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.

Upon graduation, Yale’s B.S. Electrical Engineering (ABET) students are expected to achieve “student outcomes” as defined by ABET and the program. The Electrical Engineering major produces graduates who demonstrate: (1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics; (2) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors; (3) an ability to communicate effectively with a range of audiences; (4) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts; (5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives; (6) an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions; (7) an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

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 B.S. in Electrical Engineering and Computer Science, which 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 in business, law, or medicine, for which their engineering knowledge will be valuable.

PREREQUISITES

All three engineering 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 222, MATH 225, MATH 226, MATH 253, or MATH 256. 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 (DUS).

For students in the Class of 2023 and subsequent classes, prerequisites taken Credit/D/Fail may not be counted toward the requirements of the major.

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 MATH 225 or MATH 226; 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. CPSC 365 or CPSC 366, MENG 390, MENG 403, BENG 411, PHYS 430, APHY 458, and all 400-level computer science courses qualify as ABET electives. One of EENG 468 or EENG 469, Advanced Special Projects, also qualify as a 400-level elective.

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 who 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 MATH 225 or MATH 226; ENAS 194; EENG 200, 201, 202, 203; EENG 471 and/or 472 (the senior requirement), or with permission of the instructor and the DUS, 481; and five or six electives (depending on senior requirement) approved by the DUS, at least three of which must be at the 400 level. All electives listed for the ABET-accredited B.S. major qualify as electives for this degree.

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: EENG 310, EENG 320, EENG 325, EENG 348, S&DS 238, and 1 elective
Senior: APHY 322, EENG 481, and 3 electives

The B.S. degree in Engineering Sciences (Electrical) requires fewer specific courses and 4 fewer 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 who 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, MATH 225, MATH 226 or ENAS 194; EENG 200, 201, 202, and 471 and/or 472 (the senior requirement); and two (or three) approved electives.

**Credit/D/Fail** For students in the Class of 2023 and subsequent classes, courses taken Credit/D/Fail may not be counted toward the requirements of the major, including the prerequisites.

**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 and/or 472, or 481, present a written report, and make an oral presentation. Students taking both EENG 471 and
472, Senior Advanced Special Projects, may count one as an elective. Arrangements to undertake a project in fulfillment of the senior requirement must be made by the end of the course selection 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 (EENG 468 or EENG 469) are graded on a Pass/Fail basis, but one (1) can be counted toward the requirements of the major.

REQUIREMENTS OF THE MAJOR

ELECTRICAL ENGINEERING, B.S.

Prerequisites  MATH 112, 115 if needed; ENAS 151 or MATH 120 or higher; ENAS 130 or higher; PHYS 180, 181 or higher
Number of courses  17 term courses beyond prereqs, incl senior req
Specific courses required  ENAS 194; MATH 222 or MATH 225 or MATH 226; 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 or higher; 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 MATH 225 or MATH 226; EENG 200, 201, 202, 203; B.A.  1 from ENAS 194, MATH 222, MATH 225, or MATH 226; EENG 200, 201, 202
Distribution of courses  B.S.  5 or 6 electives approved by DUS, 3 at 400 level; B.A.  2 or 3 electives approved by DUS
Senior requirement  B.S.  one or two-term research or design project (EENG 471 and/or 472 or, with permission of DUS, 481); B.A.  one or two-term research or design project (EENG 471 and/or 472)

Electrical engineering (EE) deals with the study and application of electricity, electronics, and electromagnetism, including such topics as digital computers, power engineering, telecommunications, control systems, radio-frequency engineering, signal processing, instrumentation, and microelectronics. Electrical engineers were responsible for inventing much of today’s sophisticated technology, such as the Internet, land and air transportation systems, medical devices, and many other modern features of everyday life. Yale electrical engineer graduates are highly respected and sought after for work not only in the engineering profession, but in business, start-up ventures, management consulting, investment banking, venture finance, medicine, and intellectual property law.

Four degree programs allow students to select the level of technical depth appropriate for their individual goals.

1. The B.S. in Electrical Engineering is accredited by the Engineering Accreditation Commission of ABET, Inc., and is the department’s most intensive major program. Students are trained for engineering practice, and the curriculum culminates in a major team design project that incorporates engineering standards and realistic constraints. This program is appropriate for highly motivated students who have a strong interest in the engineering profession.

2. The B.S. in Engineering Sciences (Electrical) requires a somewhat smaller number of courses than the ABET-accredited B.S. degree, in exchange for more flexibility in course selection. This program is appropriate for students who have interest in continuing either in the engineering profession or in other postgraduate options such as graduate or professional school.

3. The B.A. in Engineering Sciences (Electrical) requires substantially fewer engineering courses. It is suitable for careers outside technology in which a student nevertheless benefits from an appreciation of electrical engineering perspectives, and it is appropriate as a second major.

4. The fourth major is a joint Electrical Engineering and Computer Science B.S. degree, and has a unique blend of electrical engineering and computer science that retains the rigor of both fields. This degree is a popular choice for those interested in information technology careers.

First-year students interested in the Electrical Engineering major typically take EENG 200 and EENG 201, both excellent introductions to the major. In the sophomore year students take EENG 202 and EENG 203. However, EENG 200 and EENG 201 need not be taken in the first year since these courses are designed such that EENG 200 and EENG 202 can be taken concurrently; as can EENG 201 and EENG 203.

It is difficult to enter the major if students do not take mathematics and physical science prerequisites during the first year. Students without high school calculus should take MATH 112 and MATH 115. First-year students with high school calculus typically take MATH 120 or ENAS 151. Potential majors are also encouraged to take PHYS 180 and PHYS 181, or PHYS 200 and PHYS 201, during the first year.
The director of undergraduate studies (DUS) of Electrical Engineering welcomes consultation with students about their program opportunities at any time. For more details, see the department website.

**FACULTY OF THE DEPARTMENT OF ELECTRICAL ENGINEERING**

**Professors** †Hui Cao, †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 Tassiulas, J. Rimas Vaišnys, †Y. Richard Yang

**Associate Professors** Richard Lethin (*Adjunct, Lecturer*), Jakub Szefer, †Sekhar Tatikonda, Fengnian Xia

**Assistant Professors** Wenjun Hu, Amin Karbasi, Priyadarshini Panda

†A joint appointment with primary affiliation in another department.

**View Courses**

**Courses**

**EENG 434b / MATH 251b / S&DS 351b, Stochastic Processes** Amin Karbasi
Introduction to the study of random processes including linear prediction and Kalman filtering, Poison 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 445a / BENG 445a, Biomedical Image Processing and Analysis** James Duncan and Lawrence Staib
This course is an introduction to biomedical image processing and analysis, covering image processing basics and techniques for image enhancement, feature extraction, compression, segmentation, registration, motion analysis, and learning techniques. Student learn the fundamentals behind image processing and analysis methods and algorithms with an emphasis on biomedical applications. Prerequisite: BENG 352 or EENG 310 or permission of instructors. Recommended preparation: familiarity with probability theory.

**EENG 454b / AMTH 364b / S&DS 364b, Information Theory** Yihong Wu
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 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