

# 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” 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, Optimization, and Machine Learning
- 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, Nanofabrication 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. These challenges are addressed by 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 before the end of the quarter following the quarter in which 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. 5)" 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 <sup>1</sup>

Select one sequence: May also be satisfied with AP Calculus. 10

MATH 19 Calculus  
& MATH 20 and Calculus  
& MATH 21 and Calculus

Select one 2-course sequence: 10

CME 100 Vector Calculus for Engineers  
& CME 102 and Ordinary Differential Equations for Engineers  
(Same as ENGR 154 and ENGR 155A)

MATH 51 Linear Algebra and Differential Calculus of Several  
& MATH 53 Variables  
and Ordinary Differential Equations with Linear  
Algebra <sup>2</sup>

EE Math. One additional 100-level course. Select one: 3

EE 103 Introduction to Matrix Methods (Preferred)

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

Minimum 12 units

Select one sequence: 12

PHYSICS 41 Mechanics  
& EE 42 and Introduction to Electromagnetics and Its  
Applications <sup>3</sup>

PHYSICS 41 Mechanics  
& PHYSICS 43 and Electricity and Magnetism <sup>3</sup>

PHYSICS 61 Mechanics and Special Relativity  
& PHYSICS 63 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/ Programming Abstractions 5  
ENGR 70B

or CS 106X/ Programming Abstractions (Accelerated)  
ENGR 70X

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 <sup>4</sup>

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 <sup>5</sup>

**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) <sup>6</sup>

EE 264W Digital Signal Processing (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) <sup>7</sup>

EE 264W Digital Signal Processing (WIM/Design)

EE 267 Virtual Reality (Design) <sup>7</sup>

CS 194 Software Project (Design)

CS 194W Software Project (WIM/Design)

**Electives** 17

Minimum 17 units. 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 Sophomore 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.

<sup>1</sup> Math 41 and Math 42 are no longer offered and have been replaced by Math 19, Math 20, and Math 21.

<sup>2</sup> MATH 52 may be taken in place of MATH 51. CME 102 can be taken in place of MATH 53.

<sup>3</sup> 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.

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

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

<sup>6</sup> 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.

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

## Disciplinary Areas

### Hardware and Software

		Units
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 213	Digital MOS Integrated Circuits	3
EE 264	Digital Signal Processing (Design)	3-4
EE 264W	Digital Signal Processing	5
EE 267	Virtual Reality	3-4
EE 271	Introduction to VLSI Systems	3
EE 272		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	Introduction to Databases	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
<b>Information Systems and Science</b>		
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 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 107	Embedded Networked Systems	3
EE 114	Fundamentals of Analog Integrated Circuit Design	3-4
EE 116	Semiconductor Device Physics	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 136		
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 213	Digital MOS Integrated Circuits	3
EE 214B	Advanced Analog 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 267	Virtual Reality (Design)	3-4
EE 271	Introduction to VLSI Systems	3
EE 272		3-4
EE 273	Digital Systems Engineering	3
EE 282	Computer Systems Architecture	3
CS 107	Computer Organization and Systems	3-5

### 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
<b>Energy and Environment</b>		
EE 101B	Circuits II	4
EE 103	Introduction to Matrix Methods	3-5
EE 116	Semiconductor Device Physics	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 293A	Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution	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	Electric Power: Renewables and Efficiency	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	3
<b>Music</b>		
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 250B	Interactive Sound Art	1-4
MUSIC 256A	Music, Computing, Design I: Art of Design for Computer Music	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 320A	Introduction to Audio Signal Processing Part I: Spectrum Analysis	3-4
MUSIC 320B	Introduction to Audio Signal Processing Part II: Digital Filters	3-4
MUSIC 420A	Signal Processing Models in Musical Acoustics <sup>1</sup>	3-4
MUSIC 421A	Audio Applications of the Fast Fourier Transform <sup>1</sup>	3-4
MUSIC 422	Perceptual Audio Coding <sup>1</sup>	3
MUSIC 424	Signal Processing Techniques for Digital Audio Effects <sup>1</sup>	3-4

<sup>1</sup> Best taken as a cotermin student.

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

### Honors Program

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:

	<b>Units</b>
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.

## 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 is 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 Office before the end of the first quarter of graduate study (second quarter for Honors Cooperative Program students); a final revised version is due early in 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://exploreddegrees.stanford.edu/cotermdegrees>)" section. University requirements for the master's degree are described in the "Graduate Degrees (<http://exploreddegrees.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/dhubl4flfcpuj49zn1k9b8py57197bp>) 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” 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, given once a year in winter quarter. Students are allowed two attempts to pass the examination. Students are required to take the exam in their first year of study. Students who have never taken the qualifying examination by the end of the second year of study 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. Students who do not pass the qualifying examination after two attempts 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 have either a full, joint or courtesy 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.

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 (<http://ee.stanford.edu/gradhandbook>).

## 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.

*Emeriti: (Professors)* Clayton W. Bates, Richard Bube, John Cioffi\*, Donald C. Cox, Von R. Eshleman, Michael J. Flynn\*, James F. Gibbons\*, Joseph W. Goodman, Robert M. Gray, Stephen E. Harris, Martin E. Hellman, Umran S. Inan\*, Thomas Kailath\*, Gordon S. Kino, Gregory T.A. Kovacs\*, Marc Levoy\*, Albert Macovski\*, Malcolm M. McWhorter, James D. Meindl, Teresa Meng, Richard H. Pantell, R. Fabian W. Pease, Leonard Tyler, Robert L. White, Bernard Widrow, Bruce A. Wooley, Yoshihisa Yamamoto; (*Associate Professor*) Bruce B. Lusignan; (*Professors, Research*) Donald L. Carpenter, Antony Fraser-Smith\*, C. Robert Helms, Leonid Kazovsky\*, Ingolf Lindau\*, David Luckham, Yoshio Nishi\*, Arogyaswami J. Paulraj, Calvin F. Quate (*\*Recalled to active duty*)

*Chair:* Abbas El Gamal (through December 2017); Stephen Boyd (effective January 2018)

*Associate Chairs:* Robert W. Dutton (*Undergraduate Education*), Olav Solgaard (*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, Hector Garcia-Molina, 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, Ada Poon, 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

*Associate Professors:* Audrey Bowden, Dawson Engler, John T. Gill III, Sachin Katti, Philip Levis, Eric Pop

*Assistant Professors:* Amin Arbabian, John Duchi, Jonathan Fan, Ayfer Ozgur Aydin, Juan Rivas, Gordon Wetzstein, Mary Wootters

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

*Courtesy Professors:* Stacey Bent, Kim Butts-Pauly, Emmanuel Candes, Amir Dembo, Utkan Demirci, David L. Dill, Per Enge, Gary Glover, Peter Glynn, Leonidas Guibas, 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, Yinyu Ye

*Courtesy Associate Professors:* Mohsen Bayati, Sigrid Close, Brian Hargreaves, Ramesh Johari, Jin Hyung Lee, Amin Saberi

*Courtesy Assistant Professors:* Adam de la Zerda, Surya Ganguli, Paul Nuyujukian, Marco Pavone, Ram Rajagopal, Debbie Senesky, Kuang Xu, James Zou

*Lecturers:* Dennis Allison, Andrea Di Blas, Abbas Emami-Naeini, Trevor Feagin, Leslie Field, J. Andrew Freeman, Fred Gibbons, My T. Le, Roger Melen, Dante Muratore, Reza Nasiri, David Obershaw, Dan O'Neill, Christopher Rowen, Jatinder Singh, James Weaver

*Adjunct Professors:* Ahmad Bahai, Rick Bahr, Fred M. Gibbons, Dimitry Gorinevsky, Bob S. Hu, Theodore Kamins, Fred Kish, David Leeson, Fernando Mujica, Guru Parulkar, Stephen Ryu, Ronald Schafer, Ashok Srivastava, David Sussillo, John Wenstrand

*Visiting Associate Professors:* Chan-Byoung Chae, Hyuk-Jun Lee, Van Tam Nguyen, Jin Hong Park, Changho Suh, Shobha Vasudevan