ELECTRICAL ENGINEERING

Emeriti: (Professors) Clayton W. Bates, Ronald N. Bracewell,* Richard Bube, Von R. Eshleman,* Michael J. Flynn,* Gene F. Franklin,* Joseph W. Goodman, Robert A. Helliwell,* Martin E. Hellman, Thomas Kailath,* Gordon S. Kino, John G. Linvill, Albert Macovski,* Laurence A. Manning, Edward J. McCluskey,* Malcolm M. McWhorter, James D. Meindl, Richard H. Pantell,* William R. Rambo, Anthony E. Siegman, Leonard Tyler,* Alan T. Waterman, Robert L. White; *(Professors, Research)* Donald L. Carpenter,* Aldo da Rosa,* Antony Fraser-Smith,* C. Robert Helms, Ingolf Lindau, David Luckham, Calvin F. Quate

Chair: Bruce A. Wooley

Vice Chair: Robert M. Gray

Associate Chair (Admissions): R. Fabian Pease

Assistant Chair: Sharon A. Gerlach

Professors: Nicholas Bambos, Stephen P. Boyd, John M. Cioffi, Thomas M. Cover, Donald C. Cox, William J. Dally, Robert W. Dutton, Abbas El Gamal, Hector Garcia-Molina, Bernd Girod, Robert M. Gray, Patrick Hanrahan, James S. Harris, Stephen E. Harris, John L. Hennessy, Lambertus Hesselink, Mark A. Horowitz, Roger T. Howe, Umran S. Inan, Joseph M. Kahn, Gregory T. A. Kovacs, Marc Levoy, Teresa H. Y. Meng, David A. B. Miller, Dwight G. Nishimura, Brad G. Osgood, R. Fabian W. Pease, James D. Plummer, Krishna Saraswat, Fouad A. Tobagi, Shan X. Wang, Jennifer Widom, Bernard Widrow, H. S. Philip Wong, S. Simon Wong, Bruce A. Wooley, Yoshihisa Yamamoto, Howard Zebker

Associate Professors: Dan Boneh, Dawson Engler, John T. Gill III, Andrea J. Goldsmith, Thomas H. Lee, Bruce B. Lusignan, Nick McKeown, Oyekunle Olukotun, John Pauly, Balaji Prabhakar, Olav Solgaard, Sebastian Thrun, Benjamin Van Roy, Shan X. Wang

Assistant Professors: Shanhui Fan, Christoforos E. Kozyrakis, Philip Levis, Subhasish Mitra, Andrea Montanari, Boris Murmann, Peter Peumans, Krishna V. Shenoy, Jelena Vuckovic, Tsachy Weissman

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

Lecturers: Dennis Allison, SooSung Hwang, Eileen Long, Dieter Scherer, Jason Stinson, Howard Swain, Meenaradchagan Vishnu

Courtesy Professors: John Bravman, David Cheriton, David L. Dill, Per Enge, Gary Glover, Peter Glynn, Gene Golub, Leonidas Guibas, Donald E. Knuth (emeritus), Monica S. Lam, David G. Luenberger, John C. Mitchell, Sandy Napel, Richard Olshen, Norbert Pelc, Vaughan R. Pratt (emeritus), Zhi-Xun Shen, Jeffrey D. Ullman (emeritus), Brian Wandell, Gio Wiederhold (emeritus), Yinyu Ye, Shoucheng Zhang

Courtesy Associate Professors: Stacey Bent, Kwabena Boahen, Peter Fitzgerald, Michael McConnell, Mendel Rosenblum, Julius Smith, Daniel Spielman, Claire Tomlin

Courtesy Assistant Professors: Ramesh Johari, Sanjay Lall, David H. Liang, Hari Manoharan, David Mazieres, Andrew Ng, Gunter Niemeyer, Ramin Shahidi (Research)

Consulting Professors: Ahmad Bahai, Marina Bosi-Goldberg, Nim K. Cheung, Richard Dasher, Bruce Deal, John Doolittle, Victor Eliashberg, Abbas Emami-Naeini, G. David Forney, Fred M. Gibbons, Dimitry Gorinevsky, Timothy Groves, Sam Haddad, Berrtrand Hochwald, Homayoun Hashemi, Richard Hester, Bob S. Hu, Theodore Kamins, John Koza, Rajeev Krishnamoorhy, David Leeson, Nadim Maluf, Roger D. Melen, Martin Morf, Madihally Narasimha, Debajyoti Pal, Yi-Ching Pao, Marcel Pelgrom, Kurt Petersen, Richard Reis, Nirmal Saxena, Ronald Schafer, Micah Siegel, James Spilker, Baylor Triplett, Martin Walt, Yao-Ting Wang, John Wenstrand

Consulting Associate Professors: Hamid Aghajan, John Apostolopoulos, David Burns, Timothy Drabik, Ludwig Galambos, Stuart Oberman, Sergei Orlov, Stephen Richardson, Glenn Solomon, David K. Su, Noel Thompson, Jun Ye

Consulting Assistant Professors: Erik Chmelar, Mar Hershenson, Patrick Hung, Seung J. Kim, My T. Le, Ravi Narasimhan, Mehdi Soltan, Olaf Tornblad, Katelijn Vleugels, Eric Volkerink, Susie Wee

Visiting Professors: Giovanni DeMicheli, Sam Dong Kim, Essam Marouf, Stephen McLaughlin

Visiting Associate Professors: David Elata, Yuji Wasaka

Visiting Assistant Professors: Markus Flierl, Maneesh Sahani

Teaching Fellow: Moshe Malkin

*recalled to active duty

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Web Site: http://ee.stanford.edu/

Courses given in Electrical Engineering have the subject code EE. For a complete list of subject codes, see Appendix.

UNDERGRADUATE PROGRAMS

The mission of the undergraduate program of the Department of Electrical Engineering is to augment the liberal education expected of all Stanford undergraduates and impart a basic understanding of electrical engineering built on a foundation of physical science, mathematics, computing, and technology.

Graduates of the undergraduate program are expected to possess knowledge of the fundamentals of electrical engineering and of at least one specialty area. The graduates are expected to have the basic experimental, design, and communication skills to be prepared for continued study at the graduate level or for entry-level positions that require a basic knowledge of electrical engineering, science, and technology.

The educational objectives of the program are:

1. Technical knowledge: provide a basic 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 computer hardware, computer software, controls, circuits, fields and waves, communication and signal processing, and semiconductor and photonic devices.
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.

To specialize in Electrical Engineering (EE), undergraduates should follow the depth sequence given in the discussion of undergraduate programs in the "School of Engineering" section of this bulletin. Students are required to have a program planning sheet approved by their adviser and the department prior to the end of the quarter following the quarter in which they declare their major and at least one year prior to graduation. Program sheets for the general EE requirements and for each of the EE specialty sequences may be found 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.

For information about an EE minor, see the "School of Engineering" section of this bulletin.

A Stanford undergraduate may work simultaneously toward the B.S. and M.S. degrees. See "Dual and Coterminal Degree Programs" in the "School of Engineering" section of this bulletin.

For University coterminal degree program rules and University application forms, see http://registrar.stanford.edu/shared/publications.htm#Coterm.

SCHOOL OF ENGINEERING

HONORS

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

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

1. maintain a grade point average (GPA) of at least 3.5 in EE courses
2. complete at least 10 units of EE 191 for a letter grade with their project adviser
3. submit two final copies of the honors thesis approved by the adviser and second reader
4. attend poster and oral presentation in the Electrical Engineering Honors Symposium held at the end of Spring Quarter or present in another suitable forum approved by the faculty adviser.

GRADUATE PROGRAMS

University regulations governing the M.S., Engineer, 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 man. 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.

A one- to two-year program of graduate study in Electrical Engineering may lead to the degree of Master of Science. The program is typically completed in five academic quarters. A two- to three-year program, offering a wider selection of engineering course work, more opportunity for study in the related fields of engineering, mathematics, and physics, and in particular, more independent work and individual guidance, may lead to the degree of Engineer.

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 admission with graduate standing in Electrical Engineering (EE) should be completed electronically at http://gradadmissions.stanford.edu. For more information concerning Electrical Engineering graduate admissions, see http://ee-admissions.stanford.edu. The application deadline for admission for Autumn Quarter 2007-08 is December 12, 2006.

MASTER OF SCIENCE

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 academic quarters; note that many courses are not taught during the summer. Students with undergraduate degrees in other fields may also be admitted for graduate study; see below.

The master's degree program may provide advanced preparation for professional practice or for teaching on the junior college level, or it may serve as the first step in graduate work leading to the degree of Engineer or Ph.D. 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 faculty for approval. The master's program proposal must be submitted to the department office during the first quarter of graduate study; modifications may be made later. Detailed requirements and instructions are in the *Handbook for Graduate Students in Electrical Engineering at Stanford University* (http://ee.stanford.edu/gradhandbook/). Programs of at least 45 quarter units that meet the following guidelines are normally approved. Cognate (extradepartmental) courses of the appropriate level are considered as Electrical Engineering courses.

1. A sequence of three or more letter-graded electrical engineering courses numbered above 200, to provide depth in one area. The student must maintain an average 3.0 grade point average (GPA) or better in both the depth area and overall.
2. At least one letter-graded EE course numbered above 200 in each of three distinct course areas outside of the area selected under item 1 to provide breadth. Two courses are not considered to be in distinct areas if they can be found under a common depth area.
3. Enough additional units of EE courses so that items 1 through 3 total at least 21 units of letter-graded EE courses numbered above 200, including at least 9 units of such courses numbered in the 300s or 400s. Some 600- or 700-level summer courses may also be considered for inclusion in the M.S. program. Special studies units may not be used.
4. Additional course work to bring the total to 45 or more quarter units, including:
   a) at least 36 letter-graded units
   b) at least 36 units at or above the 100 level
   c) at least 30 units in technical areas such as engineering, mathematics, and science; thesis and special studies units cannot be included.
5. The EE 201A seminar in Autumn Quarter and either (a) one formal EE seminar course for credit, or (b) attend a minimum of eight informal or formal EE research seminars, and submit with the final M.S. program a list of the seminars with a paragraph describing the content and the signature of the M.S. adviser. This requirement is to ensure that students sample the many available research seminars. In case of conflict with EE 201A, tapes may be viewed in Terman Library.

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. Each student, with the help of an adviser, prepares a program of study to meet particular needs and submits it to the faculty for approval. A student with adequate preparation in mathematics through calculus and college physics including electricity can usually complete the M.S. degree requirements within two academic years. A student with some additional preparation in electrical engineering may be able to complete the M.S. requirements in only one academic year.

Graduate study in EE demands that students be adequately prepared in circuits, digital systems, fields, lab work, mathematics, and physics. Skill in using modern computing facilities is essential for electrical engineers, and an increasing number of courses routinely require it. Skill should be acquired early in the program, either by taking one of the regular computer science courses or one of the special short courses given by the Computation Center, or by self-study.

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 typical 45 units, and the time required to meet the degree requirements may be increased.

Students working toward the Master of Science degree in Electrical Engineering who are considering a Ph.D. or Engineer degree program in Electrical Engineering at Stanford must request the addition of a new degree program by submitting a Graduate Program Authorization Petition for approval by the department. Once the M.S. degree in EE has been conferred, a student may not register for additional course work without this approval. Permission to study beyond the M.S. degree is normally granted to students who were originally admitted to the Ph.D. program if the student:

1. has passed the Ph.D. qualifying examination within the past year, or
2. has a written commitment from a regular member of the EE faculty to serve as an Engineer or Ph.D. dissertation adviser, and has a satisfactory academic record to date.

Students originally admitted only for the M.S. degree and not to the Ph.D. program may petition the EE graduate admissions committee during Autumn Quarter of their second year at Stanford for a change of status to the Ph.D. program with permission to take the Ph.D. qualifying exam in January. Requirements for the petition include a grade point average of 3.5 on Stanford courses and a written statement of support from an EE faculty member with whom the student has conducted preliminary research through directed reading (EE 390 or 391) or as part of a 300-level project course. Decisions are based on performance and the strength of the support letter. If admitted to the Ph.D. program, permission to study beyond the M.S. degree is normally granted under the same conditions as those described above for students originally admitted to the Ph.D. program. Students not admitted to the Ph.D. program are normally granted permission to continue past the M.S. degree only if there is a written commitment from a regular member of the EE faculty to serve as an Engineer dissertation supervisor. The student should file for candidacy for the Engineer degree within one quarter of receiving the M.S.

ENGINEER

The degree of Engineer requires a minimum of 90 units of residency. Units completed at Stanford towards a master's degree in an Engineering discipline may be used towards the 90-unit residency requirement for the Engineer degree. A student who received an M.S. degree elsewhere can transfer in 45 units towards the 90-unit requirement for an Engineer's degree. A student would need to fill out the Application for Graduate Residency Credit form to be filed with the Degree Progress Office in the Registrar's Office.

Work toward the degree of Engineer in Electrical Engineering normally includes the requirements for work toward the master's degree in Electrical Engineering, including qualifications for admission.

An additional year allows time for a broader program, or a more concentrated program, or whatever arrangement may seem suitable to the candidate, his adviser, and the department. Advanced study at other universities, or in other departments at Stanford, may be allowed within the foregoing consideration. The equivalent of approximately one quarter is devoted to independent study and thesis work with faculty guidance. The thesis is often of the nature of a professional report on the solution of a design problem. The degree of Engineer differs from the Ph.D. in that it prepares for professional engineering work rather than theoretical research. The candidate may select courses that are suitable for either the degree of Engineer or the Ph.D. degree and decide later which program to pursue.

The best procedure for the applicant to follow is (1) if now working toward the Stanford M.S. degree in Electrical Engineering, request permission to continue graduate studies beyond the master's degree, using the Graduate Program Authorization Petition form obtained from the Department of Electrical Engineering office, or (2) if not planning to receive the Stanford M.S. degree in Electrical Engineering, apply for admission to the Department of Electrical Engineering as a candidate for the degree of Engineer.

During the first quarter of work beyond the M.S. degree, formal application for admission to candidacy for the degree of Engineer is made on a form that can be obtained from the department office. The program of study is prepared by the student with the help of the thesis adviser and submitted to the academic associate for approval. The form should contain a list of all graduate courses completed at Stanford and elsewhere and all courses yet to be completed. For the most recent information, see http://ee.stanford.edu/gradhandbook/engineer.html.

DOCTOR OF PHILOSOPHY

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 a supervisor.

Students admitted to the Ph.D. program should submit an application to take the department qualifying examination (given each Winter Quarter). Upon completion of the qualifying examination and after securing agreement by two faculty members to serve as dissertation advisers, the student should file an Application for Doctoral Candidacy. 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. Normally the majority of units are drawn from EE department or cognate courses, with typically 9 units from related advanced physics, mathematics, engineering, or computer science courses, depending on the area of research. Only after receiving department approval to that application does the student become a candidate for the Ph.D. degree.

Requirements may be summarized as follows. The student must complete (1) a minimum of 135 units of residence with graduate standing at Stanford; (2) one or more qualifying examinations given by the faculty of the Department of Electrical Engineering; (3) an approved course of study in Electrical Engineering; (4) an approved program of research and a written dissertation, based on research, which must be a contribution to knowledge; (5) an oral examination that is a defense of dissertation research and is taken near the completion of the doctoral program.

PH.D. MINOR

For a minor in Electrical Engineering (EE), the student must fulfill the M.S. depth requirement, complete a total of at least 20 units of course work at the 200-plus level in electrical engineering (of which 15 units must be graded) and be approved by the department's Ph.D. Degree Committee. A grade point average (GPA) of at least 3.35 on these courses is required.

FINANCIAL ASSISTANCE

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

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 graduate 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 graduate students. For more information regarding the Honors Cooperative Program, see the "School of Engineering" section of this bulletin.

AREAS OF RESEARCH

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. A new applicant should express a second choice of research interest in the event that there are no vacancies in the primary area of interest. At present, faculty members and students are actively engaged in research in the areas listed below.

COMMUNICATIONS

Adaptive Modulation and Coding
Adaptive Multiuser Coding and Reception
Applied Optics and Optoelectronics
Cellular Radio Systems/Networks
Coding and Coded Modulation
Communication Channels and Signal Propagation
Communication and Information Theory
Digital Subscriber Lines
Digital Transmission
Frequency Reuse in Large Wireless Networks
Mobility in Wireless Networks
Multicarrier Modulation and OFDM
Multipath Mitigation Techniques
Multiple Access Techniques
Multiple Antenna and MIMO Systems

Optical Communications
Optical Networks
Optoelectronic Components and Systems
Resource Allocation/Channel Assignment/Handoff in Wireless Networks
Wavelength Division Multiplexing
Wireless Ad-Hoc Networks
Wireless Communications
Wireless Local Area Networks
Wireless Personal Communication Systems

COMPUTER SYSTEMS

Asynchronous Circuits
Compilers
Computer-Aided Design
Computer Architecture
Computer Graphics
Computer Networks
Computer Organization
Computer Reliability
Concurrent Languages
Concurrent Processes and Processors
Database and Information Systems
Distributed Systems
Embedded System Design
Hardware/Software Co-Design
Hardware Verification
Human Computer Interaction
Multimedia Systems
Operating Systems
Performance Measurement and Modeling
Programming Languages
Program Verification
VLSI Design

INFORMATION SYSTEMS

Adaptive Control and Signal Processing
Adaptive Neural Networks
Biomedical Signal Analysis
Computer-Aided Design and Analysis of Systems
Data Communications
Digital Signal Processing
Estimation Theory and Applications
Fourier and Statistical Optics
Information and Coding Theory
Medical Imaging and Image Processing
Multivariable Control
Optical Communications
Optimization-Based Design
Pattern Recognition and Complexity
Quantization and Data Compression
Real-Time Computer Applications
Signal Processing
Speech and Image Coding

INTEGRATED CIRCUITS

Analog Integrated Circuits
Biomedical Sensors, Circuits, and Signal Processing
Bipolar, MOS, and other Device and Circuit Technologies
CAD of Processes, Devices, and Equipment
Custom Integrated Circuits for Computers and Telecommunications
Digital Integrated Circuits
Integrated Sensors and Actuators
Mixed Signal Integrated Circuits
Nanostructures
Neural Recording and Signal Processing
Optoelectronic Integrated Circuits
Organic Materials, Devices and Circuits
Process, Device, Circuit, and Equipment Modeling
RF Circuits for Wireless Transmission
Sensors and Control for VLSI Manufacturing
VLSI Device Structures and Physics
VLSI Fabrication Technology
VLSI Materials, Interconnections, and Contacts
VLSI Packaging and Testing

LASERS AND QUANTUM ELECTRONICS

Coherent UV and X-Ray Sources
Free-Electron Lasers
Laser Applications in Aeronautics, Biology, Chemistry, Communications, Electronics, and Physics
Laser Devices and Laser Physics
Nonlinear Optical Devices and Materials
Optoelectronic Devices
Photoacoustic Phenomena
Semiconductor Diode Lasers
Ultrafast Optics and Electronics

MICROWAVES, ACOUSTICS, AND OPTICS

Acoustic Microscopy
Acousto-Optic Devices
Fiber Optics
Holography
Microwave Integrated Circuits and Devices
Nanophotonics
Nondestructive Testing
Optical Interferometry
Scanning Optical Microscopes

RADIOSCIENCE AND REMOTE SENSING

Environmental Studies using Satellite Technology
Exploration of the Earth from Space
Interferometric and Holographic Imaging with Radio Waves
Numerical Methods for Science Data Analysis
Optical Remote Sensing
Planetary Exploration
Radar Interferometry
Radar Remote Sensing
Radio Occultation Studies
Radio Wave Scattering
Remote Sensing of Atmospheres and Surfaces
Signal and Image Processing Methods
Space Data Management
Spaceborne Radio Receiver Development
Synthetic Aperture Radar Satellites

SOLID STATE

Applied and Fundamental Superconductivity
Crystal Preparation: Epitaxy and Ion Implantation, and Molecular Beam Epitaxy
Defect Analysis in Semiconductors
Electron and Ion Beam Optics
Electron Spectroscopy
Experimental Determination of the Electronic Structure of Solids
High Resolution Lithography
Laser, Electron, and Ion Beam Processing and Analysis
Magnetic Information Storage
Magnetic Materials Fundamentals and Nanostructures
Nanostructure Fabrication and Applications
Nanophotonics
Molecular Beam Epitaxy
Novel Packaging Approaches for Electronic Systems
Optoelectronic Devices
Physics and Chemistry of Surfaces and Interfaces
Semiconductor and Solid State Physics
Solid State Devices: Physics and Fabrication
Ultrasmall Electron and Photodevices

SPACE PHYSICS AND ELECTROMAGNETICS

Computational Electromagnetics
Detection of Electromagnetic Fields from Earthquakes
Electromagnetic Waves and Plasmas
Geomagnetically Trapped Radiation
Ionospheric and Magnetospheric Physics
Ionospheric Modification
Lightning Discharges
Lightning-Ionosphere Interactions
Space Engineering (also see the "Space Science and Astrophysics" section of this bulletin)
Ultra-Low Frequency Fluctuations of the Earth's Magnetic Field
Very Low Frequency Wave Propagation and Scattering

COURSES

WIM indicates that the course satisfies the Writing in the Major requirements. (AU) indicates that the course is subject to the University Activity Unit limitations (8 units maximum).

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

10- 99	first or second year
100-199	second through fourth year
200-299	mezzanine course for advanced undergraduates or graduates
300-399	first graduate year
400-499	second or third graduate year
600-799	special summer courses

The Department of Electrical Engineering (EE) offers courses in the following areas:

Communication Systems
Computer Hardware
Computer Software Systems
Control and System Engineering
Dynamic Systems and Optimization
Electronic Circuits
Electronic Devices, Sensors, and Technology
Fields, Waves, and Radioscience
Image Systems
Lasers, Optoelectronics, and Quantum Electronics
Network Systems
Signal Processing
Solid State Materials and Devices

Cognate courses offered by other departments are listed following the EE courses.

UNDERGRADUATE

EE 10N. How Musical Instruments Work—Stanford Introductory Seminar. Preference to freshmen. Musical instruments as examples of science, engineering, and the interplay between the two. The principles of operation of wind, string, and percussion instruments. Concepts include waves, resonators, sound spectra and the harmonic structure of instruments, engineering design, and the historical co-development of instruments and the science and engineering that makes them possible. Prerequisites: high school math and physics. Recommended: some experience playing a musical instrument. GER:DB-EngrAppSci

3 units, Spr (Miller,D)

EE 18N. Pi and Other Physical Constants in Math, Physics, and Engineering—Stanford Introductory Seminar. Preference to freshmen. Famous mathematical and physical constants, including pi, e, golden ratio, gravitational constant, speed of light, and electron mass. Their history; how to calculate or measure them; their consequences on the physical world; what would happen if they were different; and how to memorize them. GER:DB-EngrAppSci

3 units, Spr (McKeown, N)

EE 19N. How the Internet Works—Stanford Introductory Seminar. Preference to freshmen. Issues faced by develops and possible solutions. Functions required for building this complex system; how a large and complex system can be designed by dividing it into elements which can be organized into a well defined structure. GER:DB-EngrAppSci

3 units, Win (Tobagi, F)

EE 20N. Hacking Stuff—Stanford Introductory Seminar. Preference to freshmen. The design of a complete system by combining electrical engineering disciplines such as control theory, circuit design, microprocessors, and semiconductor devices. Based on radio-controlled toy cars, the design and construction of a robot capable of autonomously following a track. Teams compete in a race against the clock in a version of the DARPA Grand Challenge. GER:DB-EngrAppSci

3 units, Win (Peumans, P)

EE 21N. What is Nanotechnology?—Stanford Introductory Seminar. Preference to freshmen. Possibilities and impossibilities of nanotechnology. Sources include Feynman's *There's Plenty of Room at the Bottom,* Drexler's *Engines of Creation: The Coming Era of Nanotechnology,* and Crichton's *Prey*. Assumptions and predictions of these classic works; what nano machinery may do; scenarios of a technology that may go astray. Prerequisites: high school math, physics and chemistry. GER: DB-EngrAppSci

3 units, Aut (Wong, P)

EE 41. Physics of Electrical Engineering—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 basic EM waves are essential in all high-speed communication systems. How to propagate energy 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. GER:DB-EngrAppSci

5 units, Win (Solgaard, O)

EE 60Q. Man versus Nature: Coping with Disasters Using Space Technology—(Same as GEOPHYS 60Q.) Stanford Introductory Seminar. Preference to sophomores. Natural hazards (earthquakes, volcanoes, floods, hurricanes, and fires) affect thousands of people everyday. Disasters such as asteroid impacts periodically obliterate many species of life. Spaceborne imaging technology makes it possible to respond quickly to such threats to mitigate consequences. How these new tools are applied to natural disasters, and how remotely sensed data are manipulated and analyzed. Basic scientific issues, political and social consequences, costs of disaster mitigation, and how scientific knowledge affects policy. GER: DB-EngrAppSci

3 units, Aut (Zebker, H)

EE 100. The Electrical Engineering Profession—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.

1 unit, Aut (Gray, R)

EE 101A. Circuits I—First of two-course sequence. Introduction to circuit modeling and analysis. Topics include creating the models of typical components in electronic circuits and simplifying non-linear models for restricted ranges of operation (small signal model); and using network theory to solve linear and non-linear circuits under static and dynamic operations. GER:DB-EngrAppSci

4 units, Win (Wong, S)

EE 101B. Circuits II—Second of two-course sequence. MOS large-signal and small-signal models. MOS amplifier design including DC bias, small signal performance, multistage amplifiers, frequency response, and feedback. Prerequisite: 101A. GER:DB-EngrAppSci

4 units, Aut (Shenoy, K; Hershenson, M), Spr (Shenoy, K)

EE 102A. Signal Processing and Linear Systems I—Concepts and mathematical tools in continuous-time signal processing and linear systems analysis, illustrated with examples from signal processing, communications, and control. Mathematical representation of signals and systems. Linearity and time-invariance. System impulse and step 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. Stability and causality in linear systems. Laplace transforms and Bode plots. Feedback and control system design. Examples from filter design and linear control. Prerequisite: Math 53 or Engr 155A. GER:DB-EngrAppSci

4 units, Win (Pauly, J)

EE 102B. Signal Processing and Linear Systems II—Concepts and mathematical tools in discrete-time signal processing and linear systems analysis with examples from digital signal processing, communications, and control. Discrete-time signal models. Continuous-discrete-continuous signal conversion. Discrete-time impulse and step response. Frequency domain representations: Fourier series and transforms. Connection between continuous and discrete time frequency representations. Discrete Fourier transform (DFT) and fast Fourier transform (FFT). Digital filter and signal processing examples. Discrete-time and hybrid linear systems. Stability and causality. Z transforms and their connection to Laplace transforms. Frequency response of discrete-time systems. Discrete-time control. Prerequisite: 102A. GER:DB-EngrAppSci

4 units, Spr (Kahn, J)

EE 106. Planetary Exploration—The other worlds of the solar system as revealed by electromagnetic emissions and recent space missions. Planetary interiors, surfaces, atmospheres, moons, rings, and the interplanetary environment, including its gas, dust, meteors, and comets. Orbital data and Hohmann orbits for spacecraft. Stanford EE department radio experiments that have been a part of every major NASA planetary mission. Prerequisite: one year of college engineering. GER:DB-EngrAppSci

3 units, Spr (Fraser-Smith, A)

EE 108A. Digital Systems I—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. Prerequisite: ENGR 40. Corequisite for WIM: ENGR 102E. GER:DB-EngrAppSci, WIM

3-4 units, Aut (Dally, W), Win (Mitra, S)

EE 108B. Digital Systems II—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. Prerequisites: 108A, CS 106B. GER: DB-EngrAppSci

3-4 units, Aut (Olukotun, O), Win (Kozyrakis, C)

EE 109. Digital Systems Design Lab—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. GER:DB-EngrAppSci

4 units, Spr (Olukotun, O)

EE 114X. Simulation-Based Circuit Design—Electronic circuit design based on hand analysis and circuit simulations. Concepts of design space, robust design, and constraint-driven optimization. Hands-on, simulation lab experience. Hands on, simulation lab-based experience that bridges electronics fundamentals and more advanced electronics design classes. Prerequisite: 101B.

2 units, Aut (Dutton, R)

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

3 units, Spr (Peumans, P)

EE 118. Introduction to Mechatronics—Technologies involved in mechatronics (intelligent electro-mechanical systems) and techniques to integrate these technologies into mechatronic systems. Topics: electronics (A/D, D/A converters, op-amps, filters, power devices); software program design (event-driven programming, state machine based design); DC and stepper motors; basic sensing; mechanical design (machine elements and mechanical CAD). Lab component of structured assignments combined with large, open-ended team project. Limited enrollment. Prerequisites: ENGR 40, and CS 106A or 106X (preferred).

4 units, Win (Carryer, J)

EE 122. Analog Circuits Laboratory—Practical applications of analog circuits, including simple amplifiers, filters, oscillators, power supplies, and sensors. Design skills, computer-aided design, and circuit fabrication and debugging. The design process through proposing, designing, simulating, building, debugging, and demonstrating a project. Radio frequency and largely digital projects not suitable for EE122. Prerequisite: ENGR 40 or equivalent. GER:DB-EngrAppSci

3 units, Aut, Spr (Kovacs, G)

EE 133. Analog Communications Design Laboratory—Design, testing, and applications. Amplitude modulation (AM) using multiplier circuits. Frequency modulation (FM) based on discrete oscillator and integrated modulator circuits such as voltage-controlled oscillators (VCOs). Phased-lock loop (PLL) techniques, characterization of key parameters, and their applications. Practical aspects of circuit implementations. Labs involve building and characterization of AM and FM modulation/demodulation circuits and subsystems. Enrollment limited to 30 undergraduates and coterminal EE students. Prerequisite: 101B. GER:DB-EngrAppSci

4 units, Win (Dutton, R)

EE 134. Introduction to Photonics—Photonics, optical sensors, and fiber optics. Conceptual and mathematical tools for design and analysis of optical communication and sensor systems. Experimental characterization of semiconductor lasers, optical fibers, photodetectors, receiver circuitry, fiber optic links, optical amplifiers, and optical sensors. Class project aimed on confocal microscopy for biomedical applications. Laboratory experiments. Prerequisite: 41 or equivalent. GER:DB-EngrAppSci

4 units, Spr (Solgaard, O)

EE 136. Introduction to Nanophotonics and Nanostructures—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: familiarity with electromagnetic and quantum mechanical waves and semiconductors at the level of EE 41 or equivalent. GER:DB-EngrAppSci

3 units, Win (Vuckovic, J)

EE 141. Engineering Electromagnetics—Lumped versus distributed circuits. Transient response of transmission lines with resistive and reactive loads. Reflection, transmission, attenuation and dispersion. Steady-state waves on transmission lines. Standing wave ratio, impedance matching, and power flow. Coulomb's law, electrostatic field, potential and gradient, electric flux and Gauss's Law and divergence. Metallic conductors, Poisson's and Laplace's equations, capacitance, dielectric materials. Electrostatic energy and forces. Steady electric currents, Ohm's Law, Kirchoff's Laws, charge conservation and the continuity equation, Joule's Law. Biot-Savart's law and the static magnetic field. Ampere's Law and curl. Vector magnetic potential and magnetic dipole. Magnetic materials, forces and torques. Faraday's Law, magnetic energy, displacement current and Maxwell's equations. Uniform plane waves. Prerequisites: 102A, MATH 52. GER:DB-EngrAppSci

4 units, Aut (Inan, U)

EE 142. Electromagnetic Waves—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. GER:DB-EngrAppSci

3 units, Win (Inan, U)

EE 144. Wireless Electromagnetic Design Laboratory—Hands-on experiments and projects with antennas, transmission lines and propagation for wireless communications and remote sensing. Using spectrum analysers, swept frequency generators, frequency counters, couplers, detectors and slotted lines, develop measurement and design capability in the 1-20 GHz range in support of chosen design projects. Team projects from antenna, guided wave distributed circuits, remote sensing, or related topics. Working model constructed and demonstrated; some funding available for project costs. Lab. Enrollment limited to 30. Prerequisite: 122 or 142, or consent of instructor. GER:DB-EngrAppSci

3 units, Spr (Leeson, D)

EE 168. Introduction to Digital Image Processing—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. GER:DB-EngrAppSci

3-4 units, Win (Zebker, H)

EE 178. Probabilistic Systems Analysis—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, hypothesis testing, estimation and detection, Bayesian analysis. Prerequisites: basic calculus and linear algebra. GER:DB-EngrAppSci

3 units, Win (El Gamal, A)

EE 179. Introduction to Communications—Communication system design and performance analysis. Topics include current communication systems (cellular, WLANs, radio and TV broadcasting, satellites, Internet), Fourier techniques, energy and power spectral density, random variables and random (noise) signals, filtering and modulation of noise, analog modulation (AM and FM) and its performance in noise, digital modulation (PSK and FSK), optimal receiver design, and probability of bit error for digital modulation. Prerequisite: 102A. GER:DB-EngrAppSci

3 units, Win (Gray, R)

EE 190. Special Studies or Projects in Electrical Engineering—Independent work under the direction of a faculty member. Individual or team activities involve lab experimentation, design of devices or systems, or directed reading.

1-15 units, Aut, Win, Spr, Sum (Staff)

EE 191. Special Studies and Reports in Electrical Engineering—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.

1-15 units, Aut, Win, Spr, Sum (Staff)

COGNATE COURSES

Courses approved to fulfill EE program requirements at the level of 100-199 EE courses are listed below according to the undergraduate specialty areas or as "Other." See respective department listings for course descriptions and General Education Requirements (GER) information.

COMPUTER HARDWARE

CS 107. Programming Paradigms

3-5 units, Aut, Spr (Cain, G)

COMPUTER SOFTWARE

CS 107. Programming Paradigms

3-5 units, Aut, Spr (Cain, G)

CS 108. Object-Oriented Systems Design

3-4 units, Aut, Win (Parlante, N)

CS 194. Software Project

3 units, Spr (Plummer, R)

CONTROLS

ENGR 105. Feedback Control Design

3 units, Win, Sum (Emami-Naeini, A)

OTHER

APPPHYS 207,208. Laboratory Electronics

207: *3 units, Win (Fox, J)*

208: *3 units, Spr (Fox, J), alternate years, not given next year*

CS 148. Introductory Computer Graphics

3 units, Win (Hanrahan, P), Sum (Staff)

GEOPHYS 140. Introduction to Remote Sensing

3 units, Aut (Zebker, H)

UNDERGRADUATE AND GRADUATE

EE 201A. Introductory Graduate EE Seminar—Topics of current interest in Electrical Engineering. Orientation to Stanford and the EE department. Students with a conflict may view via videotape in the library.

1 unit, Aut (Reis, R)

EE 201B. Life after Stanford for Master's Students—Activities of graduates in industry, startups, government laboratories, and community colleges.

1 unit, Win (Reis, R)

EE 202. Medical Electronics—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.

3 units, Aut (Thompson, N)

EE 203. The Entrepreneurial Engineer—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.

1 unit, Win (Melen, R)

EE 212. Integrated Circuit Fabrication Processes—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 and provide a virtual lab experience. 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. Prerequisite: undergraduate semiconductor device physics.

3 units, Aut (Plummer, J)

EE 214. Analog Integrated Circuit Design—Analysis and design of MOS analog integrated circuits, emphasizing quantitative measures of performance and circuit limitations. Evaluation of circuit performance by means of hand calculations and computer-aided circuit simulations. Design of operational amplifiers and transconductance stages, biasing circuits, and voltage references. Feedback amplifier design. Prerequisite: 101B.

3 units, Aut (Murmann, B)

EE 215. Bipolar Analog Integrated Circuit Design—Bipolar analog circuits for high-frequency operation, including applications for networking and communications, such as video and broadband RF amplifiers. Device operation and compact modeling in support of circuit simulations needed for design. Circuit building blocks, including current and voltage references, and cascaded multi-stage amplifiers. Analysis and design of feedback circuits. Small design projects and use of SPICE models representative of state-of-the-art bipolar technology. Prerequisite: 101B.

3 units, Win (Dutton, R; Wooley, B)

EE 216. Principles and Models of Semiconductor Devices—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.

3 units, Aut (Harris, J), Win (Saraswat, K; Pease, R)

EE 218. Introduction to Nanotechnology and Nanoelectronics—Device physics and operation principles. Device and material options for advanced silicon FETs at the nanoscale. Topics identified by the International Technology Roadmap for Semiconductors, emerging research devices section; see http://public.itrs.net. Non-silicon-based devices such as carbon nanotubes, semiconductor nanowires, and molecular devices; and non-FET based devices such as single electron transistors (SET), resonant tunneling diodes (RTD), and quantum dots. Logic and memory devices. Prerequisite: undergraduate device physics.

3 units, Spr (Wong, P)

EE 222. Applied Quantum Mechanics I—Emphasis is on applications in modern devices and systems. Topics include: Schrodinger's equation, eigenfunctions and eigenvalues, operator approach to quantum mechanics, Dirac notation, solutions of simple problems including quantum wells and tunneling. Quantum harmonic oscillator, coherent states. Calculation techniques including matrix diagonalization, perturbation theory, and variational method. Time-dependent perturbation theory, applications to optical absorption, nonlinear optical coefficients, and Fermi's golden rule. Quantum mechanics in crystalline materials. Prerequisites: MATH 52 and 53, PHYSICS 65 (or PHYSICS 43 and 45).

3 units, Aut (Vuckovic, J)

EE 223. Applied Quantum Mechanics II—Continuation of 222, including more advanced topics: angular momentum in quantum mechanics, spin, hydrogen atom, systems of identical particles (bosons and fermions), methods for one-dimensional problems, 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.

3 units, Win (Miller, D)

EE 228. Basic Physics for Solid State Electronics—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.

3 units, Aut (Peumans, P)

EE 231. Introduction to Lasers—How lasers work, including quantum transitions in atoms, stimulated emission and amplification, rate equations, saturation, feedback, coherent optical oscillation, laser resonators, and optical beams. Limited primarily to steady-state behavior; classical models for atomic transitions with little quantum mechanics background required. Prerequisites: electromagnetic theory to the level of 142, preferably 241, and some atomic or modern physics such as PHYSICS 70 or 130, 131.

3 units, Spr (Digonnet, M)

EE 232. Laser Dynamics—Continuation of 231, emphasizing dynamic and transient effects including spiking, Q-switching, mode locking, frequency modulation, frequency and spatial mode competition, linear and nonlinear pulse propagation, short pulse expansion, and compression. Prerequisite: 231.

3 units, Aut (Fan, S)

EE 234. Photonics Laboratory—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. Prerequisite: 142.

3 units, Win (Kahn, J)

EE 235. Guided Wave Optical Devices—Guided wave optics, optical waveguide devices, and integrated optics. Wave propagation in layered media, slab waveguides, and optical fibers. Rectangular waveguides. Optical waveguide technology. Coupled-mode theory. Numerical analysis of complex waveguides. Photonic crystals. Physics and design of waveguide devices. Fiber sensors, waveguide gratings, waveguide modulators, directional couplers, ring filters. Prerequisite: electromagnetic theory to the level of 142 or equivalent.

3 units, Spr (Fan, S)

EE 241. Waves I—Waves and wave phenomena in natural, lab, and application settings. Electromagnetic, acoustic, seismic, atmospheric, plasma, and water waves and their mathematical and physical correspondence in terms of Hamilton's principle. Propagation, attenuation, reflection, refraction, surface and laminal guiding, and intrinsic and structural dispersion; energy density, power flow, and phase and group velocities. Geometric and structural complexities are minimized to stress basic wave concepts. Analysis in terms of transmission line and impedance concepts using exponential notation and vector phasors. Treatment limited to plane harmonic waves in isotropic media. Nonhomogeneous cases limited to plane interfaces and exponentially stratified media. Prerequisite: 142 or equivalent, or other wave course.

3 units, not given this year

EE 243. Semiconductor Optoelectronic Devices—Operating principles and practical device features. Semiconductor physics and optical processes in semiconductors. Semiconductor heterostructures and optical detectors including p-i-n, avalanche, and MSM, light emitting diodes, electroabsorptive modulators (Franz-Keldysh, QCSE), electrorefractive (directional couplers, Mach-Zehnder), switches (SEEDs), and lasers (waveguide and vertical cavity). Prerequisites: basic quantum mechanics, solid state physics, and lasers, such as 222, 228, 231, or equivalents.
3 units, Win (Harris, J)

EE 245. Wireless Electromagnetic Design Laboratory—Same content as 144 but with a higher level project.
3 units, Spr (Leeson, D)

EE 246. Microwave Engineering—Microwave applications (terrestrial and satellite communications, radar, remote sensing, wireless communications) and their system and component requirements. Review of Maxwell's equations. Propagation modes of transmission lines (TEM, waveguide, microstrip), S-parameter matrix modeling of discontinuities, junctions and circuits (impedance transformers, directional couplers, hybrids, filters, circulators, solid state amplifiers and oscillators). Microwave computer-aided design examples. General flow of course is application to system to component; individual components are modeled by fields to modes to equivalent network. Prerequisite: 142.
3 units, alternate years, not given this year

EE 247. Introduction to Optical Fiber Communications—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: 102A or 261, and 142 or 235 or 241, and 178 or 179.
3 units, Aut (Kahn, J)

EE 248. Fundamentals of Noise Processes—Mathematical methods and physical principles: statistics, Fourier analysis, statistical and quantum mechanics. Circuit theory: thermal noise, quantum noise, fluctuation-dissipation theorem. Macroscopic and mesoscopic conductors. Macroscopic and mesoscopic pn junctions. 1/f noise and random telegraphic noise. Negative conductance oscillators (lasers) and nonlinear susceptance oscillators (optical parametric amplifier). Optical and quantum communication systems. Weak force detection systems. Prerequisites: elementary device, circuit, and electromagnetic waves to the level of 101A,B and 142.
3 units, Aut (Yamamoto, Y)

EE 249. Introduction to the Space Environment—The environment in which space probes and vehicles travel and orbit and which moderates the gases and radiation from the sun. Experimentation and the tools used. Its regions including the ionosphere, magnetosphere, and interplanetary space. The role of the sun, the effects of changes in solar activity, charged particle motion which in combination with the earth's magnetic field leads to auroras and the Van Allen belts. Prerequisites: familiarity with electromagnetics at the level of 142; senior or graduate standing.
3 units, alternate years, not given this year

EE 252. Antennas for Telecommunications and Remote Sensing—Fundamental properties. Dipoles, loops, reflectors, Yagis, helices, slots, horns, micro-strips. Antennas as transitions between guided and free radiation, ultrasound analogue. Famous antennas. Pattern measurements. Friis and radar equations. Feeds, matching, baluns. Broadbanding. Arrays, aperture synthesis, interferometry, very-long-baseline interferometry. Thermal radiation, antenna temperature, microwave passive remote sensing. Prerequisite: 142 or equivalent.
3 units, not given this year

EE 254. Principles of Radar Systems—Analysis and design. Radar equation and systems parameters, components of radar systems, radar cross-section and target characteristics, signal detection in noise, ambiguity function (with applications to measurement precision, resolution, clutter rejection, and waveform design); pulse compression waveforms, synthetic aperture radar, tracking and scanning radars, HF (OTH) radar, radar environmental and remote sensing, radar astronomy. Prerequisite: senior or graduate standing.
3 units, alternate years, not given this year

EE 256. Numerical Electromagnetics—Principles and applications of numerical techniques for solving practical electromagnetics problems. Time domain solutions of Maxwell's equations. Finite difference time domain (FDTD) methods. Numerical stability, dispersion, and dissipation. Step and pulse response of lossy transmission lines and interconnects. Absorbing boundary conditions. FDTD modeling of propagation and scattering in dispersive media. Near-to-far-zone transformations. Moment method solutions of integral equations, with applications to antenna problems. Computational problems require programming and use of MATLAB and other tools. Prerequisite: 142 or equivalent.
3 units, Spr (Inan, U), alternate years, not given next year

EE 261. The Fourier Transform and its Applications—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: Fourier series at the level of 102A, and linear algebra.
3 units, Aut (Osgood, B), Win (Hesselink, L)

EE 262. Two-Dimensional Imaging—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: 261. Recommended: 278, 279.
3 units, alternate years, not given this year

EE 263. Introduction to Linear Dynamical Systems—Applied linear algebra and linear dynamical systems with application to circuits, signal processing, communications, and control systems. Topics: least-squares approximations of over-determined equations and least-norm solutions of underdetermined equations. Symmetric matrices, matrix norm, and singular value decomposition. Eigenvalues, left and right eigenvectors, with dynamical interpretation. Matrix exponential, stability, and asymptotic behavior. Multi-input/multi-output systems, impulse and step matrices; convolution and transfer matrix descriptions. Control, reachability, and state transfer. Least-norm inputs and associated Gramians. Prerequisites: linear algebra and matrices as in MATH103; differential equations and Laplace transforms as in 102A.
3 units, Aut (Boyd, S), Spr (Osgood, B)

EE 264. Digital Filtering—Introduction to digital signal processing techniques. Two sided Z-transform. SISO and MIMO flowgraphs, Markov graphs. Discrete-time Wiener filtering. Laplace transform, mixed discrete and continuous feedback systems. Interpolation techniques for D/A conversion. Discrete Fourier transform and its applications. Finite impulse response (FIR) and infinite impulse response (IIR) filter designs. Theory of quantization noise. Prerequisite: 102B. Recommended: 261, 278.
3 units, Aut (Widrow, B)

EE 265. Signal Processing Laboratory—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, IIR filters, FIR filters, filter design and implementation, spectral analysis, rate conversion, wireless data communication. Prerequisites: 102A,B. Recommended: 261.
3-4 units, Spr (Meng, T)

EE 268. Introduction to Modern Optics—Geometrical optics: ray matrices, Gaussian beams, optical instruments, and radiometry. Wave nature of light: Maxwell's equations, propagation through media with varying index of refraction (e.g., fibers). Interferometry: basic principles, practical systems, and applications.
3 units, Aut (Hesselink, L)

EE 271. Introduction to VLSI Systems—Large-scale MOS design. Topics: MOS transistors, static and dynamic MOS gates, MOS circuit fabrication, design rules, resistance and capacitance extraction, power and delay estimation, scaling, MOS combinational and sequential logic design, registers and clocking schemes, memory, data-path, and control-unit design. Elements of computer-aided circuit analysis, synthesis, and layout techniques. Prerequisites: 101A and 108B; familiarity with circuits, logic design, and digital system organization.
3 units, Aut (Horowitz, M; Mitra, S)

EE 273. Digital Systems Engineering—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: 102B and 108A, or equivalents. Recommended: 214.
3 units, not given this year

EE 276. Introduction to Wireless Personal Communications—Frequency reuse, cellular concepts, cochannel interference, handoff. Radio propagation in and around buildings: Friis equation, multipath, narrow-band and wide-band channels, small scale and large-scale statistics, space and time signal variation. Diversity. Receiver sensitivity, sources of noise, range. Performance statistics: coverage, margin, digital modulation, adjacent channel interference, and digital error rates. Wide band channels: maximum transmission rates. Multi-server queuing and traffic: Erlang formulas. Prerequisites: 142 and 278 or equivalent. Corequisite: 279 or equivalent.
3 units, Spr (Cox, D)

EE 278. Introduction to Statistical Signal Processing—Random variables, 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. Prerequisites: 178 or STATS 116, and linear systems and Fourier transforms at the level of 102A,B or 261.
3 units, Aut (Gill III, J), Spr (El Gamal, A)

EE 279. Introduction to Communication Systems—Analysis and design of communication systems; analog and digital modulation and demodulation, frequency conversion, multiplexing, noise and distortion; spectral and signal-to-noise ratio analysis, probability of error in digital systems, spread spectrum. Prerequisites: 179 or 261, and 178 or 278.
3 units, Win (Cox, D)

EE 282. Computer Systems Architecture—Advanced architecture topics for systems such as personal computers, servers, and embedded or portable devices. Cache hierarchies, memory systems, storage and IO systems, clusters, fault-tolerance, and low power design. Programming assignments; introduction to performance analysis and optimization techniques for small- and large-scale systems. Locality, coarse-grain parallelism, overlapping communication and computation, performance/power trade-offs, and reliability. How computer systems are organized and why they are organized that way. Characteristics of modern processors that affect system architecture. Prerequisite: 108B.
3 units, Spr (Kozyrakis, C)

EE 284. Introduction to Computer Networks—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.
3 units, Aut (Tobagi, F)

EE 290A,B,C. Curricular Practical Training for Electrical Engineers—For EE majors who need relevant work experience as part of their program of study. Final report required. Prerequisite for 290B: candidate for Engineer or Ph.D. in Electrical Engineering. Prerequisite for 290C: candidate for Ph.D. degree in Electrical Engineering.
1 unit, Aut, Win, Spr, Sum (Gray, R)

EE 292E. Analysis and Control of Markov Chains—Finite-state and countable-state Markov chains. Controlled Markov chains and dynamic programming algorithms. Application to modeling and analysis of engineering systems. Prerequisites: 263, 278.
3 units, alternate years, not given this year

EE 292F. Digital Processing of Speech Signals—How digital signal processing techniques are used in applications such as speech coding, speech synthesis, speech recognition, and speaker verification. Short MATLAB projects. Prerequisite: 102B.
3 units, Win (Schafer, R)

EE 293A. Fundamentals of Energy Processes—For seniors and graduate students. The physics and chemistry underlying topics in renewable energy processes. Generalities applicable to all energy systems. Thermodynamics and kinetic theory of gases. Mechanical heat engines as a basis for comparison. The basics of wind energy and of thermoelectric devices. Recommended: MATH 41, 43; PHYSICS 41, 43, 45.
3-4 units, Aut (da Rosa, A)

EE 293B. Fundamentals of Energy Processes—For seniors and graduate students. The physics and chemistry underlying topics in renewable energy processes. Hydrogen fuel cells, and hydrogen production and storage. Photodiodes and thethermodynamic needed for the electrochemistry of fuel cells. Recommended: EE 293A; MATH 41; PHYSICS 41, 43, 45.
3-4 units, Win (da Rosa, A)

COGNATE COURSES

Courses approved to fulfill EE program requirements at the level of 200-299 EE courses are listed below according to the undergraduate specialty, M.S. depth areas, or as "Other." See respective department listings for course descriptions.

COMPUTER SOFTWARE SYSTEMS

CS 140. Operating Systems and Systems Programming
3-4 units, Aut, Win (Rosenblum, M), Sum (Staff)

CS 143. Compilers
3-4 units, Aut, Win, Sum (Staff)

CS 240. Advanced Topics in Operating Systems
3 units, Aut (Mazieres, D), Spr (Engler, D)

CS 242. Programming Languages
3 units, Aut (Mitchell, J)

CS 248. Introduction to Computer Graphics
3-5 units, Aut (Levoy, M)

CONTROL AND SYSTEM ENGINEERING

ENGR 205. Introduction to Control Design Techniques
3 units, Aut (Rock, S)

ENGR 207A. Modern Control Design I
3 units, Win (Lall, S)

ENGR 207B. Modern Control Design II
3 units, Spr (Lall, S)

ENGR 209A. Analysis and Control of Nonlinear Systems
3 units, Win (Rock, S)

ENGR 209B. Advanced Nonlinear Control
3 units, not given this year

ENGR 210B. Advanced Topics in Computation for Control
3 units, not given this year

CONTROLS (UNDERGRADUATE SPECIALTY)

ENGR 205. Introduction to Control Design Techniques
3 units, Aut (Rock, S)

ENGR 206. Control System Design
4 units, Spr (Niemeyer)

ENGR 207A,B. Modern Control Design
3 units, **A:** *Win,* **B:** *Spr (Lall, S)*

ENGR 209A. Analysis and Control of Nonlinear Systems
3 units, Win (Rock, S)

ELECTRONIC DEVICES, SENSORS, AND TECHNOLOGY

ENGR 240. Introduction to Micro and Nano Electromechanical Systems (M/NEMS)
3 units, Win (Pruitt, B; Howe, R)

IMAGE SYSTEMS

CS 248. Introduction to Computer Graphics
3-5 units, Aut (Levoy, M)

NETWORK SYSTEMS

CS 244A. Introduction to Computer Networks
3-4 units, Win (McKeown, N)

SIGNAL PROCESSING

CS 221. Artificial Intelligence: Principles and Techniques
3-4 units, Aut (Ng, A)

CS 228. Probabilistic Models in Artificial Intelligence
3 units, Win (Koller, D)

CS 229. Machine Learning
3 units, Aut (Ng, A)

STATS 315A. Modern Applied Statistics: Learning
2-3 units, Aut (Hastie, T)

STATS 315B. Modern Applied Statistics: Data Mining
2-3 units, Win (Friedman, J)

SOLID STATE MATERIALS AND DEVICES

MATSCI 209. Electronic and Optical Properties of Solids—(Same as MATSCI 199.)
3-4 units, Spr (Brongersma, M)

MATSCI 323. Thin Film and Interface Microanalysis
3 units, Aut (Koster, G)

MATSCI 347. Introduction to Magnetism and Magnetic Nanostructures
3 units, Spr (Staff)

OTHER

AA 272C. Global Positioning Systems
3 units, Win (Enge, P)

AA 278. Optimal Control and Hybrid Systems
3 units, not given this year

APPPHYS 226. Physics of Quantum Information
3 units, Spr (Yamamoto, Y), alternate years, not given next year

APPPHYS 227. Applications of Quantum Information
3 units, not given this year

APPPHYS 272,273. Solid State Physics
3 units, **272:** *Win,* **273:** *Spr (Laughlin, R)*

CS 205. Mathematical Methods for Robotics, Vision, and Graphics
3 units, Aut (Fedkiw, R)

CS 223B. Introduction to Computer Vision
3 units, Win (Thrun, S)

CS 255. Introduction to Cryptography
3 units, Win (Boneh, D)

MS&E 237. Progress in Worldwide Telecommunications
3 units, Sum (Ivanek, F; Chiu, S)

MS&E 246. Game Theory with Engineering Applications
3 units, Win (Johari, R)

MS&E 251. Stochastic Decision Models
3 units, Win (Staff)

ME 358. Heat Transfer in Microdevices
3 units, Spr (Goodson, K)

GRADUATE

EE 300. Master's Thesis and Thesis Research—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.
1-15 units, Aut, Win, Spr, Sum (Staff)

EE 309. Semiconductor Memory Devices and Technology—Memory devices such as SRAM, DRAM, and NVRAM. Operation principles, device design considerations, device scaling, device fabrication, addressing, and readout circuits. Cell structures including 1T-1C, 6T, 4T, 1T-1R, 0T-1R, floating gate FLASH, SONOS, and NROM; memory organization including open bit-line, folded bit-line, NAND, NOR, and cross-point. New memory concepts such as nanocrystal memory, single-electron memory, magnetic tunnel junction memory (MRAM), ferroelectric memory (FRAM), phase change memory (PRAM), T-RAM, polymer memory. Prerequisite: 216.
3 units, alternate years, not given this year

EE 310. Integrated Circuits Technology and Design Seminar—Device structures, fabrication technologies, and circuit design issues in integrated circuits. Current research.
1 unit, Win (Nishi, Y; Wong, P; Saraswat, K)

EE 311. Advanced Integrated Circuit Fabrication Processes—Practical and fundamental limits to the evolution of the technology of modern MOS and bipolar devices. Modern device and circuit fabrication and likely future changes. Advanced techniques and models of device and back-end (interconnect and contact) processing. Use of TSUPREM4 and PISCES for process and device modeling. MOS and bipolar process integration. Prerequisites: 212, 216.
3 units, Spr (Staff)

EE 312. Micromachined Sensors and Actuators—Solid-state sensors and actuators, focusing on the use of integrated circuit fabrication technology for their realization. Categories of sensors and actuators include biological, chemical, mechanical, optical, and thermal. Basic mechanisms of transduction, fabrication techniques, and the relative merits of different technologies. Micromachining techniques for monolithic integration of active circuits with sensors or actuators and directions for future research. Prerequisite: 212 or equivalent.
3 units, Win (Kovacs, G)

EE 313. Digital MOS Integrated Circuits—Analysis and design of digital MOS integrated circuits. Development of different models for MOS transistors and how to use them to analyze circuit performance. Use of computer-aided circuit analysis. Logic styles include static, dynamic and pass logic, pulse-mode gates, and current-mode logic. 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. Prerequisites: 101B, 108A. Recommended: 271.
3 units, Win (Horowitz, M)

EE 314. RF Integrated Circuit Design—Design of RF integrated circuits for communications systems, primarily in CMOS. Topics: the design of matching networks and low-noise amplifiers at RF, passive and active filters, 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: 214.
3 units, Win (Lee, T)

EE 315. VLSI Data Conversion Circuits—Design of mixed-signal integrated circuits for implementing the interfaces between analog and digital signals in CMOS VLSI systems. Fundamental circuit elements such as sample-and-hold circuits, comparators, analog gain blocks and integrators. The design of the constituent circuits for Nyquist-rate and oversampling analog-to-digital and digital-to-analog converters, sampled-data and continuous-time analog filters, and digital decimation and interpolation filters. Prerequisite: 214.
3 units, Spr (Murmann, B)

EE 316. Advanced VLSI Devices—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.
3 units, Win (Wong, P)

EE 317. Micropatterning for Integrated Circuits—The fundamentals of generating submicron patterns in integrated circuit manufacturing. Technologies include the formation of submicron images of ultraviolet light, the resulting exposure of polymeric resists, the subsequent development of resist patterns and their transfer into functional circuit material patterns through plasma etching and other techniques. Use of phase-shifting masks and other wavefront-engineering approaches. Hands-on computer simulations. Prerequisites: 141 or equivalent, 212 or equivalent.
3 units, Spr (Pease, R), alternate years, not given next year

EE 322. Molecular Electronics and Photonics—Physics of charge and energy transfer in molecular systems and connection with traditional mesoscopic transport theories. Analysis of molecular organic light-emitting diodes, photovoltaic cells and transistors. Technology and applications of molecular semiconductors. Prerequisite: 228 or equivalent.
3 units, not given this year

EE 327. Properties of Semiconductor Materials—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, semiclassical transport theory, semiconductor statistics, carrier scattering, electro-magneto transport effects, high field ballistic transport, Boltzmann transport equation, quantum mechanical transitions, optical absorption, and radiative and non-radiative recombination. Prerequisites: 216, 228.
3 units, Spr (Harris, J), alternate years, not given next year

EE 328. Physics of Advanced Semiconductor Devices—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 ATLAS, 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.
3 units, alternate years, not given this year

EE 329. The Electronic Structure of Surfaces and Interfaces—Physical concepts and phenomena for surface science techniques probing the electronic structure of surfaces and interfaces. Microscopic and atomic models of microstructures; applications such as within semiconductor device technology and catalysis. Physical processes of low energy electron diffraction, Auger electron spectroscopy, UV and X-ray photoemission spectroscopy, electron/photon stimulated ion desorption, inelastic tunneling spectroscopy, ion scattering, surface EXAFS, and energy loss spectroscopy; and experimental aspects of these surface science techniques. Prerequisites: PHYSICS 70 and 238, or consent of instructor.
3 units, Aut (Pianetta, P), alternate years, not given next year

EE 335. Introduction to Information Storage Systems—Data storage technologies including optical data storage (CD-ROM, DVD, magneto-optic recording, and holographic recording), solid state memory (flash memory, ferroelectric memory, and emerging magnetic random access memory), probe-based storage, and magnetic disk drives. Comparisons among data storage technologies. Related nanotechnologies. Prerequisites: electromagnetism, optics, transistors, binary algebra, probability, and Fourier transform.
3 units, Win (Wang, S)

EE 336. Nanophotonics—(Same as MATSCI 346.) Recent developments in micro- and nanophotonic materials and devices. 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. SITN/SCPD televised. Prerequisite: electromagnetic theory at the level of 142.
3 units, Win (Fan, S; Brongersma, M)

EE 340. Advanced Topics in Optics and Quantum Optics—Optical microcavities and their device applications. Types of optical microcavities (microdisks, microspheres, and photonic crystal 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 microcavities, including low-threshold lasers, resonant cavity light-emitting diodes, and single-photon sources. Prerequisites: advanced undergraduate- or basic graduate-level knowledge of electromagnetics, quantum mechanics, and physics of semiconductors.
3 units, Spr (Vuckovic, J)

EE 343. Advanced Optoelectronic Devices—Semiconductor quantum well structures; superlattices and coupled quantum wells; optical properties of quantum wells; valence band structure; effects of strain; quantum well lasers; intersubband detectors; excitons in quantum wells; absorption saturation; electroabsorption; quantum well modulators and switches. Prerequisites: 222 or equivalent quantum mechanics, 243.

3 units, alternate years, not given this year

EE 344. High Frequency Laboratory—Lecture/lab emphasizing lab. Techniques in the 1MHz-1GHz range useful in designing and measuring oscillators, amplifiers, and mixers. High frequency measurement techniques including s-parameter measurements, amplifier noise figure, and oscillator phase noise. Guest speakers from Lucent and Hewlett-Packard. Enrollment limited to 20. Prerequisites: transmission lines, Smith charts.

3 units, Aut (Cox, D)

EE 345. Optical Fiber Communication Laboratory—Experimental techniques in optical fiber communications. Experimental investigation of key optical communications components including fibers, lasers, modulators, photodiodes, optical amplifiers, and WDM multiplexers and demultiplexers. Key optical communications systems techniques: eye diagrams and BER measurements. Prerequisite: 247.

3 units, alternate years, not given this year

EE 346. Introduction to Nonlinear Optics—Wave propagation in anisotropic, non-linear, and time-varying media. Microscopic and macroscopic description of electric dipole susceptibilities. Free and forced waves-phasematching; slowly varying envelope approximation-dispersion, diffraction, space-time analogy; harmonic generation; frequency conversion; parametric amplification and oscillation; electro-optic light modulation; nonlinear processes in optical fibers. Prerequisites: 141, 142.

3 units, Spr (Harris, S)

EE 347. Optical Methods in Engineering Science—Design and understanding of modern optical systems. Topics: geometrical optics; aberration theory; systems layout; applications such as microscopes, telescopes, optical processors. Computer ray tracing program as a design tool. Prerequisite: 268 or 366, or equivalent.

3 units, alternate years, not given this year

EE 348. Advanced Optical Fiber Communications—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. Solitons, loss- and dispersion-managed solitons. Comparison of modulation techniques: duobinary, pulse-amplitude modulation, differential phase-shift keying, phase-shift keying, quadrature-amplitude modulation. Comparison of detection techniques: noncoherent, differentially coherent, coherent. Spectral efficiency limits. Error-control coding. Prerequisite: 247.

3 units, not given this year

EE 349. Nano Optics and Grating Photonics—Coupled wave analysis of periodic structures, gratings structures for optical communcations, wave-matter interactions with periodic media and photonic crystals, applications of periodic structures. Prerequisite: 268 or 366, or equivalent.

3 units, Spr (Hesselink, L), alternate years, not given next year

EE 350. STARLab Seminar—Research topics from space physics, planetary exploration, ionospheric and magnetospheric physics, radar and remote sensing of the environment, applied electromagnetics, waves in optical fibers, and information systems with space applications. Applied research areas include wireless personal communications, high bandwidth wired and wireless transmission, optical communication systems, sensor networks, and related underlying and advancing technologies.

1 unit, Win (Inan, U)

EE 353. Business Management for Electrical Engineers and Computer Scientists—Business decision making in computer, high tech, and Silicon Valley firms. Corporate strategy, product development, and organizational behavior. Case method. Marketing, sales, distribution, customer service, and financial accounting. How to determine the best course of action to resolve and implement recommendations. Enrollment limited to 60. Prerequisite: graduate standing.

3 units, Spr (Gibbons, F; Siegel, M)

EE 354. Introduction to Radio Wave Scattering—Integral and differential equations of radio wave scattering; exact, approximate, and numerical solutions of single particle scattering for spheres, edges, points, and cylinders. Scattering from rough surfaces with large and small roughness scales, as time permits. Multiple scattering; formulation and solution techniques for equation of transfer in discrete media and scattering by continuous media in weak and strong regimes. Applications to radar, radar astronomy, remote sensing, and biological media. Prerequisites: electromagnetic theory through standard graduate engineering topics; partial differential equations, boundary value problems in rectangular and spherical coordinates; and consent of instructor.

3 units, Win (Tyler, G), alternate years, not given next year

EE 355. Imaging Radar and Applications—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: polarimetry and target discrimination, topographic mapping surface displacements, velocities of ice fields. Prerequisite: 261. Recommended: 254, 278, 279.

3 units, Win (Zebker, H) alternate years, not given next year

EE 356. Elementary Plasma Physics: Principles and Applications—Plasmas in nature and industry. Single particle motions. Plasma kinetic theory. The Boltzmann equation and its moments. Cold and warm plasma models. Plasma as a fluid. Magnetohydrodynamics. Plasma conductivity and diffusion. Langmuir oscillations. Debye shielding. Plasma sheath. Waves in magnetized, cold, warm, and hot plasmas. Electron and ion waves. MHD waves. Landau damping. Nonlinear effects. Applications in industry and space science. Prerequisite: 142 or PHYSICS 122.

3 units, alternate years, not given this year

EE 359. Wireless Communication—Design, performance analysis, and performance limits of wireless systems. Topics include: current wireless systems, path loss and shadowing, statistical multipath channel models, capacity of wireless channels, digital modulation and its performance in fading and intersymbol interference, adaptive modulation, diversity, multiple antenna systems (MIMO), equalization, multicarrier modulation, and spread spectrum and RAKE receivers. Multiuser system design issues such as multiple access, frequency reuse in cellular systems, and ad hoc wireless network design. Optional term project for 4 units; otherwise 3 units. Prerequisite: 279.

3-4 units, Aut (Hashemi, H)

EE 360. Multiuser Wireless Systems and Networks—Possible topics include multiuser detection and interference cancellation, cellular system design and optimization, dynamic resource allocation and power control, random and multiple access, Shannon capacity and achievable rate regions of wireless networks, ad hoc wireless network design, sensor and energy-constrained networks, QoS support, and joint network and application design. Student input in topic selection. Prerequisite: 359.

3 units, alternate years, not given this year

EE 363. Linear Dynamic Systems—Continuation of 263. Optimal control and dynamic programming; linear quadratic regulator. Lyapunov theory and methods. Linear estimation and the Kalman filter. Perron-Frobenius theory. Examples and applications from digital filters, circuits, signal processing, and control systems. Prerequisites: 263 or equivalent; basic probability.

3 units, not given this year

EE 364A. Convex Optimization I—Convex sets, functions, and optimization problems. 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 equivalent to 263.
3 units, not given this year

EE 364B. Convex Optimization II— Continuation of 364A. Subgradient, cutting-plane, and ellipsoid methods. Decentralized convex optimization via primal and dual decomposition. Alternating projections. Exploiting problem structure in implementation. Convex relaxations of hard problems, and global optimization via branch and bound. Robust optimization. Applications in areas such as control, circuit design, signal processing, and communications. Substantial project. Prerequisite: 364A.
3 units, Win (Boyd, S), alternate years, not given next year

EE 366. Introduction to Fourier Optics—Applications of Fourier theory to the analysis and synthesis of optical imaging and optical data processing systems. Propagation and diffraction of light, Fresnel and Fraunhofer approximations, Fourier transforming properties of lenses, image formation with coherent and incoherent light, transform functions of imaging systems, optical data processing, and holography. Prerequisite: familiarity with Fourier analysis. Recommended: 261.
3 units, alternate years, not given this year

EE 368. Digital Image Processing—Image sampling and quantization, point operations, linear image filtering and correlation, image transforms, eigenimages, multidimensional signals and systems, multiresolution image processing, wavelets, morphological image processing, noise reduction and restoration, simple feature extraction and recognition tasks, image registration. Emphasis is on the general principles of image processing. Students write and investigate image processing algorithms in Matlab. Competitive term project. Prerequisites: 261, 278.
3 units, Spr (Girod, B)

EE 369A. Medical Imaging Systems I—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: 261.
3 units, Win (Nishimura, D)

EE 369B. Medical Imaging Systems II—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: 261.
3 units, Spr (Nishimura, D)

EE 369C. Medical Image Reconstruction—Reconstruction from non-uniform frequency domain data, automatic deblurring, phase unwrapping, reconstruction from incomplete data. Examples from fast magnetic resonance imaging methods including spiral, echo-planar, multi-coil/parallel and partial k-space reconstructions. Prerequisite: 369B.
3 units, not given this year

EE 371. Advanced VLSI Circuit Design—Issues in high performance digital CMOS VLSI design from a system perspective. Topics: wire modeling, logic families, latch design and clocking issues, clock distribution, RAMs, ALUs, I/O and I/O noise issues. Final project involves the design of a subsystem for a high-speed processor. Extensive use of SPICE. Prerequisites: 271 and 313, or consent of instructor.
3 units, Spr (Horowitz, M)

EE 372. Quantization and Compression—Theory and design of codes for quantization and signal compression systems (source coding systems), systems which convert analog or high bit rate digital signals into low bit rate digital signals while optimizing fidelity subject to available communication or storage capacity. Applications to the design of systems for compression, statistical classification, and density estimation using statistical clustering techniques. Asymptotic theory: Zador/Gersho theory for high rate quantization theory and Shannon rate-distortion theory. Code structures: uniform and lattice codes, tree structured codes, transform codes, composite codes, universal codes. Mismatch and dithering. Prerequisites: 261, 278. Recommended: 376A, MATH 137.
3 units, Spr (Gray, R), alternate years, not given next year

EE 373A. Adaptive Signal Processing—Self-optimizing systems whose performance is improved through contact with their environments. Feedback models for least mean-square adaptation processes. Steepest descent, Newton's method, and Southwell relaxation methods. Random search. LMS algorithm. Efficiency measures for adaptive processes. Adaptive digital filters, noise canceling and signal enhancement, adaptive antennas, adaptive control systems. Original theoretical and experimental research projects in electrical engineering and biomedical engineering, teamwork. Prerequisites: 263, 264. Recommended: 278.
3 units, Win (Widrow, B)

EE 373B. Adaptive Neural Networks—Adaptive threshold elements, Feedforward layered networks, Back propagation algorithm. Optimal decision making. Learning by punish/reward. Adaptive gaming. Experimental and theoretical applications of neural networks to pattern recognition, speech recognition, and self-learning adaptive control systems. Nonlinear adaptive filtering. Volterra adaptive filtering. Self-organizing maps. Support vector machines. Radial basis functions. Recurrent neural networks. Original theoretical and experimental research projects in electrical engineering and biomedical engineering, teamwork. Continuation of projects begun in 373A. Prerequisite: 373A.
3 units, Spr (Widrow, B)

EE 376A. Information Theory—Information theory and statistics. The extreme points of communication theory: data compression to the entropy limit, and communication at the channel capacity limit. Shannon entropy. Rate distortion theory. Huffman coding and random coding. Unified treatment based on the asymptotic equipartition theorem. Prerequisite: 178 or 278 or STATS 116, or equivalent.
3 units, Win (Weissman, I)

EE 376B. Information Theory—Rate distortion theory and Kolmogorov complexity. Information theory and statistics. Method of types. Stein's lemma. AEP. Information capacity of networks. Slepian-Wolf theorem. Optimal investment and information theory. Universal portfolios and universal data compression. Maximum entropy and Burg's theorem. Prerequisite: 376A.
3 units, not given this year

EE 378. Statistical Signal Processing—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. Prerequisite: 278.
3 units, Spr (Weissman, I)

EE 379A. Digital Communication I—Maximum-likelihood data detection, modulation methods and bandwidth requirements, bandpass systems and analysis, intersymbol interference and equalization methods, diversity, phase-locking, and synchronization. Prerequisites: 102B, 278.
3 units, Win (Malkin, M)

EE 379B. Digital Communication II—Basic channel capacity formulae, decoding algorithms: Viterbi detection, sequence detectors, and iterative decoding methods; partial-response methods, convolutional, trellis, turbo codes, and low-density parity check codes. Prerequisites: 278, 379A. Recommended: 387.
3 units, alternate years, not given this year

EE 379C. Advanced Digital Communication—Multi-dimensional modulation and basis functions, transmit optimization for channels with intersymbol interference, discrete multitone (DMT), orthogonal frequency division multiplexing (OFDM), vector modulation, generalized decision-feedback equalization (GDFE). Prerequisite: 379A.
3 units, alternate years, not given this year

EE 380. Seminar on Computer Systems—Current research in the design, implementation, analysis, and use of computer systems from integrated circuits to operating systems and programming languages.
1 unit, Aut, Win, Spr, Sum (Allison, D; Long, E)

EE 382A. Advanced Processor Architecture—Topics include advanced instruction-set design and pipelining, wide instruction fetch, branch prediction, out-of-order and speculative execution, memory disambiguation, vector processors, simultaneous multithreading, and low-level compiler optimizations for instruction-level parallelism. Trade-offs among performance, power, and complexity, and techniques for addressing them. The design of out-of-order processor core using the Verilog hardware design language. Prerequisites: 108B, 282.
3 units, not given this year

EE 382C. Interconnection Networks—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.
3 units, Spr (Dally, W), alternate years, not given next year

EE 382D. Advanced Computer Arithmetic—Number systems, floating point representation, state of the art in arithmetic algorithms, problems in the design of high speed arithmetic units. Prerequisite: 282.
3 units, alternate years, not given this year

EE 384A. Internet Routing Protocols and Standards—Local area networks: MAC addressing; IEEE 802.1 bridging protocols (transparent bridging, virtual LANs). Internet routing protocols: Internet protocol (IPv4, IPv6, ICMP); interior gateways (RIP, OSPF) and exterior gateways (BGP, policy routing); IP multicast (IGMP, DVMRP, CBT, MOSPF, PIM); multiprotocol label switching (MPLS). Prerequisite: 284 or CS 244A.
3 units, not given this year

EE 384B. Multimedia Communication over the Internet—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). Prerequisite: 284 or CS 244A. Recommended: 384A.
3 units, Win (Tobagi, F), alternate years, not given next year

EE 384C. Wireless Local Area Networks—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. Current research papers in the open literature. Prerequisite: 284 or CS 244A.
3 units, alternate years, not given this year

EE 384M. Network Algorithms—Theory and practice of designing and analyzing algorithms arising in networks. Topics include: designing algorithms for load balancing, switching, congestion control, network measurement, the web infrastructure, and wireless networks; and analyzing the performance of algorithms via stochastic network theory. Algorithm design using randomization, probabilistic sampling, and other approximation methods. Analysis methods include the use of large deviation theory, fluid models, and stochastic comparison. Research project. Prerequisite: EE 278 or CS 365.
3 units, not given this year

EE 384S. Network Architectures and Performance Engineering—Modeling and control methodologies used in network performance engineering: Markov chains and stochastic modeling, queueing networks, stochastic simulation, dynamic programming, network optimization algorithms, large-scale distributed computation for networking operations. Applications to design issues in high-performance network architectures for wireline and wireless networking: traffic modeling, congestion control, IP network dynamics, TCP flow control, quality of service support, network admission control and operations management, power control and dynamic bandwidth allocation in wireless networks. Prerequisites: 284 and good understanding of probability and general systems modeling.
3 units, Spr (Bambos, N)

EE 384X. Packet Switch Architectures I—First of two-course sequence. Theory and practice of designing packet switches and routers. Evolution of switches and routers. Output scheduling: fairness, delay guarantees, algorithms. Unicast switching: blocking phenomena and their alleviation, connection between switch scheduling and bipartite graph matching. Multicast switching. Theoretical complements: simple queueing models, Bernoulli and Poisson processes, graph matching algorithms, urn problems, stability analysis using Lyapunov functions, fluid models. Prerequisites: 284 or CS 244A, 178 or 278 or STAT 116.
3 units, not given this year

EE 384Y. Packet Switch Architectures II—Second of two-course sequence. Theory and practice of designing packet switches and routers. Address lookup: exact matches, longest prefix matches, performance metrics, hardware and software solutions. Packet classifiers: for firewalls, QoS, and policy-based routing; graphical description and examples of 2-D classification, examples of classifiers, theoretical and practical considerations.
3 units, not given this year

EE 385A. Digital Systems Reliability Seminar—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. Prerequisite: consent of instructor.
1-4 units, Aut, Win, Spr, Sum (McCluskey, E)

EE 386. Robust System Design—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-recovery, and self-repair; case studies and new research problems. Prerequisites: 108A,B, 282.
3 units, Spr (Mitra, S)

EE 387. Error-Correcting Codes—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, Fire codes, BCH codes, Reed-Solomon codes. Decoding algorithms for BCH and Reed-Solomon codes. Prerequisites: elementary probability, linear algebra.

3 units, Spr (Gill III, J)

EE 390. Special Studies or Projects in Electrical Engineering—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.

1-15 units, Aut, Win, Spr, Sum (Staff)

EE 391. Special Studies and Reports in Electrical Engineering—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.

1-15 units, Aut, Win, Spr, Sum (Staff)

EE 392B. Introduction to Imaging Sensors—Design and analysis: silicon photodetectors; CCD and CMOS passive and active sensor operation; noise and FPN analysis; spatial resolution and MTF; SNR and dynamic range; high dynamic range architectures; A/D conversion approaches. Analysis of the signal path in a digital camera starting from the optics, through the sensor, the A/D converter, to the different color processing steps. MATLAB camera simulator is used to explore various tradeoffs in camera design. Prerequisites: undergraduate level device, circuit, and system background equivalent to 102A, 101A,B; and familiarity with noise analysis.

3 units, alternate years, not given this year

EE 392D. Channel Coding: Techniques, Analysis and Design Principles—Coding techniques, performance analysis, and design principles for approaching the Shannon limit of additive white Gaussian noise channels. Small signal constellations. Hard- and soft-decision decoding. Binary linear block codes; Reed-Muller codes. Finite fields. Reed-Solomon and BCH codes. Binary linear convolutional codes; the Viterbi and BCJR algorithms. Trellis representations of binary linear block codes; trellis-based ML decoding. Codes on graphs. Sum- and max-product decoding algorithms. Turbo, LDPC, and RA codes. Coding for the bandwidth-limited regime. Lattice codes. Trellis-coded modulation. Multilevel coding. Shaping. Prerequisite: 379A.

3 units, Win (Forney, G)

EE 392E. Probabilistic Error Control Codes—Block, convolutional, and trellis codes. Error models: random and burst errors. Turbo, low density parity-check, product, digital fountain, and raptor codes. Final project requires software implementation and performance analysis of actual codes. Prerequisites: 278, C, and MATLAB. Recommended: 379B, 387.

3 units, not given this year

EE 392F. Logic Synthesis of VLSI Circuits—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 sequencial functions and networks (retiming), semicustom libraries, and library binding. Prerequisites: familiarity with logic design, algorithm development, and programming.

3 units, Win (Vishnu, M)

EE 392J. Digital Video Processing—Spatio-temporal sampling, motion analysis, parametric motion models, motion-compensated filtering, and video processing operations including noise reduction, restoration, super-resolution, deinterlacing and video sampling structure conversion, and compression (frame-based and object-based methods). Video segmentation and layered video representations, video streaming, compressed-domain video processing, and digital TV. Prerequisite: 368.

3 units, alternate years, not given this year

EE 392R. Charged Particle Optics—Electron optics of charged particle instruments including transmission electron microscope, scanning electron microscope and related tools, mass and energy spectrometers, electron beam lithography tools, focused ion beam systems, electron diffraction, proximal probe tools such as the scanning tunneling microscope. Topics include sources, first-order focusing of electrons and ions, third-order aberrations, space-charge effects and diffraction. Goal is to compute the optical parameters of axially-symmetric magnetic and electric lenses and to be familiar with the principles of operation of the above charged-particle systems and the factors limiting their performance. Prerequisites: undergraduate geometrical optics and vector calculus or 217.

3 units, alternate years, not given this year

EE 392S. Sensor Networks Seminar—Silicon-based sensors, local computation, and the emerging technology of low power, ad hoc radio networks as enablers of networked sensing systems. Integration issues, information theory, and networking concerns suggest capabilities for smart sensing network nodes and system trade-offs. Human factors and practical considerations for widespread, consumer adoption of smart sensing networks. Future applications and barriers to adoption. Speakers from industry and academia.

1 unit, not given this year

EE 392T. Seminar in Chip Test and Debug—Seminars by industry professionals in the area of digital IC manufacturing test and silicon debug. Topics covered will include yield and binsplit modeling, defect types and detection, debug hardware, physical analysis, and design for test/debug circuits. Case studies of real silicon failures will be discussed. Prerequisite: Basic understanding of digital IC design (271 or 371).

1 unit, Aut (Stinson, J)

EE 392W. Wireless Sensor Networks: Concepts and Implementation—Hands-on experience with existing systems and application development work. The collection of development and testing platforms at the Wireless Sensor Networks Lab available to facilitate access to algorithm implementation and analysis efforts.

3 units, not given this year

EE 395. Electrical Engineering Instruction: Practice Teaching—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.

1-15 units, Aut, Win, Spr (Gray, R)

EE 398. Image and Video Compression—Condensed version of 398A,B sequence. The principles of source coding for the efficient storage and transmission of still and moving images. Discrete cosine transform. Wavelet image coding. Interframe coding. Motion compensation and motion estimation. Emphasis is on rate distortion analysis and optimization of image and video coding schemes. Standards: JPEG, JPEG-2000, MPEG-1, MPEG-2, MPEG-4, H.261, H.263, H.264. Students investigate image and video compression algorithms in Matlab or C. Prerequisites: 261, 278.

3 units, alternate years, not given this year

EE 398A. Image Communication I—First of two-course series. Principles and systems for digital image communication, emphasizing source coding for efficient storage and transmission of still and moving images. Fundamentals and still image communication techniques. Lossless coding principles. Arithmetic coding, run-length coding. Facsimile coding. Lossy compression principles, scalar quantization, vector quantization. Lossless and lossy predictive coding. Transform coding. Multiresolution coding, subband coding, and wavelets. EZW and SPIHT coding. Embedded image representations. Standards: ITU-T T.4, T.6, JBIG, JPEG, JPEG-2000. Students investigate image compression algorithms in Matlab. Prerequisites: 261, 278.

3 units, Win (Girod, B), alternate years, not given next year

EE 398B. Image Communication II—Second of two-course series. Digital video communication techniques. DPCM. Interframe coding. Motion-compensated prediction. Motion-compensated hybrid coding. Motion estimation. Rate distortion analysis and optimization of video coding schemes. Advanced motion compensation techiques. Scalable layered video representations. Error-resilient video coding. Applications: videotelephony, videoconferencing, digital TV broadcasting, Internet video streaming, wireless video. Standards: MPEG-1, MPEG-2, MPEG-4, ITU-T H.261, H.263, H264. Students investigate video compression algorithms in Matlab or C. Term project. Prerequisite: 398A.
3 units, Spr (Girod, B), alternate years, not given next year

EE 400. Thesis and Thesis Research—Limited to candidates for the degree of Engineer or Ph.D.
1-15 units, Aut, Win, Spr, Sum (Staff)

EE 402A. Topics in International Technology Management—Theme for 2006-07 is IP management for technology businesses in Asia. Challenges and solutions to patenting, copyright, trademarks, standards in high-growth markets. Employee turnover issues, IP-based business models. Guest speakers from industry and government. May be repeated for credit.
1 unit, Aut (Dasher, R)

EE 402S. Topics in International Advanced Technology Research—Theme for 2006-07 is advanced technologies for biomedical applications. Photonic and electronic systems and components for imaging, micro-arrays, drug delivery, artificial organs, and robot-assisted surgery. Guest speakers from industry, government, and universities. May be repeated for credit. Recommended: basic electronics.
1 unit, Spr (Dasher, R)

EE 402T. Entrepreneurship in Asian High Tech Industries—Entrepreneurship in Asian high tech industries. Patterns and challenges of entrepreneurship in Asia. Business and technology issues in start-up companies in Asian economies. Guest speakers from industry, government, and universities. May be repeated for credit.
1 unit, Spr (Dasher, R)

EE 410. Integrated Circuit Fabrication Laboratory—Fabrication, simulation, and testing of a highly simplified 1.5 micron CMOS process developed for this course. Practical aspects of IC fabrication including silicon wafer cleaning, photolithography, etching, oxidation, diffusion, ion implantation, chemical vapor deposition, physical sputtering, and wafer testing. Students perform simulations of the CMOS process using process simulator TSUPREM4 of the structures and electrical parameters that should result from the process flow in the lab. Taught in the Stanford Nanofabrication Facility (SNF) in the Center for Integrated Systems (CIS). Preference to students pursuing doctoral research program requiring SNF facilities. Enrollment limited to 20. Prerequisites: 212, 216, consent of instructor.
3-4 units, Win (Saraswat, K)

EE 414. Design of Discrete RF Circuits for Communications Systems—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: 314, 344.
3 units, Spr (Lee, T)

EE 418. Topics in Neuroengineering—Neuroscience and electrical engineering, focusing on principles and theory in modern neural prosthetic systems (brain-computer or brain-machine interfaces). Electrical properties of neurons, information encoding, neural measurement techiques and technology, processing electronics, information decoding and estimators, and statistical data analysis. Prerequisites: 214, 278.
3 units, Win (Shenoy, K)

EE 453. Geomagnetically Trapped Radiation—Research on the radiation belts of Earth and other planets. Physical processes which lead to magnetic trapping of electrons and ions. Analytical tools for trapped radiation research. The nature of radiation belts, source and loss mechanisms, and the relation of radiation belts to other geophysical phenomena.
3 units, not given this year

EE 469B. RF Pulse Design for Magnetic Resonance Imaging—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.
3 units, Aut (Pauly, J), alternate years, not given next year

EE 477. Universal Schemes in Information Theory—Universal schemes for lossless and lossy compression, channel coding and decoding, prediction, denoising, and filtering. Characterization of performance limitations in the stochastic settting: entropy rate, rate-distortion function, channel capacity, Bayes envelope for prediction, denoising, and filtering. Lempel-Ziv lossless compression, and Lempel-Ziv based schemes for lossy compression, channel coding, prediction, and filtering. Discrete universal denoising. Compression-based approach to denoising. The compound decision problem. Prerequisites: 278, 376A,B.
3 units, not given this year

EE 478. Topics in Multiple User Information Theory—Topics in multiple user source and channel coding; multiple access channel, correlated source coding, broadcast channel, interference channel, relay channel, and channels with feedback; asymptotic capacity of networks; source coding with side information, multiple descriptions, channels with state, MIMO channels. Prerequisite: 376A.
3 units, Aut (El Gamal, A), alternate years, not given next year

EE 479. Multiuser Digital Transmission Systems—Multiuser communications design, modulation, and reception. Capacity regions and fundamentally optimum designs for multiple access, broadcast, and interference channels. Iterative waterfilling, vectoring, and multi-user generalized decision feedback equalization (GDFE) as used for vector broadcast and multiple access. Prerequisite: 379C.
3 units, alternate years, not given this year

EE 487. Communication SoC Design—Design and implementation of communication systems-on-a-chip (SoC) using state-of-the-art integrated circuit technology. The choice of architecture for applications and its impact on performance, area, and energy efficiencies. Related topics such as digital communication, modeling of analog subsystems and their impairments, and the incorporation of flexibility into the design. Wireless system design used as the application because it provides a concrete realization of issues in an SoC design. Prerequisites: 264 or 265, 271.
3 units, alternate years, not given this year

EE 492M. Space-Time Wireless Communications—For EE graduate students and wireless systems engineers. Space-time (ST) wireless communications offer performance improvements in capacity, coverage, and quality. Aspects of ST technology are already part of 2.5G/3G systems. More advanced aspects (MIMO) are being incorporated into several standards. Prerequisites: 276, 278, 279. Recommended: 359.
3 units, alternate years, not given this year

COGNATE COURSES

Courses approved to fulfill EE program requirements at the level of 300-499 EE courses are listed below according to the M.S. depth areas or as "Other." See respective department listings for course descriptions.

COMPUTER HARDWARE

CS 315A. Parallel Computer Architecture and Programming
3 units, Win (Olukotun, O)

COMPUTER SOFTWARE SYSTEMS

CS 243. Advanced Compiling Techniques
3-4 units, Win (Lam, M)

CS 245. Database Systems Principles
3 units, Win (Staff)

CS 343. Advanced Topics in Compilers
3 units, Spr (Lam, M)

CS 348A. Computer Graphics: Geometric Modeling
3-4 units, Aut (Guibas, L)

CS 348B. Computer Graphics: Image Synthesis Techniques
3-4 units, Spr (Hanrahan, P)

DYNAMIC SYSTEMS AND OPTIMIZATION

MS&E 339. Approximate Dynamic Programming
3 units, not given this year

MS&E 351. Dynamic Programming and Stochastic Control
3 units, Spr (Veinott, A)

ELECTRONIC DEVICES, SENSORS, AND TECHNOLOGY

ENGR 341. Micro/Nano Systems Design and Fabrication
3-5 units, Spr (Solgaard, O; Pruitt,B)

ME 342B. MEMS Laboratory II
3-4 units, Sum (Pruitt, B)

IMAGE SYSTEMS

CS 348A. Computer Graphics: Geometric Modeling
3-4 units, Aut (Guibas, L)

CS 348B. Computer Graphics: Image Synthesis Techniques
3-4 units, Spr (Hanrahan, P)

PSYCH 221. Applied Vision and Image Systems
1-3 units, Win (Wandell, B)

LASERS, OPTOELECTRONICS, AND QUANTUM ELECTRONICS

APPPHYS 304. Lasers Laboratory
3 units, Win (Byer, R)

APPPHYS 305. Nonlinear Optics Laboratory
3 units, Spr (Byer, R)

NETWORK SYSTEMS

CS 344. Projects in Computer Networks
3 units, Spr (McKeown, N)

MS&E 336. Topics in Game Theory with Engineering Applications
3 units, Spr (Johari, R)

SIGNAL PROCESSING

MUSIC 420. Signal Processing Methods in Musical Acoustics
3-4 units, Win (Smith, J)

MUSIC 421. Audio Applications of the Fast Fourier Transform (FFT)
3-4 units, Spr (Smith, J)

MUSIC 422. Perceptual Audio Coding
3 units, Win (Bosi-Goldberg, M)

OTHER

APPPHYS 387. Quantum Optics and Measurements
3 units, alternate years, not given this year

APPPHYS 388. Mesoscopic Physics and Nanostructures
3 units, alternate years, not given this year

CS 346. Database System Implementation
3-5 units, Spr (Widom, J)

CS 347. Transaction Processing and Distributed Databases
3 units, Spr (Staff)

CS 528. Broad Area Colloquium for Artificial Intelligence, Geometry, Graphics, Robotics, and Vision
1 unit, Aut, Spr (Batzoglou, S)

GEOPHYS 265. Imaging Radar and Applications
3 units, Win (Zebker, H)

MATSCI 316. Nanoscale Science, Engineering, and Technology
3 units, Win (Cui, Y; McGehee, M)

MATSCI 343. Organic Semiconductors for Electronics and Photonics
3 units, Spr (McGehee, M)

MS&E 338. Advanced Topics in Information Science and Technology
3 units, not given this year

RAD 226. In Vivo Magnetic Resonance Spectroscopy and Imaging
3 units, Win (Staff)

OVERSEAS STUDIES

Courses approved for the Electrical Engineering major and taught overseas can be found in the "Overseas Studies" section of this bulletin, or in the Overseas Studies office, 126 Sweet Hall.

KYOTO

EE 101B. Circuits II
4 units, Spr (Shenoy, K)

EE 108B. Digital Systems II
4 units, Spr (Olukotun, O)