

ELECTRICAL ENGINEERING

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Electrical Engineering broadly encompasses disciplines such as microelectronics, photonics, computer engineering, signal processing, control systems, and communications. Three electrical engineering degree programs are offered, as well as a joint degree between the electrical engineering and computer science departments.

1. The B.S. in Electrical Engineering, accredited by the Engineering Accreditation Commission of ABET, Inc., is the flagship degree program and is the most challenging program in electrical engineering. This program is appropriate for highly motivated students who are interested in entering the engineering profession, and who wish for a flexible enough program to consider a variety of other career paths.
2. The B.S. in Engineering Sciences (Electrical) provides similar technical exposure and equivalent rigor as the ABET program, while retaining the flexibility for students to take a broader range of courses than those mandated by the ABET curriculum. The B.S. in Engineering Sciences (Electrical) is suitable for careers in technology and is a popular choice for those choosing academic, industrial, or entrepreneurial career paths.
3. The B.A. in Engineering Sciences (Electrical) is suitable for careers outside of technology, including managerial, financial, and entrepreneurial career options.
4. The fourth program is a joint Electrical Engineering and Computer Science B.S. degree, that offers a unique blend of electrical engineering and computer science courses that retains the rigor of both fields. This degree is a popular choice for those interested in information technology careers.

The program's educational objectives prepare students for four potential paths. An academic path qualifies graduates to enter a top-tier graduate program conducting research with broad applications or significant consequences, and eventually to teach at an academic or research institution. Graduates following an industrial path can enter a technical path or a managerial path. An entrepreneurial path allows graduates to bring broad knowledge to a startup company, which can deliver a product or service that meets societal needs. Graduates who elect a nontraditional engineering path might complete a professional program such as business, law, or medicine, to which their engineering knowledge will be valuable.

PREREQUISITES

See Electrical Engineering and Computer Science for the requirements of the joint B.S. degree

All three remaining degree programs require MATH 112 and MATH 115 if applicable, ENAS 151 or MATH 120 or higher, ENAS 130 (CPSC 100 and 112 do not fulfill this requirement), and PHYS 180, 181 or higher (PHYS 170, 171 is acceptable for the B.A. degree). Acceleration credits awarded on entrance can be used to satisfy the MATH 112 and 115 requirements. Students whose preparation exceeds the level of ENAS 151 or MATH 120 are asked to take a higher-level mathematics course instead, such as MATH 250. Similarly, students whose preparation at entrance exceeds the level of PHYS 180, 181 are asked to take higher-level physics courses instead, such as PHYS 200, 201. Students whose programming skills exceed the level of ENAS 130 are asked to take a more advanced programming course instead, such as CPSC 201; consult with the director of undergraduate studies.

REQUIREMENTS OF THE MAJOR

Because the introductory courses are common to all three degree programs, students do not usually need to make a final choice before the junior year. Each student's program must be approved by the DUS.

B.S. degree program in Electrical Engineering The ABET-accredited B.S. in Electrical Engineering requires, beyond the prerequisites, four term courses in mathematics and science and thirteen term courses covering topics in engineering. These courses include:

1. Mathematics and basic science (four term courses): ENAS 194; MATH 222 or 225; APHY 322 or equivalent; S&DS 238, or S&DS 241, or equivalent.
2. Electrical engineering and related subjects (thirteen term courses): EENG 200, 201, 202, 203, 310, 320, 325, 348, and 481 (the ABET design project senior requirement); and four engineering electives, at least three of which should be at the 400 level. MENG 390, CPSC 365 or CPSC 366, and all 400-level Computer Science courses qualify as ABET electives. The senior independent research project EENG 471 and/or EENG 472 also qualify.

The introductory engineering courses are designed such that they may be taken concurrently in the sophomore year; for example, in the fall term students may take EENG 200 and EENG 202, followed by EENG 201 and EENG 203 in the spring term. These courses may be taken in any order, with the exception of EENG 203, which requires EENG 200 as a prerequisite. In this case, it would be helpful to take ENAS 194 and/or ENAS 130 in the first year.

A sample ABET-accredited B.S. degree schedule for students who have taken the equivalent of one year of calculus in high school (and thus are not required to take MATH 112 and MATH 115) could include:

First Year: EENG 200, EENG 201, ENAS 151, PHYS 180, and PHYS 181

Sophomore: EENG 202, EENG 203, ENAS 130, ENAS 194, and MATH 222
 Junior: EENG 310, EENG 320, EENG 325, EENG 348, S&DS 238, and 1 elective
 Senior: APHY 322, EENG 481, and 3 electives

A sample schedule for students that enter into the ABET-accredited B.S. major at the sophomore year could include:

First Year: ENAS 151, ENAS 130, ENAS 194, PHYS 180, and PHYS 181
 Sophomore: EENG 200, EENG 201, EENG 202, EENG 203, and MATH 222
 Junior: EENG 310, EENG 320, EENG 325, EENG 348, S&DS 238, and 1 elective
 Senior: APHY 322, EENG 481, and 3 electives

A sample schedule for students who enter into the ABET-accredited B.S. major in the first year (and are required to take MATH 112 and MATH 115) and only seek to fulfill basic distribution requirements with no engineering courses, could be:

First Year: MATH 112, MATH 115, PHYS 180, PHYS 181, and ENAS 130
 Sophomore: ENAS 151, EENG 200, EENG 201, EENG 202, EENG 203, and MATH 222
 Junior: ENAS 194, EENG 310, EENG 320, EENG 325, EENG 348, and S&DS 238
 Senior: APHY 322, EENG 481, and 4 electives

B.S. degree program in Engineering Sciences (Electrical) This program requires fewer technical courses and allows more freedom for work in technical areas outside the traditional electrical engineering disciplines (e.g., biomedical engineering, mechanical engineering, physics, etc.). It requires thirteen technical term courses beyond the prerequisites, specifically: MATH 222 or 225; ENAS 194; EENG 200, 201, 202, 203; EENG 471 or 472 (the senior requirement), or with permission of the instructor and the director of undergraduate studies, 481; and six electives approved by the DUS, at least three of which must be at the 400 level.

For students who have taken the equivalent of one year of calculus in high school (and thus are not required to take MATH 112 and MATH 115), a sample schedule for the B.S. degree in Engineering Science (Electrical) could be:

First Year: EENG 200, EENG 201, ENAS 151, PHYS 180, and PHYS 181
 Sophomore: EENG 202, EENG 203, ENAS 130, ENAS 194, and MATH 222
 Junior: 3 electives
 Senior: EENG 471 and/or EENG 472, and 3 electives

The B.S. degree in Engineering Sciences (Electrical) requires fewer specific courses and 4 less courses overall than the ABET-accredited degree. Any of the courses required for the ABET-accredited major qualify as electives for this degree, as well as other courses with substantial electrical engineering context, subject to the approval of the DUS. For students entering the major during the sophomore year, or those that need introductory calculus in their first year, sample schedules are similar to those described for the ABET-accredited degree program, with the differences in the B.S. Engineering Sciences (Electrical) degree applied.

The flexibility during the junior and senior years in the schedule above is often used to accommodate a second major, such as Economics, Applied Physics, Computer Science, Physics, or Mechanical Engineering.

B.A. degree program in Engineering Sciences (Electrical) This program is appropriate for those planning a career in fields such as business, law, or medicine where scientific and technical knowledge is likely to be useful. It requires eight technical term courses beyond the prerequisites, specifically: MATH 222 or 225, or ENAS 194; EENG 200, 201, 202, and 471 and/or 472 (the senior requirement); and three approved electives.

Credit/D/Fail Courses taken Credit/D/Fail may not be counted toward the requirements of the major.

SENIOR REQUIREMENT

A research or design project carried out in the senior year is required in all three programs and must be approved by the DUS. Students take EENG 471, 472, or 481, present a written report, and make an oral presentation. Arrangements to undertake a project in fulfillment of the senior requirement must be made by the end of shopping period in the term in which the student will enroll in the course; by this date, a prospectus approved by the intended faculty adviser must be submitted to the DUS.

ADVISING AND APPROVAL OF PROGRAMS

All Electrical Engineering and Engineering Sciences majors must have their programs approved by the DUS. Arrangements to take EENG 471, 472, or 481 are strongly suggested to be made during the term preceding enrollment in the course. Independent research courses taken before the senior year are graded on a Pass/Fail basis but may be counted toward the requirements of the major.

REQUIREMENTS OF THE MAJOR

ELECTRICAL ENGINEERING, B.S.

Prerequisites MATH 112, 115; ENAS 151 or MATH 120 or higher; ENAS 130; PHYS 180, 181 or higher

Number of courses 17 term courses beyond prereqs, incl senior req

Specific courses required ENAS 194; MATH 222 or 225; APHY 322; S&DS 238 or S&DS 241; EENG 200, 201, 202, 203, 310, 320, 325, 348

Distribution of courses 4 engineering electives, 3 at 400 level

Senior requirement One-term design project (EENG 481)

ENGINEERING SCIENCES (ELECTRICAL), B.S. AND B.A.

Prerequisites *Both degrees* – MATH 112, 115; ENAS 151 or MATH 120 or higher; ENAS 130; *B.S.* – PHYS 180, 181 or higher; *B.A.* – PHYS 170, 171 or higher

Number of courses *B.S.* – 13 term courses beyond prereqs, incl senior req; *B.A.* – 8 term courses beyond prereqs, incl senior req

Specific courses required *B.S.* – ENAS 194; MATH 222 or 225; EENG 200, 201, 202, 203; *B.A.* – 1 from ENAS 194 or MATH 222 or 225; EENG 200, 201, 202

Distribution of courses *B.S.* – 6 electives approved by DUS, 3 at 400 level; *B.A.* – 3 electives approved by DUS

Senior requirement *B.S.* – one-term research or design project (EENG 471 or 472 or, with permission of DUS, 481); *B.A.* – one-term research or design project (EENG 471 or 472)

FACULTY OF THE DEPARTMENT OF ELECTRICAL ENGINEERING

Professors James Duncan, Jung Han, Roman Kuc, Tso-Ping Ma, Rajit Manohar, A. Stephen Morse, Kumpati Narendra, Daniel Prober, Mark Reed, Peter Schultheiss (*Emeritus*), Lawrence Staib, Hemant Tagare, Hongxing Tang, Leandros Tassioulas, J. Rimas Vaišnys, Y. Richard Yang

Associate Professors Richard Lethin (*Adjunct*), Sekhar Tatikonda, Fengnian Xia

Assistant Professors Wenjun Hu, Amin Karbasi, Jakub Szefer

Courses

EENG 200a, Introduction to Electronics Mark Reed

Introduction to the basic principles of analog and digital electronics. Analysis, design, and synthesis of electronic circuits and systems. Topics include current and voltage laws that govern electronic circuit behavior, node and loop methods for solving circuit problems, DC and AC circuit elements, frequency response, nonlinear circuits, semiconductor devices, and small-signal amplifiers. A lab session approximately every other week. After or concurrently with MATH 115 or equivalent. QR, SC

EENG 201b, Introduction to Computer Engineering Jakub Szefer

Introduction to the theoretical principles underlying the design and programming of simple processors that can perform algorithmic computational tasks. Topics include data representation in digital form, combinational logic design and Boolean algebra, sequential logic design and finite state machines, and basic computer architecture principles. Hands-on laboratory involving the active design, construction, and programming of a simple processor. QR

EENG 202a, Communications, Computation, and Control Wenjun Hu

Introduction to systems that sense, process, control, and communicate. Topics include communication systems (compression, channel coding); network systems (network architecture and routing, wireless networks, network security); estimation and learning (classification, regression); and signals and systems (linear systems, Fourier techniques, bandlimited sampling, modulation). MATLAB programming and laboratory experiments illustrate concepts. Prerequisite: MATH 115. QR

EENG 203b, Circuits and Systems Design Hong Tang

Introduction to design in a laboratory setting. A wide variety of practical systems are designed and implemented to exemplify the basic principles of systems theory. Systems include audio filters and equalizers, electrical and electromechanical feedback systems, radio transmitters and receivers, and circuits for sampling and reconstructing music. Prerequisites: EENG 200 and 202. QR, SC RP

* **EENG 235a and EENG 236b, Special Projects** Mark Reed

Faculty-supervised individual or small-group projects with emphasis on laboratory experience, engineering design, or tutorial study. Students are expected to consult the director of undergraduate studies and appropriate faculty members about ideas and suggestions for suitable topics during the term preceding enrollment. These courses may be taken at any time during the student's career. Enrollment requires permission of both the instructor and the director of undergraduate studies, and submission to the latter of a one- to two-page prospectus signed by the instructor. The prospectus is due in the departmental office one day prior to the date that the student's course schedule is due. ½ Course cr per term

EENG 310b, Signals and Systems Kumpati Narendra

Concepts for the analysis of continuous and discrete-time signals including time series. Techniques for modeling continuous and discrete-time linear dynamical systems including linear recursions, difference equations, and shift sequences. Topics include continuous and discrete Fourier analysis, Laplace and Z transforms, convolution, sampling, data smoothing, and filtering. Prerequisite: MATH 115. Recommended preparation: EENG 202. QR

EENG 320a, Introduction to Semiconductor Devices Hong Tang

An introduction to the physics of semiconductors and semiconductor devices. Topics include crystal structure; energy bands in solids; charge carriers with their statistics and dynamics; junctions, p-n diodes, and LEDs; bipolar and field-effect transistors; and device fabrication. Additional lab one afternoon per week. Prepares for EENG 325 and 401. Recommended preparation: EENG 200. PHYS 180 and 181 or permission of instructor QR, SC

EENG 325a, Electronic Circuits Fengnian Xia

Models for active devices; single-ended and differential amplifiers; current sources and active loads; operational amplifiers; feedback; design of analog circuits for particular functions and specifications, in actual applications wherever possible, using design-oriented methods. Includes a team-oriented design project for real-world applications, such as a high-power stereo amplifier design. Electronics Workbench is used as a tool in computer-aided design. Additional lab one afternoon per week. Prerequisite: EENG 200. QR RP

EENG 348b / CPSC 338b, Digital Systems Rajit Manohar

Development of engineering skills through the design and analysis of digital logic components and circuits. Introduction to gate-level circuit design, beginning with single gates and building up to complex systems. Hands-on experience with circuit design using computer-aided design tools and microcontroller programming. Recommended preparation: EENG 201. QR

EENG 401b / APHY 321b, Semiconductor Silicon Devices and Technology Tso-Ping Ma

Introduction to integrated circuit technology, theory of semiconductor devices, and principles of device design and fabrication. Laboratory involves the fabrication and analysis of semiconductor devices, including Ohmic contacts, Schottky diodes, p-n junctions, solar cells, MOS capacitors, MOSFETs, and integrated circuits. Prerequisite: EENG 320 or equivalent or permission of instructor. QR, SC

EENG 406b, Photovoltaic Energy Fengnian Xia

Survey of photovoltaic energy devices, systems, and applications, including review of optical and electrical properties of semiconductors. Topics include solar radiation, solar cell design, performance analysis, solar cell materials, device processing, photovoltaic systems, and economic analysis. Prerequisite: EENG 320 or permission of instructor. QR, SC

EENG 408a, Electronic Materials: Fundamentals and Applications Jung Han

Survey and review of fundamental issues associated with modern microelectronic and optoelectronic materials. Topics include band theory, electronic transport, surface kinetics, diffusion, materials defects, elasticity in thin films, epitaxy, and Si integrated circuits. Prerequisite: EENG 320 or permission of instructor. QR, SC

*** EENG 410b, Photonics and Optical Electronics** Jung Han

A survey of the enabling components and devices that constitute modern optical communication systems. Focus on the physics and principles of each functional unit, its current technological status, design issues relevant to overall performance, and future directions. QR, SC

*** EENG 416a, CMOS Devices and Beyond** Tso-Ping Ma

The science and technology of modern CMOS devices and circuits, as well as emerging technologies. Topics may include basic CMOS device physics; interface properties of MOS structures; hot-carrier effects; experimental techniques to probe MOS parameters; and scaling of CMOS devices. Prerequisite: EENG 320 or equivalent, or permission by instructor.

EENG 418b / APHY 418b, Advanced Electron Devices Mark Reed

The science and technology of semiconductor electron devices. Topics include compound semiconductor material properties and growth techniques; heterojunction, quantum well and superlattice devices; quantum transport; graphene and other 2D material systems. Prerequisite: EENG 320 or equivalent. QR, SC

EENG 426a / ENAS 876a, Silicon Compilation Rajit Manohar

An upper-level course on compiling computations into digital circuits using asynchronous design techniques. Emphasis is placed on the synthesis of circuits that are robust to uncertainties in gate and wire delays by the process of program transformations. Topics include circuits as concurrent programs, delay-insensitive design techniques, synthesis of circuits from programs, timing analysis and performance optimization, pipelining, and case studies of complex asynchronous designs. Prerequisite: EENG 201 and introductory programming, or permission of instructor.

EENG 434b / ENAS 496b / MATH 251b / S&DS 351b, Stochastic Processes Yihong Wu and Sahand Negahban

Introduction to the study of random processes including linear prediction and Kalman filtering, Poisson counting process and renewal processes, Markov chains, branching processes, birth-death processes, Markov random fields, martingales, and random walks. Applications chosen from communications, networking, image reconstruction, Bayesian statistics, finance, probabilistic analysis of algorithms, and genetics and evolution. Prerequisite: S&DS 241 or equivalent. QR

EENG 436a, Systems and Control Kumpati Narendra

Design of feedback control systems with applications to engineering, biological, and economic systems. Topics include state-space representation, stability, controllability, and observability of discrete-time systems; system identification; optimal control of systems with multiple outputs. Prerequisites: ENAS 194, MATH 222 or 225, and EENG 310 or permission of instructor. QR

*** EENG 437a / AMTH 437a / ECON 413a / S&DS 430a, Optimization Techniques** Sekhar Tatikonda

Fundamental theory and algorithms of optimization, emphasizing convex optimization. The geometry of convex sets, basic convex analysis, the principle of optimality, duality. Numerical algorithms: steepest descent, Newton's method, interior point methods, dynamic programming, unimodal search. Applications from engineering and the sciences. Prerequisites: MATH 120 and 222, or equivalents. May not be taken after AMTH 237. QR

* **EENG 442a / AMTH 342a, Linear Systems** A. Stephen Morse

Introduction to finite-dimensional, continuous, and discrete-time linear dynamical systems. Exploration of the basic properties and mathematical structure of the linear systems used for modeling dynamical processes in robotics, signal and image processing, economics, statistics, environmental and biomedical engineering, and control theory. Prerequisite: MATH 222 or permission of instructor. QR

* **EENG 449a / CPSC 449a, Computer Architectures and Artificial Intelligence** Richard Lethin

Introduction to the development of computer architectures specialized for cognitive processing, including both offline 'thinking machines' and embedded devices. The history of machines, from early conceptions in defense systems to contemporary initiatives. Instruction sets, memory systems, parallel processing, analog architectures, probabilistic architectures. Application and algorithm characteristics. Prerequisites: CPSC 100, CPSC 112, or equivalent programming experience; EENG 325, EENG 348, or equivalent circuits and digital logic experience; or permission of instructor. QR

EENG 450a, Applied Digital Signal Processing J. Rimas Vaišnys

An analysis, by computer, of processing requirements. Relevant probability and estimation theories applied to measurements corrupted by noise. Point estimates and system identification from random processes. MATLAB simulations verify the analysis. Prerequisite: EENG 310 or permission of instructor. QR

* **EENG 451b / CPSC 456b, Wireless Technologies and the Internet of Things** Wenjun Hu

Fundamental theory of wireless communications and its application explored against the backdrop of everyday wireless technologies such as WiFi and cellular networks. Channel fading, MIMO communication, space-time coding, opportunistic communication, OFDM and CDMA, and the evolution and improvement of technologies over time. Emphasis on the interplay between concepts and their implementation in real systems. Prerequisites: 1) Introductory courses in mathematics, engineering, or computer science covering basics of the following topics: Linux skills, Matlab programming, probability, linear algebra, and Fourier transform; 2) Or by permission of the instructor. The course material will be self-contained as much as possible. The labs and homework assignments require Linux and MatLab skills and simple statistical and matrix analysis (using built-in Matlab functions). There will be a couple of introductory labs to refresh Linux and matlab skills if needed.

* **EENG 452a, Internet Engineering** Leandros Tassioulas

Introduction to basic Internet protocols and architectures. Topics include packet-switch and multi-access networks, routing, flow control, congestion control, Internet protocols (IP, TCP, BGP), the client-server model, IP addressing and the domain name system, wireless access networks, and mobile communications. Prerequisite: a college-level course in mathematics, engineering, or computer science, or with permission of instructor. QR

EENG 454b / AMTH 364b / S&DS 364b, Information Theory Andrew Barron

Foundations of information theory in communications, statistical inference, statistical mechanics, probability, and algorithmic complexity. Quantities of information and their properties: entropy, conditional entropy, divergence, redundancy, mutual information, channel capacity. Basic theorems of data compression, data summarization, and channel coding. Applications in statistics and finance. After STAT 241. QR

* **EENG 455b, Network Algorithms and Stochastic Optimization** Leandros Tassioulas

This course focuses on resource allocation models as well as associated algorithms and design and optimization methodologies that capture the intricacies of complex networking systems in communications computing as well as transportation, manufacturing, and energy systems. Max-weight scheduling, back-pressure routing, wireless opportunistic scheduling, time-varying topology network control, and energy-efficient management are sample topics to be considered, in addition to Lyapunov stability and optimization, stochastic ordering, and notions of fairness in network resource consumption.

* **EENG 471a and EENG 472b, Advanced Special Projects** Mark Reed

Faculty-supervised individual or small-group projects with emphasis on research (laboratory or theory), engineering design, or tutorial study. Students are expected to consult the director of undergraduate studies and appropriate faculty members about ideas and suggestions for suitable topics during the term preceding enrollment. These courses may be taken at any appropriate time during the student's career and may be taken more than once. Enrollment requires permission of both the instructor and the director of undergraduate studies, and submission to the latter of a one- to two-page prospectus signed by the instructor. The prospectus is due in the departmental office one day prior to the date that the student's course schedule is due.

EENG 475a / BENG 475a / CPSC 475a, Computational Vision and Biological Perception Steven Zucker

An overview of computational vision with a biological emphasis. Suitable as an introduction to biological perception for computer science and engineering students, as well as an introduction to computational vision for mathematics, psychology, and physiology students. Prerequisite: CPSC 112 and MATH 120, or with permission of instructor. QR, SC RP

* **EENG 481b, Advanced ABET Projects** Roman Kuc

Study of the process of designing an electrical device that meets performance specifications, including project initiation and management, part specification, teamwork, design evolution according to real-world constraints, testing, ethics, and communication skills. Design project consists of electronic sensor, computer hardware, and signal analysis components developed by multidisciplinary teams. Prerequisites: EENG 310, 320, 325, and 348. RP