

Electrical Engineering

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

Mission of the Undergraduate Program in Electrical Engineering

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

The program includes a balanced foundation in the physical sciences, mathematics and computing; core courses in electronics, information systems and digital systems; and develops specific skills in the analysis and design of systems. Students in the major have broad flexibility to select from many specialization areas beyond the core, including areas in electronics, optics, information systems and hardware and software systems as well as application-oriented cross-cuts in bio-instrumentation and bio-imaging, energy and environment and music.

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

Learning Outcomes (Undergraduate)

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

1. Technical knowledge—provide a knowledge of electrical engineering principles along with the required supporting knowledge of computing, engineering fundamentals, mathematics, and science. The program must include depth in at least one 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 the Graduate Admissions (<http://gradadmissions.stanford.edu>) web site. See the Electrical Engineering graduate admissions (<http://ee.stanford.edu/admissions>) web site for department specific information. The application deadline for full-time admission for Autumn Quarter 2016-17 is December 8, 2015.

Electrical Engineering Course Catalog Numbering System

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

Number	Year
010-099	first or second year undergraduate
100-199	second through fourth year undergraduate
200-299	mezzanine courses for advanced undergraduate or first-year graduate

300-399	second through fourth year graduate
400-499	specialized courses for advanced graduate
600-799	special summer courses

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
- Secure Distributed Systems
- Energy-Efficient Hardware Systems
- Integrated Circuits and Power Electronics
- 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, Sensors and Systems
- Electronic Devices

- Energy Harvesting and Conversion
- Integrated Circuits and Power Electronics
- Nanotechnology, Nanofabrication and NEMS/MEMS
- Photonics, Nanoscience and Quantum Technologies

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

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 basic understanding of electrical engineering and to develop skills in the design and building of systems that directly impact societal needs. The program includes a balanced foundation in the physical sciences, mathematics and computing; core courses in electronics, information systems and digital systems; and develops specific skills in the analysis and design of systems. Students in the major have broad flexibility to select from many specialization areas beyond the core, including areas in electronics, optics, information systems and hardware and software systems as well as application-oriented cross-cuts in bio-instrumentation and bio-imaging, energy and environment and music. The program prepares students for a broad range of careers—both industrial and government—as well as for professional and academic graduate education.

Requirements

Mathematics

MATH 41	Calculus	5
MATH 42	Calculus	5
Select one 2-course sequence:		10
CME 100 & CME 102	Vector Calculus for Engineers and Ordinary Differential Equations for Engineers (Same as ENGR 154)	
MATH 52 & MATH 53	Integral Calculus of Several Variables and Ordinary Differential Equations with Linear Algebra	

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

EE 102B	Signal Processing and Linear Systems II (if not used in Depth)	
EE 103	Introduction to Matrix Methods	
EE 142	Engineering Electromagnetics	
CME 104/ ENGR 155B	Linear Algebra and Partial Differential Equations for Engineers	
MATH 113	Linear Algebra and Matrix Theory	
CS 103	Mathematical Foundations of Computing	

Statistics/Probability. Select one of the following: ¹ 3-4

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

Science

Select one of the following sequences: 8

PHYSICS 41 & PHYSICS 43	Mechanics and Electricity and Magnetism ²	
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 3-2. ³ 4-5

Technology in Society

One course, see Basic Requirement 4 in the School of Engineering section 3-5

Engineering Fundamentals ⁴

Select one of the following:

CS 106B/ENGR 70B	Programming Abstractions	5
or CS 106X/ ENGR 70X	Programming Abstractions (Accelerated)	

At least two additional courses, at least one of which is not in EE or CS (CS 106A is not allowed). Choose from table in Undergraduate Handbook, Figure 3-4. One from ENGR 40 or ENGR 40M recommended. 8-10

Writing in the Major (WIM)

Select one of the following: 3-4

EE 109	Digital Systems Design Lab (WIM/Design)	
EE 133	Analog Communications Design Laboratory (WIM/Design)	
EE 134	Introduction to Photonics (WIM/Design)	
EE 153	Power Electronics (WIM/Design)	
EE 155	Green Electronics (WIM/Design)	
EE 168	Introduction to Digital Image Processing (WIM/Design)	
EE 191W	Special Studies and Reports in Electrical Engineering (WIM; Department approval required) ⁵	
CS 194W	Software Project (WIM/Design)	

Core Electrical Engineering Courses

EE 100	The Electrical Engineering Profession ⁶	1
EE 101A	Circuits I	4
EE 102A	Signal Processing and Linear Systems I	4
EE 108	Digital System Design	4

Physics in Electrical Engineering. Students must complete one of the following courses: 3-5

EE 65	Modern Physics for Engineers (Preferred)	
EE 142	Engineering Electromagnetics ⁷	

Depth Courses 14

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 3-4

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 153	Power Electronics (WIM/Design)	
EE 155	Green Electronics (WIM/Design)	
EE 168	Introduction to Digital Image Processing (WIM/Design)	
EE 262	Two-Dimensional Imaging (Design)	
EE 264	Digital Signal Processing ⁸	
CS 194W	Software Project (WIM/Design)	

Additional Electives 12

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. PHYSICS 43 is not a prerequisite for ENGR 40 or 40M. Many students find the material complementary in terms of fundamental and applied perspectives on electronics.

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 142 cannot be double counted. It may be used for only one of: Math; Physics in Electrical Engineering; or as a depth elective.

⁸ To satisfy Design, EE 264 must be taken for 4 units and complete the laboratory project.

Depth Areas

		Units
Bio-electronics and Bio-imaging		
EE 101B	Circuits II (Required)	4
or EE 102B	Signal Processing and Linear Systems II	
EE 122B	Introduction to Biomedical Electronics	3
EE 124	Introduction to Neuroelectrical Engineering	3
EE 134	Introduction to Photonics (WIM/Design)	4
EE 168	Introduction to Digital Image Processing (WIM/Design)	4
EE 169	Introduction to Bioimaging	3
EE 202	Electrical Engineering in Biology and Medicine	3
EE 225	Biochips and Medical Imaging	3
MED 275B	Biomedical Innovation Incubator	2-5
Circuits and Devices		
EE 101B	Circuits II (Required)	4

EE 114	Fundamentals of Analog Integrated Circuit Design	3
EE 116	Semiconductor Device Physics	3
EE 118	Introduction to Mechatronics	4
EE 122A	Analog Circuits Laboratory	3
EE 133	Analog Communications Design Laboratory (WIM/Design)	4
EE 153	Power Electronics (WIM/Design)	3-4
EE 155	Green Electronics (WIM/Design)	4
EE 212	Integrated Circuit Fabrication Processes	3
EE 213	Digital MOS Integrated Circuits	3
EE 214B	Advanced Analog Integrated Circuit Design	3
EE 216	Principles and Models of Semiconductor Devices	3
EE 271	Introduction to VLSI Systems	3
Computer Hardware		
CS 107	Computer Organization and Systems (Prerequisite for EE 180)	3-5
or CS 107E	Computer Systems from the Ground Up	
EE 107	Networked Systems	3
EE 180	Digital Systems Architecture (Required)	4
EE 109	Digital Systems Design Lab (WIM/Design)	4
EE 118	Introduction to Mechatronics	4
EE 155	Green Electronics (WIM/Design)	4
EE 213	Digital MOS Integrated Circuits	3
EE 271	Introduction to VLSI Systems	3
EE 273	Digital Systems Engineering	3
EE 282	Computer Systems Architecture	3
CS 110	Principles of Computer Systems	3-5
CS 140	Operating Systems and Systems Programming	3-4
CS 143	Compilers	3-4
CS 144	Introduction to Computer Networking	3-4
CS 148	Introduction to Computer Graphics and Imaging	3-4
Computer Software		
CS 107	Computer Organization and Systems (Prerequisite for EE 180)	3-5
or CS 107E	Computer Systems from the Ground Up	
EE 107	Networked Systems	3
EE 180	Digital Systems Architecture (Required)	4
CS 108	Object-Oriented Systems Design	3-4
CS 110	Principles of Computer Systems	3-5
CS 140	Operating Systems and Systems Programming	3-4
CS 143	Compilers	3-4
CS 144	Introduction to Computer Networking	3-4
CS 145	Introduction to Databases	3-4
CS 148	Introduction to Computer Graphics and Imaging	3-4
CS 155	Computer and Network Security	3
EE 155	Green Electronics (WIM/Design)	4
CS 194W	Software Project (WIM/Design)	3
Energy and Environment		
EE 101B	Circuits II (Required)	4
or EE 180	Digital Systems Architecture	
EE 116	Semiconductor Device Physics	3
EE 134	Introduction to Photonics (WIM/Design)	4
EE 151	Sustainable Energy Systems	3
EE 155	Green Electronics (WIM/Design)	4
EE 153	Power Electronics (WIM/Design)	3-4
EE 168	Introduction to Digital Image Processing (WIM/Design)	3-4
EE 263	Introduction to Linear Dynamical Systems	3
EE 293A	Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution	3-4
EE 293B	Fundamentals of Energy Processes	3
CEE 155	Introduction to Sensing Networks for CEE	4
CEE 107A	Understanding Energy (Formerly CEE 173A)	3
CEE 176A	Energy Efficient Buildings	3-4
CEE 176B	Electric Power: Renewables and Efficiency	3-4
ENGR 105	Feedback Control Design	3
ENGR 205	Introduction to Control Design Techniques	3
MATSCI 156	Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution	3-4
ME 185	Electric Vehicle Design	3
Music		
EE 102B	Signal Processing and Linear Systems II (Required)	4
or MUSIC 320B	Introduction to Audio Signal Processing Part II: Digital Filters	
EE 109	Digital Systems Design Lab (WIM/Design)	4
EE 122A	Analog Circuits Laboratory	3
EE 264	Digital Signal Processing	4
MUSIC 256A	Music, Computing, Design I: Art of Design for Computer Music	1-4
MUSIC 256B	Music, Computing, Design II: Virtual and Augmented Reality for Music	3-4
MUSIC 320A	Introduction to Audio Signal Processing Part I: Spectrum Analysis	3-4
MUSIC 420A	Signal Processing Models in Musical Acoustics	3-4
MUSIC 421A	Audio Applications of the Fast Fourier Transform	3-4
MUSIC 422	Perceptual Audio Coding	3
MUSIC 424	Signal Processing Techniques for Digital Audio Effects	3-4
Photonics, Solid State and Electromagnetics		
EE 101B	Circuits II (Required)	4
EE 116	Semiconductor Device Physics	3
EE 134	Introduction to Photonics (WIM/Design)	4
EE 136	Introduction to Nanophotonics and Nanostructures	3
EE 142	Engineering Electromagnetics	3
EE 216	Principles and Models of Semiconductor Devices	3
EE 222	Applied Quantum Mechanics I	3
EE 223	Applied Quantum Mechanics II	3
EE 228	Basic Physics for Solid State Electronics	3
EE 236A	Modern Optics	3
EE 236B	Guided Waves	3
EE 242	Electromagnetic Waves	3
EE 247	Introduction to Optical Fiber Communications	3
Signal Processing, Communications and Controls		
EE 102B	Signal Processing and Linear Systems II (Required)	4
EE 107	Networked Systems	3
EE 124	Introduction to Neuroelectrical Engineering	3
EE 169	Introduction to Bioimaging	3
EE 261	The Fourier Transform and Its Applications	3
EE 263	Introduction to Linear Dynamical Systems	3
EE 264	Digital Signal Processing	4
EE 278	Introduction to Statistical Signal Processing	3
EE 279	Introduction to Digital Communication	3

ENGR 105	Feedback Control Design	3
ENGR 205	Introduction to Control Design Techniques	3

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

Honors Program

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

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

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

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

Electrical Engineering (EE) Minor

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

Select one of the following courses:

EE 65	Modern Physics for Engineers	3
ENGR 40	Introductory Electronics	
ENGR 40M	An Intro to Making: What is EE	

Select one of the following options: 8

Option I:

EE 101A	Circuits I	4
EE 101B	Circuits II	

Option II:

EE 102A	Signal Processing and Linear Systems I	4
EE 102B	Signal Processing and Linear Systems II	

Option III:

EE 108	Digital System Design	4
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. 12

Master of Science in Electrical Engineering

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

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

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

University Coterminal Requirements

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

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

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

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

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

Master of Science with Distinction in Research

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

1. *Research Experience*—The program must include significant research experience at the level of a half-time commitment over the course of three academic quarters. In any given quarter, the half-time research commitment may be satisfied by:
 - a. a 50 percent appointment to a departmentally supported research assistantship,
 - b. 6 units of independent study (EE 300, EE 390, or EE 391)
 - c. a prorated combination of the two (such as a 25 percent research assistantship supplemented by 3 units of independent study).
 - d. An equivalent research experience while fully supported on a Stanford-funded or externally funded fellowship. Student and research adviser must document the planned research-experience before the quarter starts and its completion at the end. Note: Fellowship must provide full support at the 10-unit tuition level, and allow the student to pursue degree-related research in addition to his/her fulltime course enrollment. This research must be carried out under the direction of the primary or secondary adviser.
2. *Supervised Writing and Research*—In addition to the research experience outlined in the previous requirement, students must enroll in at least 3 units of independent research (EE 300, EE 390, or EE 391) under the direction of their primary or secondary adviser. These units should be closely related to the research described in the first requirement, but focused more directly on the preparation of the research report described in the next section. The writing and research units described in parts (1) and (2) may be counted toward the 45 units required for the degree.
3. All independent study units (EE 300, EE 390, or EE 391) must be taken for letter grades and a GPA of 3.0 (B) or better must be maintained.
4. *Research Report*—Students must complete a significant report describing their research and its conclusions. The research report represents work that is publishable in a journal or at a high-quality conference, although it is presumably longer and more expansive in scope than a typical conference paper. A copy of the research report must be submitted to the student services office in the department three weeks before the beginning of the examination period in the student's final quarter. Both the primary and secondary adviser must approve the research report before the distinction-in-research designation can be conferred.

The Honors Cooperative Program

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

Cooperative Program, see the "School of Engineering" section of this bulletin.

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

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

Admission to the joint M.S./M.B.A. program requires that students apply and be accepted independently to both the Electrical Engineering

Department at the School of Engineering and the Graduate School of Business. Students may apply concurrently, or elect to begin their course of study in EE and apply to the GSB during their first year.

Doctor of Philosophy in Electrical Engineering

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

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

Students admitted to the Ph.D. program must sign up to take the department qualifying examination, given once a year in winter quarter. Students are allowed two attempts to pass the examination. Students are encouraged to take the exam in their first year of study. The first attempt must be made no later than the second year of study. Students who have never taken the qualifying examination by the end of the second year of study will be dismissed from the Ph.D. program for failure to progress. Such students may be allowed to complete a master’s degree in Electrical Engineering instead. Students who do not pass the qualifying examination after two attempts will be dismissed from the Ph.D. program for failure to progress. Such students may be allowed to complete a master’s degree in Electrical Engineering instead.

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

The Ph.D. in Electrical Engineering is a specialized degree, and is built on a broad base of physics, mathematics, and engineering skills. The course program is expected to reflect competency in Electrical Engineering and specialized study in other areas relevant to the student’s research focus. 90 units must be completed at Stanford beyond the 45 units for a master’s degree (completed either at Stanford or at another institution and transferred in via the Application for Graduate Residency Credit form), for a total of 135 units. Students must complete 21 units of letter-graded lecture courses in related advanced physics, mathematics, engineering, or computer science courses, depending on the area of research. 12 of these 21 units must be EE/EE Related courses at the 200 level or higher. The remaining 69 units should be research with the dissertation advisor (EE 400, or the corresponding course number if the dissertation advisor’s primary appointment is in another department).

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

For additional information, see the department’s web site (<http://ee.stanford.edu/gradhandbook>).

Financial Assistance

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

Ph.D. Minor in Electrical Engineering

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

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

Chair: Abbas El Gamal

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

Academic Affairs Committee Chair: Joseph M. Kahn

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

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

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

Professors (Research): William J. Dally, James F. Gibbons, 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, Leonidas Guibas, Monica S. Lam, Craig Levin, David G. Luenberger, Michael McConnell, John C. Mitchell, Sandy Nepal, Richard Olshen, John Ousterhout, Norbert Pelc, Julius Smith, Brian Wandell, Lei Xing, Yinyu Ye

Courtesy Associate Professors: Kwabena Boahen, Utkan Demirci, Brian Hargreaves, Ramesh Johari, Andrew Ng, Amin Saberi, Daniel Spielman,

Courtesy 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, Andrea Di Blas, Abbas Emami-Naeini, Leslie Field, Nicola Femia, Andrew Freeman, Laurent Blaise Giovannardi, My Le, Heiner Litz, Blanka Magyari Kope, Roger Melen, Scott Murray, David Obershaw, Dan O’Neill, John Provine, Partha Ranganathan, Sriram Sundararajan, Jason Stinson, James Weaver

Consulting Professors: Rick Bahr, Richard Dasher, Michael Garner, Fred M. Gibbons, Dmitry Gorinevsky, Bob S. Hu, Theodore Kamins, David Leeson, Fernando Mujica, Guru Parulkar, Stephen Ryu, Ronald Schafer, Ashok Srivastava, John Wenstrand

Consulting Associate Professors: Jun Ye

Consulting Assistant Professor: Aneesh Nainani

Visiting Professors: Lihua Li, Yingxu Wang

Visiting Associate Professors: Diego Gutierrez, Shiyun Hu, SoYoung Kim, Liyang Yu, Feng Zhan

Visiting Assistant Professors: Meik Dorpinghaus, Daisuke Kanemoto, 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 Nanocharacterization Laboratory (SNL) and field trips to local companies and other research centers to illustrate the many applications; these include semiconductor integrated circuits ('chips'), DNA microarrays, microfluidic bio-sensors and microelectromechanical systems (MEMS). The second part is to create, design, propose and execute a project. Most of the grade will be based on the project. By the end of the course you will, of course, be able to read critically a New York Times article on nanotechnology. More importantly you will have experienced the challenge (and fun) of designing, carrying out and presenting your own experimental project. As a result you will be better equipped to choose your major. This course can complement (and differs from) the seminars offered by Profs Philip Wong and Hari Manoharan in that it emphasizes laboratory work and an experimental student-designed project. Prerequisites: high-school physics.

EE 21N. What is Nanotechnology?. 3 Units.

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

EE 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 obliged 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 (but are not limited to) microcontrollers such as the Arduino, LED's, sensors, wireless connections to the network or a laptop, and software/firmware as needed. Examples 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 29N. Electromagnetic Sensors for the Internet of Things. 3 Units.

Have you ever wondered how your phone know what way is up? How the traffic light know your car is there? How you can monitor your health with a smart bracelet? If so, you want to learn about electromagnetic sensors. In this course we will the electromagnetic principles that allows us to sense things and communicate with things at a distance. You will learn the fundamentals of electromagnetic sensing and build practical sensors in the laboratory.

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-mechanical 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 42. Introductory Engineering Electromagnetics. 5 Units.

Electricity and magnetism and its essential role in modern electrical engineering devices and systems, such as sensors, displays, DVD players, and optical communication systems. The topics that will be covered include electrostatics, magnetostatics, Maxwell's equations, one-dimensional wave equation, electromagnetic waves, transmission lines, and one-dimensional resonators. Pre-requisites: MATH 42 or MATH 51 or CME 100 or equivalent.

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

EE 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 design. Activities will feature a wide and evolving range of domains such as textile sensors, 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.

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.

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

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

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

EE 102B. Signal Processing and Linear Systems II. 4 Units.

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

EE 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.

Digital circuit, logic, and system design. Digital representation of information. CMOS logic circuits. Combinational logic design. Logic building blocks, idioms, and structured design. Sequential logic design and timing analysis. Clocks and synchronization. Finite state machines. Microcode control. Digital system design. Control and datapath partitioning. Lab. Undergraduates must enroll for 4 units. *In Autumn, enrollment preference is given to EE majors. Formerly EE 108A.

EE 109. Digital Systems Design Lab. 4 Units.

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

EE 114. Fundamentals of Analog Integrated Circuit Design. 3-4 Units.

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

EE 116. Semiconductor 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. Recommended corequisites: EE 65 and EE 101B. Non-EE majors are encouraged to take ENGR 40 before EE 116.

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 coterminial 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: EE 42 and EE 102A 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 42 and EE 65 or equivalent.

EE 142. Engineering Electromagnetics. 3 Units.

Introduction to electromagnetism and Maxwell's equations in static and dynamic regimes. Electrostatics and magnetostatics: Gauss's law, Coulomb's law, Faraday's law, Ampere's law, 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 the wave equation in 1D free space: Wavelength, wave-vector, forward and backward propagating plane waves. Poynting's theorem. Propagation in lossy media, skin depth. Reflection and refraction at planar boundaries, total internal reflection. Solutions of wave equation for various 1D-3D problems: Electromagnetic resonators, waveguides periodic media, transmission lines. Formerly EE 141. Pre-requisites: Phys 43 or EE 42, CME 100, CME 102 (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 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 155. Green Electronics. 4 Units.

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

EE 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 Biomaging. 3 Units.

Biomaging is important for both clinical medicine, and medical research. This course will provide an 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 AY 14-15, and students are encouraged to enroll in EE 107 instead.

EE 180. Digital Systems Architecture. 4 Units.

The design of processor-based digital systems. Instruction sets, addressing modes, data types. Assembly language programming, low-level data structures, introduction to operating systems and compilers. Processor microarchitecture, microprogramming, pipelining. Memory systems and caches. Input/output, interrupts, buses and DMA. System design implementation alternatives, software/hardware tradeoffs. Labs involve the design of processor subsystems and processor-based embedded systems. Formerly EE 108B. Prerequisite: 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. EE 191A counts as a Math one unit seminar course: it is this unit that constitutes the ACE program.

EE 191W. Special Studies and Reports in Electrical Engineering. 3-10 Units.

WIM-version of EE 191. For EE students using special studies (e.g., honors project, independent research project) to satisfy thenwriting-in-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. The class is designed to provide students with the opportunity to learn about the fundamental activities of businesses: Identifying new markets, developing successful products, marketing and selling, building and managing teams, and measuring results. Learning about these activities is accomplished through case studies. The cases are chosen from the technology sector including consumer electronics, semiconductor, software, consulting services, and e-commerce. Understanding the activities of business will provide engineers, scientists, and educators with a broader perspective on how to contribute to their organizations and achieve their personal career. Prerequisite: graduate standing.

EE 204S. Business Management for Electrical Engineers and Computer Scientists. 3 Units.

For SCPD students including NDOs; see EE204 for description.

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 gate 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 the circuit's operation, using both hand and computer analysis. We explore static, dynamic, pulse-mode, and current mode logic, and show how they 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.

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

EE 214B. Advanced 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. Same as: MATSCI 382, SBIO 225

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 coterminous EE students. Prerequisite: EE101B. Undergraduate students enroll in EE133 and Graduate students enroll in EE233. Recommended: EE114/214A. Same as: EE 133

EE 234. Photonics Laboratory. 3 Units.

Photonics and fiber optics with a focus on communication and sensing. Experimental characterization of semiconductor lasers, optical fibers, photodetectors, receiver circuitry, fiber optic links, optical amplifiers, and optical sensors and photonic crystals. Prerequisite: EE 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.

Maxwell's equations, constitutive relations. Kramers-Kronig relations. Modes in waveguides: slab, rectangular, circular. Photonic crystals, surface plasmon modes. General properties of waveguide modes: orthogonality, phase and group indices, group velocity dispersion. Chirped pulse propagation in dispersive media and its connection to Gaussian beam propagation. Time lens. Waveguide technologies: glass, silicon, III-V semiconductor, metallic. Waveguide devices: fibers, lasers, modulators, arrayed waveguide gratings. Scattering matrix description of passive optical devices, and constraints from energy conservation, time-reversal symmetry and reciprocity. Mode coupling, directional couplers, distributed-feedback structures. Resonators from scattering matrix and input-output perspective. Micro-ring resonators. Formerly EE 235. Prerequisites: EE 236A and EE 242 or familiarity with differential form of Maxwell's equations.

EE 236C. Lasers. 3 Units.

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

EE 237. Solar Energy Conversion. 3 Units.

Basics of solar energy conversion in photovoltaic devices. Solar cell device physics: electrical and optical. Crystalline silicon, thin film and multi-junction solar cells. Solar system issues including module assembly, inverters, and micro-inverters. Concentrated solar power. Flip classroom model is used supplementing classroom lectures with short videos. Guest speakers include distinguished engineers, entrepreneurs and venture capitalists actively engaged in solar industry. Recommended: EE116, EE216.

EE 242. Electromagnetic Waves. 3 Units.

Continuation of 141. Maxwell's equations. Plane waves in lossless and lossy media. Skin effect. Flow of electromagnetic power (Poynting's theorem). Reflection and refraction of waves at planar boundaries. Snell's law and total internal reflection. Reflection and refraction from lossy media. Guided waves. Parallel-plate and dielectric-slab waveguides. Hollow wave-guides, cavity resonators, microstrip waveguides, optical fibers. Interaction of fields with matter and particles. Antennas and radiation of electromagnetic energy. Prerequisite: 141 or PHYSICS 120.

EE 243. Semiconductor Optoelectronic Devices. 3 Units.

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

EE 247. Introduction to Optical Fiber Communications. 3 Units.

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

EE 248. Fundamentals of Noise Processes. 3 Units.

Fundamentals of statistic, Fourier analysis, statistical and quantum mechanics, and linear and nonlinear circuit theory. Thermal, quantum and 1/f noise in resistors, pn junctions, lasers, and parametric amplifiers. Energy efficiency (bit/photon) and spectral efficiency (bit/s/Hz) in coherent and single photon optical communications. Protocols and security in quantum cryptography. Decoherence of qubits in quantum computation. Prerequisites: elementary device, circuit, and electromagnetic waves to the level of 101A,B and 242.

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 Hertzian dipole, duality, equivalence principle, reciprocity, linear wire antenna, circular loop antenna, antenna array, slot and patch antennas, helical antennas, wideband antennas, size reduction techniques, wideband small antennas, and circularly polarized (CP) small antennas. Students will learn to use a commercial electromagnetic stimulator in lab sessions. A final project is designed to solve a research antenna design problem in biomedical area or wireless communications. Prerequisite: EE 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. Same as: EE 153

EE 254. Advanced Topics in Power Electronics. 3 Units.

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

EE 255. Green Electronics. 4 Units.

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

EE 256. Numerical Electromagnetics. 3 Units.

Principles and applications of numerical techniques for solving practical 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/SF) 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 applications to circuits, signal processing, communications, and control systems. Topics: least-squares approximations of over-determined equations, and least-norm solutions of underdetermined equations. Symmetric matrices, matrix norm, and singular-value decomposition. Eigenvalues, left and right eigenvectors, with dynamical interpretation. Matrix exponential, stability, and asymptotic behavior. Multi-input/multi-output systems, impulse and step matrices; convolution and transfer-matrix descriptions. Control, reachability, and state transfer; observability and least-squares state estimation. Prerequisites: linear algebra and matrices as in MATH104; differential equations and Laplace transforms as in EE102B. 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 267. Virtual Reality. 3 Units.

OpenGL, real-time rendering, 3D display systems, display optics & electronics, IMUs and sensors, tracking, haptics, rendering pipeline, multimodel human perception and depth perception, stereo rendering, presence. Emphasis is on VR technology. Hands-on programming assignments. Final project: create your own virtual environment. Prerequisites: strong programming skills. Helpful: basic computer graphics / OpenGL.

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 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 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 diagnostics. 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; 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, Entrepreneurship & Climate Change. 1 Unit.

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

EE 292I. Insanely Great Products: How do they get built?. 1 Unit.

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

EE 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 and thermal design and 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 19-21, or Math 41,42; PHYSICS 41, 43, 45. Same as: ENERGY 293B

EE 300. Master's Thesis and Thesis Research. 1-15 Unit.

Independent work under the direction of a department faculty. Written thesis required for final letter grade. The continuing grade 'N' is given in quarters prior to thesis submission. See 390 if a letter grade is not appropriate. Course may be repeated for credit.

EE 303. Autonomous Implantable Systems. 3 Units.

Integrating electronics with sensing, stimulation, and locomotion capabilities into the body will allow us to restore or enhance physiological functions. In order to be able to insert these electronics into the body, energy source is a major obstacle. This course focuses on the analysis and design of wirelessly powered catheter-deliverable electronics. Emphases will be on the interaction between human and electromagnetic fields in order to transfer power to the embedded electronics via electromagnetic fields, power harvesting circuitry, electrical-tissue interface, and sensing and actuating frontend designs. 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 to reroutable interconnection. At the end of the course, you will understand how various neuromorphic architectures request; 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 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. 1T-1C, 6T, 4T, 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 memory (FRAM), phase change memory (PCM), metal oxide resistive switching memory (RRAM), nanoconductive bridge memory (CBRAM)). Offered Alternate years. Pre-requisite: EE 216. Preferred: EE 316.

EE 310. SystemX: Ubiquitous Sensing, Computing and Communication Seminar. 1 Unit.

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

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 transmission lines, unilateralization techniques, in-tegrated antennas, harmonic generation, etc) will also be studied. Prerequisite: EE314A or equivalent course in RF or microwave.

EE 315. Analog-Digital Interface Circuits. 3 Units.

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

EE 316. Advanced VLSI Devices. 3 Units.

In modern VLSI technologies, device electrical characteristics are sensitive to structural details and therefore to fabrication techniques. How are advanced VLSI devices designed and what future changes are likely? What are the implications for device electrical performance caused by fabrication techniques? Physical models for nanometer scale structures, control of electrical characteristics (threshold voltage, short channel effects, ballistic transport) in small structures, and alternative device structures for VLSI. Prerequisites: 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 applied topics including 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 is on quantum mechanical foundations of the properties of solids, energy bandgap engineering, semi-classical transport theory, semi-conductor statistics, carrier scattering, electro-magneto transport effects, high field ballistic transport, Boltzmann transport equation, quantum mechanical transitions, optical absorption, and radiative and non-radiative recombination that are the foundations of modern transistors and optoelectronic devices. Prerequisites: EE216 or equivalent.

EE 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 SENTARUS, 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.

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

EE 340. Optical Micro- and Nano-Cavities. 3 Units.

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

EE 346. Introduction to Nonlinear Optics. 3 Units.

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

EE 348. Advanced Optical Fiber Communications. 3 Units.

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

EE 349. Advanced Topics in Nano-Optics and Plasmonics. 3 Units.

Electromagnetic phenomena at the nanoscale. Dipolar interactions between emitters and nanostructures, weak and strong coupling, surface plasmon polaritons and localized plasmons, electromagnetic field enhancements, and near-field coupling between metallic nanostructures. Numerical tools will be taught and used to simulate nano-optical phenomena.

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 356A. Resonant Converters. 3 Units.

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

EE 356B. Magnetics Design in Power Electronics. 3 Units.

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

EE 359. Wireless Communications. 3-4 Units.

This course will cover advanced topics in wireless communications 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, multicarrier modulation (OFDM), and spread spectrum; and an overview of wireless network design. Prerequisite: 279 or instructor consent.

EE 360. Multiuser 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.

Convex sets, functions, and optimization problems. The basics of convex analysis and theory of convex programming: optimality conditions, duality theory, theorems of alternative, and applications. Least-squares, linear and quadratic programs, semidefinite programming, and geometric programming. Numerical algorithms for smooth and equality constrained problems; interior-point methods for inequality constrained problems. Applications to signal processing, communications, control, analog and digital circuit design, computational geometry, statistics, machine learning, and mechanical engineering. Prerequisite: linear algebra such as EE263, basic probability. Same as: CME 364A, CS 334A

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.

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

EE 373B. Adaptive Neural Networks. 3 Units.

Artificial neural networks. Feedforward layered networks. Backpropagation algorithm. Recurrent neural networks. Autoassociative neural networks. Principal component analysis. Clustering algorithms. Applications of neural networks to pattern recognition, speech recognition, adaptive control, nonlinear adaptive filtering, and cognitive memory. Modeling human memory. Design of human-like memory for computers, with applications to face recognition, image processing, and complex control. Continuation of research projects begun in 373A. Prerequisite: 373A.

EE 376A. Information Theory. 3 Units.

The fundamental ideas of information theory. Entropy and intrinsic randomness. Data compression to the entropy limit. Huffman coding. Arithmetic coding. Channel capacity, the communication limit. Gaussian channels. Kolmogorov complexity. Asymptotic equipartition property. Information theory and Kelly gambling. Applications to communication and data compression. Prerequisite: EE178 or STATS 116, or equivalent. 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.

Universal schemes for lossless and lossy compression, channel coding and decoding, prediction, denoising, and filtering. Characterization of performance limitations in the stochastic setting: entropy rate, rate-distortion function, channel capacity, Bayes envelope for prediction, denoising, and filtering. Lempel-Ziv lossless compression, and Lempel-Ziv based schemes for lossy compression, channel coding, prediction, and filtering. Discrete universal denoising. Compression-based approach to denoising. The compound decision problem. Prerequisites: EE278, EE376A, EE376B.

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, and Le Cam methods for optimality guarantees in estimation. Large deviations and concentration inequalities (Sanov's theorem, hypothesis testing, then entropy method, concentration of measure). Approximation of (Bayes) optimal procedures, surrogate risks, f-divergences. Penalized estimators and minimum description 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.

Random signals in electrical engineering. Discrete-time random processes: stationarity and ergodicity, covariance sequences, power spectral density, parametric models for stationary processes. Fundamentals of linear estimation: minimum mean squared error estimation, optimum linear estimation, orthogonality principle, the Wold decomposition. Causal linear estimation of stationary processes: the causal Wiener filter, Kalman filtering. Parameter estimation: criteria of goodness of estimators, Fisher information, Cramer-Rao inequality, Chapman-Robbins inequality, maximum likelihood estimation, method of moments, consistency, efficiency. ARMA parameter estimation: Yule-Walker equations, Levinson-Durbin algorithm, least squares estimation, moving average parameter estimation, modified Yule-Walker method for model order selection. Spectrum estimation: sample covariances, covariance estimation, Bartlett formula, periodogram, periodogram averaging, windowed periodograms. Prerequisites: EE 278.

EE 378B. Inference, Estimation, and Information Processing. 3 Units.

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

EE 379. Digital Communication. 3 Units.

Modulation: linear, differential and orthogonal methods; signal spaces; power spectra; bandwidth requirements. Detection: maximum likelihood and maximum a posteriori probability principles; sufficient statistics; correlation and matched-filter receivers; coherent, differentially coherent and noncoherent methods; error probabilities; comparison of modulation and detection methods. Intersymbol interference: single-carrier channel model; Nyquist requirement; whitened matched filter; maximum likelihood sequence detection; Viterbi algorithm; linear equalization; decision-feedback equalization. Multi-carrier modulation: orthogonal frequency-division multiplexing; capacity of parallel Gaussian channels; comparison of single- and multi-carrier techniques. Prerequisite: EE102B, EE278.

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 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 modems, 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 (CCK), and 802.11a/g (OFDM). IEEE 802.11 media access control protocols: carrier sense multiple access with collision avoidance (CSMA/CA), point coordination function (PCF), IEEE802.11e for differentiated services. IEEE 802.11 network architecture: ad hoc and infrastructure modes, access point functionality. Management functions: synchronization, power management and association. IEEE 802.11s Mesh Networks. IEEE 802.16 (WiMAX) network architecture and protocols: Physical Layer (OFDMA) and Media Access Control Layer. Current research papers in the open literature. Prerequisite: EE 284 or CS 244A.

EE 384E. Networked Wireless Systems. 3 Units.

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

EE 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: EE178 or CS365.

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 queueing, 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 388. Modern Coding Theory. 3 Units.

Tools for analysis and optimization of iterative coding systems. LDPC, turbo and, RA codes. Optimized ensembles, message passing algorithms, density evolution, and analytic techniques. Prerequisite: 376A.

EE 390. Special Studies or Projects in Electrical Engineering. 1-15 Unit.

Independent work under the direction of a faculty member. Individual or team activities may involve lab experimentation, design of devices or systems, or directed reading. May be repeated for credit.

EE 391. Special Studies and Reports in Electrical Engineering. 1-15 Unit.

Independent work under the direction of a faculty member; written report or written examination required. Letter grade given on the basis of the report; if not appropriate, student should enroll in 390. May be repeated for credit.

EE 392AA. 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 392B. Industrial Internet of Things. 1 Unit.

The seminar will feature guest lectures from the industry to discuss the state of the affairs in the Industrial Internet of Things (IoT) with emphasis on existing and new Data Science, analytics, and Big Data applications. The class will address several verticals. One of them is electrical power industry, which is undergoing transition to renewables and distributed generation. Another one is aerospace industry including airlines and equipment vendors. Other verticals are oil and gas, data centers, and semiconductor manufacturing.

EE 392D. Designing Civic Technologies with Virtual Reality. 3-4 Units.

In this class students develop prototypes for virtual reality applications, which strive for a positive impact on society. The students work in interdisciplinary teams, and the projects are developed following the human-centered design process of need-finding, rapid prototyping, user-testing and iterations. We approach virtual reality as a civic technology in the following focus areas: education, environment, health care, democratic decision-making and journalistic storytelling. The class collaborates with industry and organizational partners in those respective areas for needfinding, prototyping and user-testing.

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 on evolving cloud computing architectures and their impact on the enterprise; big data trends and rise of the third platform; software as a service; wireless and cellular network architectures; mobility and mobile data proliferation; open mobile platforms (e.g. Android); multi-homed mobile networking, associated data communication and mobile resource trade-offs, and system implementation in smartphones and Android devices.

EE 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 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"), Man-delbrot set, analysis of parallel performance.

EE 392T. Seminar in Chip Test and Debug. 1 Unit.

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

EE 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 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.

EE 400. Thesis and Thesis Research. 1-15 Unit.

Limited to candidates for the degree of Engineer or Ph.D. May be repeated for credit.

EE 402A. Topics in International Technology Management. 1 Unit.

Theme for Autumn 2015 is *International Partnerships for Advanced Intelligent Systems*. This series features distinguished speakers from industry and government who are involved with international R&D projects in areas such as IOT (Internet of Things), autonomous vehicles and other robotics, smart medical devices and services, and next generation energy and transportation systems. The focus is on projects involving at least one Asia-based partner. Please see syllabus for specific requirements, which may differ from those of other seminars at Stanford.

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.

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EE 802. TGR Dissertation. 0 Units.

May be repeated for credit.