dynamics models; perception subsystems including sensors such as sonar, Lidar, camera, or inertial measurement units (IMU); Robotic Operating Systems (ROS), racing simulators, autonomous driving methods including reactive and deliberative methods; simultaneous localization and mapping (SLAM); path planning and race-line optimization; learning and vision with image classification and obstacle detection. This course is a version of ECE306 for graduate students. Credit will not be given for both ECE306 and ECE406.
Prerequisites: ECE 108 and (MATH 205 or CSE 140)

ECE 411 Information Theory 3 Credits
Introduction to information theory. Topics covered include: development of information measures for discrete and continuous spaces study of discrete-stochastic information courses, derivation of noiseless coding theorems, investigation of discrete and continuous memoryless channels, development of noisy channel coding theorems.

ECE 413 Power Electronics 3 Credits
Introduction to power semiconductor devices, circuits, and applications. Diodes, thyristors, bipolar and MOS transistors, IGBTs, and other emerging types, and their use in typical power conversion circuits such as rectifiers, buck and boost converters, and dc-dc, dc-ac, and ac-ac inverters and converters. Application examples in motor drives, power supplies and HVDC transmission. This course, a version of ECE 313 for graduate students, requires research projects and advanced assignments. Credit will not be given for both ECE 313 and ECE 413.
Prerequisites: ECE 081

ECE 414 Statistical Decision Making and Machine Learning Theory 3 Credits
Overview of Machine Learning. Overview of decision making based on data. Overview of discovery of unknown quantities based on data. Description of the popular algorithms for decision making and for discovery of unknown quantities based on data. Performance analysis via comparison to optimum methods and bounds on optimum performance for assumed models. The emphasis is on statistical analysis of various algorithms using well established statistical theory. Exposure to probability and random process theory is assumed.
Prerequisites: ECE 108 and MATH 231 or MATH 309

ECE 416 VLSI Signal Processing 3 Credits
The fundamentals of performance-driven VLSI systems for signal processing. Analysis of signal processing algorithms and architectures in terms of VLSI implementation. VLSI design methodology. Includes a design project which requires use of a set of tools installed on SUN workstations for behavioral simulation, structural simulation, circuit simulation, layout, functional simulation, timing and critical path analysis, functional testing, and performance measurement.

ECE 420 Advanced Circuits and Systems 3 Credits
Review of the fundamentals of Circuits and Systems theory, including the time and frequency domain response of linear time-invariant circuits. Equation formulation for general lumped circuits, including node voltage and loop current analysis. Basic graph theoretic properties of circuits including Tellegen's Theorem. Discussion of passivity and reciprocity including multiport network properties. State space formulation and solution of general circuits (and systems). Modern filter concepts, including synthesis techniques for active filters and externally linear filters, such as Log Domain filters. Techniques for the analysis of weakly nonlinear systems, as time permits. Must have graduate standing.
Prerequisites: ECE 125

ECE 421 Introduction to Power Systems 3 Credits
Power systems engineering relating to generation, transmission, distribution and utilization of electric power. This course introduces basic yet critical concepts of large-scale power systems. Topics include power system modeling, power flow, symmetrical faults, unsymmetrical faults, transient stability, and optimal power flow. This course, a version of ECE 321 for graduate students, requires research projects and advanced assignments. ECE 321 and ECE 421 may not both be taken for credit.
Prerequisites: ECE 123

ECE 422 Introduction to Photovoltaic Energy Systems 3 Credits
Basic principles for design, installation, and operation of photovoltaic energy systems. Properties of sunlight and physics of photovoltaic cells. Photovoltaic cells, modules, and arrays. Inverters and other system components. Site assessment. Design and installation of grid-connected and stand-alone PV systems. Systems operation. Maintenance, performance, and economic analysis. Relevant design and simulation tools are introduced. This course, a version of ECE 321 for graduate students, requires research projects and advanced assignments. Credit not given for both ECE322 and ECE422.
Prerequisites: ECE 081

ECE 425 Semiconductor Lasers I 3 Credits
Review of elementary solid-state physics. Relationships between Fermi energy and carrier density and leakage. Introduction to optical waveguiding in simple doubleheterostructures. Density of optical modes, Blackbody radiation and the spontaneous emission factor. Modal gain, modal loss, and confinement factors. Einstein's approach to gain and spontaneous emission. Periodic structures and the transmission matrix. Ingredients. A phenomenological approach to diode lasers. Mirrors and resonators for diode lasers. Gain and current relations. This course, a version of ECE 325 for graduate students, requires research projects and advanced assignments. Credit will not be given for both ECE 325 and ECE 425.
Prerequisites: ECE 203

ECE 426 Semiconductor Lasers II 3 Credits
Continuation of Semiconductor Lasers I. Topics covered include: Gain and current relations; dynamic effects; perturbation and coupled-mode theory; dielectric waveguides; and photonic integrated circuits. This course, a version of ECE326 for graduate students, requires research projects and advanced assignments. Credit will not be given for both ECE 326 and ECE 426.
Prerequisites: ECE 203

ECE 427 Communications & Networking for Smart Grids 3 Credits
Overview of smart grid electricity systems. Concepts covered include power system background and operations, electricity markets, legacy grid communications, and the smart grid vision and objectives. Additional focus on relevant communications and networking technologies that enable smart grid applications, such as real-time grid monitoring, automated control, demand response, distributed energy systems, microgrids, vehicle-to-grid integration, and smart homes and buildings. This course is a version of ECE327 for graduate students. Credit will not be given for both ECE327 and ECE427.
Prerequisites: ECE 108

ECE 428 (ECO 428) Electricity Economics 3 Credits
Course focuses on the intersection between economics & electricity systems, and market structures available in the electric energy industry. Background provided on basic economic theory applied to power systems to understand operations objectives, pricing & incentives, as well as non-perfect competition situations that arise in the network. Different dispatch optimization problems used in electricity market restructuring, approaches to solving these, and the existence of non-convex markets will be discussed. Credit will not be given for both ECO/ECE328 and ECO/ECE428.

ECE 429 Power System Modeling and Computation 3 Credits
A comprehensive study of various computational methods that form the basis of many analytical studies of power systems. Topics include power system modeling, solution of linear systems, systems of nonlinear equations, sparse matrix solution techniques, numerical integration, optimization, and their applications in power system analysis. Students are enabled to make informed decisions in their use of commercial software packages and correctly interpret the results. Matlab is used extensively. ECE 329 and ECE 429 may not both be taken for credit.
Prerequisites: ECE 136 or ECE 321 or ECE 421

ECE 432 Spread Spectrum and CDMA 3 Credits
Fading and dispersive channel model, direct sequence spread spectrum, frequency hopping spread spectrum, DS-CDMA, FH-CDMA, spread sequences and their properties, multi-user detection, PN code acquisition, wireless communication systems, industrial standards (IS-95, WCDMA, CDMA2000).

ECE 433 (CHE 433, ME 433) Linear Systems and Control 3 Credits
This course covers the following topics in linear systems and control theory: review of fundamental concepts in linear algebra, state-space representation of linear systems, linearization, time-variance and linearity properties of systems, impulse response, transfer functions and their state-space representations, solution to LTI and LTV state equations, Jordan form, Lyapunov stability, input-output stability, controllability, stabilizability, observability, detectability, Canonical forms, minimal realizations, introduction to optimal control theory, Linear Quadratic Regulator (LQR), Algebraic Riccati Equation (ARE), frequency domain properties of LQR controllers.
Prerequisites: ME 343 or ECE 212 or CHE 386

ECE 434 (CHE 434, ME 434) Multivariable Process Control 3 Credits
A state-of-the-art review of multivariable methods of interest to process control applications. Design techniques examined include loop interaction analysis, frequency domain methods (Inverse Nyquist Array, Characteristic Loci and Singular Value Decomposition) feed forward control, internal model control and dynamic matrix control. Special attention is placed on the interaction of process design and process control. Most of the above methods are used to compare the relative performance of intensive and extensive variable control structures.
Prerequisites: CHE 433 or ME 433 or ECE 433

ECE 435 Error-Correcting Codes 3 Credits
Error-correcting codes for digital computer and communication systems. Review of modern algebra concentrating on groups and finite fields. Structure and properties of linear and cyclic codes for random or burst error correction covering Hamming, Golay, Reed-Muller, BCH and Reed-Solomon codes. Decoding algorithms and implementation of decoders.

ECE 436 (CHE 436, ME 436) Systems Identification 3 Credits
The determination of model parameters from time-history and frequency response data by graphical, deterministic and stochastic methods. Examples and exercises taken from process industries, communications and aerospace testing. Regression, quasilinearization and invariant-imbedding techniques for nonlinear system parameter identification included.
Prerequisites: ECE 433 or ME 433 or ECE 433

ECE 437 (CHE 437, ME 437) Stochastic Control 3 Credits
Linear and nonlinear models for stochastic systems. Controllability and observability. Minimum variance state estimation. Linear quadratic Gaussian control problem. Computational considerations. Nonlinear control problem in stochastic systems.
Prerequisites: ME 433 or CHE 433 or ECE 433

ECE 438 Quantum Electronics 3 Credits
Electromagnetic fields and their quantization. propagation of optical beams in homogeneous and lens-like media. Modulation of optical radiation. Coherent interactions of radiation fields and atomic systems. Introduction to nonlinear optics-second-harmonic generation. Parametric amplification, oscillation, and fluorescence. Third-order optical nonlinearities. This course, a version of ECE 338 for graduate students, requires research projects and advanced assignments. Credit will not be given for both ECE 338 and ECE 438.

ECE 440 Introduction to Online and Reinforcement Learning 3 Credits
Review of probability and random processes, basic reinforcement learning framework, learning from streaming data, actions in response to changing environment through Markov Decision Processes, elements of artificial intelligence. Exploration-Exploitation tradeoffs through bandit problems, and different methods for reinforcement learning including dynamic programming, Monte Carlo methods, temporal difference and Q-learning. Approximate solutions for very large state space systems, policy iteration and actor critic methods, introduction of deep reinforcement learning. Credit will not be given for both ECE 340 and ECE 440.
Repeat Status: Course may be repeated.
Prerequisites: MATH 231 or MATH 309

ECE 441 Fundamentals of Wireless Communications 3 Credits
Characterization of mobile radio channels. Wireless information transmission: modulation/demodulation, equalization, diversity combining, coding/decoding, multiple access methods. Overview of cellular concepts and wireless networking. This course, a version of ECE 341 for graduate students, requires research projects and advanced assignments. Credit will not be given for both ECE 341 and ECE 441.
Prerequisites: ECE 342 or ECE 342

ECE 443 RF Power Amplifiers for Wireless Communications 3 Credits
Review of linear power amplifier design. Discussion of major nonlinear effects, such as high-efficiency amplifiers modes, matching network design for reduced conduction angle, overdrive and limiting effects, and switching mode amplifiers. Discussion of other nonlinear effects, efficiency enhancement and linearization techniques. Companion course to ECE 463.

ECE 445 Fundamentals of Data Networks 3 Credits
This course provides analytical foundations in the design and evaluation of data networks. Graphical and dynamical models underlying network design will be discussed with applications in practical networks such as the Internet and Social Media. Key topics covered include queuing, Dynamic Programming, Optimization and Auctions with application in network delay analysis, packet routing, cellular networking, and social media advertising. Background on probability and random processes will be reviewed. Credit will not be given for both ECE 345 and ECE 445.
Prerequisites: (MATH 231 or MATH 309) and ECE 108
Can be taken Concurrently: MATH 231, MATH 309

ECE 448 Fundamentals of Photonics 3 Credits
Overview of optical fiber communications. Optical fibers, structures and waveguiding fundamentals. Signal degradation in fibers arising from attenuation, intramodal and intermodal dispersion. Optical sources, semiconductor lasers and LEDs. Rate equations and frequency characteristics of a semiconductor laser. Coupling efficiency of laser diodes and LEDs to single-mode and multimode fibers. PIN and avalanche photodetectors. Optical receiver design. Transmission link analysis. The course is an extension of ECE 348 for graduate students and it will include research projects and advanced assignments.

ECE 450 Special Topics 1-3 Credits
Selected topics in electrical and computer engineering not covered in other courses.
Repeat Status: Course may be repeated.

ECE 451 Physics of Semiconductor Devices 3 Credits
Crystal structure and space lattices, crystal binding, lattice waves and vibrations, electrons and atoms in crystal lattices. Quantum mechanics and energy band theory, carrier statistics, Boltzmann transport theory, interaction of carriers with scattering centers, electronic and thermal conduction. Magnetic effects. Generation and recombination theory. Application to p-n junctions.
Repeat Status: Course may be repeated.
Prerequisites: ECE 126

ECE 454 Turbo Codes and Iterative Decoding 3 Credits
Capacity-approaching error correcting codes. Soft-in soft-out iterative decoding. Parallel/serial/hybrid concatenated convolutional codes—and turbo-like codes. Iterative decoding algorithms and performance analysis of parallel/serial turbo codes. Low density parity check (LDPC) codes and product codes. Code graph and message passing decoding algorithms. Turbo and LDPC code design and construction. Performance analysis using density evolution and extrinsic information transfer charts. Applications of turbo and LDPC codes.

ECE 455 Theory of Metal Semiconductor and Heterojunction Transistors 3 Credits
Physics of metal semiconductor and heterojunction field effect transistors (MESFET and HEMT). Theory of semiconductor heterojunctions. Properties of heterojunction bipolar transistors (HBT): Equivalent circuits, applications to microwave amplifiers, oscillators, and switching circuits.

ECE 460 Engineering Project 3-6 Credits
Project work in an area of student and faculty interest. Selection and direction of the project may involve interaction with industry. Consent of department required.

ECE 463 Design of Microwave Solid State Circuits 3 Credits
Equivalent circuit modeling and characterization of microwave semiconductor devices, principles of impedance matching, noise properties and circuit interaction, introduction to the design of high power and non-linear circuits.

ECE 464 Introduction to Cryptography and Network Security 3 Credits
Introduction to cryptography, classical cipher systems, cryptanalysis, perfect secrecy and the one time pad, DES and AES, public key cryptography covering systems based on discrete logarithms, the RSA and the knapsack systems, and various applications of cryptography. This graduate version of ECE 364 requires additional work. May not be taken with ECE 364 for credit. Must have graduate student status.

ECE 465 VLSI Implementation of Error Control Coding 3 Credits
Error control coding, finite field arithmetic, encoding and decoding of BCH and Reed-Solomon codes, efficient iterative decoders for convolutional and Turbo codes, message passing and high performance decoders for low-density parity-check codes.
Prerequisites: ECE 435

ECE 466 (BIOE 466) 3 Credits
Neural system interfaces for scientific and health applications. Basic properties of neurons, signal detection and stimulation, instrumentation and microfabricated electrode arrays. Fundamentals of peripheral and central neural signals and EEG, and applications such as neural prostheses, implants and brain-computer interfaces. Closed to students who have taken BIOE 366, ECE 366, or BIOE 466. Students enrolled in the course at the 400-level must complete additional advanced assignments, as defined by the course instructor.

ECE 468 (BIOE 468) Introduction to Biophotonics and Optical Biomedical Imaging 3 Credits
Optical principles, techniques, and instruments used in biomedical research and clinical medicine. Fundamental concepts of optical imaging and spectroscopy systems, and details of light-tissue interaction. Commercial devices and instruments, as well as novel optical imaging technologies in development. Closed to students who have taken BIOE 468, ECE 368, or ECE 468. Students enrolled in the course at the 400-level must complete additional advanced assignments, as defined by the course instructor.

ECE 471 Optical Information Processing 3 Credits
Introduction to optical information processing and applications. Interference and diffraction of optical waves. 2D optical matched filters that use lenses for Fourier transforms. Methods and devices for modulating light beams for information processing, communications, and optical computing. Construction and application of holograms for optical memory and interconnections. The course is an extension of ECE 371 for graduate students and it will include research projects and advanced assignments.
Prerequisites: (ECE 108)

ECE 472 Optical Networks 3 Credits
Study the design of optical fiber local, metropolitan, and wide area networks. Topics include: passive and active photonic components for optical switching, tuning, modulation and amplification; optical interconnection switches and buffering; hardware and software architectures for packet switching and wavelength division multiaccess systems. This class is supported with a laboratory. The course is an extension of ECE 372 for graduate students and it will include research projects and advanced assignments.
Prerequisites: ECE 081

ECE 475 Semiconductor Optoelectronics 3 Credits
Theory and practical implementation of semiconductor optoelectronic devices. Broad coverage of the fundamentals of the propagation, modulation, generation, and detection of light. Topics include the energy transfer between photons and electron-hole pairs, light emission and absorption, radiative and non-radiative processes, electrical and optical characteristics, carrier diffusion and mobility, light extraction and trapping. Specific devices include laser diodes, light-emitting diodes, electroabsorption modulators, photodetectors, and solar cells. Credit will not be given for both ECE 375 and ECE 475.

ECE 485 Heterojunction Materials and Devices 3 Credits
Material properties of compound semiconductor heterojunctions, quantum wells and superlattices. Strained layer epitaxy and band-gap engineering. Theory and performance of novel devices such as quantum well lasers, resonant tunneling diodes, high electron mobility transistors, and heterojunction bipolar transistors. Complementary to ECE 452.
Prerequisites: ECE 451

ECE 490 Thesis 1-6 Credits

ECE 491 Research Seminar 1-3 Credits
Regular meetings focused on specific topics related to the research interests of department faculty. Current research will be discussed. Students may be required to present and review relevant publications. Consent of instructor required.
Repeat Status: Course may be repeated.

ECE 492 Independent Study 1-3 Credits
An intensive study, with report, of a topic in electrical and computer engineering which is not treated in other courses. Consent of instructor required.
Repeat Status: Course may be repeated.

ECE 493 Solid-State Electronics Seminar 3 Credits
Discussion of current topics in solid-state electronics. Topics selected depend upon the interests of the staff and students and are allied to the research programs of the Sherman Fairchild Laboratory for Solid State Studies. Student participation via presentation of current research papers and experimental work. Consent of instructor required.
Repeat Status: Course may be repeated.

ECE 499 Dissertation 1-15 Credits
Repeat Status: Course may be repeated.