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. Electrical and electronic devices—realized in both hardware and software—are integral to daily life, whether in the home, in health care, in recreation, or in the infrastructure for communication 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's 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's 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
- Machine Learning
- Societal Networks
- Signal Processing and Multimedia

Physical Technology and Science

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

Multidisciplinary Research

EE faculty collaborate with researchers from other departments and schools across campus. While some of the most prominent applications of electrical engineering in the past few 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.

On the macro level, electronic loads, such as data centers, smart appliances, and electric vehicles, are poised to overtake traditional industrial loads in consumption share. Renewable energy will make up at least half of the generation mix and drive adoption of novel technologies such as storage, fuel cells, waste to power and distributed generation. Our research investigates techniques such as demand response and the use of energy storage to reduce peak demand and address variability of renewable energy.

On the micro level, we are exploring energy efficient devices, power electronics, system architectures, and network protocols, as well as ways to harvest energy from the environment for wearable devices and the Internet of things.

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 advisor 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 in the Undergraduate Handbook (https://ughb.stanford.edu). Students must receive at least a 2.0 grade point average (GPA) in courses taken for the EE major; all classes, except for classes taken from Spring 2019-2020 to Summer 2020-2021, 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

		Units
MATHEMATICS AND SCIENCE		
Minimum 40 units Math and Science combined.		
Mathematics [1]		
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
CS 103	Mathematical Foundations of Computing	
ENGR 108	Introduction to Matrix Methods (Preferred) [3]	
MATH 113	Linear Algebra and Matrix Theory	
Statistics/Probability		3-4
EE 178	Probabilistic Systems Analysis [3]	
Science		
Minimum 12 units		
Select one sequence:		12
PHYSICS 41 & EE 65	Mechanics and Modern Physics for Engineers [4]	
PHYSICS 61 & EE 65	Mechanics and Special Relativity and Modern Physics for Engineers [4]	
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		**10**
2 courses required; minimum 10 units.		
Select one:		
CS 106B	Programming Abstractions	5
or CS 106X	Programming Abstractions	
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		**16**
Minimum 16 units.		
EE 42	Introduction to Electromagnetics and Its Applications [5]	
EE 100	The Electrical Engineering Profession [6]	
EE 101A	Circuits I	
EE 102A	Signal Processing and Linear Systems I	
EE 108	Digital System Design	
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) [7]	
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 185C	Engineering a Smart Object - Adding connectivity and Putting it ALL together (Design)	
EE 262	Three-Dimensional Imaging (Design)	
EE 264	Digital Signal Processing (Design) [8]	
EE 264W	Digital Signal Processing (WIM/Design)	
EE 267	Virtual Reality (Design) [8]	
EE 267W	Virtual Reality (WIM/Design)	
CS 194	Software Project (Design)	
CS 194W	Software Project (WIM/Design)	
Electives [9]		**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 Disciplinary 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 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.

1 MATH 41 and MATH 42 are no longer offered and have been replaced by MATH 19, MATH 20, and MATH 21.

2 MATH 51 may be replaced by MATH 52. MATH 53 may be replaced by CME 102.

3 If used for math, ENGR 108 may not be used as an EE disciplinary elective. Students may petition to use CS 109 in place of EE 178.

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

5 Students may petition to use PHYSICS 43 or PHYSICS 63 in place of EE 42. 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.

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

7 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.

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

9 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 180	Digital Systems Architecture (Required)	4
EE 104	Introduction to Machine Learning	3-5
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 185C	Engineering a Smart Object - Adding connectivity and Putting it ALL together (Design)	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 272A	Design Projects in VLSI Systems I	3-4
EE 272B	Design Projects in VLSI Systems II	3-4
EE 273	Digital Systems Engineering	3
EE 282	Computer Systems Architecture	3
EE 285	Embedded Systems Workshop	3
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	3
CS 244	Advanced Topics in Networking	3-4
Information Systems and Science		
EE 102B	Signal Processing and Linear Systems II (Required)	4
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 260A	Principles of Robot Autonomy I	3-5
EE 260B	Principles of Robot Autonomy II	3-4
EE 261	The Fourier Transform and Its Applications	3
EE 262	Three-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 266	Introduction to Stochastic Control with Applications	3
EE 267	Virtual Reality (Design)	3-4
EE 267W	Virtual Reality (WIM/Design)	5
EE 269	Signal Processing for Machine Learning	3
EE 276	Information Theory	3

EE 278	Introduction to Statistical Signal Processing	3
EE 279	Introduction to Digital Communication	3
ENGR 105	Feedback Control Design	3
ENGR 205	Introduction to Control Design Techniques	3
CS 107	Computer Organization and Systems	3-5
CS 229	Machine Learning	3-4
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 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 157	Electric Motors for Renewable Energy, Robotics, and Electric Vehicles	3
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 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 272A	Design Projects in VLSI Systems I	3-4
EE 272B	Design Projects in VLSI Systems II	3-4
EE 273	Digital Systems Engineering	3
EE 282	Computer Systems Architecture	3
ENGR 105	Feedback Control Design	3
ENGR 205	Introduction to Control Design Techniques	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
EE 235	Analytical Methods in Biotechnology	3
BIOE 131	Ethics in Bioengineering	3
BIOE 248	Neuroengineering Laboratory	3
MED 275B	Biodesign Fundamentals	4
Energy and Environment		
EE 101B	Circuits II	4
EE 116	Semiconductor Devices for Energy and Electronics	3
EE 134	Introduction to Photonics (WIM/Design)	4
EE 153	Power Electronics (WIM/Design)	3-4
EE 155	Green Electronics (WIM/Design)	4
EE 157	Electric Motors for Renewable Energy, Robotics, and Electric Vehicles	3
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
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
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 227	Vehicle Dynamics and Control	3
ME 271E		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: 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 320A	Introduction to Audio Signal Processing Part I: Spectrum Analysis	3
MUSIC 320B	Introduction to Audio Signal Processing Part II: Digital Filters	3-4
MUSIC 420A	Signal Processing Models in Musical Acoustics [2]	3-4
MUSIC 421A	Time-Frequency Audio Signal Processing [2]	3-4
MUSIC 422	Perceptual Audio Coding [2]	3
MUSIC 424	Signal Processing Techniques for Digital Audio Effects [2]	3-4

[1] ENGR 108 may be used for disciplinary area if not used for EE Math.
[2] 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 advisor 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 adviser 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 advisor.

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	
ENGR 108	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 advisor, 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 are assigned as program advisors who provide guidance in course selection and in exploring academic opportunities and professional pathways. Each student, with the help of a program advisor, 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 the EE Grad Handbook (http://ee.stanford.edu/gradhandbook/) website. 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 advisor 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 advisor 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 advisor must also identify another faculty member, who need not be in the Department of Electrical Engineering, to serve as a secondary advisor 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 advisor 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 advisor.
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 advisor. 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, except for classes taken in Spring 2019-2020, 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 advisor must approve the research report before the distinction-in-research designation can be conferred.

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 advisor and second reader, the student files an Application for Candidacy for Doctoral Degree. The dissertation advisor 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, except for courses taken in Spring 2019-2020), 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.

COVID-19 Policies

On July 30, the Academic Senate adopted grading policies effective for all undergraduate and graduate programs, excepting the professional Graduate School of Business, School of Law, and the School of Medicine M.D. Program. For a complete list of those and other academic policies relating to the pandemic, see the "COVID-19 and Academic Continuity (http://exploredegrees.stanford.edu/covid-19-policy-changes/#tempdepttemplatetabtext)" section of this bulletin.

The Senate decided that all undergraduate and graduate courses offered for a letter grade must also offer students the option of taking the course for a “credit” or “no credit” grade and recommended that deans, departments, and programs consider adopting local policies to count courses taken for a “credit” or “satisfactory” grade toward the fulfillment of degree-program requirements and/or alter program requirements as appropriate.

Undergraduate Degree Requirements

Grading

The new EE COVID-19 grading policy for this year with respect to the Satisfactory (S) and Credit (CR) grades counting toward the EE program requirements are stated below:

1. Students will be able to take courses with Satisfactory/Credit (S/CR) grades to count toward the EE degree requirements for all undergraduate degree programs. This policy is valid in all six quarters from Spring Quarter 2019-20 through Summer Quarter 2020-21.
2. The new S/CR grading policy does not apply to students pursuing the EE minor. The requirements for the EE minor has not changed, and all courses, except for courses taken in Spring 2019-20, must be taken for a letter grade.
3. Students in the EE B.S. Honors Program are required to take all courses, except for courses taken in Spring 2019-20, for a letter grade in order to count them toward the EE major. There is no EE COVID-19 exception for the EE-BSH program for AY 2020-21. For further information, see the "EE Undergraduate Honors Program requirements (p. 6)" section of this bulletin.
4. Students taking courses with S/CR grades while the letter grade option is available should consider the impact of S/CR grades on their future applications for admission to graduate/professional school, fellowships, or employment. Therefore, students should select their grade option carefully when enrolling in a course.
5. When a course is offered for an optional letter/CR-NC grading basis, students are encouraged to take that course for a letter grade when they feel comfortable in doing so.

Graduate Degree Requirements

Grading

The new EE COVID-19 grading policy for this year with respect to the Satisfactory (S) and Credit (CR) grades counting toward the EE program requirements are stated below:

1. Students will be able to take courses with Satisfactory/Credit (S/CR) grades to count toward the EE degree requirements for all graduate degree programs. This policy is valid in all six quarters from Spring Quarter 2019-20 through Summer Quarter 2020-21.
2. The new S/CR grading policy does not apply to students pursuing the EE Ph.D. Minor. The requirements for the EE Ph.D. Minor has not changed, and all courses, except for courses taken in Spring 2019-20, must be taken for a letter grade.
3. Students taking courses with S/CR grades while the letter grade option is available should consider the impact of S/CR grades on their future applications for admission to graduate/professional school, fellowships, or employment. Therefore, students should select their grade option carefully when enrolling in a course.
4. When a course is offered for an optional letter/CR-NC grading basis, students are encouraged to take that course for a letter grade when they feel comfortable in doing so.

Graduate Advising Expectations

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

Master's Students

The Department of Electrical Engineering is committed to providing academic advising in support of M.S. students' education and professional development. When most effective, this advising relationship entails collaborative engagement by both the advisor and the advisee. As a best practice, advising expectations should be discussed and reviewed to ensure mutual understanding. Both the advisor and the advisee are expected to maintain professionalism, respect, and integrity. They should also be responsive to one another in a timely manner.

At the start of graduate study, each student is assigned a master's program advisor: a member of faculty who provides guidance in course selection and in exploring academic opportunities and professional pathways. Students are encouraged to meet with the program advisor during the first quarter to go over their proposed master's plan. Usually, the same faculty member serves as program advisor for the duration of master's study. If a student wishes to change their program advisor, they may contact the Degree Progress Officer to initiate the formal process of changing advisor.

In addition to the program advisor, the Electrical Engineering Graduate Student Teaching Advisor is a peer advisor who is available to advise students on the aspects of course selection and academic opportunities on campus and off campus.

The department's student services office is also an important part of the master's advising team. They inform students and advisors about university and department requirements, procedures, and opportunities, and they maintain the official records of advising assignments and approvals. Their contact information can be found on the department's

Graduate Degree Progress (https://ee.stanford.edu/academics/graduate-degree-progress/) website.

Finally, 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 more information, see the Electrical Engineering Department Graduate Handbook (https://stanford.app.box.com/v/EE-Graduate-Handbook/) (pdf).

Ph.D. Students

The Department of Electrical Engineering is committed to providing academic advising in support of doctoral student scholarly and professional development. When most effective, this advising relationship entails collaborative and sustained engagement by both the advisor and the advisee. As a best practice, advising expectations should be periodically discussed and reviewed to ensure mutual understanding. Both the advisor and the advisee are expected to maintain professionalism, respect, and integrity. They should also be responsive to one another in a timely manner.

Faculty advisors 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. The department's Graduate Handbook provides information and suggested timelines for different stages of the doctoral program. For more information, see the department's Graduate Degree Progress (https://ee.stanford.edu/academics/graduate-degree-progress/) website.

Ph.D. students are initially assigned a program advisor on the basis of the interests expressed in their application. This faculty member provides initial guidance in course selection, in exploring academic opportunities and professional pathways, and in identifying doctoral research opportunities. The department does not require formal lab rotations, but students are encouraged to consider exploring research activities in two or three labs during their first academic year.

Students identify their doctoral research/thesis advisor, pass the qualifying exam, and advance to candidacy prior to the end of the second year of study. The research supervisor assumes primary responsibility for the future direction of the student, taking on the roles previously filled by the program advisor, and ultimately direct the student's dissertation. Most students find an advisor from among the primary faculty members of the department. However, the research advisor may be a faculty member from another Stanford department who is familiar with supervising doctoral students and able to provide both advising and funding for the duration of the doctoral program. When the research advisor is from outside the department, the student still has the same program advisor from the primary faculty, to provide guidance on departmental requirements and opportunities.

The faculty Associate Chair of Graduate Education is available during the academic year by email and during office hours. The department's student services office is also an important part of the doctoral advising team: they inform students and advisors about university and department requirements, procedures, and opportunities, and they maintain the official records of advising assignments and approvals. Students are encouraged to talk with their doctoral program advisor, the Graduate Student Teaching Advisor, and the Degree Progress Officer from the student services office as they consider advisor selection, or for guidance in working with their advisor(s).

The department's doctoral 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 more information, see the Electrical Engineering Department Graduate Handbook (https://stanford.app.box.com/v/EE-Graduate-Handbook/) (pdf).

Faculty

Emeriti: (Professors) Clayton W. Bates, John Cioffi*, Donald C. Cox, Michael J. Flynn, James F. Gibbons, Andrea G. Goldsmith, Joseph W. Goodman, Robert M. Gray, James Harris, Stephen E. Harris, Martin E. Hellman, Umran S. Inan*, Thomas Kailath*, Gregory T.A. Kovacs*, Marc Levoy, Albert Macovski, Malcolm M. McWhorter, Teresa Meng, R. Fabian W. Pease, Leonard Tyler, Robert L. White, Bernard Widrow, Bruce A. Wooley, Yoshihisa Yamamoto; (*Associate Professors*) John T. Gill III, Bruce B. Lusignan; *(Professors, Research)* Antony Fraser-Smith*, C. Robert Helms, Leonid Kazovsky, Ingolf Lindau*, David Luckham, Yoshio Nishi, Arogyaswami J. Paulraj

(**Recalled to active duty*)

Chair: Stephen P. Boyd

Associate Chairs: John Pauly *(Undergraduate Education),* Brad Osgood *(Graduate Education),* Howard Zebker *(Admissions)*

Academic Affairs Committee Chair: Joseph M. Kahn

Director of Graduate Studies: Brad Osgood

Professors: Nicholas Bambos, Kwabena Boahen, Dan Boneh, Stephen P. Boyd, Robert W. Dutton, Abbas El Gamal, Shanhui Fan, Bernd Girod, Patrick Hanrahan, 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, Eric Pop, Balaji Prabhakar, Mendel Rosenblum, Krishna Saraswat, Krishna V. Shenoy, H. 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: Amin Arbabian, Srabanti Chowdhury, Dawson Engler, Sachin Katti, Philip Levis, Ayfer Ozgur Aydin, Ada Poon, Juan Rivas-Davila

Assistant Professors: Daniel Congreve, John Duchi, Jonathan Fan, Chelsea Finn, Mert Pilanci, Priyanka Raina, Dorsa Sadigh, Caroline Trippel, 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, David L. Dill, Gary Glover, Peter Glynn, Leonidas Guibas, Brian Hargreaves, Tony Heinz, Ramesh Johari, Oussama Khatib, Monica S. Lam, Craig Levin, John C. Mitchell, Sandy Napel, John Ousterhout, Daniel Palanker, Norbert Pelc, Amin Saberi, Julius Smith, Dan Spielman, Brian Wandell, Lei Xing, Yinyu Ye

Courtesy Associate Professors: Mohsen Bayati, Sigrid Close, Adam de la Zerda, Surya Ganguli, Hanlee Ji, Jin Hyung Lee, Marco Pavone, Ram Rajagopal, Debbie Senesky, Kawin Setsompop, Kuang Xu

Courtesy Assistant Professors: Grace Gao, Paul Nuyujukian, Simona Onori, Dustin Schroeder, Adam Wang, Keith Winstein, Serena Yeung, Matei Zaharia, James Zou

Lecturers: Dennis Allison, Zain Asgar, Raul Camposano, Jonathan Candelaria, Andrea Di Blas, Antun Domic, Abbas Emami-Naeini, Leslie Field, J. Andrew Freeman, Patrick Groeneveld, David Obershaw, Dan O'Neill, David Stork

Adjunct Professors: Sherif Ahmed, Ahmad Bahai, Rick Bahr, Fred M. Gibbons, Dimitry Gorinevsky, Bob S. Hu, Waguih Ishak, Theodore

Kamins, Ali Keshavarzi, David Leeson, Narasimha Madihally, Georgios Michelogiannakis, Fernando Mujica, Reza Nasiri Mahalati, John Provine, Stephen Ryu, Ronald Schafer, Ashok Srivastava, David Sussillo, John Wenstrand

Visiting Associate Professors: Shuo Cao, Ron Dabora

Visiting Assistant Professor: Tamay Aykut

Courses

EE 14N. Things about Stuff. 3 Units.
Preference to freshmen. The stories behind disruptive inventions such as the telegraph, telephone, wireless, television, transistor, and chip are as important as the inventions themselves, for they elucidate broadly applicable scientific principles. Focus is on studying consumer devices; projects include building batteries, energy conversion devices and semiconductors from pocket change. Students may propose topics and projects of interest to them. The trajectory of the course is determined in large part by the students themselves.

EE 15N. The Art and Science of Engineering Design. 3 Units.
The goal of this seminar is to introduce freshmen to the design process associated with an engineering project. The seminar will consist of a series of lectures. The first part of each lecture will focus on the different design aspects of an engineering project, including formation of the design team, developing a project statement, generating design ideas and specifications, finalizing the design, and reporting the outcome. Students will form teams to follow these procedures in designing a term project of their choice over the quarter. The second part of each lecture will consist of outside speakers, including founders of some of the most exciting companies in Silicon Valley, who will share their experiences about engineering design. On-site visits to Silicon Valley companies to showcase their design processes will also be part of the course. The seminar serves three purposes: (1) it introduces students to the design process of turning an idea into a final design, (2) it presents the different functions that people play in a project, and (3) it gives students a chance to consider what role in a project would be best suited to their interests and skills.

EE 17N. Engineering the Micro and Nano Worlds: From Chips to Genes. 3 Units.
Preference to freshmen. The first part is hands-on micro- and nano-fabrication including the Stanford Nanofabrication Facility (SNF) and the Stanford Nanocharacterization Laboratory (SNL) and field trips to local companies and other research centers to illustrate the many applications; these include semiconductor integrated circuits ('chips'), DNA microarrays, microfluidic bio-sensors and microelectromechanical systems (MEMS). The second part is to create, design, propose and execute a project. Most of the grade will be based on the project. By the end of the course you will, of course, be able to read critically a New York Times article on nanotechnology. More importantly you will have experienced the challenge (and fun) of designing, carrying out and presenting your own experimental project. As a result you will be better equipped to choose your major. This course can complement (and differs from) the seminars offered by Profs Philip Wong and Hari Manoharan in that it emphasizes laboratory work and an experimental student-designed project. Prerequisites: high-school physics.

EE 21N. What is Nanotechnology?. 3 Units.
Nanotechnology is an often used word and it means many things to different people. Scientists and Engineers have some notion of what nanotechnology is, societal perception may be entirely different. In this course, we start with the classic paper by Richard Feynman ("There's Plenty of Room at the Bottom"), which laid down the challenge to the nanotechnologists. Then we discuss two classic books that offer a glimpse of what nanotechnology is: Engines of Creation: The Coming Era of Nanotechnology by Eric Drexler, and Prey by Michael Crichton. Drexler's thesis sparked the imagination of what nano machinery might do, whereas Crichton's popular novel channeled the public's attention to this subject by portraying a disastrous scenario of a technology gone astray. We will use the scientific knowledge to analyze the assumptions and predictions of these classic works. We will draw upon the latest research advances to illustrate the possibilities and impossibilities of nanotechnology.

EE 23N. Imaging: From the Atom to the Universe. 3 Units.
Preference to freshmen. Forms of imaging including human and animal vision systems, atomic force microscope, microscope, digital camera, holography and three-dimensional imaging, telescope, synthetic aperture radar imaging, nuclear magnetic imaging, sonar and gravitational wave imaging, and the Hubble Space telescope. Physical principles and exposure to real imaging devices and systems.

EE 25N. Science of Information. 4 Units.
We live in the Information Age, but what is information, anyway? In 1948, Claude Shannon published a seminal paper formalizing our modern notion of information. Through lectures and lab visits, we'll learn how information can be measured and represented, why bits are the universal currency for information exchange, and how these ideas led to smartphones, the Internet, and more. We will get a glimpse of information elements in other domains, including neural codes of the brain, cryptographic codes, genetic code, quantum information, and even entertainment. As a final project, students will create podcast episodes on one of the topics explored in the course.

EE 26N. The Wireless World, and the Data You Leak. 3 Units.
The world is increasingly based on wireless communication. Cell phones and WiFi are the most visible examples. Others are key fobs, water meters, gas and electric meters, garage door openers, baby monitors, and the list continues to expand. All of these produce RF signals you can detect and often decode. This seminar will explore how much information you broadcast throughout your day, and how it can easily be received and decoded using inexpensive hardware and public domain software. You will be able to explain why different information services use different frequencies, why they encode the information the way they do, and what security risks they present.

EE 42. Introduction to Electromagnetics and Its Applications. 5 Units.
Electricity and magnetism and its essential role in modern electrical engineering devices and systems, such as sensors, displays, DVD players, and optical communication systems. The topics that will be covered include electrostatics, magnetostatics, Maxwell's equations, one-dimensional wave equation, electromagnetic waves, transmission lines, and one-dimensional resonators. Pre-requisites: none.
Same as: ENGR 42

EE 46. Engineering For Good: Contributing to Saving the World and Having Fun Doing It. 3 Units.
Projects that provide immediate and positive impact on the world. Focus is on global health and sustainable development by learning from experts in these fields. Students work on real-world projects with help from members of NGOs and social entrepreneurial companies as part of the hand-on learning experience. Prerequisite: ENGR 21 or ENGR 40M or EE 122A or CS 106B or consent of instructor.

EE 60N. Man versus Nature: Coping with Disasters Using Space Technology. 4 Units.
Preference to freshman. Natural hazards, earthquakes, volcanoes, floods, hurricanes, and fires, and how they affect people and society; great disasters such as asteroid impacts that periodically obliterate many species of life. Scientific issues, political and social consequences, costs of disaster mitigation, and how scientific knowledge affects policy. How spaceborne imaging technology makes it possible to respond quickly and mitigate consequences; how it is applied to natural disasters; and remote sensing data manipulation and analysis. GER:DB-EngrAppSci.
Same as: GEOPHYS 60N

EE 64SI. Mechanical Prototyping for Electrical Engineers. 2 Units.
This course will give non-mechanical engineers experience designing mechanical assemblies specifically for manufacture by readily accessible tools, such as 3-D printers and laser cutters. It will also teach students to debug their own mechanical designs, and interface them with other components (such as store-bought parts). By the end of the quarter students will feel comfortable independently designing and manufacturing simple assemblies to serve useful functions in their lives.

EE 65. Modern Physics for Engineers. 4 Units.
This course introduces the core ideas of modern physics that enable applications ranging from solar energy and efficient lighting to the modern electronic and optical devices and nanotechnologies that sense, process, store, communicate and display all our information. Though the ideas have broad impact, the course is widely accessible to engineering and science students with only basic linear algebra and calculus through simple ordinary differential equations as mathematics background. Topics include the quantum mechanics of electrons and photons (Schrödinger's equation, atoms, electrons, energy levels and energy bands; absorption and emission of photons; quantum confinement in nanostructures), the statistical mechanics of particles (entropy, the Boltzmann factor, thermal distributions), the thermodynamics of light (thermal radiation, limits to light concentration, spontaneous and stimulated emission), and the physics of information (Maxwell¿s demon, reversibility, entropy and noise in physics and information theory). Pre-requisite: Physics 41. Pre- or co-requisite: Math 53 or CME 102.

EE 100. The Electrical Engineering Profession. 1 Unit.
Lectures/discussions on topics of importance to the electrical engineering professional. Continuing education, professional societies, intellectual property and patents, ethics, entrepreneurial engineering, and engineering management.

EE 101A. Circuits I. 4 Units.
Introduction to circuit modeling and analysis. Topics include creating the models of typical components in electronic circuits and simplifying non-linear models for restricted ranges of operation (small signal model); and using network theory to solve linear and non-linear circuits under static and dynamic operations. Prerequisite: ENGR40 or ENGR40M is strongly recommended.

EE 101B. Circuits II. 4 Units.
Continuation of EE101A. Introduction to circuit design for modern electronic systems. Modeling and analysis of analog gain stages, frequency response, feedback. Filtering and analog to digital conversion. Fundamentals of circuit simulation. Prerequisites: EE101A, EE102A. Recommended: CME102.

EE 102A. Signal Processing and Linear Systems I. 4 Units.
Concepts and tools for continuous- and discrete-time signal and system analysis with applications in signal processing, communications, and control. Mathematical representation of signals and systems. Linearity and time invariance. System impulse and step responses. System frequency response. Frequency-domain representations: Fourier series and Fourier transforms. Filtering and signal distortion. Time/frequency sampling and interpolation. Continuous-discrete-time signal conversion and quantization. Discrete-time signal processing. Prerequisite: MATH 53 or CME 102.

EE 102B. Signal Processing and Linear Systems II. 4 Units.
Continuation of EE 102A. Concepts and tools for continuous- and discrete-time signal and system analysis with applications in communications, signal processing and control. Analog and digital modulation and demodulation. Sampling, reconstruction, decimation and interpolation. Finite impulse response filter design. Discrete Fourier transforms, applications in convolution and spectral analysis. Laplace transforms, applications in circuits and feedback control. Z transforms, applications in infinite impulse response filter design. Prerequisite: EE 102A.

EE 104. Introduction to Machine Learning. 3-5 Units.
Introduction to machine learning. Formulation of supervised and unsupervised learning problems. Regression and classification. Data standardization and feature engineering. Loss function selection and its effect on learning. Regularization and its role in controlling complexity. Validation and overfitting. Robustness to outliers. Simple numerical implementation. Experiments on data from a wide variety of engineering and other disciplines. Undergraduate students should enroll for 5 units, and graduate students should enroll for 3 units. Prerequisites: ENGR 108; EE 178 or CS 109; CS106A or equivalent.
Same as: CME 107

EE 107. Embedded Networked Systems. 3 Units.
Networked embedded systems are often hidden from our view, but they are a key component that enables our modern society. Embedded systems bridge our physical world with powerful digital measurement and control systems. Applications of today's embedded systems range from stabilization in drones authentication in credit cards, and even temperature control in toasters. In this class, students will learn about how to build an networked embedded system from the ground up. The lectures will focus on the key enabling components of embedded systems, including: Clocks, GPIO, Interrupts, Busses, Amplifiers, Regulators, Power supplies, ADC/DAC, DMA, and Storage. The goal of the class is to familiarize the students with these components such that they can build their own embedded systems in devices. Prerequisites: EE 102A or ENGR 40M.

EE 108. Digital System Design. 4 Units.
Digital circuit, logic, and system design. Digital representation of information. CMOS logic circuits. Combinational logic design. Logic building blocks, idioms, and structured design. Sequential logic design and timing analysis. Clocks and synchronization. Finite state machines. Microcode control. Digital system design. Control and datapath partitioning. Lab. *In Autumn, enrollment preference is given to EE majors. Any EE majors who must enroll in Autumn are invited to contact the instructor. Formerly EE 108A.

EE 109. Digital Systems Design Lab. 4 Units.
The design of integrated digital systems encompassing both customized software and hardware. Software/hardware design tradeoffs. Algorithm design for pipelining and parallelism. System latency and throughput tradeoffs. FPGA optimization techniques. Integration with external systems and smart devices. Firmware configuration and embedded system considerations. Enrollment limited to 25; preference to graduating seniors. Prerequisites: 108B, and CS 106B or X.

EE 114. Fundamentals of Analog Integrated Circuit Design. 3-4 Units.
Analysis and simulation of elementary transistor stages, current mirrors, supply- and temperature-independent bias, and reference circuits. Overview of integrated circuit technologies, circuit components, component variations and practical design paradigms. Differential circuits, frequency response, and feedback will also be covered. Performance evaluation using computer-aided design tools. Undergraduates must take EE 114 for 4 units. Prerequisite: 101B. GER:DB-EngrAppSci.
Same as: EE 214A

EE 116. Semiconductor Devices for Energy and Electronics. 3 Units.
The underpinnings of modern technology are the transistor (circuits), the capacitor (memory), and the solar cell (energy). EE 116 introduces the physics of their operation, their historical origins (including Nobel prize breakthroughs), and how they can be optimized for future applications. The class covers physical principles of semiconductors, including silicon and new material discoveries, quantum effects, band theory, operating principles, and device equations. Recommended (but not required) co-requisite: EE 65 or equivalent.

EE 118. Introduction to Mechatronics. 4 Units.
Technologies involved in mechatronics (intelligent electro-mechanical systems), and techniques to apply this technology to mecatronic system design. Topics include: electronics (A/D, D/A converters, op-amps, filters, power devices); software program design, event-driven programming; hardware and DC stepper motors, solenoids, and robust sensing. Large, open-ended team project. Prerequisites: ENGR 40, CS 106, or equivalents.
Same as: ME 210

EE 124. Introduction to Neuroelectrical Engineering. 3 Units.
Fundamental properties of electrical activity in neurons, technology for measuring and altering neural activity, and operating principles of modern neurological and neural prosthetic medical systems. Topics: action potential generation and propagation, neuro-MEMS and measurement systems, experimental design and statistical data analysis, information encoding and decoding, clinical diagnostic systems, and fully-implantable neural prosthetic systems design. Prerequisite: EE 101A and EE 102A.

EE 133. Analog Communications Design Laboratory. 3-4 Units.
Design, testing, and applications of Radio Frequency (RF) electronics: Amplitude Modulation (AM), Frequency Modulation (FM) and concepts of Software Define Radio (SDR) systems. Practical aspects of circuit implementations are developed; labs involve building and characterization of subsystems as well as integration of a complete radio system and a final project. Total enrollment limited to 25 students, undergraduate and graduate levels. Prerequisite: EE101B. Undergraduate students enroll in EE133 for 4 units and Graduate students enroll in EE233 for 3 units. Recommended: EE114/214A.
Same as: EE 233

EE 134. Introduction to Photonics. 4 Units.
Photonics, optical components, and fiber optics. Conceptual and mathematical tools for design and analysis of optical communication, sensor and imaging systems. Experimental characterization of semiconductor lasers, optical fibers, photodetectors, receiver circuitry, fiber optic links, optical amplifiers, and optical sensors. Class project on confocal microscopy or other method of sensing or analyzing biometric data. Laboratory experiments. Prerequisite: EE 102A and one of the following: EE 42, Physics 43, or Physics 63.

EE 142. Engineering Electromagnetics. 3 Units.
Introduction to electromagnetism and Maxwell's equations in static and dynamic regimes. Electrostatics and magnetostatics: Gauss's, Coulomb's, Faraday's, Ampere's, Biot-Savart's laws. Electric and magnetic potentials. Boundary conditions. Electric and magnetic field energy. Electrodynamics: Wave equation; Electromagnetic waves; Phasor form of Maxwell's equations.nSolution of the wave equation in 1D free space: Wavelength, wave-vector, forward and backward propagating plane waves.Poynting's theorem. Propagation in lossy media, skin depth. Reflection and refraction at planar boundaries, total internal reflection. Solutions of wave equation for various 1D-3D problems: Electromagnetic resonators, waveguides periodic media, transmission lines. Formerly EE 141. Pre-requisites: Phys 43 or EE 42, CME 100, CME 102.

EE 153. Power Electronics. 3-4 Units.
Addressing the energy challenges of today and the environmental challenges of the future will require efficient energy conversion techniques. This course will discuss the circuits used to efficiently convert ac power to dc power, dc power from one voltage level to another, and dc power to ac power. The components used in these circuits (e.g., diodes, transistors, capacitors, inductors) will also be covered in detail to highlight their behavior in a practical implementation. A lab will be held with the class where students will obtain hands on experience with power electronic circuits. For WIM credit, students must enroll in EE 153 for 4 units. No exceptions. Formerly EE 292J. Prerequisite: EE 101B.
Same as: EE 253

EE 155. Green Electronics. 4 Units.
Many green technologies including hybrid cars, photovoltaic energy systems, efficient power supplies, and energy-conserving control systems have at their heart intelligent, high-power electronics. This course examines this technology and uses green-tech examples to teach the engineering principles of modeling, optimization, analysis, simulation, and design. Topics include power converter topologies, periodic steady-state analysis, control, motors and drives, photovol-taic systems, and design of magnetic components. The course involves a hands-on laboratory and a substantial final project. Formerly EE 152. Required: EE101B, EE102A, EE108. Recommended: ENGR40 or EE122A.
Same as: EE 255

EE 157. Electric Motors for Renewable Energy, Robotics, and Electric Vehicles. 3 Units.
An introduction to electric motors and the principles of electromechanical energy conversion. Students will learn about, design, and build an electric motor system, choosing from one of three application areas: renewable energy (wind turbines), robotics (drones and precision manufacturing), or electric vehicles (cars, ships, and airplanes). Topics covered include ac and dc rotating machines, power electronics inverters and drives, and control techniques. Prerequisite: EE 42, Physics 43, ENGR 40M or equivalent.

EE 168. Introduction to Digital Image Processing. 3-4 Units.
Computer processing of digital 2-D and 3-D data, combining theoretical material with implementation of computer algorithms. Topics: properties of digital images, design of display systems and algorithms, time and frequency representations, filters, image formation and enhancement, imaging systems, perspective, morphing, and animation applications. Instructional computer lab exercises implement practical algorithms. Final project consists of computer animations incorporating techniques learned in class. For WIM credit, students must enroll for 4 units. No exceptions. Prerequisite: Matlab programming.

EE 169. Introduction to Bioimaging. 3 Units.
Bioimaging is important for both clinical medicine, and medical research. This course will provide a introduction to several of the major imaging modalities, using a signal processing perspective. The course will start with an introduction to multi-dimensional Fourier transforms, and image quality metrics. It will then study projection imaging systems (projection X-Ray), backprojection based systems (CT, PET, and SPECT), systems that use beam forming (ultrasound), and systems that use Fourier encoding (MRI). Prerequisites: EE102A, EE102B.

EE 178. Probabilistic Systems Analysis. 3-4 Units.
Introduction to probability and its role in modeling and analyzing real world phenomena and systems, including topics in statistics, machine learning, and statistical signal processing. Elements of probability, conditional probability, Bayes rule, independence. Discrete and continuous random variables. Signal detection. Functions of random variables. Expectation; mean, variance and covariance, linear MSE estimation. Conditional expectation; iterated expectation, MSE estimation, quantization and clustering. Parameter estimation. Classification. Sample averages. Inequalities and limit theorems. Confidence intervals. Prerequisites: Calculus at the level of MATH 51, CME 100 or equivalent and basic knowledge of computing at the level of CS106A.

EE 179. Analog and Digital Communication Systems. 3 Units.
This course covers the fundamental principles underlying the analysis, design and optimization of analog and digital communication systems. Design examples will be taken from the most prevalent communication systems today: cell phones, Wifi, radio and TV broadcasting, satellites, and computer networks. Analysis techniques based on Fourier transforms and energy/power spectral density will be developed. Mathematical models for random variables and random (noise) signals will be presented, which are used to characterize filtering and modulation of random noise. These techniques will then be used to design analog (AM and FM) and digital (PSK and FSK) communication systems and determine their performance over channels with noise and interference. Prerequisite: 102A.

EE 180. Digital Systems Architecture. 4 Units.
The design of processor-based digital systems. Instruction sets, addressing modes, data types. Assembly language programming, low-level data structures, introduction to operating systems and compilers. Processor microarchitecture, microprogramming, pipelining. Memory systems and caches. Input/output, interrupts, buses and DMA. System design implementation alternatives, software/hardware tradeoffs. Labs involve the design of processor subsystems and processor-based embedded systems. Formerly EE 108B. Prerequisite: one of CS107 or CS 107E (required) and EE108 (recommended but not required).

EE 185. Interactive Light Sculpture Project. 3 Units.
Design, prototype, build, refine, program, and install a large interactive light sculpture in the Packard Building to celebrate the 125th anniversary of the EE department. Students may take the course for 1, 2, or 3 quarters; each quarter focuses on a different phase of the project. Topics covered include energy budgeting, communication, enclosure design, scalability, timing, circuit design, structural design, and safety. Prerequisite: ENGR 40M, or an introductory EE or CS course in circuits or programming.

EE 185A. Engineering a Smart Object - Intro to Systems & Fabrication. 3 Units.
EE 185A/B/C is a full-year sequence that teaches all of the concepts, knowledge, skills, and techniques to engineer all aspects of a smart object. Students learn to specify and analyze designs precisely, such that the first version of the object constructed works exactly as expected. This first course focuses on building an object to specification. Students will learn and use modern fabrication methods including machine tools (milling machine, lathe, etc.), laser cutters, and 3D printers to demonstrate their ability to build it right the first time. Course prerequisites: Physics 43 (or equivalent) and ENGR 40M or instructor approval.

EE 185B. Engineering a Smart Object - Specifications and Embedded Design. 3 Units.
EE 185A/B/C is a full-year sequence that teaches all of the concepts, knowledge, skills, and techniques to engineer all aspects of a smart object. This second course focuses on understanding the art of specification by writing a specification and fabricating to someone else is written specification. We will also explore embedded system design and the impact of design decisions by redesigning the electronics from EE 185A to meet low power specifications. Students will learn about power, energy, micro controllers, low-level software and how, in embedded systems, electronic hardware, mechanical design, and software are coupled. Course prerequisites: EE 185A as well as CS107, CS107E or instructor approval.

EE 185C. Engineering a Smart Object - Adding connectivity and Putting it ALL together. 3 Units.
EE 185A/B/C is a full-year sequence that teaches all of the concepts, knowledge, skills, and techniques to engineer all aspects of a smart object. In this third course, the students bring everything they have learned in EE 185 A/B to bear by engineering a simple smart object of their choosing. We will add an essential ingredient of a Smart Object - connectivity and learn about how this effects system design. During this Quarter, each student will write a precise specification, create and analyze their design to a degree such that it is certain it will work as intended the first time they build it. They will also fabricate and demonstrate their Smart Object by the end of the Quarter. Course prerequisites: EE 185B or instructor approval.

EE 190. Special Studies or Projects in Electrical Engineering. 1-15 Unit.
Independent work under the direction of a faculty member. Individual or team activities involve lab experimentation, design of devices or systems, or directed reading. Course may be repeated for credit.

EE 191. Special Studies and Reports in Electrical Engineering. 1-15 Unit.
Independent work under the direction of a faculty member given for a letter grade only. If a letter grade given on the basis of required written report or examination is not appropriate, enroll in 190. Course may be repeated for credit.

EE 191A. Special Studies and Reports in Electrical Engineering. 1 Unit.
EE191A is part of the Accelerated Calculus for Engineers program. Independent work under the direction of a faculty member given for a letter grade only. EE 191A counts as a Math one unit seminar course: it is this unit that constitutes the ACE program.

EE 191W. Special Studies and Reports in Electrical Engineering. 3-10 Units.
WIM-version of EE 191. For EE students using special studies (e.g., honors project, independent research project) to satisfy the writing-in-major requirement. A written report that has gone through revision with an adviser is required. An adviser from the Technical Communication Program is recommended.
Same as: WIM

EE 192T. Project Lab: Video and Audio Technology for Live Theater in the Age of COVID. 3 Units.
This class is part of a multi-disciplinary collaboration between researchers in the CS, EE, and TAPS departments to design and develop a system to host a live theatrical production that will take place over the Internet in the winter quarter. The performing arts have been greatly affected by a transition to theater over Zoom and its competitors, none of which are great at delivering low-latency audio to actors, or high-quality audio and video to the audience, or feedback from the audience back to actors. These are big technical challenges. During the fall, we'll build a system that improves on current systems in certain areas: audio quality and latency over spotty Internet connections, video quality and realistic composited scenes with multiple actors, audience feedback, and perhaps digital puppetry. Students will learn to be part of a deadline-driven software development effort working to meet the needs of a theater director and creative specialists -- while communicating the effect of resource limits and constraints to a nontechnical audience. This is an experimental hands-on laboratory class, and our direction may shift as the creative needs of the theatrical production evolve. Based on the success of class projects and subsequent needs, some students may be invited to continue in the winter term with a research appointment (for pay or credit) to operate the system you have built and instruct actors and creative professionals how to work with the system through rehearsals and the final performance before spring break. Prerequisites: CS110 or EE102A. Recommended: familiarity with Linux, C++, and Git.
Same as: CS 349T

EE 195. Electrical Engineering Instruction. 1-3 Unit.
Students receive training from faculty or graduate student mentors to prepare them to assist in instruction of Electrical Engineering courses. The specific training and units of credit received are to be defined in consultation with one of the official instructors of EE 195. Note that University regulations prohibit students from being paid for the training while receiving academic credit for it. Enrollment limited.

EE 203. The Entrepreneurial Engineer. 1 Unit.
Seminar. For prospective entrepreneurs with an engineering background. Contributions made to the business world by engineering graduates. Speakers include Stanford and other engineering and M.B.A. graduates who have founded large and small companies in nearby communities. Contributions from EE faculty and other departments including Law, Business, and MS&E.May be repeated for credit.

EE 205. Product Management for Electrical Engineers and Computer Scientists. 3 Units.
Successful products are the highest impact contribution anyone can make in product development. Students will learn to build successful products using fundamental concepts in Product Management. These include understanding customers, their job to be done, Identifying new product opportunities, and defining what to build that is technically feasible, valuable to the customer, and easy to use The course has two components, Product Management Project with corporate partners, and case-based classroom discussion of PM concepts and application. Prerequisite: Students must be currently enrolled in a MS or PhD engineering degree program.

EE 207. Neuromorphics: Brains in Silicon. 3 Units.
(Formerly EE 304) Neuromorphic systems run perceptual, cognitive and motor tasks in real-time on a network of highly interconnected nonlinear units. To maximize density and minimize energy, these units--like the brain's neurons--are heterogeneous and stochastic. The first half of the course covers learning algorithms that automatically synthesize network configurations to perform a desired computation on a given heterogeneous neural substrate. The second half of the course surveys system-on-a-chip architectures that efficiently realize highly interconnected networks and mixed analog-digital circuit designs that implement area and energy-efficient nonlinear units. Prerequisites: EE102A is required.
Same as: BIOE 313

EE 212. Integrated Circuit Fabrication Processes. 3 Units.
For students interested in the physical bases and practical methods of silicon VLSI chip fabrication, or the impact of technology on device and circuit design, or intending to pursue doctoral research involving the use of Stanford's Nanofabrication laboratory. Process simulators illustrate concepts. Topics: principles of integrated circuit fabrication processes, physical and chemical models for crystal growth, oxidation, ion implantation, etching, deposition, lithography, and back-end processing. Required for 410.

EE 214A. Fundamentals of Analog Integrated Circuit Design. 3-4 Units.
Analysis and simulation of elementary transistor stages, current mirrors, supply- and temperature-independent bias, and reference circuits. Overview of integrated circuit technologies, circuit components, component variations and practical design paradigms. Differential circuits, frequency response, and feedback will also be covered. Performance evaluation using computer-aided design tools. Undergraduates must take EE 114 for 4 units. Prerequisite: 101B. GER:DB-EngrAppSci.
Same as: EE 114

EE 214B. Advanced Integrated Circuit Design. 3 Units.
Analysis and design of analog integrated circuits in advanced MOS and bipolar technologies. Device operation and compact modeling in support of circuit simulations needed for design. Emphasis on quantitative evaluations of performance using hand calculations and circuit simulations; intuitive approaches to design. Analytical and approximate treatments of noise and distortion; analysis and design of feedback circuits. Design of archetypal analog blocks for networking and communications such as broadband gain stages and transimpedance amplifiers. Prerequisites: EE114/214A.

EE 216. Principles and Models of Semiconductor Devices. 3 Units.
Carrier generation, transport, recombination, and storage in semiconductors. Physical principles of operation of the p-n junction, heterojunction, metal semiconductor contact, bipolar junction transistor, MOS capacitor, MOS and junction field-effect transistors, and related optoelectronic devices such as CCDs, solar cells, LEDs, and detectors. First-order device models that reflect physical principles and are useful for integrated-circuit analysis and design. Prerequisite: 116 or equivalent.

EE 218. Power Semiconductor Devices and Technology. 3 Units.
This course starts by covering the device physics and technology of current silicon power semiconductor devices including power MOSFETs, IGBTs, and Thyristors. Wide bandgap materials, especially GaN and SiC are potential replacements for Si power devices because of their fundamentally better properties. This course explores what is possible in these new materials, and what the remaining challenges are for wide bandgap materials to find widespread market acceptance in power applications. Future clean, renewable energy systems and high efficiency power control systems will critically depend on the higher performance devices possible in these new materials. Prerequisites: EE 116 or equivalent.

EE 222. Applied Quantum Mechanics I. 3 Units.
Emphasis is on applications in modern devices and systems. Topics include: Schrödinger's equation, eigenfunctions and eigenvalues, solutions of simple problems including quantum wells and tunneling, quantum harmonic oscillator, coherent states, operator approach to quantum mechanics, Dirac notation, angular momentum, hydrogen atom, calculation techniques including matrix diagonalization, perturbation theory, variational method, and time-dependent perturbation theory with applications to optical absorption, nonlinear optical coefficients, and Fermi's golden rule. Prerequisites: MATH 52 and 53, EE 65 or PHYSICS 65 (or PHYSICS 43 and 45).
Same as: MATSCI 201

EE 223. Applied Quantum Mechanics II. 3 Units.
Continuation of 222, including more advanced topics: quantum mechanics of crystalline materials, methods for one-dimensional problems, spin, systems of identical particles (bosons and fermions), introductory quantum optics (electromagnetic field quantization, coherent states), fermion annihilation and creation operators, interaction of different kinds of particles (spontaneous emission, optical absorption, and stimulated emission). Quantum information and interpretation of quantum mechanics. Other topics in electronics, optoelectronics, optics, and quantum information science. Prerequisite: 222.

EE 225. Biochips and Medical Imaging. 3 Units.
The course covers state-of-the-art and emerging bio-sensors, bio-chips, imaging modalities, and nano-therapies which will be studied in the context of human physiology including the nervous system, circulatory system and immune system. Medical diagnostics will be divided into bio-chips (in-vitro diagnostics) and medical and molecular imaging (in-vivo imaging). In-depth discussion on cancer and cardiovascular diseases and the role of diagnostics and nano-therapies.
Same as: MATSCI 225, SBIO 225

EE 233. Analog Communications Design Laboratory. 3-4 Units.
Design, testing, and applications of Radio Frequency (RF) electronics: Amplitude Modulation (AM), Frequency Modulation (FM) and concepts of Software Define Radio (SDR) systems. Practical aspects of circuit implementations are developed; labs involve building and characterization of subsystems as well as integration of a complete radio system and a final project. Total enrollment limited to 25 students, undergraduate and graduate levels. Prerequisite: EE101B. Undergraduate students enroll in EE133 for 4 units and Graduate students enroll in EE233 for 3 units. Recommended: EE114/214A.
Same as: EE 133

EE 234. Photonics Laboratory. 3 Units.
Photonics and fiber optics with a focus on communication and sensing. Experimental characterization of semiconductor lasers, optical fibers, photodetectors, receiver circuitry, fiber optic links, optical amplifiers, and optical sensors and photonic crystals. Prerequisite: EE 236A (recommended).

EE 235. Analytical Methods in Biotechnology. 3 Units.
This course provides fundamental principles underlying important analytical techniques used in modern biotechnology. The course comprises of lectures and hands-on laboratory experiments. Students will learn the core principles for designing, implementing and analyzing central experimental methods including polymerase chain reaction (PCR), electrophoresis, immunoassays, and high-throughput sequencing. The overall goal of the course is to enable engineering students with little or no background in molecular biology to transition into research in the field of biomedicine.
Same as: BIOS 212, RAD 236

EE 236A. Modern Optics. 3 Units.
Geometrical optics; lens analysis and design, aberrations, optical instruments, radiometry. ray matrices. Wave nature of light; polarization, plane waves at interfaces and in media with varying refractive index, diffraction, Fourier Optics, Gaussian beams. Interference; single-beam interferometers (Fabry-Perot), multiple-beam interferometers (Michelson, Mach-Zehnder). Prerequisites: EE 142 or familiarity with electromagnetism and plane waves.

EE 236AL. Modern Optics - Laboratory. 1 Unit.
The Laboratory Course allows students to work hands-on with optical equipment to conduct five experiments that compliment the lecture course. Examples are Gaussian Beams and Resonators, Interferometers, and Diffraction.

EE 236B. Guided Waves. 3 Units.
Maxwell's equations, constitutive relations. Kramers-Kronig relations. Modes in waveguides: slab, rectangular, circular. Photonic crystals, surface plasmon modes. General properties of waveguide modes: orthogonality, phase and group indices, group velocity dispersion. Chirped pulse propagation in dispersive media and its connection to Gaussian beam propagation. Time lens. Waveguide technologies: glass, silicon, III-V semiconductor, metallic. Waveguide devices: fibers, lasers, modulators, arrayed waveguide gratings. Scattering matrix description of passive optical devices, and constraints from energy conservation, time-reversal symmetry and reciprocity. Mode coupling, directional couplers, distributed-feedback structures. Resonators from scattering matrix and input-output perspective. Micro-ring resonators. Prerequisites: EE 236A and EE 242 or familiarity with differential form of Maxwell's equations.

EE 236C. Lasers. 3 Units.
Atomic systems, spontaneous emission, stimulated emission, amplification. Three- and four-level systems, rate equations, pumping schemes. Laser principles, conditions for steady-state oscillation. Transverse and longitudinal mode control and tuning. Exemplary laser systems: gas (HeNe), solid state (Nd:YAG, Ti:sapphire) and semiconductors. Elements of laser dynamics and noise. Formerly EE231. Prerequisites: EE 236B and familiarity with modern physics and semiconductor physics. Recommended: EE 216 and EE 223 (either may be taken concurrently).

EE 237. Solar Energy Conversion. 3 Units.
This course will be an introduction to solar photovoltaics. No prior photovoltaics knowledge is required. Class lectures will be supplemented by guest lectures from distinguished engineers, entrepreneurs and venture capitalists actively engaged in solar industry. Past guest speakers include Richard Swanson (CEO, SunPower), Benjamin Cook (Managing Partner at NextPower Capital) and Shahin Farshchi (Partner, Lux Capital). Topics Include: Economics of solar energy. Solar energy policy. Solar cell device physics: electrical and optical. Different generations of photovoltaic technology: crystalline silicon, thin film, multi-junction solar cells. Perovskite and silicon tandem cells. Advanced energy conversion concepts like photon up-conversion, quantum dot solar cells. Solar system issues including module assembly, inverters, micro-inverters and microgrid. No prior photovoltaics knowledge is required. Recommended: EE116, EE216 or equivalent.

EE 238. Introduction to Fourier Optics. 3 Units.
Fourier analysis applied to optical imaging. Theoretical topics include Fourier transform and angular spectrum to describe diffraction, Fourier transforming properties of lenses, image formation with coherent and incoherent light and aberrations. Application topics will cover image deconvolution/reconstruction, amplitude and phase pupil engineering, computational adaptive optics, and others motivated by student interest. Prerequisites: familiarity with Fourier transform and analysis, EE 102 and EE 142 or equivalent.

EE 242. Electromagnetic Waves. 3 Units.
This course will provide an advanced treatment of electromagnetic waves in free space and media. The first part of the course will cover reflection, refraction, resonators, photonic crystals, and waveguides. The second part will cover finite-difference time-domain (FDTD) computation and introduce students to commercial FDTD software. The third part will focus on an analysis of EM waves in matter. The fourth part will cover potentials, Green's functions, far-field radiation, near-field radiation, antennas, and phased arrays. In lieu of a final exam, students will perform a group project demonstrating theoretical and application proficiency in a topic of their choosing. Homeworks and the final project will tie into real world applications of electromagnetics and utilize scientific computing (Matlab, Mathematica, or Python). Prerequisites: EE 142 or PHYSICS 120, and prior programming experience (Matlab or other language at level of CS 106A or higher).

EE 243. Semiconductor Optoelectronic Devices. 3 Units.
Semiconductor physics and optical processes in semiconductors. Operating principles and practical device features of semiconductor optoelectronic materials and heterostructures. Devices include: optical detectors (p-i-n, avalanche, and MSM); light emitting diodes; electroabsorptive modulators (Franz-Keldysh and QCSE), electrorefractive (directional couplers, Mach-Zehnder), switches (SEEDs); and lasers (waveguide and vertical cavity surface emitting). Prerequisites: semiconductor devices and solid state physics such as EE 216 or equivalent.

EE 247. Introduction to Optical Fiber Communications. 3 Units.
Fibers: single- and multi-mode, attenuation, modal dispersion, group-velocity dispersion, polarization-mode dispersion. Nonlinear effects in fibers: Raman, Brillouin, Kerr. Self- and cross-phase modulation, four-wave mixing. Sources: light-emitting diodes, laser diodes, transverse and longitudinal mode control, modulation, chirp, linewidth, intensity noise. Modulators: electro-optic, electro-absorption. Photodiodes: p-i-n, avalanche, responsivity, capacitance, transit time. Receivers: high-impedance, transimpedance, bandwidth, noise. Digital intensity modulation formats: non-return-to-zero, return-to-zero. Receiver performance: Q factor, bit-error ratio, sensitivity, quantum limit. Sensitivity degradations: extinction ratio, intensity noise, jitter, dispersion. Wavelength-division multiplexing. System architectures: local-area, access, metropolitan-area, long-haul. Prerequisites: EE 102A and EE 142.

EE 251. High-Frequency Circuit Design Laboratory. 3 Units.
Students will study the theory of operation of instruments such as the time-domain reflectometer, sampling oscilloscope and vector network analyzer. They will build on that theoretical foundation by designing, constructing and characterizing numerous wireless building blocks in the upper-UHF range (e.g., up to about 500MHz), in a running series of laboratory exercises that conclude in a final project. Examples include impedance-matching and coupling structures, filters, narrowband and broadband amplifiers, mixers/modulators, and voltage-controlled oscillators. Prerequisite: EE 114 or EE 214A.

EE 252. Antennas. 3 Units.
This course aims to cover the theory, simulation, and hands-on experiment in antenna design. Topics include: basic parameters to describe the performance and characteristics of an antenna, link budget analyses, solving the fields from a Hertizian dipole, duality, equivalence principle, reciprocity, linear wire antenna, circular loop antenna, antenna array, slot and patch antennas, helical antennas, wideband antennas, size reduction techniques, wideband small antennas, and circularly polarized (CP) small antennas. Students will learn to use a commercial electromagnetic stimulator in lab sessions. A final project is designed to solve a research antenna design problem in biomedical area or wireless communications. Prerequisite: EE 142 or Physics 120 or equivalent. Enrollment capacity limited to 25 students.

EE 253. Power Electronics. 3-4 Units.
Addressing the energy challenges of today and the environmental challenges of the future will require efficient energy conversion techniques. This course will discuss the circuits used to efficiently convert ac power to dc power, dc power from one voltage level to another, and dc power to ac power. The components used in these circuits (e.g., diodes, transistors, capacitors, inductors) will also be covered in detail to highlight their behavior in a practical implementation. A lab will be held with the class where students will obtain hands on experience with power electronic circuits. For WIM credit, students must enroll in EE 153 for 4 units. No exceptions. Formerly EE 292J. Prerequisite: EE 101B.
Same as: EE 153

EE 254. Advanced Topics in Power Electronics. 3 Units.
In this course, we will study the practical issues related to the practical design of power electronic converters. We will also explore the trade-offs involved in selecting among the different circuits used to convert ac to dc, dc to ac and back to dc over a wide range of power levels suitable for different applications. In Advanced Topics in Power Electronic, as a multidisciplinary field, we will discuss power electronics circuits, extraction of transfer functions in Continuous and discontinuous conduction mode, voltage and current control of power converters, design of input/output filters to meet Electro Magnetic Interference specifications, layout of power electronics circuits and put this knowledge in a very practical context. Prerequisites: EE 153/253.

EE 255. Green Electronics. 4 Units.
Many green technologies including hybrid cars, photovoltaic energy systems, efficient power supplies, and energy-conserving control systems have at their heart intelligent, high-power electronics. This course examines this technology and uses green-tech examples to teach the engineering principles of modeling, optimization, analysis, simulation, and design. Topics include power converter topologies, periodic steady-state analysis, control, motors and drives, photovol-taic systems, and design of magnetic components. The course involves a hands-on laboratory and a substantial final project. Formerly EE 152. Required: EE101B, EE102A, EE108. Recommended: ENGR40 or EE122A.
Same as: EE 155

EE 256. Numerical Electromagnetics. 3 Units.
Principles and applications of numerical techniques for solving practical problems of electromagnetics. Finite-difference time-domain (FDTD) method and finite-difference frequency-domain (FDFD) method for solving Maxwell's equations. Numerical analysis of stability. Perfectly matched layer (PML) absorbing boundaries. Total-field/scattered-field (TF/SF) method. Waveguide mode analysis. Bloch boundary conditions. The course requires programming and the use of MATLAB or other equivalent tools. Prerequisite: EE 242 or equivalent.

EE 260A. Principles of Robot Autonomy I. 3-5 Units.
Basic principles for endowing mobile autonomous robots with perception, planning, and decision-making capabilities. Algorithmic approaches for robot perception, localization, and simultaneous localization and mapping; control of non-linear systems, learning-based control, and robot motion planning; introduction to methodologies for reasoning under uncertainty, e.g., (partially observable) Markov decision processes. Extensive use of the Robot Operating System (ROS) for demonstrations and hands-on activities. Prerequisites: CS 106A or equivalent, CME 100 or equivalent (for linear algebra), and CME 106 or equivalent (for probability theory).
Same as: AA 174A, AA 274A, CS 237A

EE 260B. Principles of Robot Autonomy II. 3-4 Units.
This course teaches advanced principles for endowing mobile autonomous robots with capabilities to autonomously learn new skills and to physically interact with the environment and with humans. It also provides an overview of different robot system architectures. Concepts that will be covered in the course are: Reinforcement Learning and its relationship to optimal control, contact and dynamics models for prehensile and non-prehensile robot manipulation, imitation learning and human intent inference, as well as different system architectures and their verification. Students will earn the theoretical foundations for these concepts and implement them on mobile manipulation platforms. In homeworks, the Robot Operating System (ROS) will be used extensively for demonstrations and hands-on activities. Prerequisites: CS106A or equivalent, CME 100 or equivalent (for linear algebra), CME 106 or equivalent (for probability theory), and AA 171/274.
Same as: AA 174B, AA 274B, CS 237B

EE 261. The Fourier Transform and Its Applications. 3 Units.
The Fourier transform as a tool for solving physical problems. Fourier series, the Fourier transform of continuous and discrete signals and its properties. The Dirac delta, distributions, and generalized transforms. Convolutions and correlations and applications; probability distributions, sampling theory, filters, and analysis of linear systems. The discrete Fourier transform and the FFT algorithm. Multidimensional Fourier transform and use in imaging. Further applications to optics, crystallography. Emphasis is on relating the theoretical principles to solving practical engineering and science problems. Prerequisites: Math through ODEs, basic linear algebra, Comfort with sums and discrete signals, Fourier series at the level of 102A.

EE 262. Three-Dimensional Imaging. 3 Units.
Multidimensional time and frequency representations, generalization of Fourier transform methods to non-Cartesian coordinate systems, Hankel and Abel transforms, line integrals, impulses and sampling, reconstruction tomography, imaging radar. The projection-slice and layergram reconstruction methods as developed in radio interferometry. Radar imaging and backprojection algorithms for 3- and 4-D imaging. In weekly labs students create software to form images using these techniques with actual data. Final project consists of design, analysis and simulation of an advanced imaging system. Prerequisites: None required, but recommend EE103, EE261, EE278, some inverse method concepts such as from Geophys281.
Same as: GEOPHYS 264

EE 263. Introduction to Linear Dynamical Systems. 3 Units.
Applied linear algebra and linear dynamical systems with applications to circuits, signal processing, communications, and control systems. Topics: least-squares approximations of over-determined equations, and least-norm solutions of underdetermined equations. Symmetric matrices, matrix norm, and singular-value decomposition. Eigenvalues, left and right eigenvectors, with dynamical interpretation. Matrix exponential, stability, and asymptotic behavior. Multi-input/multi-output systems, impulse and step matrices; convolution and transfer-matrix descriptions. Control, reachability, and state transfer; observability and least-squares state estimation. Prerequisites: Linear algebra and matrices as in ENGR 108 or MATH 104; ordinary differential equations and Laplace transforms as in EE 102B or CME 102.
Same as: CME 263

EE 264. Digital Signal Processing. 3-4 Units.
Digital signal processing (DSP) techniques and design of DSP applications. Topics include: discrete-time random signals; sampling and multi-rate systems; oversampling and quantization in A-to-D conversion; properties of LTI systems; quantization in fixed-point implementations of filters; digital filter design; discrete Fourier Transform and FFT; spectrum analysis using the DFT; parametric signal modeling and adaptive filtering. The course also covers applications of DSP in areas such as speech, audio and communication systems. The optional lab section (Section 02) provides a hands-on opportunity to explore the application of DSP theory to practical real-time applications in an embedded processing platform. See ee264.stanford.edu for more information. Register in Section 02 to take the lab. Undergraduate students taking the lab should register for 4 units to meet the EE design requirement. The optional lab section is not available to remote SCPD students. Prerequisites: EE 102A and EE 102B or equivalent, basic programming skills (Matlab and C++).

EE 264W. Digital Signal Processing. 5 Units.
Writing in the Major (WIM) version of the 4-unit EE 264 theory + lab course. Digital signal processing (DSP) techniques and design of DSP applications. Topics include: discrete-time random signals; sampling and multi-rate systems; oversampling and quantization in A-to-D conversion; properties of LTI systems; quantization in fixed-point implementations of filters; digital filter design; discrete Fourier Transform and FFT; spectrum analysis using the DFT; parametric signal modeling and adaptive filtering. The course also covers applications of DSP in areas such as speech, audio and communication systems. The lab component provides a hands-on opportunity to explore the application of DSP theory to practical real-time applications in an embedded processing platform. See ee264.stanford.edu for more information. Prerequisites: EE 102A and EE 102B or equivalent, basic programming skills (Matlab and C++).
Same as: WIM

EE 266. Introduction to Stochastic Control with Applications. 3 Units.
Focuses on conceptual foundation and algorithmic methodology of Dynamic Programming and Stochastic Control with applications to engineering, operations research, management science and other fields. Elaborates on the concept of probing, learning and control of stochastic systems, and addresses the practical application of the concept and methodology through the use of approximations. Prerequisites: 201, 221, or equivalents.
Same as: MS&E 251

EE 267. Virtual Reality. 3-4 Units.
OpenGL, real-time rendering, 3D display systems, display optics & electronics, IMUs and sensors, tracking, haptics, rendering pipeline, multimodal human perception and depth perception, stereo rendering, presence. Emphasis on VR technology. Hands-on programming assignments. The 3-unit version requires a final programming assignment in which you create your own virtual environment. The 4-unit version requires a final course project and written report in lieu of the final assignment. Prerequisites: Strong programming skills, ENGR 108 or equivalent. Helpful: basic computer graphics / OpenGL.

EE 267W. Virtual Reality. 5 Units.
Writing in the Major (WIM) version of the 4-unit EE 267 theory + lab/ project course. This course also meets the EE design requirement. Topics include: OpenGL, real-time rendering, 3D display systems, display optics & electronics, IMUs and sensors, tracking, haptics, rendering pipeline, multimodal human perception and depth perception, stereo rendering, presence. Emphasis on VR technology. Hands-on programming assignments. The 5-unit WIM version requires everything the 4-unit version does, i.e. a final course project and written report in lieu of the final assignment. The 5-unit WIM version additional requires participation in 2 writing in the major workshops, and weekly writing assignments. Prerequisites: Strong programming skills, ENGR 108 or equivalent. Helpful: basic computer graphics / OpenGL.
Same as: WIM

EE 269. Signal Processing for Machine Learning. 3 Units.
This course will introduce you to fundamental signal processing concepts and tools needed to apply machine learning to discrete signals. You will learn about commonly used techniques for capturing, processing, manipulating, learning and classifying signals. The topics include: mathematical models for discrete-time signals, vector spaces, Fourier analysis, time-frequency analysis, Z-transforms and filters, signal classification and prediction, basic image processing, compressed sensing and deep learning. This class will culminate in a final project. Prerequisites: EE 102A and EE 102B or equivalent, basic programming skills (Matlab). ENGR 108 and EE 178 are recommended.

EE 270. Large Scale Matrix Computation, Optimization and Learning. 3 Units.
Massive data sets are now common to many different fields of research and practice. Classical numerical linear algebra can be prohibitively costly in many modern problems. This course will explore the theory and practice of randomized matrix computation and optimization for large-scale problems to address challenges in modern massive data sets. Applications in machine learning, statistics, signal processing and data mining will be surveyed. Prerequisites: familiarity with linear algebra (ENGR 108 or equivalent), basic probability and statistics (EE 178 or equivalent), basic programming skills.

EE 271. Introduction to VLSI Systems. 3 Units.
Provides a quick introduction to MOS transistors and IC fabrication and then creates abstractions to allow you to create and reason about complex digital systems. It uses a switch resistor model of a transistor, uses it to model gates, and then shows how gates and physical layout can be synthesized from Verilog or SystemVerilog descriptions. Most of the class will be spent on providing techniques to create designs that can be validated, are low power, provide good performance, and can be completed in finite time. Prerequisites: 101A, 108A and 108B; familiarity with transistors, logic design, Verilog and digital system organization.

EE 272A. Design Projects in VLSI Systems I. 3-4 Units.
This course will introduce you to mixed signal design and the electronic design automation (EDA) tools used for it. Working in teams, you will create a chip with a digital deep neural network (DNN) accelerator and a small analog block using a modern design flow and EDA tools. The project involves writing a synthesizable C++ and a Verilog model of your chip, creating a testing/debug strategy for your chip, wrapping custom layout to fit into a standard cell system, using synthesis and place and route tools to create the layout of your chip, and understanding all the weird stuff you need to do to tape-out a chip. Useful for anyone who will build a chip in their Ph.D. Pre-requisites: EE271 and experience in digital/ analog circuit design.

EE 272B. Design Projects in VLSI Systems II. 3-4 Units.
This is a follow on course to EE272A. While in EE272A you learn the EDA tool flow and design a pre-specified digital neural network accelerator and an analog block, in EE272B you will leverage your knowledge from EE272A and design and fabricate your own digital/analog/mixed-signal chip. This is a completely project-based course where, working in teams, you will propose your own mixed-signal chip, write a Verilog or a synthesizable C++ model of your chip, create a testing/debug strategy for your chip, wrap custom layout to fit into a standard cell system, use synthesis and place and route tools to create the layout of your chip, perform physical verification of your chip and finally tape it out. Useful for anyone who will build a chip in their Ph.D. Pre-requisites: EE271, EE272A and experience in digital/analog circuit design.

EE 273. Digital Systems Engineering. 3 Units.
Electrical issues in the design of high-performance digital systems, including signaling, timing, synchronization, noise, and power distribution. High-speed signaling methods; noise in digital systems, its effect on signaling, and methods for noise reduction; timing conventions; timing noise (skew and jitter), its effect on systems, and methods for mitigating timing noise; synchronization issues and synchronizer design; clock and power distribution problems and techniques; impact of electrical issues on system architecture and design. Prerequisites: EE101A and EE108A. Recommended: EE114/214A.

EE 276. Information Theory. 3 Units.
(Formerly EE 376A.) Project-based course about how to measure, represent, and communicate information effectively. Why bits have become the universal currency for information exchange. How information theory bears on the design and operation of modern-day systems such as smartphones and the Internet. The role of entropy and mutual information in data compression, communication, and inference. Practical compressors and error correcting codes. The information theoretic way of thinking. Relations and applications to probability, statistics, machine learning, biological and artificial neural networks, genomics, quantum information, and blockchains. Prerequisite: a first undergraduate course in probability.
Same as: STATS 376A

EE 277. Reinforcement Learning: Behaviors and Applications. 3 Units.
Reinforcement learning addresses the design of agents that improve decisions while operating within complex and uncertain environments. This course covers principled and scalable approaches to realizing a range of intelligent learning behaviors. Topics include environment models, planning, abstraction, prediction, credit assignment, exploration, and generalization. Motivating examples will be drawn from web services, control, finance, and communications. Prerequisites: EE278 or MS&E 221, EE104 or CS229, CS106A.

EE 278. Introduction to Statistical Signal Processing. 3 Units.
Review of basic probability and random variables. Random vectors and processes; convergence and limit theorems; IID, independent increment, Markov, and Gaussian random processes; stationary random processes; autocorrelation and power spectral density; mean square error estimation, detection, and linear estimation. Formerly EE 278B. Prerequisites: EE178 and linear systems and Fourier transforms at the level of EE102A,B or EE261.

EE 279. Introduction to Digital Communication. 3 Units.
Digital communication is a rather unique field in engineering in which theoretical ideas have had an extraordinary impact on the design of actual systems. The course provides a basic understanding of the analysis and design of digital communication systems, building on various ideas from probability theory, stochastic processes, linear algebra and Fourier analysis. Topics include: detection and probability of error for binary and M-ary signals (PAM, QAM, PSK), receiver design and sufficient statistics, controlling the spectrum and the Nyquist criterion, bandpass communication and up/down conversion, design trade-offs: rate, bandwidth, power and error probability, coding and decoding (block codes, convolutional coding and Viterbi decoding). Prerequisites: 179 or 261, and 178 or 278.

EE 282. Computer Systems Architecture. 3 Units.
Course focuses on how to build modern computing systems, namely notebooks, smartphones, and data centers, covering primarily their hardware architecture and certain system software aspects. For each system class, we cover the system architecture, processor technology, advanced memory hierarchy and I/O organization, power and energy management, and reliability. We will also cover topics such as interactions with system software, virtualization, solid state storage, and security. The programming assignments allow students to explore performance/energy tradeoffs when using heterogeneous hardware resources on smartphone devices. Prerequisite: EE108B. Recommended: CS 140.

EE 284. Introduction to Computer Networks. 3 Units.
Structure and components of computer networks; functions and services; packet switching; layered architectures; OSI reference model; physical layer; data link layer; error control; window flow control; media access control protocols used in local area networks (Ethernet, Token Ring, FDDI) and satellite networks; network layer (datagram service, virtual circuit service, routing, congestion control, Internet Protocol); transport layer (UDP, TCP); application layer.

EE 284A. Introduction to Internet of Things. 3 Units.
Internet of Things (IoT) origin, vision and definition. Application domains, use case scenarios and value propositions. Functional blocks of IoT systems: devices, communications, services, management, security, and application. Architectural reference model and design methodology. IoT Devices: sensors, actuators and embedded systems. Communications aspects of IoT systems: Internet infrastructure; wireless local area networks; radio access networks; wireless personal area networks; wireless sensor networks; wireless communication in vehicular environments; 5G. Current IoT frameworks and underlying architectures. Data storage and analytics. Web services. IoT system management tools. Security aspects of IoT systems. Open issues.

EE 285. Embedded Systems Workshop. 3 Units.
Project-centric building hardware and software for embedded computing systems. Students work on an existing project of their own or join one of these projects. Syllabus topics will be determined by the needs of the enrolled students and projects. Examples of topics include: interrupts and concurrent programming, deterministic timing and synchronization, state-based programming models, filters, frequency response, and high-frequency signals, low power operation, system and PCB design, security, and networked communication. Prerequisite: CS107 (or equivalent).
Same as: CS 241

EE 290A. Curricular Practical Training for Electrical Engineers. 1 Unit.
For EE majors who need work experience as part of their program of study. Final report required. Prerequisites: for 290B, EE MS and PhD students who have received a Satisfactory ("S") grade in EE290A; for 290C, EE PhD degree candidacy and an "S" grade in EE 290B; for 290D, EE PhD degree candidacy, an "S" grade in EE 290C and instructor consent.

EE 290B. Curricular Practical Training for Electrical Engineers. 1 Unit.
For EE majors who need work experience as part of their program of study. Final report required. Prerequisites: for 290B, EE MS and PhD students who have received a Satisfactory ("S") grade in EE290A; for 290C, EE PhD degree candidacy and an "S" grade in EE 290B; for 290D, EE PhD degree candidacy, an "S" grade in EE 290C and instructor consent.

EE 290C. Curricular Practical Training for Electrical Engineers. 1 Unit.
For EE majors who need work experience as part of their program of study. Final report required. Prerequisites: for 290B, EE MS and PhD students who have received a Satisfactory ("S") grade in EE290A; for 290C, EE PhD degree candidacy and an "S" grade in EE 290B; for 290D, EE PhD degree candidacy, an "S" grade in EE 290C and instructor consent.

EE 290D. Curricular Practical Training for Electrical Engineers. 1 Unit.
For EE majors who need work experience as part of their program of study. Final report required. Prerequisites: for 290B, EE MS and PhD students who have received a Satisfactory ("S") grade in EE290A; for 290C, EE PhD degree candidacy and an "S" grade in EE 290B; for 290D, EE PhD degree candidacy, an "S" grade in EE 290C and instructor consent.

EE 290E. Curricular Practical Training for Electrical Engineers. 1 Unit.
For EE majors who need work experience as part of their program of study. Final report required. Prerequisites: for 290B, EE MS and PhD students who have received a Satisfactory ("S") grade in EE290A; for 290C, EE PhD degree candidacy and an "S" grade in EE 290B; for 290D, EE PhD degree candidacy, an "S" grade in EE 290C and instructor consent; for 290E, EE PhD degree candidacy, an "S" grade in EE 290D and instructor consent.

EE 290F. Curricular Practical Training for Electrical Engineers. 1 Unit.
For EE majors who need work experience as part of their program of study. Final report required. Prerequisites: EE PhD degree candidacy, an "S" grade in EE 290E and instructor consent.

EE 290G. Curricular Practical Training for Electrical Engineers. 1 Unit.
For EE majors who need work experience as part of their program of study. Final report required. Prerequisites: EE PhD degree candidacy, an "S" grade in EE 290F and instructor consent.

EE 292A. Electronic Design Automation (EDA) and Machine Learning Hardware. 3 Units.
The class teaches cutting-edge optimization and analysis algorithms for the design of complex digital integrated circuits and their use in designing machine learning hardware. It provides working knowledge of the key technologies in Electronic Design Automation (EDA), focusing on synthesis, placement and routing algorithms that perform the major transformations between levels of abstraction and get a design ready to be fabricated. As an example, the design of a convolutional neural network (CNN) for basic image recognition illustrates the interaction between hardware and software for machine learning. It will be implemented on a state-of-the-art FPGA board. Prerequisite: EE 108.

EE 292C. Chemical Vapor Deposition and Epitaxy for Integrated Circuits and Nanostructures. 1 Unit.
Fundamental aspects of CVD are initially considered, first focusing on processes occurring in the gas phase and then on those occurring on the surface. Qualitative understanding is emphasized, with minimal use of equations. Adding energy both thermally and by using a plasma is discussed; atomic-layer deposition is briefly considered. Examples of CVD equipment are examined. The second portion of the tutorial examines layers deposited by CVD. The focus is on group IV semiconductors ¿ especially epitaxial and heteroepitaxial deposition, in which the crystal structure of the depositing layer is related to that of the substrate. Polycrystalline silicon and the IC interconnect system are then discussed. Finally, the use of high-density plasmas for rapid gap filling is contrasted with alternative CVD dielectric deposition processes.

EE 292D. Machine Learning on Embedded Systems. 3 Units.
This is a project-based class where students will learn how to develop machine learning models for execution in resource constrained environments such as embedded systems. In this class students will learn about techniques to optimize machine learning models and deploy them on a device such as a Arduino, Raspberry PI, Jetson, or Edge TPUs. The class has a significant project component. Prerequisites: CS 107(required), CS 229 (recommended), CS 230 (recommended).

EE 292E. Seminar Series for Image Systems Engineering. 1 Unit.
Seminar. For engineering students interested in camera and display engineering, computer vision, and computational imaging. Speakers include Stanford faculty and research scientists as well as industry professionals, mostly from consumer electronics companies.

EE 292F. Image Processing of Fine Art. 3 Units.
This course presents the application of rigorous digital image processing to problems in visualization and understanding of fine paintings, drawings, and other two-dimensional artworks. It builds upon a wealth of techniques but modifies and applies them to cases of interest to the technical art community. Such techniques include transforms such as DCT and wavelets, color quantization, blind source (image) separation, edge detection, super-resolution, visual style learning and transfer, digital in-painting, color transforms, level-set analysis, estimation of region statistics, Affine image transforms, and many others. Students will perform several projects which will involve coding, mathematical/statistical analysis, and explaining the relevance of the work to art scholarship.

EE 292H. Engineering, Entrepreneurship & Climate Change. 1 Unit.
The purpose of this seminar series course is to help students and professionals develop the tools to apply the engineering and entrepreneurial mindset to problems that stem from climate change, in order to consider and evaluate possible stabilizing, remedial and adaptive approaches. This course is not a crash course on climate change or policy. Instead we will focus on learning about and discussing the climate problems that seem most tractable to these approaches. Each week Dr. Field and/or a guest speaker will lead a short warm-up discussion/activity and then deliver a talk in his/her area of expertise. We will wrap up with small-group and full-class discussions of related challenges/opportunities and possible engineering-oriented solutions. Class members are asked to do background reading before each class, to submit a question before each lecture, and to do in-class brainstorming. May be repeated for credit.

EE 292I. Insanely Great Products: How do they get built?. 1 Unit.
Great products emerge from a sometimes conflict-laden process of collaboration between different functions within companies. This Seminar seeks to demystify this process via case-studies of successful products and companies. Engineering management and businesspeople will share their experiences in discussion with students. Previous companies profiled: Apple, Intel, Facebook, and Genentech -- to name a few. Previous guests include: Jon Rubinstein (NeXT, Apple, Palm), Diane Greene (VMware), and Ted Hoff (Intel). Pre-requisites: None.

EE 292N. Seminars in Wireless Frontiers. 1 Unit.
This course aims to raise the interest of senior undergraduate students and junior graduate students to the area of wireless from communication, gesture detection, power delivery to radar applications. It serves as an introduction to wireless through a series of seminars with invited speakers from both industry and academia.

EE 292T. SmartGrids and Advanced Power Systems Seminar. 1-2 Unit.
A series of seminar and lectures focused on power engineering. Renowned researchers from universities and national labs will deliver bi-weekly seminars on the state of the art of power system engineering. Seminar topics may include: power system analysis and simulation, control and stability, new market mechanisms, computation challenges and solutions, detection and estimation, and the role of communications in the grid. The instructors will cover relevant background materials in the in-between weeks. The seminars are planned to continue throughout the next academic year, so the course may be repeated for credit.
Same as: CEE 272T

EE 292X. Battery Systems for Transportation and Grid Services. 1-3 Unit.
Driven by high-capacity battery systems, electrification is transforming mobility solutions and the grid that powers them. This course provides an introduction to battery systems for transportation and grid services: cell technologies, topology selection, thermal and aging management, safety monitoring, AC and DC charging, and operation control/optimization. Invited experts introduce students to the state of the heart of each topic. The course is aimed at mezzanine and graduate levels students who wish to design battery systems, model them from data, integrate them into applications, or just learn about them. It can be taken for 1 unit (Credit/ no Credit) for attending seminars, or for 3 units (letter grade only) for also doing an optional project. Prerequisites: No prerequisites needed for taking the course for 1 unit. Relevant background in selected project area is recommended, for example, CEE 272R for grid applications; EE 253 for AC or DC charging and battery controller design; CEE 322, CS 229 or EE 104 for data-based projects.
Same as: CEE 292X

EE 293. Energy storage and conversion: Solar Cells, Fuel Cells, Batteries and Supercapacitors. 3 Units.
This course provides an introduction and engineering exposure to energy storage and conversion systems and will cover the basic physics, chemistry and electrochemistry of solar cells, fuel cells, batteries and supercapacitors, state of the art of such technologies and recent developments. The course will also cover experimental methods and modeling tools for simulation and optimization aimed at characterizing efficiency and performance issues. Prerequisites: Equivalent coursework in thermodynamics, electronic properties, chemical principles, electricity, and magnetism.
Same as: ENERGY 293

EE 293B. Fundamentals of Energy Processes. 3 Units.
For seniors and graduate students. Covers scientific and engineering fundamentals of renewable energy processes involving heat. Thermodynamics, heat engines, solar thermal, geothermal, biomass. Recommended: MATH 19-21; PHYSICS 41, 43, 45.
Same as: ENERGY 293B

EE 300. Master's Thesis and Thesis Research. 1-15 Unit.
Independent work under the direction of a department faculty. Written thesis required for final letter grade. The continuing grade 'N' is given in quarters prior to thesis submission. See 390 if a letter grade is not appropriate. Course may be repeated for credit.

EE 301. Introductory Research Seminar in Electrical Engineering. 1 Unit.
The EE 301 seminar course is offered primarily for incoming EE PhD students. All students and faculty in the Department are welcome to attend. EE faculty members present seminars on their research, giving new PhD students an overview of research opportunities across the Department.

EE 303. Autonomous Implantable Systems. 3 Units.
Integrating electronics with sensing, stimulation, and locomotion capabilities into the body will allow us to restore or enhance physiological functions. In order to be able to insert these electronics into the body, energy source is a major obstacle. This course focuses on the analysis and design of wirelessly powered catheter-deliverable electronics. Emphases will be on the interaction between human and electromagnetic fields in order to transfer power to the embedded electronics via electromagnetic fields, power harvesting circuitry, electrical-tissue interface, and sensing and actuating frontend designs.

EE 308. Advanced Circuit Techniques. 3 Units.
Design of advanced analog circuits at the system level, including switching power converters, amplitude-stabilized and frequency-stabilized oscillators, voltage references and regulators, power amplifiers and buffers, sample-and-hold circuits, and application-specific op-amp compensation. Approaches for finding creative design solutions to problems with difficult specifications and hard requirements. Emphasis on feedback circuit techniques, design-oriented thinking, and hands-on experience with modern analog building blocks. Several designs will be built and evaluated, along with associated laboratory projects. Prerequisite: EE 251 or EE 314A.

EE 309A. Semiconductor Memory Devices and Circuit Design. 3 Units.
The functionality and performance of ULSI systems are increasingly dependent upon the characteristics of the memory subsystem. This course introduces students to various semiconductor memory devices: SRAM, DRAM and FLASH, that are used in today's memory subsystems. The course will cover various aspects of semiconductor memories, including basic operation principles, device design considerations, device scaling, device fabrication, memory array architecture, and addressing and readout circuits. The course will also introduce students to recent research in near- and in-memory computing using these memory technologies. The next course is this series is EE 309B, which talks about emerging non-volatile memory devices and circuit design. Pre-requisite: EE 216. Preferred: EE 316.

EE 309B. Emerging Non-Volatile Memory Devices and Circuit Design. 3 Units.
The functionality and performance of ULSI systems are increasingly dependent upon the characteristics of the memory subsystem. This course starts off where EE 309A leaves, and introduces students to various emerging non-volatile memory devices: metal oxide resistive switching memory (RRAM), nanoconductive bridge memory (CBRAM), phase change memory (PCM), magnetic tunnel junction memory, spin-transfer-torque random access memory (MRAM, STT-RAM), ferroelectric memory (FRAM) and ferroelectric transistor (FeFET). For each of these memories, the course will cover basic operation principles, device design considerations, device scaling, device fabrication, memory array architecture, and addressing and readout circuits. The course will also introduce students to recent in-memory computing research using these memory technologies. Pre-requisite: EE 216. Preferred: EE 316, EE 309A.

EE 310. SystemX: Ubiquitous Sensing, Computing and Communication Seminar. 1 Unit.
This is a seminar course with invited speakers. Sponsored by Stanford's SystemX Alliance, the talks will cover emerging topics in contemporary hardware/software systems design. Special focus will be given to the key building blocks of sensors, processing elements and wired/ wireless communications, as well as their foundations in semiconductor technology, SoC construction, and physical assembly as informed by the SystemX Focus Areas. The seminar will draw upon distinguished engineering speakers from both industry and academia who are involved at all levels of the technology stack and the applications that are now becoming possible. May be repeat for credit.

EE 311. Advanced Integrated Circuits Technology. 3 Units.
What are the practical and fundamental limits to the evolution of the technology of modern MOS devices and interconnects? How are modern devices and circuits fabricated and what future changes are likely? Advanced techniques and models of MOS devices and back-end (interconnect and contact) processing. What are future device structures and materials to maintain progress in integrated electronics? MOS front-end and back-end process integration. Prerequisites: EE 216 or equivalent. Recommended: EE 212.

EE 312. Integrated Circuit Fabrication Laboratory. 3-4 Units.
Formerly EE 410. Fabrication, simulation, and testing of a submicron CMOS process. Practical aspects of IC fabrication including silicon wafer cleaning, photolithography, etching, oxidation, diffusion, ion implantation, chemical vapor deposition, physical sputtering, and electrical testing. Students also simulate the CMOS process using process simulator TSUPREM4 of the structures and electrical parameters that should result from the process flow. Taught in the Stanford Nanofabrication Facility (SNF). Preference to students pursuing doctoral research program requiring SNF facilities. Enrollment limited to 20. Prerequisites: EE 212, EE 216, or consent of instructor.

EE 314A. RF Integrated Circuit Design. 3 Units.
Design of RF integrated circuits for communications systems, primarily in CMOS. Topics: the design of matching networks and low-noise amplifiers at RF, mixers, modulators, and demodulators; review of classical control concepts necessary for oscillator design including PLLs and PLL-based frequency synthesizers. Design of low phase noise oscillators. Design of high-efficiency (e.g., class E, F) RF power amplifiers, coupling networks. Behavior and modeling of passive and active components at RF. Narrowband and broadband amplifiers; noise and distortion measures and mitigation methods. Overview of transceiver architectures. Prerequisite: EE214B.

EE 315. Analog-Digital Interface Circuits. 3 Units.
Analysis and design of circuits and circuit architectures for signal conditioning and data conversion. Fundamental circuit elements such as operational transconductance amplifiers, active filters, sampling circuits, switched capacitor stages and voltage comparators. Sensor interfaces for micro-electromechanical and biomedical applications. Nyquist and oversampling A/D and D/A converters. Prerequisite: EE 214B.

EE 316. Advanced VLSI Devices. 3 Units.
In modern VLSI technologies, device electrical characteristics are sensitive to structural details and therefore to fabrication techniques. How are advanced VLSI devices designed and what future changes are likely? What are the implications for device electrical performance caused by fabrication techniques? Physical models for nanometer scale structures, control of electrical characteristics (threshold voltage, short channel effects, ballistic transport) in small structures, and alternative device structures for VLSI. Prerequisites: 216 or equivalent. Recommended: EE 212.

EE 317. Special Topics on Wide Bandgap Materials and Devices. 3 Units.
Wide-bandgap (WBG) semiconductors present a pathway to push the limits of efficiency in optoelectronics and electronics enabling significant energy savings, offering new and compact architecture, and more functionality. We will first study the examples set by GaN and SiC in lighting, radiofrequency and power applications, then use it to explore new materials like Ga2O3, AlN and diamond to understand their potential to drive the future semiconductor industry. The term papers will include a short project that may require simulation to conduct device design and analysis. Prerequisites: EE 216 or EE 218.

EE 320. Nanoelectronics. 3 Units.
This course covers the device physics and operation principles of nanoelectric devices, with a focus on devices for energy-efficient computation. Topics covered include devices based on new nanomaterials such as carbon nanotubes, semiconductor nanowires, and 2D layered materials such as graphene; non-FET based devices such as nanoelectromechanical (NEM) relay, single electron transistors (SET) and resonant tunneling diodes (RTD); as well as FET-based devices such as tunnel FET. Devices targeted for both logic and memory applications are covered. Prerequisites: Undergraduate device physics, EE222, EE216, EE316. Recommended courses: EE223, EE228, EE311.

EE 323. Energy in Electronics. 3 Units.
EE 323 examines energy in modern nanoelectronics, from fundamentals to systems. Fundamental topics include energy storage and transfer via electrons and phonons, ballistic limits of current and heat, meso- to macroscale mobility and thermal conductivity. Applied topics include power in nanoscale devices (1D nanotubes and nanowires, 2D materials, 3D silicon CMOS, resistive memory and interconnects), circuit leakage, temperature measurements, thermoelectric energy conversion, and thermal challenges in densely integrated systems. Basic knowledge of semiconductors, transistors, and Matlab (or similar) are recommended.

EE 327. Properties of Semiconductor Materials. 3 Units.
Modern semiconductor devices and integrated circuits are based on unique energy band, carrier transport, and optical properties of semiconductor materials. How to choose these properties for operation of semiconductor devices. Emphasis is on quantum mechanical foundations of the properties of solids, energy bandgap engineering, semi-classical transport theory, semi-conductor statistics, carrier scattering, electro-magneto transport effects, high field ballistic transport, Boltzmann transport equation, quantum mechanical transitions, optical absorption, and radiative and non-radiative recombination that are the foundations of modern transistors and optoelectronic devices. Prerequisites: EE216 or equivalent.

EE 329. The Electronic Structure of Surfaces and Interfaces. 3 Units.
Physical concepts and phenomena for surface science techniques probing the electronic and chemical structure of surfaces, interfaces and nanomaterials. Microscopic and atomic models of microstructures; applications including semiconductor device technology, catalysis and energy. Physical processes of UV and X-ray photoemission spectroscopy, Auger electron spectroscopy, surface EXAFS, low energy electron diffraction, electron/photon stimulated ion desorption, scanning tunneling spectroscopy, ion scattering, energy loss spectroscopy and related imaging methods; and experimental aspects of these surface science techniques. Prerequisites: PHYSICS 70 and MATSCI 199/209, or consent of instructor.
Same as: PHOTON 329

EE 332. Laser Dynamics. 3 Units.
Dynamic and transient effects in lasers including spiking, Q-switching, mode locking, frequency modulation, frequency and spatial mode competition, linear and nonlinear pulse propagation, pulse shaping. Formerly EE 232. Prerequisite: 236C.

EE 336. Nanophotonics. 3 Units.
Recent developments in micro- and nanophotonic materials and devices. Basic concepts of photonic crystals. Integrated photonic circuits. Photonic crystal fibers. Superprism effects. Optical properties of metallic nanostructures. Sub-wavelength phenomena and plasmonic excitations. Meta-materials. Prerequisite: Electromagnetic theory at the level of 242.
Same as: MATSCI 346

EE 340. Optical Micro- and Nano-Cavities. 3 Units.
Optical micro- and nano-cavities and their device applications. Types of optical cavities (microdisks, microspheres, photonic crystal cavities, plasmonic cavities), and their electromagnetic properties, design, and fabrication techniques. Cavity quantum electrodynamics: strong and weak-coupling regime, Purcell factor, spontaneous emission control. Applications of optical cavities, including low-threshold lasers, optical modulators, quantum information processing devices, and bio-chemical sensors. Prerequisites: Advanced undergraduate or basic graduate level knowledge of electromagnetics, quantum.

EE 346. Introduction to Nonlinear Optics. 3 Units.
Wave propagation in anisotropic, nonlinear, and time-varying media. Microscopic and macroscopic description of electric-dipole susceptibilities. Free and forced waves; phase matching; slowly varying envelope approximation; dispersion, diffraction, space-time analogy. Harmonic generation; frequency conversion; parametric amplification and oscillation; electro-optic light modulation. Raman and Brillouin scattering; nonlinear processes in optical fibers. Prerequisites: 242, 236C.

EE 347. Optical Methods in Engineering Science. 3 Units.
Design and understanding of modern optical systems. Topics: geometrical optics; aberration theory; systems layout; applications such as microscopes, telescopes, optical processors. Computer ray tracing program as a design tool. Prerequisite: 236A or equivalent.

EE 348. Advanced Optical Fiber Communications. 3 Units.
Optical amplifiers: gain, saturation, noise. Semiconductor amplifiers. Erbium-doped fiber amplifiers. System applications: preamplified receiver performance, amplifier chains. Raman amplifiers, lumped vs. distributed amplification. Group-velocity dispersion management: dispersion-compensating fibers, filters, gratings. Interaction of dispersion and nonlinearity, dispersion maps. Multichannel systems. Wavelength-division multiplexing components: filters, multiplexers. WDM systems, crosstalk. Time, subcarrier, code and polarization-division multiplexing. Comparison of modulation techniques: differential phase-shift keying, phase-shift keying, quadrature-amplitude modulation. Comparison of detection techniques: noncoherent, differentially coherent, coherent. Prerequisite: 247.

EE 349. Advanced Topics in Nano-Optics and Plasmonics. 3 Units.
Electromagnetic phenomena at the nanoscale. Dipolar interactions between emitters and nanostructures, weak and strong coupling, surface plasmon polaritons and localized plasmons, electromagnetic field enhancements, and near-field coupling between metallic nanostructures. Numerical tools will be taught and used to simulate nano-optical phenomena. Prerequisite: EE 242 or equivalent.

EE 355. Imaging Radar and Applications. 3 Units.
Radar remote sensing, radar image characteristics, viewing geometry, range coding, synthetic aperture processing, correlation, range migration, range/Doppler algorithms, wave domain algorithms, polar algorithm, polarimetric processing, interferometric measurements. Applications: surfafe deformation, polarimetry and target discrimination, topographic mapping surface displacements, velocities of ice fields. Prerequisites: EE261. Recommended: EE254, EE278, EE279.
Same as: GEOPHYS 265

EE 356A. Resonant Converters. 3 Units.
Miniaturization of efficient power converters remain a challenge in power electronics whose goal is improving energy use and reducing waste. In this course, we will study the design of Resonant converters which are capable of operating at higher frequencies than their 'hard-switch' counterparts. Resonant converter are found in high performance applications where high control bandwidth and high power density are required. We will also explore practical design issues and trade off in selecting converter topologies in high performance applications. Prerequisites: EE153/EE253.

EE 356B. Magnetics Design in Power Electronics. 3 Units.
Inductors and transformers are ubiquitous components in any power electronics system. They are components that offer great design flexibility, provide electrical isolation and can reduce semiconductor stresses, but they often dominate the size and cost of a power converter and are notoriously difficult to miniaturize. In this class we will discuss the design and modeling of magnetic components, which are essential tasks in the development of high performance converters and study advanced applications. Prerequisites: EE153/EE253.

EE 359. Wireless Communications. 3-4 Units.
This course will cover advanced topics in wireless communications as well as current wireless system design. Topics include: an overview of current and future wireless systems; wireless channel models including path loss, shadowing, and statistical multipath channel models; fundamental capacity limits of wireless channels; digital modulation and its performance in fading and under intersymbol interference; techniques to combat fading including adaptive modulation and diversity; multiple antenna (MIMO) techniques to increase capacity and diversity, intersymbol interference including equalization, multicarrier modulation (OFDM), and spread spectrum; and multiuser system design, including multiple access techniques. Course is 3 units but can be taken for 4 units with an optional term project. Prerequisite: 279 or instructor consent.

EE 364A. Convex Optimization I. 3 Units.
Convex sets, functions, and optimization problems. The basics of convex analysis and theory of convex programming: optimality conditions, duality theory, theorems of alternative, and applications. Least-squares, linear and quadratic programs, semidefinite programming, and geometric programming. Numerical algorithms for smooth and equality constrained problems; interior-point methods for inequality constrained problems. Applications to signal processing, communications, control, analog and digital circuit design, computational geometry, statistics, machine learning, and mechanical engineering. Prerequisite: linear algebra such as EE263, basic probability.
Same as: CME 364A

EE 364B. Convex Optimization II. 3 Units.
Continuation of 364A. Subgradient, cutting-plane, and ellipsoid methods. Decentralized convex optimization via primal and dual decomposition. Monotone operators and proximal methods; alternating direction method of multipliers. Exploiting problem structure in implementation. Convex relaxations of hard problems. Global optimization via branch and bound. Robust and stochastic optimization. Applications in areas such as control, circuit design, signal processing, and communications. Course requirements include project. Prerequisite: 364A.
Same as: CME 364B

EE 367. Computational Imaging and Display. 3 Units.
Spawned by rapid advances in optical fabrication and digital processing power, a new generation of imaging technology is emerging: computational cameras at the convergence of applied mathematics, optics, and high-performance computing. Similar trends are observed for modern displays pushing the boundaries of resolution, contrast, 3D capabilities, and immersive experiences through the co-design of optics, electronics, and computation. This course serves as an introduction to the emerging field of computational imaging and displays. Students will learn to master bits and photons.
Same as: CS 448I

EE 368. Digital Image Processing. 3 Units.
Image sampling and quantization color, point operations, segmentation, morphological image processing, linear image filtering and correlation, image transforms, eigenimages, multiresolution image processing, noise reduction and restoration, feature extraction and recognition tasks, image registration. Emphasis is on the general principles of image processing. Students learn to apply material by implementing and investigating image processing algorithms in Matlab and optionally on Android mobile devices. Term project. Recommended: EE261, EE278.
Same as: CS 232

EE 369A. Medical Imaging Systems I. 3 Units.
Imaging internal structures within the body using high-energy radiation studied from a systems viewpoint. Modalities covered: x-ray, computed tomography, and nuclear medicine. Analysis of existing and proposed systems in terms of resolution, frequency response, detection sensitivity, noise, and potential for improved diagnosis. Prerequisite: EE 261.

EE 369B. Medical Imaging Systems II. 3 Units.
Imaging internal structures within the body using magnetic resonance studied from a systems viewpoint. Analysis of magnetic resonance imaging systems including physics, Fourier properties of image formation, effects of system imperfections, image contrast, and noise. Prerequisite: EE 261.

EE 369C. Medical Image Reconstruction. 3 Units.
Reconstruction problems from medical imaging, including magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography (PET). Problems include reconstruction from non-uniform frequency domain data, automatic deblurring, phase unwrapping, reconstruction from incomplete data, and reconstruction from projections. Prerequisite: 369B.

EE 371. Advanced VLSI Circuit Design. 3 Units.
Design of high-performance digital systems, the things that cause them to fail, and how to avoid these problems. Topics will focus on current issues including: wiring resistance and how to deal with it, power and Gnd noise and regulation, clock (or asynchronous) system design and how to minimize clocking overhead, high-speed I/O design, energy minimization including leakage control, and structuring your Verilog code to result in high-performance, low energy systems. Extensive use of modern CAD tools. Prerequisites: EE 213 and EE 271, or consent of instructor.

EE 372. Data Science for High Throughput Sequencing. 3 Units.
Extraordinary advances in sequencing technology in the past decade have revolutionized biology and medicine. Many high-throughput sequencing based assays have been designed to make various biological measurements of interest. This course explores the various computational and data science problems that arises from processing, managing and performing predictive analytics on this high throughput sequencing data. Specific problems we will study include genome assembly, haplotype phasing, RNA-Seq assembly, RNA-Seq quantification, single cell RNA-seq analysis, multi-omics analysis,nand genome compression. We attack these problems through a combination of tools from information theory, combinatorial algorithms, machine learning and signal processing. Through this course, the student will also get familiar with various software tools developed for the analysis of real sequencing data. Prerequisites: Basic knowledge of probability at the level of EE 178. Some programming experience.

EE 373A. Adaptive Signal Processing. 3 Units.
Learning algorithms for adaptive digital filters. Self-optimization. Wiener filter theory. Quadratic performance functions, their eigenvectors and eigenvalues. Speed of convergence. Asymptotic performance versus convergence rate. Applications of adaptive filters to statistical prediction, process modeling, adaptive noise canceling, adaptive antenna arrays, adaptive inverse control, and equalization and echo canceling in modems. Artificial neural networks. Cognitive memory/human and machine. Natural and artificial synapses. Hebbian learning. The Hebbian-LMS algorithm. Theoretical and experimental research projects in adaptive filter theory, communications, audio systems, and neural networks. Biomedical research projects, supervised jointly by EE and Medical School faculty. Recommended: EE263, EE264, EE278.

EE 374. Internet-Scale Consensus in the Blockchain Era. 3 Units.
Consensus protocols are at the core of distributed systems to enable nodes to agree on a common record of history. Traditional consensus protocols are designed for the closed setting where nodes are permissioned and fixed. Blockchains were invented by Nakamoto in 2008 to achieve consensus in the open permissionless setting at Internet-scale, where nodes can freely join and leave the network. Existing blockchains like Bitcoin and Ethereum have an excellent track record in operating securely in such a challenging environment but suffer from several significant drawbacks. This course studies recently proposed solutions to resolve these drawbacks and achieve: 1) throughput scalability; 2) fast confirmation; 3) finality and accountability; 4) energy efficiency and decentralization. It can be taken on a stand alone basis or as a follow-up to CS 251. Prerequisite: EE 178, CS 109 or equivalent. http://web.stanford.edu/class/ee374.

EE 375. Mathematical problems in Machine Learning. 3 Units.
Mathematical tools to understand modern machine learning systems. Generalization in machine learning, the classical view: uniform convergence, Radamacher complexity. Generalization from stability. Implicit (algorithmic) regularization. Infinite-dimensional models: reproducing kernel Hilbert spaces. Random features approximations to kernel methods. Connections to neural networks, and neural tangent kernel. Nonparametric regression. Asymptotic behavior of wide neural networks. Properties of convolutionalnnetworks. Prerequisites: EE364A or equivalent; Stat310A or equivalent.
Same as: STATS 375

EE 376B. Topics in Information Theory and Its Applications. 3 Units.
Information theory establishes the fundamental limits on compression and communication over networks. The tools of information theory have also found applications in many other fields, including probability and statistics, computer science and physics. The course will cover selected topics from these applications, including communication networks, through regular lectures and student projects. Prerequisites: EE276 (Formerly EE376A).
Same as: STATS 376B

EE 376C. Universal Schemes in Information Theory. 3 Units.
Universal schemes for lossless and lossy compression, channel coding and decoding, prediction, denoising, and filtering. Characterization of performance limitations in the stochastic settting: entropy rate, rate-distortion function, channel capacity, Bayes envelope for prediction, denoising, and filtering. Lempel-Ziv lossless compression, and Lempel-Ziv based schemes for lossy compression, channel coding, prediction, and filtering. Discrete universal denoising. Compression-based approach to denoising. The compound decision problem. Prerequisites: EE276 (Formerly EE376A).

EE 376D. Wireless Information Theory. 3 Units.
Information theory forms the basis for the design of all modern day communication systems. The original theory was primarily point-to-point, studying how fast information can flow across an isolated noisy communication channel. Until recently, there has been only limited success in extending the theory to a network of interacting nodes. Progress has been made in the past decade driven by engineering interest in wireless networks. The course provides a unified overview of this recent progress made in information theory of wireless networks. Starting with an overview of the capacity of fading and multiple-antenna wireless channels, we aim to answer questions such as: What is the optimal way for users to cooperate and exchange information in a wireless network? How much benefit can optimal cooperation provide over traditional communication architectures? How can cooperation help to deal with interference between multiple wireless transmissions? Prerequisites: EE276 (Formerly EE376A).

EE 377. Information Theory and Statistics. 3 Units.
Information theoretic techniques in probability and statistics. Fano, Assouad,nand Le Cam methods for optimality guarantees in estimation. Large deviationsnand concentration inequalities (Sanov's theorem, hypothesis testing, thenentropy method, concentration of measure). Approximation of (Bayes) optimalnprocedures, surrogate risks, f-divergences. Penalized estimators and minimumndescription length. Online game playing, gambling, no-regret learning. Prerequisites: EE 276 (or equivalent) or STATS 300A.
Same as: STATS 311

EE 378A. Statistical Signal Processing. 3 Units.
Basic concepts of statistical decision theory; Bayes decision theory; HMMs and their state estimation (Forward--backward), Kalman as special case, approximate state estimation (particle filtering, Extended Kalman Filter), unknown parameters; Inference under logarithmic loss, mutual information as a fundamental measure of statistical relevance, properties of mutual information: data processing, chain rules. Directed information. Prediction under logarithmic loss; Context Tree Weighting algorithm; Sequential decision making in general: prediction under general loss functions, causal estimation, estimation of directed information. Non-sequential inference via sequential probability assignments. Universal denoising; Denoising from a decision theoretic perspective: nonparametric function estimation, wavelet shrinkage, density estimation; Estimation of mutual information on large alphabets with applications such as boosting the Chow-Liu algorithm. Estimation of the total variation distance, estimate the fundamental limit is easier than to achieve the fundamental limit; Peetre¿s K-functional and bias analysis: bias correction using jackknife, bootstrap, and Taylor series; Nonparametric functional estimation. Prerequisites: Familiarity with probability theory and linear algebra at the undergraduate level.

EE 378B. Inference, Estimation, and Information Processing. 3 Units.
Techniques and models for signal, data and information processing, with emphasis on incomplete data, non-ordered index sets and robust low-complexity methods. Linear models; regularization and shrinkage; dimensionality reduction; streaming algorithms; sketching; clustering, search in high dimension; low-rank models; principal component analysis. Applications include: positioning from pairwise distances; distributed sensing; measurement/traffic monitoring in networks; finding communities/clusters in networks; recommendation systems; inverse problems. Prerequisites: EE278 and EE263 or equivalent. Recommended but not required: EE378A.

EE 378C. Information-theoretic Lower Bounds in Data Science. 3 Units.
Ideas and techniques for information-theoretic lower bounds, with examples in machine learning, statistics, information theory, theoretical computer science, optimization, online learning and bandits, operations research, and more. Deficiency and Le Cam¿s distance; classical asymptotics; information measures and joint range; Le Cam, Assouad, and Fano; Ingster-Suslina method; method of moments; strong converses; constrained risk inequality; compression arguments; privacy-constrained estimation; sequential experimental design; statistical/computational tradeoff. Prerequisites: EE 278, CS 229T, STATS 300A, or equivalent, or instructor¿s permission.

EE 379. Digital Communication. 3 Units.
Modulation: linear, differential and orthogonal methods; signal spaces; power spectra; bandwidth requirements. Detection: maximum likelihood and maximum a posteriori probability principles; sufficient statistics; correlation and matched-filter receivers; coherent, differentially coherent and noncoherent methods; error probabilities; comparison of modulation and detection methods. Intersymbol interference: single-carrier channel model; Nyquist requirement; whitened matched filter; maximum likelihood sequence detection; Viterbi algorithm; linear equalization; decision-feedback equalization. Multi-carrier modulation: orthogonal frequency-division multiplexing; capacity of parallel Gaussian channels; comparison of single- and multi-carrier techniques. Prerequisite: EE102B and EE278 (or equivalents). EE279 is helpful but not required.

EE 380. Colloquium on Computer Systems. 1 Unit.
Live presentations of current research in the design, implementation, analysis, and applications of computer systems. Topics range over a wide range and are different every quarter. Topics may include fundamental science, mathematics, cryptography, device physics, integrated circuits, computer architecture, programming, programming languages, optimization, applications, simulation, graphics, social implications, venture capital, patent and copyright law, networks, computer security, and other topics of related to computer systems. May be repeated for credit.

EE 382A. Parallel Processors Beyond Multicore Processing. 3 Units.
Formerly EE392Q. The current parallel computing research emphasizes multi-cores, but there are alterna-tive array processors with significant potential. This hands-on course focuses on SIMD (Single-Instruction, Multiple-Data) massively parallel processors. Topics: Flynn's Taxonomy, parallel architectures, Kestrel architecture and simulator, principles of SIMD programming, parallel sorting with sorting networks, string comparison with dynamic programming (edit distance, Smith-Waterman), arbitrary-precision operations with fixed-point numbers, reductions, vector and matrix multiplication, image processing algo-rithms, asynchronous algorithms on SIMD ("SIMD Phase Programming Model"), Man-delbrot set, analysis of parallel performance.

EE 382C. Interconnection Networks. 3 Units.
The architecture and design of interconnection networks used to communicate from processor to memory, from processor to processor, and in switches and routers. Topics: network topology, routing methods, flow control, router microarchitecture, and performance analysis. Enrollment limited to 30. Prerequisite: 282.

EE 384A. Internet Routing Protocols and Standards. 3 Units.
Local area networks addressing and switching; IEEE 802.1 bridging protocols (transparent bridging, virtual LANs). Internet routing protocols: interior gateways (RIP, OSPF) and exterior gateways (BGP); multicast routing; multiprotocol label switching (MPLS). Routing in mobile networks: Mobile IP, Mobile Ad Hoc Networks (MANET), Wireless Mesh Networks. Prerequisite: EE 284 or CS 144.

EE 384C. Wireless Local and Wide Area Networks. 3 Units.
Characteristics of wireless communication: multipath, noise, and interference. Communications techniques: spread-spectrum, CDMA, and OFDM. IEEE 802.11 physical layer specifications: FHSS, DSSS, IEEE 802.11b (CCK), and 802.11a/g (OFDM). IEEE 802.11 media access control protocols: carrier sense multiple access with collision avoidance (CSMA/CA), point coordination function (PCF), IEEE802.11e for differentiated services. IEEE 802.11 network architecture: ad hoc and infrastructure modes, access point functionality. Management functions: synchronization, power management and association. IEEE 802.11s Mesh Networks. IEEE 802.16 (WiMAX) network architecture and protocols: Physical Layer (OFDMA) and Media Access Control Layer. Current research papers in the open literature. Prerequisite: EE 284 or CS 244A.

EE 384E. Networked Wireless Systems. 3 Units.
Design and implementation of wireless networks and mobile systems. The course will commence with a short retrospective of wireless communication and initially touch on some of the fundamental physical layer properties of various wireless communication technologies. The focus will then shift to design of media access control and routing layers for various wireless systems. The course will also examine adaptations necessary at transport and higher layers to cope with node mobility and error-prone nature of the wireless medium. Finally, it will conclude with a brief overview of other related issues including emerging wireless/mobile applications. Prerequisites: EE 284.

EE 384S. Performance Engineering of Computer Systems & Networks. 3 Units.
Modeling and control methodologies for high-performance network engineering, including: Markov chains and stochastic modeling, queueing networks and congestion management, dynamic programming and task/processor scheduling, network dimensioning and optimization, and simulation methods. Applications for design of high-performance architectures for wireline/wireless networks and the Internet, including: traffic modeling, admission and congestion control, quality of service support, power control in wireless networks, packet scheduling in switches, video streaming over wireless links, and virus/worm propagation dynamics and countermeasures. Enrollment limited to 30. Prerequisites: basic networking technologies and probability.

EE 385A. Robust and Testable Systems Seminar. 1-4 Unit.
Student/faculty discussions of research problems in the design of reliable digital systems. Areas: fault-tolerant systems, design for testability, production testing, and system reliability. Emphasis is on student presentations and Ph.D. thesis research. May be repeated for credit. Prerequisite: consent of instructor.

EE 387. Algebraic Error Correcting Codes. 3 Units.
Introduction to the theory of error correcting codes, emphasizing algebraic constructions, and diverse applications throughout computer science and engineering. Topics include basic bounds on error correcting codes; Reed-Solomon and Reed-Muller codes; list-decoding, list-recovery and locality. Applications may include communication, storage, complexity theory, pseudorandomness, cryptography, streaming algorithms, group testing, and compressed sensing. Prerequisites: Linear algebra, basic probability (at the level of, say, CS109, CME106 or EE178) and "mathematical maturity" (students will be asked to write proofs). Familiarity with finite fields will be helpful but not required.
Same as: CS 250

EE 388. Modern Coding Theory. 3 Units.
Tools for analysis and optimization of iterative coding systems. LDPC, turbo and, RA codes. Optimized ensembles, message passing algorithms, density evolution, and analytic techniques. Prerequisite: EE 276.

EE 390. Special Studies or Projects in Electrical Engineering. 1-15 Unit.
Independent work under the direction of a faculty member. Individual or team activities may involve lab experimentation, design of devices or systems, or directed reading. May be repeated for credit.

EE 391. Special Studies and Reports in Electrical Engineering. 1-15 Unit.
Independent work under the direction of a faculty member; written report or written examination required. Letter grade given on the basis of the report; if not appropriate, student should enroll in 390. May be repeated for credit.

EE 392AA. Multi-Dimensional Data Transmission. 3 Units.
EE 392AA focuses on state-of-the-art data communication systems that use multiple dimensions (parallel antennas, wires, links), including the latest versions of 5G, Wi-Fi, G.MGfast wireline, DOCSIS 3.1, and other systems that stress fundamental transmission limits. Topics include system design, particularly physical-layer modulation/coding for analysis and optimization for specific channels. Included are all vectored designs (MIMO, massive MIMO, SIMO, MISO) and methods to design and adapt both transmitter and receiver to variable channels. This course is approved for satisfying the MSEE Depth Sequence on Communication and Networking. Prerequisites: EE 278, EE 279, EE 379 or instructor consent.

EE 392B. Industrial AI. 1 Unit.
The seminar features guest lectures from the industry. The Industrial AI (I-AI) computing applications are at the center of on-going digital transformation. Known as the Fourth Industrial Revolution, or Industry 4.0, this is a multi-trillion-dollar transformation of economy. The I-AI is related to Internet of Things (IoT), where 'things' include man-made systems and business processes: industrial, transportation, operations and support, and supply chains. I-AI applications are mission critical with large cost of error compared to AI apps for the Internet of People. The lecturers from technology (e.g., computing) companies, consultancies, AI vendors, OEMs, and end users of the I-AI will discuss business and 'big picture' technical issues. Example vertical industries are energy, transportation, oil and gas, data centers, and manufacturing.

EE 392E. VLSI Signal Processing Architectures. 3 Units.
DSP architecture design. Study of architecture techniques in energy-area-performance space, design methodology based on a data-flow graph model that leads to hardware implementation. High-level transformations: pipelining, retiming, folding, systolic array design, complexity reduction in convolution and parallel digital filters. Bit-level arithmetic: carry-save and redundant arithmetic. Applications to implementation of communications receivers and machine learning systems. Prerequisites: EE 102B and EE 108; Recommended: EE 264 and EE 271.

EE 392I. Seminar on Trends in Computing and Communications. 1 Unit.
Lectures series and invited talks on current trends in computing and communications, and ongoing initiatives for research and open innovation. This year's focus on evolving cloud computing architectures and their impact on the enterprise; big data trends and rise of the third platform; software as a service; wireless and cellular network architectures; mobility and mobile data proliferation; open mobile platforms (e.g. Android); multi-homed mobile networking, associated data communication and mobile resource trade-offs, and system implementation in smartphones and Android devices.

EE 392K. Self-Programming Networks. 3 Units.
This is an advanced topics course on building autonomous networks using data and techniques from machine learning. It covers two major application areas: Cloud Computing Systems and Mobile Wireless Networks. The course introduces the architecture of Self-Programming Networks for sensing, inferring, learning and control, consisting of (i) a "reflex layer" for inferring at line rate and at scale, and (ii) a "deliberate layer" for efficient resource scheduling and network control. Various sensing and inference algorithms for deriving insights and alerts from the sensed data will be discussed. Methods for synchronizing clocks across a large data center and using this to reconstruct the fine details of network performance (queue-depths, link utilizations and buffer and link compositions) in near real-time will be presented. Similarly, methods for inferring available bandwidth in dynamic mobile networks and using it to drive different application optimizations will be presented. Students will learn the use of neural networks and learning techniques (a) to accelerate inference and control algorithms, (b) for "workload fingerprinting", (c) for predicting wireless link capacities, and (d) for scheduling resources. Finally, the principles of creating an interactive database for detecting anomalies, raising alerts, and serving insights to the user will be discussed. The course involves a team-based project.

EE 392T. Seminar in Chip Test and Debug. 1 Unit.
Seminars by industry professionals in digital IC manufacturing test and silicon debug. Topics include yield and binsplit modeling, defect types and detection, debug hardware, physical analysis, and design for test/debug circuits. Case studies of silicon failures. Prerequisite: basic digital IC design (271 or 371).

EE 400. Thesis and Thesis Research. 1-15 Unit.
Limited to candidates for the degree of Engineer or Ph.D.May be repeated for credit.

EE 402A. Topics in International Technology Management. 1 Unit.
Theme for Autumn 2020 is "Digital transformation among new and traditional industries in Asia." Distinguished guest speakers and panels from industry discuss approaches in Asia to data-driven business models, influencer marketing, DevOps for new AI solutions, data privacy and security, new value chain relationships, etc. See syllabus for specific requirements, which may differ from those of other seminars at Stanford.
Same as: EALC 402A, EASTASN 402A

EE 402T. Entrepreneurship in Asian High Tech Industries. 1 Unit.
Distinctive patterns and challenges of entrepreneurship in Asia; update of business and technology issues in the creation and growth of start-up companies in major Asian economies. Distinguished speakers from industry, government, and academia.
Same as: EALC 402T, EASTASN 402T

EE 469B. RF Pulse Design for Magnetic Resonance Imaging. 3 Units.
Magnetic resonance imaging (MRI) and spectroscopy (MRS) based on the use of radio frequency pulses to manipulate magnetization. Analysis and design of major types of RF pulses in one and multiple dimensions, analysis and design of sequences of RF pulses for fast imaging, and use of RF pulses for the creation of image contrast in MRI. Prerequisite: 369B.

EE 801. TGR Project. 0 Units.
May be repeated for credit.

EE 802. TGR Dissertation. 0 Units.
May be repeated for credit.