# ELECTRICAL ENGINEERING

Courses offered by the Department of Electrical Engineering are listed under the subject code EE (https://explorecourses.stanford.edu/search?view=catalog&academicYear=&q=EE&filter-departmentcode-EE=on&filter-coursestatus-Active=on&filter-term-Autumn=on&filter-term-Winter=on&filter-term-Spring=on&filter-term-Summer=on&page=0) on the *Stanford Bulletin's* ExploreCourses web site.

The Department of Electrical Engineering (EE) at Stanford innovates by conducting fundamental and applied research to develop physical technologies, hardware and software systems, and information technologies; it educates future academic and industry leaders; and it prepares students for careers in industry, academia, and research labs.

Electrical Engineering has effected societal changes at the heart of the information revolution. All forms of electrical and electronic devices—both hardware and software—are a part of daily lives, whether these are in the home, personal devices, or the infrastructure of communications, information, and computation. Electrical engineers use theories and tools from mathematics and physics to develop systems ranging from smart electric grids, wired and wireless communications and networking, embedded systems, integrated electronics, imaging and sensing devices, to Internet-based information technology.

The Electrical Engineering Department offers the following degrees: Bachelor of Science, Master of Science, and Doctor of Philosophy. The department also offers joint degrees in Electrical Engineering and Law (M.S./J.D.) and Electrical Engineering and Business Administration (M.S./M.B.A.). A minor can be obtained for the Bachelor of Science and Doctor of Philosophy.

## Undergraduate Program in Electrical Engineering

The mission of the undergraduate program of the Department of Electrical Engineering is to augment the liberal education expected of all Stanford undergraduates, to impart basic understanding of electrical engineering, and to develop skills in the design and building of systems that directly impact societal needs.

The program includes a balanced foundation in the physical sciences, mathematics and computing; core courses in electronics, information systems and digital systems; and develops specific skills in the analysis and design of systems. Students in the major have broad flexibility to select from disciplinary areas beyond the core, including hardware and software, information systems and science, and physical technology and science, as well as electives in multidisciplinary areas, including bio-electronics and bio-imaging, energy and environment and music.

The program prepares students for a broad range of careers—both industrial and government—as well as for professional and academic graduate education.

### Learning Outcomes (Undergraduate)

The department expects undergraduate majors in the program to be able to demonstrate the following learning outcomes. These learning outcomes are used in evaluating students and the department's undergraduate program. The educational objectives of the program are:

1. Technical knowledge—provide a knowledge of electrical engineering principles along with the required supporting knowledge of computing, engineering fundamentals, mathematics, and science. The program must include depth in at least one disciplinary area, currently including hardware and software, information systems and science, and physical technology and science.

2. Laboratory and design skills—develop the basic skills needed to perform and design experimental projects. Develop the ability to formulate problems and projects and to plan a process for solution, taking advantage of diverse technical knowledge and skills.

3. Communications skills—develop the ability to organize and present information and to write and speak effective English.

4. Preparation for further study—provide sufficient breadth and depth for successful subsequent graduate study, postgraduate study, or lifelong learning programs.

5. Preparation for the profession—provide an appreciation for the broad spectrum of issues arising in professional practice, including economics, ethics, leadership, professional organizations, safety, service, and teamwork.

## Graduate Programs in Electrical Engineering

University regulations governing the M.S. and Ph.D. degrees are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees)" section of this bulletin.

The profession of electrical engineering demands a strong foundation in physical science and mathematics, a broad knowledge of engineering techniques, and an understanding of the relationship between technology and society. Curricula at Stanford are planned to offer the breadth of education and depth of training necessary for leadership in the profession. To engage in this profession with competence, four years of undergraduate study and at least one year of postgraduate study are recommended. For those who plan to work in highly technical development or fundamental research, additional graduate study is desirable.

The degree of Master of Science is offered under the general regulations of the University. The master's program, requiring a minimum of 45 units of graduate study, should be considered by those with the ability and desire to make a life work of professional practice or continued graduate study.

The degree of Doctor of Philosophy is offered under the general regulations of the University. The doctoral program, requiring a minimum of 135 units of graduate study, should be considered by those with the ability and desire to make a life work of research or teaching.

### Learning Outcomes (Graduate)

The purpose of the master's program is to provide students with the knowledge and skills necessary for a professional career or doctoral studies. This is done through course work providing specialization in one area of Electrical Engineering and breadth in several other areas. Areas of specialization include Circuits, Software and Hardware Systems, Communications and Networking, Physical Technology and Science, and Signal Processing, Control and Optimization.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship and the ability to conduct independent research. Through course work and guided research, the program prepares students to make original contributions in Electrical Engineering and related fields.

### Application for Admission

Applications for graduate admission in Electrical Engineering (EE) should be completed electronically at the Graduate Admissions (http://gradadmissions.stanford.edu) web site. See the Electrical Engineering graduate admissions (http://ee.stanford.edu/admissions) web site for department specific information.

# Disciplinary Areas in Electrical Engineering

Electrical Engineering spans a diverse set of intellectual disciplines and applications. The disciplines can be grouped into three overlapping and interrelated areas:

## Hardware/Software Systems

- Data Science
- Embedded Systems
- Energy-Efficient Hardware Systems
- Integrated Circuits and Power Electronics
- Secure Distributed Systems
- Software Defined Networking
- Mobile Networking

## Information Systems and Science

- Biomedical Imaging
- Communications Systems
- Control and Optimization
- Data Science
- Information Theory and Applications
- Societal Networks
- Signal Processing and Multimedia

## Physical Technology and Science

- Biomedical Devices, Sensors and Systems
- Electronic Devices
- Energy Harvesting and Conversion
- Integrated Circuits and Power Electronics
- Nanotechnology and NEMS/MEMS
- Photonics, Nanoscience and Quantum Technology

# Multidisciplinary Research

EE faculty collaborate with researchers from other departments and schools across campus. While the main applications of electrical engineering in the past four decades have been in information technology, EE tools and techniques are being increasingly applied more broadly to address major societal problems in areas such as:

## Biomedical

Research in the biomedical area utilizes engineering approaches to meet the unmet needs in diagnosis, staging, treatment, and mitigation of illnesses including cancer, diabetes, heart diseases, as well as brain disorders. Lower-cost, prevention-oriented health care delivery is critically needed, as well as new approaches to previously untreatable health conditions. Addressing these challenges requires discovering and creating fundamentally new devices and systems for critical diagnostics (sensors, imaging), therapeutic (lasers, pacemakers, and neural interfaces), and analytical (high-throughput sequencing, healthcare IT) technologies.

## Energy

Research in energy is motivated at the macro level by the rapid rise in worldwide demand for electricity and the threat of global climate change and on the micro level by the explosion in the number of mobile devices and sensors whose performance and lifetimes are limited by energy.

For additional information, see the Department of Electrical Engineering's Research (https://ee.stanford.edu/research/the-big-picture) web site.

# Electrical Engineering Course Catalog Numbering System

Electrical Engineering courses are typically numbered according to the year in which the courses are normally taken.

| Number | Year |
| --- | --- |
| 010-099 | first or second year undergraduate |
| 100-199 | second through fourth year undergraduate |
| 200-299 | mezzanine courses for advanced undergraduate or first-year graduate |
| 300-399 | second through fourth year graduate |
| 400-499 | specialized courses for advanced graduate |
| 600-799 | special summer courses |

# Undergraduate Programs in Electrical Engineering

To major in Electrical Engineering (EE), undergraduates should follow the requirements below. Students must have a program planning sheet approved by their adviser and the department once they declare the EE major. A final version of the completed and signed program sheet is due to the department no later than one month prior to the last quarter of senior year. Program sheets are available at http://ughb.stanford.edu. Students must receive at least a 2.0 grade point average (GPA) in courses taken for the EE major; all classes must be taken for a letter grade.

Students interested in a minor should consult the "Minor in Electrical Engineering (p. 6)" tab of this section of this bulletin.

A Stanford undergraduate may work simultaneously toward the B.S. and M.S. degrees. See the Master's tab (p. 6) of this section of the bulletin.

# Electrical Engineering (EE)

Completion of the undergraduate program in Electrical Engineering leads to the conferral of the Bachelor of Science in Electrical Engineering.

## Mission of the Undergraduate Program in Electrical Engineering

The mission of the undergraduate program of the Department of Electrical Engineering is to augment the liberal education expected of all Stanford undergraduates, to impart basic understanding of electrical engineering and to develop skills in the design and building of systems that directly impact societal needs.

The program includes a balanced foundation in the physical sciences, mathematics and computing; core courses in electronics, information systems and digital systems; and develops specific skills in the analysis and design of systems. Students in the major have broad flexibility to select from disciplinary areas beyond the core, including hardware and software, information systems and science, and physical technology and science, as well as electives in multidisciplinary areas, including bio-electronics and bio-imaging, energy and environment and music.

The program prepares students for a broad range of careers—both industrial and government—as well as for professional and academic graduate education.

## Requirements

### Mathematics [1]

| | | Units |
|---|---|---|
| Select one sequence: May also be satisfied with AP Calculus. | | 10 |
| MATH 19 & MATH 20 & MATH 21 | Calculus and Calculus and Calculus | |
| Select one 2-course sequence: | | 10 |
| CME 100 & CME 102 | Vector Calculus for Engineers and Ordinary Differential Equations for Engineers (Same as ENGR 154 and ENGR 155A) | |
| MATH 51 & MATH 53 | Linear Algebra, Multivariable Calculus, and Modern Applications and Ordinary Differential Equations with Linear Algebra [2] | |
| EE Math. One additional 100-level course. Select one: | | 3 |
| EE 103 | Introduction to Matrix Methods (Preferred) [1] | |
| MATH 113 | Linear Algebra and Matrix Theory | |
| CS 103 | Mathematical Foundations of Computing | |
| Statistics/Probability. Select one: | | 3-4 |
| EE 178 | Probabilistic Systems Analysis (Preferred) | |
| CS 109 | Introduction to Probability for Computer Scientists | |

### Science [1]

| | | |
|---|---|---|
| Minimum 12 units | | |
| Select one sequence: | | 12 |
| PHYSICS 41 & EE 42 | Mechanics and Introduction to Electromagnetics and Its Applications [3] | |
| PHYSICS 41 & PHYSICS 43 | Mechanics and Electricity and Magnetism [3] | |
| PHYSICS 61 & PHYSICS 63 | Mechanics and Special Relativity and Electricity, Magnetism, and Waves | |
| Science elective. One additional 4-5 unit course from approved list in Undergraduate Handbook, Figure 4-2. | | 4-5 |

### Technology in Society

| | |
|---|---|
| One course, see Basic Requirement 4 in the School of Engineering section. The course taken must be on the School of Engineering Approved Courses list, Fig 4-3, the year it is taken. | 3-5 |

### Engineering Topics

Minimum 60 units comprised of: Engineering Fundamentals (minimum 10 units), Core Electrical Engineering Courses (minimum 16 units) Disciplinary Area (minimum 17 units), Electives (maximum 17 units, restrictions apply).

### Engineering Fundamentals

| | | |
|---|---|---|
| 2 courses required; minimum 10 units | | |
| Select one: | | |
| CS 106B/ENGR 70B or CS 106X/ ENGR 70X | Programming Abstractions Programming Abstractions (Accelerated) | 5 |
| Choose one Fundamental from the Approved List; Recommended: ENGR 40A and ENGR 40B or ENGR 40M (recommended before taking EE 101A); taking CS 106A or a second ENGR 40-series course not allowed for the Fundamentals elective. Choose from table in Undergraduate Handbook, Approved List. | | 5 |

### Core Electrical Engineering Courses

| | |
|---|---|
| EE 100 | The Electrical Engineering Profession [4] |
| EE 101A | Circuits I |

| | | |
|---|---|---|
| EE 102A | Signal Processing and Linear Systems I | |
| EE 108 | Digital System Design | |
| Physics of Electrical Engineering. | | 4 |
| EE 65 | Modern Physics for Engineers [5] | |

### Disciplinary Area                                                                           17

| | |
|---|---|
| Minimum 17 units, 5 courses: 1-2 Required, 1 WIM/Design and 2-3 disciplinary area electives. | |

### Writing in the Major (WIM)                                                          3-5

| | | |
|---|---|---|
| Select one. A single course can concurrently meet the WIM and Design Requirements. | | |
| EE 109 | Digital Systems Design Lab (WIM/Design) | |
| EE 133 | Analog Communications Design Laboratory (WIM/Design) | |
| EE 134 | Introduction to Photonics (WIM/Design) | |
| EE 153 | Power Electronics (WIM/Design) | |
| EE 155 | Green Electronics (WIM/Design) | |
| EE 168 | Introduction to Digital Image Processing (WIM/Design) | |
| EE 191W | Special Studies and Reports in Electrical Engineering (WIM; Department approval required) [6] | |
| EE 264W | Digital Signal Processing (WIM/Design) | |
| EE 267W | Virtual Reality (WIM/Design) | |
| CS 194W | Software Project (WIM/Design) | |

### Design Course                                                                             3-5

| | | |
|---|---|---|
| Select one. Students may select their Design course from any Disciplinary Area. | | |
| EE 109 | Digital Systems Design Lab (WIM/Design) | |
| EE 133 | Analog Communications Design Laboratory (WIM/Design) | |
| EE 134 | Introduction to Photonics (WIM/Design) | |
| EE 153 | Power Electronics (WIM/Design) | |
| EE 155 | Green Electronics (WIM/Design) | |
| EE 168 | Introduction to Digital Image Processing (WIM/Design) | |
| EE 262 | Two-Dimensional Imaging (Design) | |
| EE 264 | Digital Signal Processing (Design) [7] | |
| EE 264W | Digital Signal Processing (WIM/Design) | |
| EE 267 | Virtual Reality (Design) [7] | |
| EE 267W | Virtual Reality (WIM/Design) | |
| CS 194 | Software Project (Design) | |
| CS 194W | Software Project (WIM/Design) | |

### Electives                                                                                  17

Minimum 17 units. The elective units should be sufficient to meet the 60 unit total for the major, over and above the 40 units of Math and Science. Depending on units completed in the Diciplincary Area, elective units will be in the range of 17 units or less. Students may select electives from the disciplinary areas; from the multidisciplinary elective areas; or any combination of disciplinary and multidisciplinary areas. May include up to two additional Engineering Fundamentals, any CS 193 course and any letter graded EE courses (minus any previously noted restrictions). Freshman and Sophmore seminars, EE 191 and CS 106A do not count toward the 60 units. Students may have fewer elective units if they have more units in their disciplinary area.

[1] Math 41 and Math 42 are no longer offered and have been replaced by MATH 19, MATH 20, and MATH 21. If used for math, EE 103 may not be used as an EE disciplinary elective. PHYSICS 41E may be used in place of PHYSICS 41.

2    MATH 52 may be taken in place of MATH 51. CME 102 can be taken in place of MATH 53.

3    EE 42 may be used in place of PHYSICS 43 (if not used in EE electives area). The EE introductory class ENGR 40A and ENGR 40B or ENGR 40M may be taken concurrently with either EE 42 or PHYSICS 43. There are no prerequisites for ENGR 40A and ENGR 40B or ENGR 40M.

4    For upper division students, a 200-level seminar in their disciplinary area will be accepted, on petition.

5    Students may petition to have either PHYSICS 65 or the combination of PHYSICS 45 and PHYSICS 70 count as an alternative to EE 65.

6    EE 191W may satisfy WIM only if it is a follow-up to an REU, independent study project or as part of an honors thesis project where a faculty agrees to provide supervision of writing a technical paper and with suitable support from the Writing Center.

7    To satisfy Design, must take EE 264 or EE 267 for 4 units and complete the laboratory project.

8    A course may only be counted towards one requirement; it may not be double-counted. All courses taken for the major must be taken for a letter grade if that option is offered by the instructor. Minimum Combined GPA for all courses in Engineering Fundamentals and Depth is 2.0.

## Disciplinary Areas

|  |  | Units |
|---|---|---|
| **Hardware and Software** | | |
| EE 103 | Introduction to Matrix Methods | 3-5 |
| EE 104 | Introduction to Machine Learning | 3-5 |
| EE 180 | Digital Systems Architecture (Required) | 4 |
| EE 107 | Embedded Networked Systems | 3 |
| EE 109 | Digital Systems Design Lab (WIM/Design) | 4 |
| EE 118 | Introduction to Mechatronics | 4 |
| EE 155 | Green Electronics (Design) | 4 |
| EE 264 | Digital Signal Processing (Design) | 3-4 |
| EE 264W | Digital Signal Processing (WIM/Design) | 5 |
| EE 267 | Virtual Reality (Design) | 3-4 |
| EE 267W | Virtual Reality (WIM/Design) | 5 |
| EE 271 | Introduction to VLSI Systems | 3 |
| EE 272 | Design Projects in VLSI Systems | 3-4 |
| EE 273 | Digital Systems Engineering | 3 |
| EE 282 | Computer Systems Architecture | 3 |
| EE 285 | Embedded Systems Workshop | 2 |
| CS 107 | Computer Organization and Systems (Required prerequisite for EE 180; CS 107E preferred) | 3-5 |
| or CS 107E | Computer Systems from the Ground Up | |
| CS 108 | Object-Oriented Systems Design | 3-4 |
| CS 110 | Principles of Computer Systems | 3-5 |
| CS 131 | Computer Vision: Foundations and Applications | 3-4 |
| CS 140 | Operating Systems and Systems Programming | 3-4 |
| CS 143 | Compilers | 3-4 |
| CS 144 | Introduction to Computer Networking | 3-4 |
| CS 145 | Data Management and Data Systems | 3-4 |
| CS 148 | Introduction to Computer Graphics and Imaging | 3-4 |
| CS 149 | Parallel Computing | 3-4 |
| CS 155 | Computer and Network Security | 3 |
| CS 194W | Software Project (WIM/Design) | 3 |
| CS 221 | Artificial Intelligence: Principles and Techniques | 3-4 |
| CS 223A | Introduction to Robotics | 3 |
| CS 224N | Natural Language Processing with Deep Learning | 3-4 |
| CS 225A | Experimental Robotics | 3 |
| CS 229 | Machine Learning | 3-4 |
| CS 231A | Computer Vision: From 3D Reconstruction to Recognition | 3-4 |
| CS 231N | Convolutional Neural Networks for Visual Recognition | 3-4 |
| CS 241 | Embedded Systems Workshop | 2 |
| CS 244 | Advanced Topics in Networking | 3-4 |
| **Information Systems and Science** | | |
| EE 102B | Signal Processing and Linear Systems II (Required) | 4 |
| EE 103 | Introduction to Matrix Methods | 3-5 |
| EE 104 | Introduction to Machine Learning | 3-5 |
| EE 107 | Embedded Networked Systems | 3 |
| EE 118 | Introduction to Mechatronics | 4 |
| EE 124 | Introduction to Neuroelectrical Engineering | 3 |
| EE 133 | Analog Communications Design Laboratory (WIM/Design) | 3-4 |
| EE 155 | Green Electronics (WIM/Design) | 4 |
| EE 168 | Introduction to Digital Image Processing (WIM/Design) | 3-4 |
| EE 169 | Introduction to Bioimaging | 3 |
| EE 179 | Analog and Digital Communication Systems | 3 |
| EE 261 | The Fourier Transform and Its Applications | 3 |
| EE 262 | Two-Dimensional Imaging (Design) | 3 |
| EE 263 | Introduction to Linear Dynamical Systems | 3 |
| EE 264 | Digital Signal Processing (Design) | 3-4 |
| EE 264W | Digital Signal Processing (WIM/Design) | 5 |
| EE 267 | Virtual Reality (Design) | 3-4 |
| EE 267W | Virtual Reality (WIM/Design) | 5 |
| EE 278 | Introduction to Statistical Signal Processing | 3 |
| EE 279 | Introduction to Digital Communication | 3 |
| CS 107 | Computer Organization and Systems | 3-5 |
| CS 229 | Machine Learning | 3-4 |
| ENGR 105 | Feedback Control Design | 3 |
| ENGR 205 | Introduction to Control Design Techniques | 3 |
| **Physical Technology and Science** | | |
| EE 101B | Circuits II (Required) | 4 |
| EE 103 | Introduction to Matrix Methods | 3-5 |
| EE 107 | Embedded Networked Systems | 3 |
| EE 114 | Fundamentals of Analog Integrated Circuit Design | 3-4 |
| EE 116 | Semiconductor Devices for Energy and Electronics | 3 |
| EE 118 | Introduction to Mechatronics | 4 |
| EE 124 | Introduction to Neuroelectrical Engineering | 3 |
| EE 133 | Analog Communications Design Laboratory (WIM/Design) | 3-4 |
| EE 134 | Introduction to Photonics (WIM/Design) | 4 |
| EE 142 | Engineering Electromagnetics | 3 |
| EE 153 | Power Electronics (WIM/Design) | 3-4 |
| EE 155 | Green Electronics (WIM/Design) | 4 |

| | | |
|---|---|---|
| EE 212 | Integrated Circuit Fabrication Processes | 3 |
| EE 214B | Advanced Integrated Circuit Design | 3 |
| EE 216 | Principles and Models of Semiconductor Devices | 3 |
| EE 222 | Applied Quantum Mechanics I | 3 |
| EE 223 | Applied Quantum Mechanics II | 3 |
| EE 228 | Basic Physics for Solid State Electronics | 3 |
| EE 236A | Modern Optics | 3 |
| EE 236B | Guided Waves | 3 |
| EE 242 | Electromagnetic Waves | 3 |
| EE 247 | Introduction to Optical Fiber Communications | 3 |
| EE 264 | Digital Signal Processing (Design) | 3-4 |
| EE 264W | Digital Signal Processing (WIM/Design) | 5 |
| EE 267 | Virtual Reality (Design) | 3-4 |
| EE 267W | Virtual Reality (WIM/Design) | 5 |
| EE 271 | Introduction to VLSI Systems | 3 |
| EE 272 | Design Projects in VLSI Systems | 3-4 |
| EE 273 | Digital Systems Engineering | 3 |
| EE 282 | Computer Systems Architecture | 3 |
| CS 107 | Computer Organization and Systems | 3-5 |
| ENGR 105 | Feedback Control Design | 3 |

## Multidisciplinary Area Electives

### Bio-electronics and Bio-imaging

| | | |
|---|---|---|
| EE 101B | Circuits II | 4 |
| EE 102B | Signal Processing and Linear Systems II | 4 |
| EE 107 | Embedded Networked Systems | 3 |
| EE 124 | Introduction to Neuroelectrical Engineering | 3 |
| EE 134 | Introduction to Photonics (WIM/Design) | 4 |
| EE 168 | Introduction to Digital Image Processing (WIM/Design) | 4 |
| EE 169 | Introduction to Bioimaging | 3 |
| EE 225 | Biochips and Medical Imaging | 3 |
| BIOE 248 | Neuroengineering Laboratory | 3 |
| BIOE 131 | Ethics in Bioengineering | 3 |
| MED 275B | Biodesign Fundamentals | 4 |

### Energy and Environment

| | | |
|---|---|---|
| EE 101B | Circuits II | 4 |
| EE 103 | Introduction to Matrix Methods | 3-5 |
| EE 116 | Semiconductor Devices for Energy and Electronics | 3 |
| EE 134 | Introduction to Photonics (WIM/Design) | 4 |
| EE 151 | Sustainable Energy Systems | 3 |
| EE 153 | Power Electronics (WIM/Design) | 3-4 |
| EE 155 | Green Electronics (WIM/Design) | 4 |
| EE 168 | Introduction to Digital Image Processing (WIM/Design) | 3-4 |
| EE 180 | Digital Systems Architecture | 4 |
| EE 263 | Introduction to Linear Dynamical Systems | 3 |
| EE 293 | Energy storage and conversion: Solar Cells, Fuel Cells, Batteries and Supercapacitors | 3-4 |
| EE 293B | Fundamentals of Energy Processes | 3 |
| CEE 107A | Understanding Energy (Formerly CEE 173A) | 3-5 |
| CEE 155 | Introduction to Sensing Networks for CEE | 3-4 |
| CEE 176A | Energy Efficient Buildings | 3-4 |
| CEE 176B | 100% Clean, Renewable Energy and Storage for Everything | 3-4 |

| | | |
|---|---|---|
| ENGR 105 | Feedback Control Design | 3 |
| ENGR 205 | Introduction to Control Design Techniques | 3 |
| MATSCI 142 | Quantum Mechanics of Nanoscale Materials (Formerly MATSCI 157) | 4 |
| MATSCI 152 | Electronic Materials Engineering | 4 |
| MATSCI 156 | Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution | 3-4 |
| ME 185 | Electric Vehicle Design | 3 |
| ME 227 | Vehicle Dynamics and Control | 3 |
| ME 271E | Aerial Robot Design | 4 |
| **Music** | | |
| EE 102B | Signal Processing and Linear Systems II | 4 |
| EE 109 | Digital Systems Design Lab (WIM/Design) | 4 |
| EE 264 | Digital Signal Processing (Design) | 3-4 |
| EE 264W | Digital Signal Processing (WIM/Design) | 5 |
| MUSIC 250A | Physical Interaction Design for Music | 3-4 |
| MUSIC 256A | Music, Computing, Design I: The Art of Design | 3-4 |
| MUSIC 256B | Music, Computing, Design II: Virtual and Augmented Reality for Music | 3-4 |
| MUSIC 257 | Neuroplasticity and Musical Gaming | 3-5 |
| MUSIC 320 | Introduction to Audio Signal Processing | 2-4 |
| MUSIC 420A | Signal Processing Models in Musical Acoustics [1] | 3-4 |
| MUSIC 421A | Time-Frequency Audio Signal Processing [1] | 3-4 |
| MUSIC 422 | Perceptual Audio Coding [1] | 3 |
| MUSIC 424 | Signal Processing Techniques for Digital Audio Effects [1] | 3-4 |

[1] Best taken as a coterm student.

For additional information and sample programs see the Handbook for Undergraduate Engineering Programs (UGHB) (http://ughb.stanford.edu).

# Honors Program in Electrical Engineering

The Department of Electrical Engineering offers a program leading to a Bachelor of Science in Electrical Engineering with Honors. This program offers a unique opportunity for qualified undergraduate majors to conduct independent study and research at an advanced level with a faculty mentor, graduate students, and fellow undergraduates.

Admission to the honors program is by application. Declared EE majors with a grade point average (GPA) of at least 3.5 in Electrical Engineering are eligible to submit an application. Applications must be submitted by Autumn quarter of the senior year, be signed by the thesis adviser and second reader (one must be a member of the EE Faculty), and include an honors proposal. Students need to declare honors on Axess.

In order to receive departmental honors, students admitted to the honors program must:

1. Submit an application, including the thesis proposal, by autumn quarter of senior year signed by the thesis advisor and second reader (one must be a member of the Electrical Engineering faculty).
2. Declare the EE Honors major in Axess before the end of autumn quarter of senior year.
3. Maintain a grade point average of at least 3.5 in Electrical Engineering courses.
4. Complete at least 10 units of EE 191 or EE 191W with thesis advisor for a letter grade. EE 191 units do not count toward the required 60 units, with the exception of EE 191W if approved to satisfy WIM.
5. Submit one final copy of the honors thesis approved by the advisor and second reader to the EE Degree Progress Officer by May 15.

6. Attend poster and oral presentation held at the end of spring quarter or present in another suitable forum approved by the faculty adviser.

# Electrical Engineering (EE) Minor

The options for completing a minor in EE are outlined below. Students must complete a minimum of 23-25 units, as follows:

| | | Units |
|---|---|---|
| Select one: | | 5 |
| EE 42 | Introduction to Electromagnetics and Its Applications | |
| EE 65 | Modern Physics for Engineers | |
| ENGR 40A & ENGR 40B | Introductory Electronics and Introductory Electronics Part II | |
| ENGR 40M | An Intro to Making: What is EE | |
| Select one: | | 8 |
| Option I: | | |
| EE 101A | Circuits I | |
| EE 101B | Circuits II | |
| Option II: | | |
| EE 102A | Signal Processing and Linear Systems I | |
| EE 102B | Signal Processing and Linear Systems II | |
| Option III: | | |
| EE 102A | Signal Processing and Linear Systems I | |
| EE 103 | Introduction to Matrix Methods | |
| Option IV: | | |
| EE 108 | Digital System Design | |
| EE 180 | Digital Systems Architecture | |
| In addition, four letter-graded EE courses at the 100-level or higher must be taken (12 units minimum). CS 107 is required as a prerequisite for EE 180, but can count as one of the four classes. | | 12 |

# Master of Science in Electrical Engineering

Students with undergraduate degrees in physics, mathematics, or related sciences, as well as in various branches of engineering, are invited to apply for admission. They should typically be able to complete the master's degree in five quarters; note that many courses are not taught during the summer. Capable students without formal undergraduate preparation in electrical engineering may also be admitted for graduate study. Such students may have graduated in any field and may hold either the B.S. or B.A. degree. Graduate study in electrical engineering demands that students be adequately prepared in areas such as circuits, digital systems, fields, lab work, mathematics, and physics.

It is the student's responsibility, in consultation with an adviser, to determine whether the prerequisites for advanced courses have been met. Prerequisite courses ordinarily taken by undergraduates may be included as part of the graduate program of study. However, if the number of these are large, the proposed program may contain more than the minimum 45 units, and the time required to meet the degree requirements may be increased.

The master's degree program may provide advanced preparation for professional practice or for teaching at the junior college level. The faculty does not prescribe specific courses to be taken. Each student, with the help of a program adviser, prepares an individual program and submits it to the department for approval. The Program Proposal must be submitted to the Degree Progress Officer before the end of the first quarter of graduate study (second quarter for Honors Cooperative Program students); a final revised version is due at the beginning of the final quarter of study, prior to degree conferral. Detailed requirements and instructions are available at http://ee.stanford.edu/gradhandbook. All requirements for a master's degree must be completed within three years after the student's first term of enrollment in the master's program (five years for Honors Cooperative Program students).

## University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the "Coterminal Master's Program (http://exploredegrees.stanford.edu/cotermdegrees)" section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken during or after the first quarter of the sophomore year are eligible for consideration for transfer to the graduate career; the timing of the first graduate quarter is not a factor. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate adviser be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

# Master of Science with Distinction in Research

A student who wishes to pursue the M.S. in EE with distinction in research must first identify a faculty adviser who agrees to supervise and support the research work. The research adviser must be a member of the Academic Council and must hold an appointment in Electrical Engineering. The student and principal adviser must also identify another faculty member, who need not be in the Department of Electrical Engineering, to serve as a secondary adviser and reader for the research report. In addition, the student must complete the following requirements beyond those for the regular M.S. in EE degree:

1. *Research Experience*—The program must include significant research experience at the level of a half-time commitment over the course of three academic quarters. In any given quarter, the half-time research commitment may be satisfied by:
   a. a 50 percent appointment to a departmentally supported research assistantship,
   b. 6 units of independent study (EE 300 or EE 391)
   c. a prorated combination of the two (such as a 25 percent research assistantship supplemented by 3 units of independent study).
   d. An equivalent research experience while fully supported on a Stanford-funded or externally funded fellowship. Student and research adviser must document the planned research-experience before the quarter starts and its completion at the end. Note: Fellowship must provide full support at the 10-unit tuition level, and allow the student to pursue degree-related research in addition to his/her fulltime course enrollment. This research must be carried out under the direction of the primary or secondary adviser.

2. *Supervised Writing and Research*—In addition to the research experience outlined in the previous requirement, students must enroll in at least 3 units of independent research (EE 300 or EE 391) under the direction of their primary or secondary adviser. These units should be closely related to the research described in the first requirement, but focused more directly on the preparation of the research report described in the next section. The writing and research units described in parts (1) and (2) may be counted toward the 45 units required for the degree.

3. All independent study units (EE 300 or EE 391) must be taken for letter grades and a GPA of 3.0 (B) or better must be maintained.

4. *Research Report*—Students must complete a significant report describing their research and its conclusions. The research report represents work that is publishable in a journal or at a high-quality conference, although it is presumably longer and more expansive in scope than a typical conference paper. A copy of the research report must be submitted to the student services office in the department three weeks before the beginning of the examination period in the student's final quarter. Both the primary and secondary adviser must approve the research report before the distinction-in-research designation can be conferred.

## The Honors Cooperative Program

Many of the department's graduate students are supported by the Honors Cooperative Program (HCP), which makes it possible for academically qualified engineers and scientists in nearby companies to be part-time master's students in Electrical Engineering while continuing nearly full-time professional employment. Prospective HCP students follow the same admission process and must meet the same admission requirements as full-time master's students. For more information regarding the Honors Cooperative Program, see the "School of Engineering" section of this bulletin.

## Joint Electrical Engineering and Law Degree (M.S./J.D.)

The Department of Electrical Engineering and the School of Law offer a joint degree program leading to an M.S. degree in EE combined with a J.D. degree. The J.D./M.S. program is designed for students who wish to prepare themselves for careers that involve both Law and Electrical Engineering.

Students interested in this joint degree program must apply to and gain admission separately from the Department of Electrical Engineering and the School of Law, and as an additional step, secure consent from both academic units to pursue both degrees simultaneously. Interest in the program should be noted on a student's application to each academic unit. A student currently enrolled in either the Department of Electrical Engineering or the School of Law may apply for admission to the other academic unit and for joint degree status after commencing study in that unit.

## Joint Electrical Engineering and Master's in Business Administration Degree (M.S./M.B.A.)

The Department of Electrical Engineering and the Graduate School of Business offer a joint degree program leading to an M.S. degree in EE combined with an M.B.A. degree. The joint program offers students an opportunity to develop advanced technical and managerial skills in preparation for careers in existing and new technology ventures.

Admission to the joint M.S./M.B.A. program requires that students apply and be accepted independently to both the Electrical Engineering Department at the School of Engineering and the Graduate School of Business. Students may apply concurrently, or elect to begin their course of study in EE and apply to the GSB during their first year.

See the EE Graduate Handbook (https://stanford.box.com/s/dhubl4fllfcpuj49zn1k9b8py57l97bp) for more information about the joint degree programs.

## Doctor of Philosophy in Electrical Engineering

The University requirements for the Ph.D. degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees)" section of this bulletin.

Admission to a graduate program does not imply that the student is a candidate for the Ph.D. degree. Advancement to candidacy requires superior academic achievement, satisfactory performance on a qualifying examination, and sponsorship by two faculty members. Enrollment in EE 391, Special Studies, is recommended as a means for getting acquainted with a faculty member who might be willing to serve as the dissertation advisor.

Students admitted to the Ph.D. program must sign up to take the department qualifying examination (https://ee.stanford.edu/academics/graduate-degree-progress/quals). Students are required to pass the qualifying exam prior to the end of winter quarter of their second year of study. Students who have never taken the qualifying examination or have not passed the qualifying exam will be dismissed from the Ph.D. program for failure to progress. Such students may be allowed to complete a master's degree in Electrical Engineering instead.

Upon completion of the qualifying examination and after securing agreement by two faculty members to serve as dissertation adviser and second reader, the student files an Application for Candidacy for Doctoral Degree. The dissertation adviser must be a member of the Academic Council.  One of the two faculty members must either have a full or joint appointment in the Electrical Engineering department. Students are required to advance to candidacy prior to the end of their second year in the graduate program. Students who do not advance to candidacy by the end of their second year will be dismissed from the Ph.D. program for failure to progress. Such students may be allowed to complete a master's degree in Electrical Engineering instead.

Only after receiving department approval of the Application for Candidacy does the student become a candidate for the Ph.D. degree.

For complete requirements and additional information, see the department's web site (https://ee.stanford.edu/academics/graduate-degree-progress).

### Financial Assistance

The department awards a limited number of fellowships, teaching and course assistantships, and research assistantships to incoming graduate students. Applying for financial assistance is part of the admission application.

## Ph.D. Minor in Electrical Engineering

For a minor in Electrical Engineering, students must fulfill the M.S. degree depth requirement, complete at least 20 units of lecture course work at the 200-level or higher in Electrical Engineering courses (of which 15 units must be letter-graded), and have the Application for Ph.D. Minor approved by the EE department and the major department. A grade point average of at least 3.35 on these courses is required.

## Graduate Advising Expectations

The Department of Electrical Engineering is committed to providing academic advising in support of graduate student scholarly and

professional development. When most effective, this advising relationship entails collaborative and sustained engagement by both the adviser and the advisee. As a best practice, advising expectations should be periodically discussed and reviewed to ensure mutual understanding. Both the adviser and the advisee are expected to maintain professionalism and integrity.

Faculty advisers guide students in key areas such as selecting courses, designing and conducting research, developing of teaching pedagogy, navigating policies and degree requirements, and exploring academic opportunities and professional pathways.

Graduate students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.

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*Chair:* Stephen Boyd

*Associate Chairs:* Robert W. Dutton *(Undergraduate Education),* Fouad Tobagi *(Graduate Education),* Howard Zebker *(Admissions)*

*Academic Affairs Committee Chair:* Joseph M. Kahn

*Professors:* Nicholas Bambos, Kwabena Boahen, Dan Boneh, Stephen P. Boyd, Robert W. Dutton, Abbas El Gamal, Shanhui Fan, Bernd Girod, Andrea G. Goldsmith, Patrick Hanrahan, James S. Harris, John L. Hennessy, Lambertus Hesselink, Mark A. Horowitz, Roger T. Howe, Joseph M. Kahn, Christoforos E. Kozyrakis, Sanjay Lall, Thomas H. Lee, Nick McKeown, David A. B. Miller, Subhasish Mitra, Andrea Montanari, Boris Murmann, Dwight G. Nishimura, Oyekunle Olukotun, Brad G. Osgood, John M. Pauly, James D. Plummer, Balaji Prabhakar, Mendel Rosenblum, Krishna Saraswat, Krishna V. Shenoy, Hyongsok Tom Soh, Olav Solgaard, Fouad A. Tobagi, David Tse, Benjamin Van Roy, Jelena Vuckovic, Shan X. Wang, Tsachy Weissman, Jennifer Widom, H. S. Philip Wong, S. Simon Wong, Howard Zebker

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*Assistant Professors:* Amin Arbabian, John Duchi, Jonathan Fan, Ayfer Ozgur Aydin, Mert Pilanci, Priyanka Raina, Juan Rivas, Dorsa Sadigh, Gordon Wetzstein, Mary Wootters

*Professors (Research):* William J. Dally, Butrus Khuri-Yakub, Piero Pianetta

*Courtesy Professors:* Maneesh Agrawala, Stacey Bent, Kim Butts-Pauly, Emmanuel Candes, E.J. Chichilnisky, Amir Dembo, Utkan Demirci, David L. Dill, Gary Glover, Peter Glynn, Leonidas Guibas, Brian Hargreaves, Tony Heinz, Monica S. Lam, Craig Levin, David Liang, Michael McConnell, John C. Mitchell, Sandy Napel, John Ousterhout, Daniel Palanker, Norbert Pelc, Julius Smith, Dan Spielman, Brian Wandell, Lei Xing, Yinyu Ye

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*Courtesy Assistant Professors:* Adam de la Zerda, Surya Ganguli, Paul Nuyujukian, Marco Pavone, Dustin Schroeder, Debbie Senesky, Keith Winstein, Kuang Xu, Matei Zaharia, James Zou

*Lecturers:* Dennis Allison, Raul Camposano, Jonathan Candelaria, Andrea Di Blas, Antun Domic, Abbas Emami-Naeini, Leslie Field, J. Andrew Freeman, Timothy Gould, Patrick Groeneveld, My T. Le, Scott Murray, David Obershaw, Dan O'Neill, Ronald Quan, Jatinder Singh, Jason Stinson, James Weaver

*Adjunct Professors:* Ahmad Bahai, Rick Bahr, David Bloom, Fred M. Gibbons, Dimitry Gorinevsky, Bob S. Hu, Theodore Kamins, Fred Kish, David Leeson, Georgios Michelogiannakis, Fernando Mujica, Reza Nasiri Mahalati, Stephen Ryu, Ronald Schafer, Ashok Srivastava, David Sussillo, John Wenstrand, Sebastian Thrun

*Visiting Professor:* Wei-Zen Chen

*Visiting Associate Professor*: Matthew Gilbert