Electrical Engineering

Courses offered by the Department of Electrical Engineering are listed under the subject code EE on the Stanford Bulletin’s ExploreCourses website.

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 a basic understanding of electrical engineering built on a foundation of physical science, mathematics, computing, and technology, and to provide majors in the department with knowledge of electrical engineering principles along with the required supporting knowledge of mathematics, science, computing, and engineering fundamentals. The program develops students’ skills in performing and designing experimental projects and communicating their findings to the scientific community effectively. Students in the major are required to select one sub-discipline for specialization. Choices include bio-electronics and bio-imaging; circuits and devices; computer hardware; computer software; music; signal processing, communication and controls; and photonics, solid state and electromagnetics; and energy and environment.

The program prepares students for careers in government agencies, the corporate sector, or for future study in graduate or professional schools.

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 specialty area, currently including bio-electronics and bio-imaging; circuits and devices; computer hardware; computer software; music; signal processing, communication and controls; and photonics, solid state and electromagnetics; and energy and environment.
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.

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 bio-electrical engineering; hardware; software; control and system engineering; communication systems; dynamic systems and optimization; circuits; devices, sensors and technology; fields, waves and radioscience; image systems; lasers, optoelectronics and quantum electronics; network systems; signal processing; solid state materials and devices.

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.

Graduate Programs in Electrical Engineering

University regulations governing the M.S. and Ph.D. degrees are described in the “Graduate Degrees” section of this bulletin.

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

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

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

Application for Admission

Applications for graduate admission in Electrical Engineering (EE) should be completed electronically at http://gradadmissions.stanford.edu. For information concerning Electrical Engineering graduate admissions, see http://ee.stanford.edu/admissions. The application deadline for full-time admission for Autumn Quarter 2015-16 is December 9, 2014.

Electrical Engineering Course Catalog Numbering System

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

<table>
<thead>
<tr>
<th>Number</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>010-099</td>
<td>first or second year undergraduate</td>
</tr>
<tr>
<td>100-199</td>
<td>second through fourth year undergraduate</td>
</tr>
<tr>
<td>200-299</td>
<td>mezzanine courses for advanced undergraduate or first-year graduate</td>
</tr>
<tr>
<td>300-399</td>
<td>second through fourth year graduate</td>
</tr>
<tr>
<td>400-499</td>
<td>specialized courses for advanced graduate</td>
</tr>
<tr>
<td>600-799</td>
<td>special summer courses</td>
</tr>
</tbody>
</table>

The Department of Electrical Engineering (EE) offers courses in the following areas:
• Biomedical Devices and Bioimaging
• Communication Systems: wireless, optical, wireline
• Control, Learning, and Optimization
• Electronic and Magnetic Devices
• Energy: solar cells, smart grid, load control
• Environmental and Remote Sensing: sensor nets, radar systems, space
• Fields and Waves
• Graphics, HCI, Computer Vision, Photography
• Information Theory and Coding: Image and data compression, denoising
• Integrated Circuit Design: MEMs, sensors, analog, RF
• Network Systems and Science: Next gen internet, wireless networks
• Nano and Quantum Science
• Nanofabrication Science and Technology
• Photonic Devices
• Systems Software: OS, compilers, languages
• Systems Hardware: architecture, VLSI, embedded systems

Areas of Research in Electrical Engineering
Candidates for advanced degrees participate in the research activities of the department as paid research assistants or as students of individual faculty members. At any one time, certain areas of research have more openings than others. At present, faculty members and students are actively engaged in research in the following areas:

Hardware/Software Systems
• Data Science
• Distributed Systems
• Energy-Efficient Hardware Systems
• Integrated Circuits and Power Electronics
• Programming Environments
• Security
• Software Defined Networking
• Mobile Networking

Information Systems and Science
• Bio-Medical Imaging
• Communications Systems
• Control & Optimization
• Data Science
• Information Theory and Applications
• Societal Networks
• Signal Processing and Multimedia

Physical Science and Technology
• Biomedical Devices and Systems
• Electronic Devices
• Energy Harvesting and Conversion
• Integrated Circuits and Power Electronics
• Nanotechnology and NEMS/MEMS
• Nanophotonics and Quantum Technologies
• Optics

For additional information, see the Department of Electrical Engineering’s Research page at https://ee.stanford.edu/research/the-big-picture.

Undergraduate Programs in Electrical Engineering
To major in Electrical Engineering (EE), undergraduates should follow the depth sequence in the “Undergraduate Degree in Electrical Engineering” section of this bulletin. Students must have a program planning sheet approved by their adviser and the department before the end of the quarter following the quarter in which they declare the EE major. A final version of the completed and signed program sheet is due to the department no later than one month prior to the quarter of senior year. Program sheets are available at http://ughb.stanford.edu. Majors must receive at least a 2.0 grade point average (GPA) in courses taken for the EE depth requirement; all classes must be taken for a letter grade.

Students interested in a minor should consult the “Minor in Electrical Engineering” section of this bulletin.

A Stanford undergraduate may work simultaneously toward the B.S. and M.S. degrees. University requirements for the coterminal M.A. or M.S. are described in the “Coterminal Bachelor’s and Master’s Degrees” section of this bulletin. For University coterminal degree program rules and University application forms, see http://studentaffairs.stanford.edu/registrar/publications#Coterm.

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 a basic understanding of electrical engineering built on a foundation of physical science, mathematics, computing, and technology, and to provide majors in the department with knowledge of electrical engineering principles along with the required supporting knowledge of mathematics, science, computing, and engineering fundamentals. The program develops students’ skills in performing and designing experimental projects and communicating their findings to the scientific community effectively. Students in the major are required to select one sub-discipline for specialization. Choices include: electronic circuits, devices and photonics; signal processing, communication and controls; hardware and software systems; bio-electronics and bio-imaging; music; and energy and environment. The program prepares students for careers in government agencies, the corporate sector, or for future study in graduate or professional schools.

Requirements

<table>
<thead>
<tr>
<th>Mathematics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 41</td>
<td>Calculus</td>
</tr>
<tr>
<td>MATH 42</td>
<td>Calculus</td>
</tr>
<tr>
<td>Select one 2-course sequence:</td>
<td>10</td>
</tr>
<tr>
<td>CME 100 &amp; CME 102</td>
<td>Vector Calculus for Engineers and Ordinary Differential Equations for Engineers (Same as ENGR 154)</td>
</tr>
<tr>
<td>MATH 52 &amp; MATH 53</td>
<td>Integral Calculus of Several Variables and Ordinary Differential Equations with Linear Algebra</td>
</tr>
</tbody>
</table>
Following courses:

- EE 108
- EE 102A
- EE 101A
- EE 100

Core Electrical Engineering Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE Math.</td>
<td>One additional 100-level course. Select one of the following:</td>
</tr>
<tr>
<td>EE 102B</td>
<td>Signal Processing and Linear Systems II (if not used in Depth)</td>
</tr>
<tr>
<td>EE 103</td>
<td>Introduction to Matrix Methods</td>
</tr>
<tr>
<td>EE 142</td>
<td>Engineering Electromagnetics</td>
</tr>
<tr>
<td>CME 104/ENGR 155B</td>
<td>Linear Algebra and Partial Differential Equations for Engineers</td>
</tr>
<tr>
<td>MATH 113</td>
<td>Linear Algebra and Matrix Theory</td>
</tr>
<tr>
<td>CS 103</td>
<td>Mathematical Foundations of Computing</td>
</tr>
</tbody>
</table>

Statistics/Probability. Select one of the following:

- EE 178 | Probabilistic Systems Analysis (Preferred) |
- CS 109 | Introduction to Probability for Computer Scientists |

Science

Select one of the following sequences:

- PHYSICS 41 & PHYSICS 43 | Mechanics and Electricity and Magnetism |
- PHYSICS 61 & PHYSICS 63 | Mechanics and Special Relativity and Electricity, Magnetism, and Waves |

Science elective. One additional 4-5 unit course from approved list in Undergraduate Handbook, Figure 3-4.

Technology in Society

One course, see Basic Requirement 4 in the School of Engineering section

Engineering Fundamentals

Select one of the following:

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

At least two additional courses, at least one of which is not in EE or ENGR 106A is not allowed. Choose from table in Undergraduate Handbook, Figure 3-4. One from ENGR 40, ENGR 40M or ENGR 40P recommended.

Writing in the Major (WIM)

Select one of the following:

- EE 109 | Digital Systems Design Lab (WIM/Design) |
- EE 133 | Analog Communications Design Laboratory (WIM/Design) |
- EE 134 | Introduction to Photonics (WIM/Design) |
- EE 152 | Green Electronics (WIM/Design) |
- EE 153 | Power 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) |
- CS 194W | Software Project (WIM/Design) |

Core Electrical Engineering Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE 100</td>
<td>The Electrical Engineering Profession</td>
</tr>
<tr>
<td>EE 101A</td>
<td>Circuits I</td>
</tr>
<tr>
<td>EE 102A</td>
<td>Signal Processing and Linear Systems I</td>
</tr>
<tr>
<td>EE 108</td>
<td>Digital System Design</td>
</tr>
<tr>
<td>EE 41/ENGR 40P</td>
<td>Physics of Electrical Engineering</td>
</tr>
</tbody>
</table>

Select one of the following courses:

- EE 65 | Modern Physics for Engineers (Preferred) |
- EE 142 | Engineering Electromagnetics |

Depth Courses

Select four courses from one of the following Depth areas. Courses must include one required course, one Design course, and 2 additional courses.

Design Course

Select one of the following:

- EE 109 | Digital Systems Design Lab (WIM/Design) |
- EE 133 | Analog Communications Design Laboratory (WIM/Design) |
- EE 134 | Introduction to Photonics (WIM/Design) |
- EE 152 | Green Electronics (WIM/Design) |
- EE 153 | Power Electronics (WIM/Design) |
- EE 168 | Introduction to Digital Image Processing (WIM/Design) |
- EE 262 | Two-Dimensional Imaging (Design) |
- EE 265 | Digital Signal Processing Laboratory (Design) |
- CS 194W | Software Project (WIM/Design) |

Additional Depth Electives

May include up to two additional Engineering Fundamentals, any CS 193 course and any letter graded EE or EE Related courses (minus any previously noted restrictions). Freshman and Sophomore seminars, EE191 and CS 106A do not count toward the 60 units.

1. CME 106 or STATS 116 can also fulfill the Statistics/Probability requirement, but these are not preferred.
2. The EE introductory class ENGR 40 or ENGR 40M may be taken concurrently with PHYSICS 43.
3. A minimum of 12 science units must be taken. A minimum of 40 math and science units combined must be taken.
4. EE Engineering Topics: Fundamentals and Depth courses must total 60 units minimum.
5. 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.
6. For upper division students, a 200-level seminar in their depth area will be accepted, on petition.
7. EE 41/ENGR 40P can meet this requirement only if it is not used to fulfill the Engineering Fundamentals requirement.
8. EE 142 cannot be used for both Physics in Electrical Engineering and as a depth elective.

Depth Areas

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE 101B</td>
<td>Circuits II (Required)</td>
<td>4</td>
</tr>
<tr>
<td>or EE 102B</td>
<td>Signal Processing and Linear Systems II</td>
<td></td>
</tr>
<tr>
<td>EE 122B</td>
<td>Introduction to Biomedical Electronics</td>
<td>3</td>
</tr>
<tr>
<td>EE 124</td>
<td>Introduction to Neuroelectrical Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EE 134</td>
<td>Introduction to Photonics (WIM/Design)</td>
<td>4</td>
</tr>
<tr>
<td>EE 168</td>
<td>Introduction to Digital Image Processing (WIM/Design)</td>
<td>4</td>
</tr>
<tr>
<td>EE 169</td>
<td>Introduction to Bioimaging</td>
<td>3</td>
</tr>
<tr>
<td>EE 202</td>
<td>Electrical Engineering in Biology and Medicine</td>
<td>3</td>
</tr>
<tr>
<td>EE 225</td>
<td>Biochips and Medical Imaging</td>
<td>3</td>
</tr>
</tbody>
</table>

Circuits and Devices

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE 101B</td>
<td>Circuits II (Required)</td>
<td>4</td>
</tr>
</tbody>
</table>
Bachelor of Science in Electrical Engineering with Honors. This program

The Department of Electrical Engineering offers a program leading to a

Honors Program

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

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

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

1. Maintain a grade point average (GPA) of at least 3.5 in EE courses.
2. Complete at least 10 units of EE 191 or EE 191W for a letter grade with their thesis adviser. EE 191 units do not count toward the required 60 units, with the exception of EE 191W if used to satisfy WIM.
3. Submit one final copy of the honors thesis approved by the adviser and second reader to the EE Degree Progress Officer by May 15.
4. Attend poster and oral presentation held at the end of spring quarter or present in another suitable forum approved by the faculty adviser.

**Electrical Engineering (EE) Minor**

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

<table>
<thead>
<tr>
<th>Units</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>EE 65 Modern Physics for Engineers</td>
</tr>
<tr>
<td></td>
<td>ENGR 40 Introductory Electronics</td>
</tr>
<tr>
<td></td>
<td>ENGR 40M An Intro to Making: What is EE</td>
</tr>
<tr>
<td></td>
<td>ENGR 40P/EE Physics of Electrical Engineering 41</td>
</tr>
</tbody>
</table>

Select one of the following options:

**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 108 Digital System Design
- EE 180 Digital Systems Architecture

In addition, four letter-graded EE or Related courses at the 100-level or higher must be taken (12 units minimum). CS 107 is required as a prerequisite for EE 180, but can count as one of the four classes.

**Master of Science in Electrical Engineering**

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

It is the student’s responsibility, in consultation with an adviser, to determine whether the prerequisites for advanced courses have been met.

Prerequisite courses ordinarily taken by undergraduates may be included as part of the graduate program of study. However, if the number of these is large, the proposed program may contain more than the minimum 45 units, and the time required to meet the degree requirements may be increased.

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

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

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 degree students may elect to begin their study in either the Department of Electrical Engineering or the School of Law. Faculty advisers from each academic unit participate in the planning and supervising of the student’s joint program. In the first year of the joint degree program, students must be enrolled full-time in the School of Law. Students must satisfy the requirements for both the J.D. and the M.S. degrees as specified in the Stanford Bulletin.

The Electrical Engineering Department approves courses from the Law School that may count toward the M.S. degree in Electrical Engineering, and the Law School approves courses from the Department of Electrical Engineering that may count toward the J.D. degree. In either case, approval may consist of a list applicable to all joint degree students or may be tailored to each individual student’s program.

No more than 45 quarter hours of approved courses may be counted toward both degrees. No more than 36 quarter hours of courses that originate outside the School of Law may count toward the Law degree. To the extent that courses under this joint degree program originate outside of the School of Law but count toward the Law degree, the School of Law credits permitted under Section 17(1) of the Law School Regulations shall be reduced on a unit-per-unit basis but not below zero.

The maximum number of School of Law units that may be counted toward the M.S. degree in Electrical Engineering is the greater of:

1. 12 units
2. the maximum number of units from courses outside of the department that M.S. candidates in Electrical Engineering are permitted to count toward the M.S. degree under general departmental guidelines, or as set forth in the case of a particular student’s individual program.
Tuition and financial aid arrangements are typically administered through the school in which the student is enrolled.

**Joint Electrical Engineering and Masters 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.

**The Honors Cooperative Program**

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

**Doctor of Philosophy in Electrical Engineering**

The University requirements for the Ph.D. degree are described in the “Graduate Degrees” section of this bulletin.

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

Students admitted to the Ph.D. program must sign up to take the department qualifying examination, given once a year in winter quarter. Students are encouraged to take the exam in their first year of study. Students who have never taken the qualifying examination by the end of the second year of study will be dismissed from the Ph.D. program for failure to progress. Such students may be allowed to complete a master’s degree in Electrical Engineering instead.

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 (of which 15 units must be letter-graded), and have the Application for Ph.D. Minor approved by the EE department and the major department. A grade point average of at least 3.35 on these courses is required.


**Chair:** Abbas El Gamal

**Associate Chairs:** Robert W. Dutton (Undergraduate Education), Olav Solgaard (Graduate Education), Howard Zebek (Admissions)

**Academic Affairs Committee Chair:** Joseph M. Kahn

X. Wang, Jennifer Widom, H. S. Philip Wong, S. Simon Wong, Howard Schieber

**Associate Professors:** Dawson Engler, John T. Gill III, Christoforos E. Kozyrakis, Philip Levis, Subhasish Mitra, Andrea Montanari, Boris Murmann, Eric Pop, Tsachy Weissman

**Assistant Professors:** Amin Arbabian, John Duchi, Audrey Ellerbee, Jonathan Fan, Sachin Katti, Ayfer Ozgur Aydin, Ada Poon, Juan Rivas-Davila, Gordon Wetzstein

**Professors (Research):** William J. Dally, James F. Gibbons, Leonid Kazovsky, Butrus Khuri-Yakub, Yoshio Nishi, Piero Pianetta

**Courtesy Professors:** Stacey Bent, Kim Butts-Pauly, Emmanuel Candes, EJ Chichilnisky, Amir Dembo, David L. Dill, Per Enge, Ron Fedkiw, Gary Glover, Peter Glynn, Monica S. Lam, Craig Levin, David G. Luenberger, Michael McConnell, John C. Mitchell, Sandy Napel, Richard Olshen, John Ousterhout, Norbert Pelc, Julius Smith, Brian Wandell, Lei Xing, Yinyu Ye

**Courtyard Associate Professors:** Kwabena Boahen, Brian Hargreaves, Ramesh Johari, Andrew Ng, Amin Saberi, Daniel Spielman, Barbara van Schewick

**Courtyard Assistant Professors:** Mohsen Bayati, Sigrid Close, Adam de la Zerda, Surya Ganguli, Jin Hyung Lee, David Liang, Marco Pavone, Ram Rajagopal, Debbie Senesky

**Lecturers:** Dennis Allison, Sakshi Arora, Andrea Di Blas, Abbas Emami-Naeini, Andrew Freeman, Peter Griffin, My Le, Roger Melen, Scott Murray, David Obershaw, Dan O’Neill, Marcel Pelgrom, Jason Stinson


**Consulting Associate Professors:** Jatinder Singh, Jun Ye

**Consulting Assistant Professor:** Aneesh Nainani

**Visiting Professors:** Nicola Feima, Jinliang He, Anping Jiang, Igor Markov, Naresh Shanbhag

**Visiting Associate Professors:** João Cordeiro de Oliveira Barros, Hoon Kim, Olga Munoz Medina, Aslan Tchamkerten, Shengli Zhang

**Visiting Assistant Professors:** Meili Guo, Haricharan Lakshman, Panagiotis Patrinos, Gerson Rodriguez de los Santos Lopez, Xiumin Shi

### Courses

**EE 10N. How Musical Instruments Work. 3 Units.**

Musical instruments, as well as being fun to play, are excellent examples of science, engineering, and the interplay between the two. How does an instrument make sound? Why does a trumpet sound different from a guitar, a flute, or a bell? We will examine the principles of operation of wind, string, percussion, and electronic instruments hands-on in class. Concepts to be investigated include waves, resonators, understanding and measuring sound spectra and harmonic structure of instruments, engineering design of instruments, the historical development of instruments, and the science and engineering that make them possible. Prerequisites: high school math and physics. Recommended: some experience playing a musical instrument.

**EE 10SC. Mathematics of the Information Age. 2 Units.**

The world may be made of earth, wind, fire, and water, but it runs on information. What is information? How do we measure it, manipulate it, send it, and protect it? Why has everything gone digital and what does this mean? The mathematics of the Information Age is part of your everyday life, from imaging to the Internet. We will discuss the elements of information theory and how information is represented in different ways for different purposes. We will work with the mathematical representation of signals from the classical functions of trigonometry to the spectrum of a general signal. This course will help you understand some of the profound ways mathematics is used to shape and direct these aspects of the modern world. There will be regular assignments, readings, a research project, and a presentation on a topic of your choice that goes beyond the class material.

**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 Nanofabrication 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 22N. Medical Imaging Systems. 3 Units.
Preference to freshmen. The technology of major imaging modalities used for disease diagnosis: x-ray, ultrasound, and magnetic resonance; their history, societal impact, and clinical applications. Field trips to a medical center and an imaging research lab. Term paper and presentation. Prerequisites: high school physics and calculus.

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 27N. Electronics Rocks. 3 Units.
Electronics pervades our lives, yet we often feel obligated to let a device function as it was intended. This course is about not being intimidated by voiding a warranty and modding some commercial gadget and about being confident enough to build something cool from scratch. To get there, we will study the basics of "how things work" via "dissection and discussion" and discuss how to hack/mod but focus primarily how to scratch build. Students will be mentored and encouraged to work, in teams, to design and develop a substantial project based on embedded microprocessors and custom circuits as needed. Typical projects include programmable, color-changing wireless juggling balls, a self-healing mesh-networked hide-and-seek game, and a glowing plasma based clock built from surplus Soviet vacuum tubes and a modern microprocessor. Prerequisites: good hand-eye coordination, intelligence, teamwork skills, curiosity and humility.

EE 41. Physics of Electrical Engineering. 5 Units.
How everything from electrostatics to quantum mechanics is used in common high-technology products. Electrostatics are critical in micro-electronic systems used in many sensors and displays, and Electromagnetic waves are essential in all high-speed communication systems. How to propagate energy on transmission lines, optical fibers, and in free space. Which aspects of modern physics are needed to generate light for the operation of a DVD player or TV. Introduction to semiconductors, solid-state light bulbs, and laser pointers. Hands-on labs to connect physics to everyday experience. Prerequisites: Physics 43. Same as: ENGR 40P

EE 46. Engineering For Good: Save the World and Have Fun Doing It. 3 Units.
Projects that provide immediate and positive impact on the world. Focus is on global health by learning from experts in this field. 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 40 or EE 122A or CS 106B or consent of instructor.

EE 47. Press Play: Interactive Device Design. 3 Units.
Introduction to the human-centered and technical workings behind interactive devices ranging from cellphones and video controllers to smart cars and appliances. Students build a working MP3 player prototype of their own design, using embedded microcontrollers, digital audio decoders and component sensors, and other electronic hardware. Topics include electronics prototyping, interface prototyping, sensors and actuators, microcontroller development, physical prototyping, and user testing. Prerequisite: CS106A and X or consent of instructor.

EE 60N. Man versus Nature: Coping with Disasters Using Space Technology. 4 Units.
Preference to freshmen. 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-EngAppSci. Same as: GEOPHYS 60N

EE 65. Modern Physics for Engineers. 3 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 92A. Making and Breaking Things. 1 Unit.
This course will feature weekly visiting speakers who will guide class members through the hands-on process of assembling or dissection novel interactive devices and products. The course is meant to provide students hands-on experience with component sensing and computing technologies, a working knowledge of different materials and methods used in modern-day prototyping and manufacture, and exposure to people engaged in designing novel devices within the field of interactive device de-sign. Activities will features a wide and evolving range of domains such as textile sciences, hacking wireless radio, making LED light sculptures, taking apart toys, shape deposition modeling and more.

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.
First of two-course sequence. 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 useful but not strictly required.
EE 101B. Circuits II. 4 Units.
Second of two-course sequence. MOS large-signal and small-signal models. MOS amplifier design including DC bias, small signal performance, multistage amplifiers, frequency response, and feedback. Prerequisite: EE101A, EE102A.

EE 102A. Signal Processing and Linear Systems I. 4 Units.

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 103. Introduction to Matrix Methods. 4-5 Units.
Introduction to applied linear algebra with emphasis on applications. Vectors, norm, and angle; linear independence and orthonormal sets. Matrices, left and right inverses, QR factorization. Least-squares and model fitting, regularization and cross-validation, time-series prediction, and other examples. Constrained least-squares; applications to least-norm reconstruction, optimal control, and portfolio optimization. Newton methods and nonlinear least-squares. Prerequisites: MATH 51 or CME 100. Same as: CME 103

EE 107. Networked Systems. 3 Units.
Networks form the interconnect that stitch together our digital and physical lives. They underpin cloud computing, our mobile connectivity, as well as the means to connect the large number of sensors that will pervade our physical surroundings. This class will provide hands on introduction to how networks at these different scales are designed, from datacenters to embedded low power networks. Students will learn these concepts through a project that involves building a wireless network from the ground up using software radios. Students will also learn how to use these networks to build embedded applications (e.g. wireless controlled network of drones, localization systems using WiFi). The goal is to introduce students to larger concepts in electrical engineering and computer systems: the role of abstraction and layering, building reliable systems out of unreliable components and dynamic sharing of scarce resources. Prerequisites: EE 102A or ENGR 40M.

EE 108. Digital System Design. 4 Units.

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.
Same as: EE 214A

EE 116. Semiconductor Device Physics. 3 Units.
The fundamental operation of semiconductor devices and overview of applications. The physical principles of semiconductors, both silicon and compound materials; operating principles and device equations for junction devices (diodes, bipolar transistor, photo-detectors). Introduction to quantum effects and band theory of solids. Prerequisite: ENGR 40. Corequisite: 101B.

EE 118. Introduction to Mechatronics. 4 Units.
Technologies involved in mechatronics (intelligent electro-mechanical systems), and techniques to apply this technology to mechatronic 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 122A. Analog Circuits Laboratory. 3 Units.
The course covers practical applications of mixed-signal circuits, including simple amplifiers, filters (passive, op-amp, switched-capacitor and digital-signal-processor-based), oscillators, power supplies, sensors and interface (input/output) circuits. Practical design skills, computer-aided design, and circuit fabrication and debugging are core topics. The design process is learned through proposing, designing, simulating, building, debugging, and demonstrating a substantial and novel team project. Radio frequency and largely digital projects not suitable for EE 122. Prerequisite: basic electronics laboratory experience with solid working knowledge of circuit analysis, Fourier and Laplace methods.

EE 122B. Introduction to Biomedical Electronics. 3 Units.
EE122B is a laboratory course covering the design and realization of key components and architectures of modern biomedical electronics systems, their application in clinical and research measurements, and practical matters in their safe reduction to practice. Material in each topic area begins with an overview of the underlying physiology. Details are presented beginning with the molecular, cellular, organ-level origins of the biosignals, followed by the relevant transduction principles, nature of the signals (amplitude, frequency spectrum, etc.), and their processing and clinical use. Specific engineering topics include safety in biomedical instruments, fundamentals of analog/digital conversion and filtering techniques for biosignals, typical transducers (biopotential, electrochemical, temperature, pressure, acoustic, movement), applications (cardiovascular medicine, neurology, pulmonology, etc.) and interfacing circuits. Prerequisite: EE122A or equivalent hands-on mixed-signal design experience and solid working knowledge of EE122A topics (see course description).

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. Amplitude modulation (AM) using multiplier circuits. Frequency modulation (FM) based on discrete oscillator and integrated modulator circuits such as voltage-controlled oscillators (VCOs). Phased-lock loop (PLL) techniques, characterization of key parameters, and their applications. Practical aspects of circuit implementations. Labs involve building and characterization of AM and FM modulation/demodulation circuits and subsystems. Enrollment limited to 30 undergraduates and coterminal EE students. Prerequisite: EE101B. Undergraduate students enroll in EE133 and Graduate students enroll in EE233. 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: 41 or equivalent.

EE 136. Introduction to Nanophotonics and Nanostructures. 3 Units.
Electromagnetic and quantum mechanical waves and semiconductors. Confining these waves, and devices employing such confinement. Localization of light and applications: metallic mirrors, photonic crystals, optical waveguides, microresonators, plasmonics. Localization of quantum mechanical waves: quantum wells, wires, and dots. Generation of light in semiconductors: spontaneous and stimulated emission, lasers, and light emitting diodes. Devices incorporating localization of both electromagnetic and quantum mechanical waves such as resonant cavity quantum well lasers and microcavity-based single photon sources. System-level applications such as optical communications, biochemical sensing, and quantum cryptography. Prerequisite: basic familiarity with electromagnetic and quantum mechanical waves and semiconductors at the level of EE 41 or equivalent.

EE 142. Engineering Electromagnetics. 3 Units.
Introduction to electromagnetism and Maxwell's equations in static and dynamic regimes. Electrostatics and magnetostatics: Gauss' and Coulomb's, Faraday's, Ampere's, and 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; Solution of 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 (recommended).

EE 151. Sustainable Energy Systems. 3 Units.
Energy demand is expected to grow by 30% by 2025, while at the same time the European Union is demanding a carbon footprint at 1990 levels. We examine energy flow in the US and Europe, and deduce from it a strategy for sustainable growth. Potential solutions include distributed small scale networked energy generation, solar energy, wind and water, as well as nuclear energy. A systems perspective allows optimization. Fundamental concepts will be demonstrated in class through hands-on experiments.

EE 152. 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, photovoltaic systems, and design of magnetic components. The course involves a hands-on laboratory and a substantial final project. Required: EE101B, EE102A, EE108A. Recommended: ENGR40 or EE122A.

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. Formerly EE 292J. Same as: EE 253

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. 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. 4 Units.
Introduction to probability and statistics and their role in modeling and analyzing real world phenomena. Events, sample space, and probability. Discrete random variables, probability mass functions, independence and conditional probability, expectation and conditional expectation. Continuous random variables, probability density functions, independence and expectation, derived densities. Transforms, moments, sums of independent random variables. Simple random processes. Limit theorems. Introduction to statistics: significance, estimation and detection. Prerequisites: basic calculus.

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. Not offered AT 14-15, and students are encouraged to enroll in EE 107 instead.
EE 180. Digital Systems Architecture. 3-4 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: CS107 (required) and EE108 (recommended but not required).

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. EE191A 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 their major requirement. A written report that has gone through revision with an advisor is required. An advisor from the Writing Center is recommended. Same as: WIM

EE 192X. Stanford's Little Box Challenge. 1-15 Unit.
Google has announced the "Littlebox" competition to build the smallest possible 2kW inverter. This challenge provides an ideal opportunity to provide a number of exciting educational and design opportunities for engineering students. The first few class meetings will be lecture format describing the competition and the work that has been done to date: Mechanical modeling, Matlab model, Buck and unfolding bridge designs. In parallel, students will be matched in teams for studies that need to be done: DC-Link implementation, QR-topology, Multi-level Approaches, Control implementation, GaN implementation, SiC investigations, Capacitor studies, Inductor studies, Thermal Design, EMI study, Etc. The problems span many topics: embedded and control systems design, power electronics, digital and analog design, programming in C & FPGAs, mechanical and thermal design and testing. We welcome motivated undergraduate and graduate students with a variety of backgrounds. Same as: EE 292X

EE 202. Electrical Engineering in Biology and Medicine. 3 Units.
Open to all. Primarily biological in nature, introduction to the physiological and anatomic aspects of medical instrumentation. Areas include patient monitoring, imaging, medical transducers, the unique aspects of medical electronic systems, the socio-economic impact of technology on medical care, and the constraints unique to medicine. Prerequisite: familiarity with circuit instrumentation techniques as in 101B.

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 204. Business Management for Electrical Engineers and Computer Scientists. 3 Units.
For graduate students with little or no business experience. Leading computer, high-tech, and Silicon Valley companies and their best practices, tools and frameworks for analyzing decision thes companies face. Corporate strategy, new product development, marketing, sales, distribution, customer service, financial accounting, outsourcing, and human behavior in business organizations. Case studies. Prerequisite: graduate standing.

EE 204S. Business Management for Electrical Engineers and Computer Scientists. 3 Units.
For SCPD students; see EE204.

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 213. Digital MOS Integrated Circuits. 3 Units.
Looks a little more deeply at how digital circuits operate, what makes a gates digital, and how to "cheat" to improve performance or power. To aid this analysis we create a number of different models for MOS transistors and choose the simplest one that can explain our circuit's operation, using both hand and computer analysis. We explore static, dynamic, pulse-mode, and current mode logic, and show how they are are used in SRAM design. Topics include sizing for min delay, noise and noise margins, power dissipation. The class uses memory design (SRAM) as a motivating example. DRAM and EEPROM design issues are also covered. Formerly EE 313. Prerequisites: EE 101B, EE 108A. Recommended: EE 271.

EE 214A. Fundamentals of Analog Integrated Circuit Design. 3-4 Units.
Same as: EE 114

EE 214B. Advanced Analog 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 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, PHYSICS 65 (or PHYSICS 43 and 45).

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.

EE 228. Basic Physics for Solid State Electronics. 3 Units.
Topics: energy band theory of solids, energy bandgap engineering, classical kinetic theory, statistical mechanics, and equilibrium and non-equilibrium semiconductor statistics. Prerequisite: course in modern physics.

EE 230. Biophotonics: Light in Biology. 3 Units.
This course will provide an introduction to the use of optics in biology, primarily focusing on microscopy from an engineering perspective (i.e., the focus of the course is more on technology than biology). Course material will be interspersed with labs to provide hands-on experience with common techniques in modern microscopy (e.g., brightfield, fluorescence, confocal and phase contrast microscopy). Background in college physics strongly recommended. Programming experience with Matlab required.

EE 233. Analog Communications Design Laboratory. 3-4 Units.
Design, testing, and applications. Amplitude modulation (AM) using multiplier circuits. Frequency modulation (FM) based on discrete oscillator and integrated modulator circuits such as voltage-controlled oscillators (VCOs). Phased-lock loop (PLL) techniques, characterization of key parameters, and their applications. Practical aspects of circuit implementations. Labs involve building and characterization of AM and FM modulation/demodulation circuits and subsystems. Enrollment limited to 30 undergraduates and coterminal EE students. Prerequisite: EE101B. Undergraduate students enroll in EE133 and Graduate students enroll in EE233. Recommended: EE114/214A.

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 242 or equivalent. Recommended: EE 236A.

EE 236A. Modern Optics. 3 Units.
Geometrical optics, aberrations, optical instruments, radiometry. Ray matrices and Gaussian beams. Wave nature of light. Plane waves: at interfaces, in media with varying refractive index. Diffraction and Fourier optics. Interference, single-beam interferometers (Fabry-Perot), multiple-beam interferometers (Michelson, Mach-Zehnder), Polarization, Jones and Stokes calculus. Formerly EE 268. Prerequisites: EE 141 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.

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.

EE 242. Electromagnetic Waves. 3 Units.

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 Fiber Optical Communications. 3 Units. 

EE 248. Fundamentals of Noise Processes. 3 Units. 

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.

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 simulator in lab sessions. A final project is designed to solve a research antenna design problem in biomedical area or wireless communications. Prerequisite: EE 141 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. Formerly EE 292J.

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.

EE 256. Numerical Electromagnetics. 3 Units. 
Principles and applications of numerical techniques for solving practical electromagnetics problems. Finite-difference time-domain (FDTD) method and finite-difference frequency-domain (FDFD) method for solving 2D and 3D Maxwell's equations. Numerical analysis of stability, dispersion, and dissipation. Perfectly matched layer (PML) absorbing boundaries. Total-field/scattered-field (TF/SM) method. Interaction of electromagnetic waves with dispersive and anisotropic media. Homework assignments require programming and the use of MATLAB or other equivalent tools. Prerequisite: 242 or equivalent.

EE 257. Applied Optimization Laboratory (Geophys 258). 3-4 Units. 
Application of optimization and estimation methods to the analysis and modeling of large observational data sets. Laboratory exercises using inverse theory and applied linear algebra to solve problems of indirect and noisy measurements. Emphasis on practical solution of scientific and engineering problems, especially those requiring large amounts of data, on digital computers using scientific languages. Also addresses advantages of large-scale computing, including hardware architectures, input/output and data bus bandwidth, programming efficiency, parallel programming techniques. Student projects involve analyzing real data by implementing observational systems such as tomography for medical and Earth observation uses, radar and matched filtering, multispectral/multitemporal studies, or migration processing. Prerequisites: Programming with high level language. Recommended: EE261, EE263, EE178, ME300 or equivalent. 
Same as: GEOPHYS 258

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. Two-Dimensional Imaging. 3 Units. 
Time and frequency representations, two-dimensional auto- and cross-correlation, Fourier spectra, diffraction and antennas, coordinate systems and the Hankel and Abel transforms, line integrals, impulses and sampling, restoration in the presence of noise, reconstruction and tomography, imaging radar. Tomographic reconstruction using projection-slice and layergarm methods. Students create software to form images using these techniques with actual data. Final project consists of design and simulation of an advanced imaging system. Prerequisite: EE261. Recommended: EE278, EE279.
EE 263. Introduction to Linear Dynamical Systems. 3 Units.
Applied linear algebra and linear dynamical systems with application 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 MATH 103; differential equations and Laplace transforms as in EE 102A.
Same as: CME 263

EE 264. Digital Signal Processing. 3-4 Units.
This is a course on digital signal processing techniques and their applications. Topics include: review of DSP fundamentals; 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; and parametric signal modeling. The course will also discuss applications of DSP in areas such as speech and audio processing, autonomous vehicles, and software radio. An optional (1 unit) project will provide a hands-on opportunity to explore the application of DSP theory to practical real-time applications. Prerequisite: EE102A and EE102B or equivalent.

EE 265. Digital Signal Processing Laboratory. 3-4 Units.
Applying 102A.B to real-world signal processing applications. Lab exercises use a programmable DSP to implement signal processing tasks. Topics: A/D conversion and quantization, sampling theorem, Z-transform, discrete-time Fourier transform, digital filter design and implementation, spectral analysis, rate conversion, wireless data communication, and OFDM receiver design. Prerequisites: 102A.B. Recommended: 261.

EE 266. Stochastic Control. 3 Units.
Introduction to stochastic control, with applications taken from a variety of areas including supply-chain optimization, advertising, finance, dynamic resource allocation, caching, and traditional automatic control. Markov decision processes, optimal policy with full state information for finite-horizon case, infinite-horizon discounted, and average stage cost problems. Bellman value function, value iteration, and policy iteration. Approximate dynamic programming. Linear quadratic stochastic control. Formerly EE365. Prerequisites: EE 263, EE 178 or equivalent.
Same as: MSE 251

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 272. Design Projects in VLSI Systems. 3-4 Units.
An introduction to mixed signal design. Working in teams you will create a small mixed-signal VLSI design using a modern design flow and CAD tools. The project involves writing a Verilog model of the chip, creating a testing/debug strategy for your chip, wrapping custom layout to fit into a std 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 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 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 283B. Embedded Wireless Systems. 3 Units.
The structure and implementation of hardware/software systems for low power embedded sensors; how to build hardware/software systems that can run unattended for years on small batteries. Topics: hardware trends, energy profiles, execution models, sensing, aggregation, storage, application requirements, allocation, power management, resource management, scheduling, time synchronization, programming models, software design, and fault tolerance. Students discuss papers and research a final project building working systems on low-power embedded devices.

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 284B. Advanced Topics in Networking. 3-4 Units.
Classic papers, new ideas, and research papers in networking. Architectural principles: naming, addressing, routing; congestion control, traffic management, QoS; wireless and mobility; overlay networks and virtualization; network security; switching and routing; content distribution; and proposals for future Internet structures. Prerequisite: 144 or equivalent. Same as: CS 244

EE 287A. Computer and Network Security. 3 Units.
For seniors and first-year graduate students. Principles of computer systems security. Attack techniques and how to defend against them. Topics include: network attacks and defenses, operating system security, application security (web, apps, databases), malware, privacy, and security for mobile devices. Course projects focus on building reliable code. Prerequisite: 110. Recommended: basic Unix. Same as: CS 155

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 292B. Micro and Nanoscale Biosensing for Molecular Diagnostics. 3 Units.
The course covers state-of-the-art and emerging bio-sensors, biochips, microfluidics, which will be studied in the context of molecular diagnostics. Students will briefly learn the relevant biology, biochemistry, and molecular biology pertinent to molecular diag-nostics. Students will also become equipped with a thorough understanding of the interfaces between electronics, fluidics, and molecular biology. Topics will include microfluidics and mass transfer limits, electrode-electrolyte interfaces, electrochemical noise processes, biosensor system level characterization, determination of performance parameters such as throughput, detection limit, and cost, integration of sensor with microfluidics, and electronic readout circuitry architectures. Emphasis will be placed on in-depth quantitative design of biomolecular sensing platforms.

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 (except 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 292H. Engineering and Climate Change. 1 Unit.
The purpose of this seminar series course is to help students and professionals develop the tools to apply the engineering 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 it will focus on learning about and discussing climate problems that seem most likely to benefit from the engineering mindset. 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. It will wrap up with small-group and full-class discussions of related challenges/opportunities and possible engineering-oriented solutions. nClass members are asked to do some background reading before each class and to submit a question before each lecture. 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 292K. Intelligent Energy Projects. 3 Units.
Energy systems must have the intelligence to cope with rapid changes in energy supply, demand, distribution, and storage. This course is a project course focusing on a selected areas of intelligent energy systems: Demand Response, Optimal Power Flow and Locational Marginal Pricing, energy systems monitoring, control analysis of distribution systems, and associated system architecture. Prerequisites: Consent of instructor. Basic probability (EE 278), optimization (EE 364A), Matlab and C++ programming. Experience with cvx a plus.

EE 292L. Nanomanufacturing. 3 Units.
Fundamentals of nanomanufacturing technology and applications. Topics include recent developments in process technology, lithography and patterning. Technology for FinFET transistors, NAND flash and 3D chips. Manufacturing of LEDs, thin film and crystalline solar cells. Flip classroom model is used supplementing classroom lectures with short videos. Guest speakers include distinguished engineers, entrepreneurs and venture capitalists actively engaged in nanomanufacturing. Prerequisite: background in device physics and process technology. Recommended: EE116, EE216, EE212.
EE 292M. Parallel Processors Beyond Multi-Core Processing. 2 Units.
The current parallel computing research emphasizes multi-cores, but
there are alternative array processors with significant potential. This
hands-on seminar focuses on SIMD (Single-Instruction, Multiple-Data)
 massively parallel processors, with weekly programming assignments.
Topics: Flynn's Taxonomy, parallel architectures, the K-SIMD 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, asynchronous algorithms on
SIMD ("SIMD Phase Programming Model"), Mandelbrot set, analysis of
parallel performance. Prerequisites: EE108B and EE282. Recommended:
CS140.

EE 292P. Power Management Integrated Circuits. 3 Units.
Analysis of power management architectures and circuits in CMOS VLSI
technology. Circuit-level design of integrated linear voltage regulators and
highly-efficient switching power converters. Overview of significant topics:
high-frequency converters, switched capacitor converters, battery chargers,
digital control and layout of power converters. Prerequisite: EE214A or
equivalent.

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. Stanford's Little Box Challenge. 1-15 Unit.
IGoogle has announced the "Littlebox" competition to build the smallest
possible 2kW inverter. This challenge provides an ideal opportunity to
provide a number of exciting educational and design opportunities for
engineering students. The first few class meetings will be lecture format
describing the competition and the work that has been done to date:
Mechanical modeling, Matlab model, Buck and unfolding bridge designs.
In parallel, students will be matched in teams for studies that need to be
done: DC-Link implementation, QR-topology, Multi-level Approaches,
Control implementation, GaN implementation, SiC investigations,
Capacitor studies, Inductor studies, Thermal Design, EMI study, etc.
The problems span many topics: embedded and control systems design,
power electronics, digital and analog design, programming in C & FPGAs,
mechanical thermal and design testing. We welcome motivated
undergraduate and graduate students with a variety of backgrounds.
Same as: EE 192X

EE 293A. Solar Cells, Fuel Cells, and Batteries: Materials for the
Energy Solution. 3-4 Units.
Operating principles and applications of emerging technological solutions
to the energy demands of the world. The scale of global energy usage and
requirements for possible solutions. Basic physics and chemistry of solar
 cells, fuel cells, and batteries. Performance issues, including economics,
from the ideal device to the installed system. The promise of materials
research for providing next generation solutions. Undergraduates register in
156 for 4 units; graduates register in 256 for 3 units.
Same as: ENERGY 293A, MATSCI 156, MATSCI 256

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 41, 43; PHYSICS 41, 43, 45.
Same as: ENERGY 293B

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 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 front-end designs. Prerequisites: EE 252 or equivalent.

EE 304. Neuromorphics: Brains in Silicon. 3 Units.
This course introduces neuromorphic system design, starting at the device
level, going through the circuit level, and ending up at the system level.
At the device level, it covers MOS transistor operation in the subthreshold
region. At the circuit level, it covers silicon neuron and synapse design. And
at the system level, it covers reprogrammable interconnection. At the end of
the course, you will understand how various neuromorphic architectures work;
area and energy use scale with network size. Prerequisites: EE114 &
EE108A.
Same as: BIOE 313

EE 308. Advanced Circuit Techniques. 3 Units.
Design of advanced analog circuits at the system level, including switching
circuit 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.

EE 309. Semiconductor Memory Devices and Technology. 3 Units.
The functionality and performance of ULSI systems are increasingly
dependent upon the characteristics of the memory subsystem. This course
introduces the student to various memory devices: SRAM, DRAM,
NVRAM (non-volatile memory). This course will cover various aspects
of semiconductor memories, including basic operation principles, device
design considerations, device scaling, device fabrication, memory array
addressing and readout circuits. Various cell structures (e.g. 4T-1C, 6T,
1T-1R, 0T-1R, 1S-1R, floating gate FLASH, SONOS, NROM), and
memory organization (open-bit-line, folded-bit-line, NAND, NOR, cross-
point etc.). This course will include a survey of new memory concepts
(e.g. magnetic tunnel junction memory (MRAM, SST-RAM), ferroelectric
memories (FRAM), phase change memory (PCM), metal oxide resistive
switching memory (RRAM), nonconductive bridge memory (CBRAM)).
Offered Alternate years. Pre-requisite: EE 216. Preferred: EE 316

EE 310. Integrated Circuits Technology and Design Seminar. 1 Unit.
State-of-the-art micro- and nanoelectronics, nanotechnology, advanced
materials, and nanoscience for device applications. Prerequisites: EE216,
EE316. May be repeated 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: EE212, EE216 or equivalent.
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 314B. Advanced RF Integrated Circuit Design. 3 Units.
Analysis and design of modern communication circuits and systems with emphasize on design techniques for high-frequency (into mm-wave) ICs. Topics include MOS, bipolar, and BiCMOS high-frequency integrated circuits, including power amplifiers, extremely wideband amplifiers, advanced oscillators, phase-locked loops and frequency-translation circuits. Design techniques for mm-wave silicon ICs (on-chip low-loss transmissions lines, unilateralization techniques, in-tegrated antennas, harmonic generation, etc) will also be studied. Prerequisite: EE314A or equivalent course in RF or microwave.

EE 315A. VLSI Signal Conditioning Circuits. 3 Units.
Design and analysis of integrated circuits for active filters, precision gain stages, and sensor interfaces in CMOS VLSI technology. Operational transconductance amplifiers; sampled-data and continuous-time analog filters. Analysis of noise and amplifier imperfections; compensation techniques such as correlated double sampling. Sensor interfaces for micro-electromechanical and biomedical applications. Layout techniques for analog integrated circuits. Prerequisites: EE214B.

EE 315B. VLSI Data Conversion Circuits. 3 Units.
Architectural and circuit level design and analysis of integrated analog-to-digital and digital-to-analog interfaces in CMOS VLSI technology. Fundamental circuit elements such as sampling circuits and voltage comparators. Circuits and architectures for Nyquist-rate and oversampling analog-to-digital and digital-to-analog conversion; digital decimation and interpolation filters. Examples of calibration and digital enhancement techniques. Prerequisite: EE 214B. Recommended: EE 315A.

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: 212 and 216, or equivalent.

EE 319. Advanced Nanoelectronic Devices and Technology. 3 Units.
Recent advances in materials science, device physics and structures, and processing technology, to extend VLSI device scaling towards atomistic and quantum-mechanical physics boundaries. Topics include: mobility-enhancement techniques; nanomaterial structures including tube, wire, beam, and crystal; conducting polymer; 3D FET; gate-wraparound FET; nonvolatile memory phenomena and devices; self-assembly; flash annealing; plasma doping; and nano patterning. Prerequisites: 216, 316.

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.
This course examines energy in modern nanoelectronics, from fundamentals to system-level issues. Topics include fundamental aspects like energy transfer through electrons and phonons, ballistic limits of current and heat, meso- to macroscale mobility and thermal conductivity. The course also examines applications involving power dissipation in nanoscale devices (FinFETs, phase-change memory, nanowires, graphene, nanotubes), circuit leakage, thermal breakdown, thermometry, heat sinks, and thermal challenges in densely integrated systems.

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 on quantum mechanical foundations of the properties of solids, energy bandgap engineering, semi-classical transport theory, semiconductor 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 328. Physics of Advanced Semiconductor Devices. 3 Units.
Principles governing the operation of modern semiconductor devices. Assumptions and approximations commonly made in analyzing devices. Emphasis is on the application of semiconductor physics to the development of advanced semiconductor devices such as heterojunctions, HJ-bipolar transistors, HJ-FETs, nanostructures, tunneling, single electron transistor and photonic devices. Use of SENTAUS, a 2-D Poisson solver, for simulation of ultra-small devices. Examples related to state-of-the-art devices and current device research. Prerequisite: 216. Recommended: 316.

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 331. Biophotonics: Light in Medicine and Biology. 3 Units.
Current topics and trends in the use of light in medicine and for advanced microscopy. Course begins with a review of relevant optical principles (basic physics required). Key topics include: light-tissue interactions; sensing and spectroscopy; contrast-enhanced imaging; super-resolution and label-free microscopy; medical applications of light for diagnostics, in-vivo imaging, and therapy; nanophotonics and array technologies. Open to non-majors; programming experience (Matlab and/or C) required.
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 334. Micro and Nano Optical Device Design. 3 Units.
Lecture and project course on design and analysis of optical devices with emphasis on opportunities and challenges created by scaling to the micrometer and nanometer ranges. The emphasis is on fundamentals, combined with some coverage of practical implementations. Prerequisite: EE 242 or equivalent.

EE 336. Nanophotonics. 3 Units.

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 345. Optical Fiber Communication Laboratory. 3 Units.
Experimental techniques in optical fiber communications and networking. Experimental investigation of key optical communications components including fibers, lasers, modulators, photodiodes, optical amplifiers, and WDM multiplexers and demultiplexers. Fundamental optical communications systems techniques: eye diagrams, BER measurements, experimental evaluation of nonlinearities. Prerequisites: Undergraduate physics and optics.

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 348. Advanced Optical Fiber Communications. 3 Units.

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.

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: surface deformation, polarimetry and target discrimination, topographic mapping surface displacements, velocities of ice fields. Prerequisites: EE261. Recommended: EE254, EE278, EE279. Same as: GEOPHYS 265

EE 356. Resonant Power Converters and Magnetic Design. 3 Units.
In this course, we will study the design of Resonant power converters which are capable of operating at higher frequencies than their hard-switch counterparts. Resonant converters 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 application. We will discuss the design and modeling of high frequency magnetic elements, gate drives and resonant snubbers.

EE 385. Wireless Communications. 3-4 Units.
This course will cover advanced topics in wireless communications for voice, data, and multimedia. 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 intersymbol interference; techniques to combat fading including adaptive modulation, diversity, and multiple antenna systems (MIMO); techniques to combat intersymbol interference including equalization, multicycle modulation (OFDM), and spread spectrum; and an overview of wireless network design. Prerequisite: 279 or instructor consent.

EE 360. Multisensor Wireless Systems and Networks. 3 Units.
Design, analysis, and fundamental limits. Topics include multiuser channel capacity, multiple and random access techniques, interference mitigation, cellular system design, ad hoc wireless network design, sensor networks, “green” wireless networks, cognitive radios, and cross-layer design. Prerequisite: EE 359.

EE 364A. Convex Optimization I. 3 Units.

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 376. Resonant Power Converters and Magnetic Design. 3 Units.
In this course, we will study the design of Resonant power converters which are capable of operating at higher frequencies than their hard-switch counterparts. Resonant converters 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 application. We will discuss the design and modeling of high frequency magnetic elements, gate drives and resonant snubbers.

EE 385. Wireless Communications. 3-4 Units.
This course will cover advanced topics in wireless communications for voice, data, and multimedia. 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 intersymbol interference; techniques to combat fading including adaptive modulation, diversity, and multiple antenna systems (MIMO); techniques to combat intersymbol interference including equalization, multicycle modulation (OFDM), and spread spectrum; and an overview of wireless network design. Prerequisite: 279 or instructor consent.

EE 360. Multisensor Wireless Systems and Networks. 3 Units.
Design, analysis, and fundamental limits. Topics include multiuser channel capacity, multiple and random access techniques, interference mitigation, cellular system design, ad hoc wireless network design, sensor networks, “green” wireless networks, cognitive radios, and cross-layer design. Prerequisite: EE 359.

EE 364A. Convex Optimization I. 3 Units.

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 non-ionizing radiation studied from a systems viewpoint. Modalities include ultrasound and magnetic resonance. Analysis of ultrasonic systems including diffraction and noise. Analysis of magnetic resonance systems including physics, Fourier properties of image formation, 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: 271 and 313, or consent of instructor.

EE 373A. Adaptive Signal Processing. 3 Units.

EE 373B. Adaptive Neural Networks. 3 Units.

EE 376A. Information Theory. 3 Units.
Same as: STATS 376A 

EE 376B. Network Information Theory. 3 Units.
Network information theory deals with the fundamental limits on information flow in networks and the optimal coding schemes that achieve these limits. It aims to extend Shannon's point-to-point information theory and the Ford-Fulkerson max-flow min-cut theorem to networks with multiple sources and destinations. The course presents the basic results and tools in the field in a simple and unified manner. Topics covered include: multiple access channels, broadcast channels, interference channels, channels with state, distributed source coding, multiple description coding, network coding, relay channels, interactive communication, and noisy network coding. Prerequisites: EE376A.

Same as: STATS 376B 

EE 376C. Universal Schemes in Information Theory. 3 Units.

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? Formerly EE361. Prerequisites: 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 deviations and concentration inequalities (Sanov's theorem, hypothesis testing, thentropy method, concentration of measure). Approximation of (Bayes) optimal procedures, surrogate risks, f-divergences. Penalized estimators and minimumdescription length. Online game playing, gambling, no-regret learning. Prerequisites: EE 376A (or equivalent) or STATS 300A.

Same as: STATS 311
EE 378A. Statistical Signal Processing. 3 Units.

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: EE 278 and EE 263 or equivalent. Recommended but not required: EE 378A.

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: EE 378A.

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 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 382E. Advanced Multi-Core Systems. 3 Units.
In-depth coverage of the architectural techniques used in modern, multi-core chips for mobile and server systems. Advanced processor design techniques (superscalar cores, VLIW cores, multi-threaded cores, energy-efficient cores), cache coherence, memory consistency, vector processors, graphics processors, heterogeneous processors, and hardware support for security and parallel programming. Students will become familiar with complex trade-offs between performance-power-complexity and hardware-software interactions. A central part of CS 316 is a project on an open research question on multi-core technologies. Prerequisites: EE 108B. Recommended: CS 149, EE 282.

Same as: CS 316

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 384B. Multimedia Communication over the Internet. 3 Units.
Applications and requirements. Traffic generation and characterization: voice encoding (G.711, G.729, G.723); image and video compression (JPEG, H.261, MPEG-2, H.263, H.264), TCP data traffic. Quality impairments and measures. Networking technologies: LAN technologies; home broadband services (ADSL, cable modem, PONs); and wireless LANs (802.11). Network protocols for multimedia applications: resource reservation (ST2+, RSVP); differentiated services (DiffServ); and real-time transport protocol (RTP, RTCP). Audio-video-data conferencing standards: Internet architecture (SDP, SAP, SIP); ITU recommendations (H.320, H.323 and T.120); and real-time streaming protocol (RTSP). Emphasis will be placed on advances in network infrastructure and new services (VoIP, IPTV, Peer-to-peer communications, etc.) Prerequisite: 284 or CS 144. Recommended: 384A.

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 (CCCK), 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). IEEE 802.11e 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. Recent 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. Same as: CS 244E

EE 384M. Network Science. 3 Units.
Modern large-scale networks consist of (i) Information Networks, such as the Web and Social Networks, and (ii) Data Centers, which are networks interconnecting computing and storage elements for servicing the users of an Information Network. This course is concerned with the mathematical models and the algorithms used in Information Networks and Data Centers. Prerequisite: EE 178 or CS 365.
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 384X. Packet Switch Architectures. 3 Units.
The theory and practice of designing packet switches, such as Internet routers, and Ethernet switches. Introduction: evolution of switches and routers. Output queued switches: motivation and methods for providing bandwidth and delay guarantees. Switching: output queuing, parallelism in switches, distributed shared memory switches, input-queued switches, combined input-output queued switches, how to make fast packet buffers, buffered crossbar switches. Scheduling input queued crossbars: connections with bipartite graph matching, algorithms for 100% throughput, practical algorithms and heuristics. Looking forward: Architectures and switches for data center networks. Prerequisites: EE284 or CS 244A. Recommended: EE 178 or EE 278 or STAT 116.

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 386. Robust System Design. 3 Units.
Causes of system malfunctions; techniques for building robust systems that avoid or are resilient to such malfunctions through built-in error detection and correction, prediction, self-test, self-recovery, and self-repair; case studies and new research problems. Prerequisites: 108A,B, 282.

EE 387. Algebraic Error Control Codes. 3 Units.
Theory and implementation of algebraic codes for detection and correction of random and burst errors. Introduction to finite fields. Linear block codes, cyclic codes, Hamming codes, BCH codes, Reed-Solomon codes. Decoding algorithms for BCH and Reed-Solomon codes. Prerequisites: elementary probability, linear algebra.

EE 387A. Advanced Topics in Cryptography. 3 Units.
Topics: Pseudo randomness, multiparty computation, pairing-based and lattice-based cryptography, zero knowledge protocols, and new encryption and integrity paradigms. May be repeated for credit. Prerequisite: 255.

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 392A. Advanced Digital Transmission. 3 Units.
This course will develop insights into fundamentals and design of state-of-the-art physical-layer transmission systems. Specific attention will be paid to transmission in non-ideal environments with limited spectra and spatial interference. A theory of parallel channels is used to develop multi-carrier methods, vector coding, and generalized decision-feedback approaches. Students will be expected to design and analyze performance of systems operating close to fundamental limits for a variety of practical channels, wireline or wireless. Prerequisites: EE379 or equivalent; understanding of probability, random processes, digital signal processing (including basic matrix and matlab skills).

EE 392E. VLSI Signal Processing. 3 Units.
DSP architecture design. Study of circuit and architecture techniques in energy-area-performance space. Design methodology based on a data-flow graph model that leads to hardware implementation. We explore automated wordlength reduction, direct and recursive filters, time-frequency analysis and other examples. The project focuses on architecture exploration for selected DSP algorithms. Useful for algorithm designers who consider hardware constraints and for circuit designers who prototype DSP algorithms in hardware. Prerequisites: EE102B and EE108A; Recommended: EE264 and EE271.

EE 392F. Logic Synthesis of VLSI Circuits. 3 Units.
Similar to former 318. Solving logic design problems with CAD tools for VLSI circuits. Exact and heuristic algorithms for logic synthesis. Representation and optimization of combinational logic functions (encoding problems, binary decision diagrams) and of multiple-level networks (algebraic and Boolean methods, don't-care set computation, timing verification, and optimization); and modeling and optimization of sequential functions and networks (retiming), semicustom libraries, and library binding. Prerequisites: familiarity with logic design, algorithm development, and programming.

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 is 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 392L. Modern Cellular Communication Systems. 3 Units.
Theoretical and practical aspects of design, development, and implementation of modern cellular communication systems including principles, requirements and constraints of system design and deployment using examples from real-life cellular systems. Topics include radio access network protocols; homogenous and heterogeneous network architectures; power, mobility, and interference management; spectrum allocations; network capacity and user throughput; multi-antenna transmission techniques; RF and baseband signal processing; unicast and broadcast multimedia services; multi-radio platforms; and future trends in cellular communications. Suggested prerequisites: EE359, EE264, EE279, and EE278 or equivalents.

EE 392N. INTELLIGENT ENERGY SYSTEMS. 1 Unit.
The key systems engineering steps for design of automated systems in application to of existing and future intelligent energy systems. Existing design approaches and practices for the energy systems. Every second lecture of the course will be a guest lecture discussing the communication system design for a certain type of energy system. They will alternate with guest lectures discussing the on-line analytical functions.
EE 392P. Nanoscale Device Physics. 3 Units.
The course develops an understanding of nanoscale devices relevant to information manipulation: electronic drawing on ballistic, single electron, quantum confinement, and phase transitions such as ferroelectric, metal-insulator, and structural; magnetic employing field-switching, spin-torque and spin Hall; photonic using photonic bandgaps and non-linearities; and mechanical employing deflection, torsion and resonance. The physical phenomena that these connect to are electron-phonon effects in dielectrics, mesoscopic and single-electron phenomena, phase transitions, magnetic switching, spin-torque effect, Casimir effect, plasmonics, and their coupled interactions. Prerequisites: EE 216 or equivalent. Recommended: EE 222.

EE 392Q. Parallel Processors Beyond Multicore Processing. 3 Units.
The current parallel computing research emphasizes multi-cores, but there are alternative 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 algorithms, asynchronous algorithms on SIMD ("SIMD Phase Programming Model"), Mandelbrot set, analysis of parallel performance.

EE 392R. Analog-to-Digital Conversion. 3 Units.
This course teaches the theoretical and practical aspects of designing analog-to-digital and digital-to-analog converters. During this course sampling and amplitude discretization theory are reviewed. Several converters and building blocks are analyzed on electronic circuit level and suitability for various systems is considered. Specific properties and their application are shown. Next to Nyquist converters also oversampled and noise-shaping topologies are re-viewed. Impact of mismatch of components is extensively discussed. Prerequisites: EE214B or equivalent.

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 bin-split 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 392X. Power Electronics Control and Energy-Aware Design. 3 Units.
The course surveys control techniques for power management and renewable energy sources. The overall aim is to provide a broad overview on control and power electronics for intelligent energy management. Specific topics include: (1) Systematic discussion of concepts underlying control techniques and relevant design/optimization methods, (2) Impact of the power conversion topology and the quality of the passive components on control effectiveness, and (3) Power architecture and control issues relevant to system level optimization in photovoltaic applications.

EE 395. Electrical Engineering Instruction: Practice Teaching. 1-15 Unit.
Open to advanced EE graduate students who plan to make teaching their career. Students conduct a section of an established course taught in parallel by an experienced instructor. Enrollment limited.

EE 396. Engineering Education and Online Learning. 3 Units.
An introduction to best practices in engineering education and educational technology, with a focus on online and blended learning. In addition to gaining a broad understanding of the field, students will experiment with a variety of education technologies, pedagogical techniques, and assessment methods.

EE 398A. Image and Video Compression. 3 Units.
Replaces EE398. The principles of source coding for the efficient storage and transmission of still and moving images. Entropy and lossless coding techniques. Run-length coding and fax compression. Arithmetic coding. Rate-distortion limits and quantization. Lossless and lossy predictive coding. Transform coding, JPEG. Subband coding, wavelets, JPEG2000. Motion-compensated coding. MPEG. Students investigate image and video compression algorithms in Matlab or C. Term project. Prerequisites: EE261, EE278.

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 2014 is New Trends in Start-Up Company Acceleration: Toward the Rise of the Global Start-Up. The series features new incubator and accelerator programs in Silicon Valley and select Asia economies that promote early development of international business operations by start-up companies. How can start-up companies cope with the challenges of business globalization? What are the implications of these new models of incubation for the future of Asia economies and for Silicon Valley? Distinguished speakers from industry and government. May be repeated for credit. Please see syllabus for specific requirements, which may differ from those of other seminars at Stanford.

EE 402S. Topics in International Advanced Technology Research. 1 Unit.
Theme for Spring 2013 is a survey of industry interests related to Ph.D. research in EE. Views from venture investors, corporate executives, and others in regard to mid-term future market demands in application areas such as cloud computing and analytics, energy and clean tech, robotics, transportation, medical devices and systems, etc. Perspectives into identifying and selecting a dissertation topic and maximizing the impact of research in industry and the academic world. Presentations and discussions by industry and university experts.

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. Course may be repeated for credit.

EE 410. Integrated Circuit Fabrication Laboratory. 3-4 Units.
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, consent of instructor.

EE 412. Advanced Nanofabrication Laboratory. 3 Units.
Experimental projects and seminars on integrated circuit fabrication using epitaxial, oxidation, diffusion, evaporation, sputtering, and photolithographic processes with emphasis on techniques for achieving advanced device performance. May be repeated for additional credit. Prerequisites: ENGR341 or EE410 or consent of instructor.
EE 414. RF Transceiver Design Laboratory, 3 Units.
Students design, build, and test GHz transceivers using microstrip construction techniques and discrete components. The design, construction, and experimental characterization of representative transceiver building blocks: low noise amplifiers (LNAs), diode ring mixers, PLL-based frequency synthesizers, voltage-controlled oscillators (VCOs), power amplifiers (PAs), and microstrip filters and patch antennas. The characteristics of passive microstrip components (including interconnect). Emphasis is on a quantitative reconciliation of theoretical predictions and extensive experimental measurements performed with spectrum and network analyzers, time-domain reflectometers (TDRs), noise figure meter and phase noise analyzers. Prerequisites: EE 314, EE 251.

EE 464. Semidefinite Optimization and Algebraic Techniques. 3 Units.
This course focuses on recent developments in optimization, specifically on the use of convex optimization to address problems involving polynomial equations and inequalities. The course covers approaches for finding both exact and approximate solutions to such problems. We will discuss the use of duality and algebraic methods to find feasible points and certificates of infeasibility, and the solution of polynomial optimization problems using semidefinite programming. The course covers theoretical foundations as well as algorithms and their complexity. Prerequisites: EE364A or equivalent course on convex optimization.

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.