ELECTRICAL ENGINEERING

Emeriti: (Professors) James B. Angell,* Calyton W. Bates, Ronald N. Bracewell,* Marvin Chodorow, Von R. Eshleman,* Michael J. Flynn,* Gene F. Franklin,* Joseph W. Goodman, Robert A. Helliwell,* Martin E. Hellman, Thomas Kailath,* Gordon S. Kino,* Donald E. Knuth,* John G. Linvill, Albert Macovski,* Laurence A. Manning, John McCarthy, Malcolm M. McWhorter, James D. Meindl, Richard H. Pantell,* William R. Rambo, Anthony E. Siegman, William E. Spicer,* David F. Tuttle, Alan T. Waterman, Robert L. White; *(Professors, Research)* Donald L. Carpenter,* Aldo da Rosa,* C. Robert Helms, H. Taylor Howard,* William R. Kincheloe, Jr., Ingolf Lindau,* David Luckham*

Chair: Bruce A. Wooley

Vice Chair: Robert M. Gray

Associate Chairs (Admissions): R. Fabian Pease, Dwight G. Nishimura

Assistant Chair: Sharon A. Gerlach

Professors: Stephen P. Boyd, John M. Cioffi, Thomas M. Cover, Donald C. Cox, William J. Dally, Giovanni De Micheli, 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, Umran S. Inan, Edward J. McCluskey, Teresa H. Y. Meng, David A. B. Miller, Brad G. Osgood, R. Fabian W. Pease, James D. Plummer, Krishna Saraswat, Fouad A. Tobagi, G. Leonard Tyler, Bernard Widrow, S. Simon Wong, Bruce A. Wooley, Yoshihisa Yamamoto

Associate Professors: Nicholas Bambos, John T. Gill III, Gregory T. A. Kovacs, Thomas H. Lee, Marc S. Levoy, Bruce B. Lusignan, Dwight G. Nishimura, Oyekunle Olukotun, Shan X. Wang, Jennifer Widom, Howard A. Zebker

Assistant Professors: Mary G. Baker, Dan Boneh, Dawson Engler, Shanhui Fan, Andrea J. Goldsmith, Nicholas McKeown, Balaji Prabhakar, Krishna V. Shenoy, Olav Solgaard, Benjamin VanRoy

Professors (Research): Antony Fraser-Smith, James F. Gibbons, Leonid Kazovsky, Butrus T. Khuri-Yakub, Arogyaswami J. Paulraj, Piero A. Pianetta, Calvin F. Quate

Courtesy Professors: Malcolm R. Beasley, John Bravman, David Cheriton, David L. Dill, Gary Glover, Gene Golub, Monica S. Lam, David G. Luenberger, Richard Olshen, Norbert Pelc, Vaughan R. Pratt, Jeffrey Ullman, Brian Wandell

Courtesy Associate Professors: Per Enge, David Heeger, Sandy Napel, Mendel Rosenblum, Julius Smith, Daniel Spielman

Courtesy Assistant Professors: Stacey Bent, Armando Fox, Sanjay Lall, Hari Manoharan, Claire Tomlin

Courtesy Professor (Teaching): Gilbert Masters

Courtesy Associate Professor (Research): Peter Fitzgerald

Courtesy Assistant Professor (Research): Ramin Shahidi

Acting Assistant Professor: Glen Solomon

Lecturers: Dennis Allison, Matthew W. Ashcraft, Tom Fountain, John Wharton

Consulting Professors: Carl Berglund, Elizabeth Cohen, Bruce Deal, Abbas Emami-Naeini, Michael Godfrey, Timothy Groves, Sam Haddad, Kiyoo Itoh, Theodore Kamins, Else Kooi, John Koza, David Leeson, Michael Marhic, Mark McCord, Dan Meisburger, Roger D. Melen, Madihally Narasimha, Yoshio Nishi, Kurt Petersen, Richard Reis, S. Venkat Shastri, Arden Sher, James Spilker, Jr., David Stork, John Wakerly, Martin Walt

Consulting Associate Professors: Richard Dasher, Timothy Drabik, Judy Hoyt, Mustafa Karaman, Yi-Ching Pao, Nirmal Saxena, Noel Thompson

Consulting Assistant Professors: John Apostolopoulos, Ahmed Bahai, David Burns, Santiago Fernandez-Gomez, Mikael Johansson, My T. Le, Nadim Maluf, Steven Minne, Mehrdad Moslehi, M. Allen Northrup, Eckehard Steinbach, David Su, Susie Wee, Andrew Wolfe, Patrick Yue

Visiting Professors: Jacob Abraham, Vladimir Yakovlevich Chour, Byoung Yoon Kim, Israel Koren, Jae-Chon Lee, Wayne Wolf

Visiting Associate Professors: Hiroaki Kobayashi, Jeong-A Lee, Thomas Strohmer, Chee Sun Won

Visiting Assistant Professors: Luca Benini

Teaching Fellows: Paul Hartke, Rikardur S. Rikardsson

* recalled to active duty

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, Electronics, Fields and Waves, and Communication and Signal Processing.
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, post-graduate study, or life-long 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), undergraduate students should follow the depth sequence given in the discussion of undergraduate programs in the "School of Engineering" section of this bulletin.

Majors must receive at least a 2.0 grade point average (GPA) in courses taken for the EE depth requirement.

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 the "School of Engineering" coterminal section of this bulletin.

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 relation 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-year program of graduate study in electrical engineering may lead to the degree of Master of Science. A two-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 three years (nine quarters) 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) can be completed electronically at http://www.stanford.edu/dept/registrar/admissions/applyinfo.html#electronic, or a printed application may be obtained by writing to Graduate Admissions, the Registrar's Office, Old Union, Stanford, CA 94305-3005 or by calling (650) 723-4291. Applications are submitted to and reviewed by the Department of Electrical Engineering, Graduate Admissions Office, 350 Serra Mall, Stanford University, Stanford, CA 94305-9505. Applications for full-time study are considered for the Autumn Quarter only. The application deadline is December 15.

Applicants who have not yet earned the equivalent of an M.S. degree should apply for admission to study first toward the master's degree, indicating any intention of later working toward a more advanced degree. Admission for either the Engineer or Ph.D. degree is normally available only to students who have completed a master's degree. In addition, candidacy to the Engineer or Ph.D. degree also requires that the department's Committee on Graduate Admissions identify a tentative faculty research supervisor.

MASTER OF SCIENCE

Modern electrical engineering is a broad and diverse field, and graduate education in this department may satisfy a variety of objectives. 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 will ordinarily be able to complete the master's degree in one calendar year. 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/ee/GradHandbook/html/GradHandbook.html).

Programs of at least 45 quarter units that meet the following guidelines are normally approved:

1. A sequence of three or more 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 EE course numbered above 200 in each of three additional course areas, outside of the area selected under item 1 to provide breadth.
3. Enough additional units of electrical engineering courses so that items 1 through 3 total at least 21 units of 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.
4. Additional course work to bring the total to 45 or more quarter units, including:
   a) At least 36 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 among these 30 units.
5. The EE 201A seminar in Autumn Quarter and either (a) at least one formal seminar course for credit, or (b) attend a minimum of eight informal or formal 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 all students sample the many available research seminars. In case of conflict with EE 201A, tapes may be viewed in the 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 his or her 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 electrical engineering demands that students be adequately prepared in circuits, digital systems, electronics, fields, lab work, mathematics, and physics. Skill in using modern computing facilities is essential for electrical engineers, and an increasing number of our 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 should contain more than the typical 45 units, and the time required to meet the degree requirements may be increased.

Permission to study beyond the M.S. degree must be obtained from the department (if possible, well before the M.S. degree is received). The student needs to file a Graduate Program Authorization Petition. Permission is predicated on the applicant's academic record, performance in independent work, potential for advanced study, and on the ability of the faculty to supervise such study. For the most recent information, see http://ee.stanford.edu/ee/GradHandbook/html/ms.html.

M.S. PROGRAM IN ELECTRICAL ENGINEERING (EE) AND MANAGEMENT SCIENCE AND ENGINEERING (MS&E)

Admission—For the dual degree, admission to both departments is required, but is coordinated by designated members of both Admissions Committees who make recommendations to the committees of their respective departments.

Advising—Every student in the dual degree program has one adviser in EE, and one in MS&E. In addition, a committee consisting of designated faculty from both departments serves as a review committee on performance and as an overseeing body of ongoing and graduating students of the program. The committee, consisting of designated members of both Admission Committees as described in the previous section, may initially serve as this overseeing body.

The Dual Degree Program—This dual-degree program enables a small, selective set of graduate students to obtain both the MS&E master's degree and the EE master's degree simultaneously. Students complete the course requirements for each department. However, the total number of units required to complete the dual-degree is 72 (versus 90 if the two degrees were pursued separately), and the total number of full-time quarter residency equivalents required to complete the dual degree is six (students with a 50 percent teaching or research assistantship, who average 9 units per quarter, earn .62 of a full quarter of residence).

ENGINEER

The degree of Engineer requires a minimum of two academic years (90 quarter units) of study beyond the B.S. degree (three academic quarters beyond the M.S.) including six full-time quarters of approved work as a graduate student, of which a minimum of three quarters and 36 quarter units must be in residence at Stanford.

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/ee/GradHandbook/html/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 Electrical Engineering 391, Special Studies, is recommended as a means for getting acquainted with a faculty member who might be willing to serve as a supervisor.

Not later than the first Autumn Quarter after receiving the M.S. degree, the applicant should submit an application to take the department qualifying examination (given each Winter Quarter). Upon successful 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. 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 successfully (1) a minimum of three years of residence with graduate standing, two years of which must be in residence at Stanford; (2) one or more qualifying examinations given by the faculty of the Department of Electrical Engineering; (3) an approved program of courses in electrical engineering and allied subjects; (4) an approved topic 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.

About one-fourth of the program of graduate study should be in departments other than Electrical Engineering. Courses shall be selected to form an integrated program, to be approved by the department. A student wishing to fulfill the requirements for a formal minor may elect to do so. For the most recent information, see http://ee.stanford.edu/ee/GradHandbook/html/phd.html.

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 annually awards a limited number of fellowships, teaching assistantships, and research assistantships to incoming graduate students. The fellowships are usually awarded only to first-year graduate students in the EE Master of Science program. Most awards to Engineer and Ph.D. candidates are research assistantships, which are awarded by individual faculty research supervisors working in conjunction with the department Committee on Graduate Admissions. Research assistants are often able to write their theses as an integral part of the assistantship. To be considered for department assistance, applicants are only required to submit the admission application materials. Admitted applicants are notified of their status regarding financial assistance in their acceptance letters.

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 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 Communication and Information Theory
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 Algorithms and Architectures
Speech and Image Coding

INTEGRATED CIRCUITS

Analog Integrated Circuits
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
Optoelectronic Integrated Circuits
Process, Device, Circuit, and Equipment Modeling
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
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
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 meets 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 numbered according to the year in which the courses are normally taken.

20- 99 first or second year
100-199 third or 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 Systems Engineering
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
VLSI Design

UNDERGRADUATE

17Q. Stanford Introductory Seminar: From Chips to Genes—Engineering the MicroWorld—Preference to sophomores. Lectures by instructor on the basic material followed by guest speakers from microelectronics, MEMS, and biotechnology. Reading assignments and student reports. Prerequisites: high school physics, know how a light microscope works, and the length of scales (meter, millimeter, micrometer, nanometer).

1-3 units, Win (Pease) alternate years, not given 2002-03

60Q. Stanford Introductory Seminar: Man vs. Nature—Coping with Disasters using Space Technology—(Same as Geophysics 60Q.) Preference to sophomores. Natural hazards (earthquakes, volcanoes, floods, hurricanes, and fires) affect thousands of people everyday. Twenty years of developments in spaceborne imaging technology monitor and respond to such disasters more rapidly than in the past, saving lives and money. Understanding the physical processes involved allows us to anticipate and plan for mitigation of the consequences. Students consider how these new tools are applied to natural disasters, and how remotely-sensed data are manipulated and analyzed.

3 units, Aut (Zebker)

93Q. Stanford Introductory Seminar: Energy Processes—Preference to sophomores. Serves as preparation for 293A,B. Topics in nontraditional energy processes. Students groups of 2 or 3 each select one topic for further investigations. Progress reports, final report. Discussions on the physics and chemistry of the processes, concentrating on a journalistic description of what is being accomplished in each area and the near term prospects. Prerequisite: interest in science and engineering in the energy area.

3 units, Aut (da Rosa)

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. Extensive reports for 2 units. (AU)

1-2 units, Aut (Gray)

101. Introduction to Circuits—Basic results and techniques of circuit analysis, with applications taken from amplifier, computer, and power circuits. Linear and nonlinear elements. Solution of static nonlinear circuits, linearized circuit models, small signal analysis. Matrix formulation of circuit equations, KVL and KCL; computer-aided circuit analysis. Linearity, superposition, Thevenin and Norton equivalents, maximum power transfer. Natural response of RC and RLC circuits. Sinusoidal steady-state response: phasors, impedance, average power flow. AC power, Fourier series. Weekly problem session. Prerequisite: Engineering 40.

3 units, Win (El Gamal)

102. Introduction to Signals and Systems—Laplace transform and application to circuit analysis. Quantitative analysis of linear circuit dynamics via poles. Basic theory of linear time-invariant systems. Transfer functions, convolution, impulse and step response, frequency response, Bode plots. Applications to circuit analysis and design. Prerequisite: 101 or consent of instructor.

3 units, Spr (Boyd)

103. Introduction to Signal Processing—Introduction to analog signal processing, filter synthesis, discrete-time systems, z-transforms, sampling, and quantization. Digital signal processing and filter synthesis. Discrete Fourier Transform and FFT. Prerequisite: 102.

3 units, Aut (Cioffi)

104. Introduction to Communications—Basic introduction to Fourier analysis and its application to communication systems. Overview of current communication systems (cellular, radio, and TV broadcasting, satellites, Internet), Fourier series and Fourier transforms, filtering and signal distortion, time domain and frequency domain analysis, analog modulation (AM and FM), digital modulation, noise in communication systems.

3 units, Win (Goldsmith)

105. Feedback Control Design—(Enroll in Engineering 105.)

106. Planetary Exploration—The other worlds of our solar system as revealed by recent space missions. Comparative properties of the terrestrial and Jovian planets; planetary atmospheres, surfaces, interiors, and rings; planetary and satellite orbits and spacecraft trajectories; properties of the interplanetary gas, dust, comets, and meteorites. What the planets can tell us about potential terrestrial catastrophes (acid rain, ozone depletion, nuclear winter, runaway greenhouse, collision with an asteroid or large comet). Origin and evolution of planetary systems. Remote sensing from spacecraft at radio, infrared, light, and ultraviolet wave lengths. U.S. and Russian space programs and their comparative engineering and scientific aspects. Prerequisite: one year of college engineering, mathematics, or physics.

3 units, Spr (Fraser-Smith)

111. Electronics I—The fundamental operation of semiconductor devices and their circuit applications. The physical principles of semiconductors, emphasizing silicon technology; operating principles and device equations for PN diodes, biasing, small-signal models, and elementary circuit applications of diodes. Prerequisite: Engineering 40. Corequisite: 101.

4 units, Aut (Dutton)

112. Electronics II—Basic operating principles and device equations for MOS capacitors and transistors, and bipolar junction transistors. The basics of transistor amplifier and logic circuit design using MOS transistors. Weekly one-hour recitation session. Prerequisites: 101, 102.

4 units, Win (Shenoy)

113. Electronic Circuits—Bipolar and MOS amplifier design including DC bias, small signal performance, multistage amplifiers, frequency response, feedback. Design and use of operational amplifiers. Prerequisites: 102, 112.

3 units, Aut (Staff)
Spr (Dutton)

118. Introduction to Mechatronics—Introduces the technologies involved in Mechatronics (Intelligent Electro-Mechanical Systems) and the techniques necessary to integrate these technologies into mechatronics systems. Topics: electronics (A/D, D/A converters, op-amps, filters, power devices); software program design (event-driven programming,

state machine based design); hardware and DC stepper motors; basic sensing; basic mechanical design (machine elements and mechanical CAD). Lab component of structured assignments combines with a large and open-ended team project. Limited enrollment. Prerequisite: Engineering 40 and Computer Science 106A.
4 units, Win (Carryer)

121. Digital Design Laboratory—Introduction to digital circuits and logic design. Topics: Boolean algebra, logic circuit electrical characteristics, combinational and sequential logic building blocks, state machines, programmable logic devices, hierarchical logic design, computer-aided design and logic simulation. Lab. Enrollment limit 40. Prerequisite: Engineering 40. Corequisite: Engineering 102E. (WIM)
4 units, Aut (Pease)
Win (Hartke)
Spr (Gill)

122. Analog Laboratory—Introduces the practical applications of analog circuits, including simple amplifiers, filters, oscillators, power supplies, and sensors. Goals: lab experience, basic design skills, experience with computer-aided design, and basic circuit fabrication/debugging knowledge. Prerequisite: Engineering 40 or equivalent.
3 units, Aut, Spr (Kovacs)

133. Analog Communications Design Laboratory—The design and testing of analog communications circuits, including applications. Amplitude modulation (AM) using discrete multiplier circuits and fully integrated implementations. Phase and Frequency Modulation (FM) based on discrete and integrated modulator circuits such as voltage-controlled oscillators (VCOs). Phased-Lock Loop (PLL) techniques, characterization of key parameters and their applications. Lectures on the practical aspects of circuit implementations. Labs involve the systematic building and characterization of AM, FM, and PLL circuits and subsystems. Enrollment limited to 40 undergraduate and coterminal EE students. Prerequisite: 113, 122.
3 units, Win (Dutton)

137. Laboratory Electronics—(Enroll in Applied Physics 207.)

138. Laboratory Electronics—(Enroll in Applied Physics 208.)

140. The Earth from Space: Introduction to Remote Sensing—(Enroll in Geophysics 40.)

141. Engineering Electromagnetics—Transmission lines. Reflection, transmission, attenuation, and dispersion. Standing wave ratio, impedance matching, pulses, and transients. Electrostatics, Gauss' Law, capacitance, divergence, and currents. The static magnetic field, magnetic forces, Ampere's Law, curl, and Faraday's Law. Magnetic materials and devices, inductance, electromechanics, and skin effect. Maxwell's equations. Uniform plane waves, power and energy relations. Prerequisites: 102, Mathematics 52.
4 units, Aut (Inan)

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. Guided waves. TEM waves, hollow wave-guides, cavity resonators, microstrip wave guides, optical fibers. Interaction of fields with matter and particles. Antennas and radiation of electromagnetic energy. Elements of radio transmission systems and radar. Prerequisite: 141 or Physics 120.
3 units, Win (Inan)

144. Wireless Electromagnetic Design Laboratory—Required for undergraduate Fields and Waves specialty area. Lecture, lab, and design project. Hands-on experiments and projects with antennas, transmission lines and propagation for wireless communications and remote sensing. Using spectrum analyzers, 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. Two- to three-person team projects on antenna, guided wave distributed circuits, remote sensing, or related topics. Working model constructed and demonstrated; some funding available for project costs. Prizes for best projects. Lab. Enrollment limited to 30. Prerequisites: 122, 142, or consent of instructor.
3 units, Spr (Leeson)

167. Introductory Computer Graphics—(Enroll in Computer Science 148.)

168. Introduction to Digital Image Processing—Introduction to processing of digital 2-D and 3-D data, combining theoretical material with implementation of computer algorithms. Topics: time and frequency representations of images, filters, image formation and enhancement, imaging systems, and applications. Instructional computer lab exercises implement practical algorithms. Final project consists of computer animations incorporating techniques learned in class. Prerequisites: none, but 104 or other signal processing helpful.
3-4 units, Aut (Zebker)

178. Introduction to 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.
3 units, Win (Gray)

181. Introduction to Computer Systems and Assembly Language Programming—(Enroll in Computer Science 110.)

182. Computer Organization and Design—Computer components: memory systems including caches, computer arithmetic, processors, controllers, input/output, buses, DMA. Data formats, addressing modes, instruction sets, and microcode. Study of the design of a small computer. Prerequisites: Engineering 40, Computer Science 107. Recommended: 121 or equivalent.
4 units, Aut, Spr (Fountain)

183. Advanced Logic Design Laboratory—Experiments in digital logic design using TTL integrated circuits, MSI and LSI registers and ALUs, Programmable Gate Arrays, and PLAs. Choice of projects: various sequential machines, D/A converters and CRT displays, integrators, arithmetic processors, stored program processors, game playing machines. Lab. Enrollment limited to 25; preference to graduating seniors in Spring Quarter. Prerequisites: 121, 182 (may be taken concurrently). Must know basic logic design and have dealt with lab equipment.
3 units, Win (Ashcraft)
Spr (Staff)

184. Programming Paradigms—(Enroll in Computer Science 107.)

189A. Object-Oriented Systems Design—(Enroll in Computer Science 108.)

189B. Software Project—(Enroll in Computer Science 194.)

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.
by arrangement

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.
by arrangement

192. Special Seminars—Special seminars and experimental courses are given on topics of current interest by specialists in the field. Announcements are made one or two quarters prior to presentation. See *Time Schedule* and bulletins in the department office for current listing.
by arrangement

192G. Electronic Dynamic Control Systems Laboratory—Experimental laboratory targeted at developing skills in electronic systems integration involving sensor-based closed-loop control. The demonstration vehicle is the design of an autonomous 1/10 scale electric car capable of maneuvering a track in the fastest lap time. Teams of two or three undergraduates build an entry to the Natcar engineering design competition (http://www.ece.ucdavis.edu/natcar/). Topics: optical and magnetic sensor design, proportional-integral-derivative control, pulse width modulation, servo and DC motor control, and control algorithm implementation with microcontrollers and analog circuitry. Students perform all design and construction independently with guidance from instructors. Prerequisites: Engineering 105, 121, 122.
(Staff)

UNDERGRADUATE AND GRADUATE

201A. Seminar—Weekly discussions of special topics of current interest in electrical engineering. Orientation to Stanford and to the EE department. Students with a conflict may view via videotape in the library. (AU)
1 unit, Aut (Reis)

201B. Seminar—Looks at "Life after Stanford" through a series of presentations primarily directed at MS/EE students. The activities of graduates in industry (large, medium, and small), startup companies, government laboratories, and community colleges. (AU)
1 unit, Win (Reis)

202. Medical Electronics—Open to non-electrical engineering students. Primarily biological in nature. Introduces electrical engineers to the physiological and anatomic aspects of medical monitoring and imaging. Biological content, transducers, electronic systems, the socioeconomic impact, and the constraints unique to medicine. Recommended: some familiarity with circuits and electrical instrumentation techniques (e.g., 113).
3 units, Aut (Thompson)

203. The Entrepreneurial Engineer—Seminar furthers the knowledge base of prospective entrepreneurs with an engineering background. The 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 members and other departments (law, business, and industrial engineering). (AU)
1 unit, Win (Melen)

205. Introduction to Control Design Techniques—(Enroll in Engineering 205.)

206. Control System Design and Simulation—(Enroll in Engineering 206.)

207D. Optimal Control and Hybrid Systems—(Enroll in Aeronautics and Astronautics 278A.)

209A. Analysis and Control of Nonlinear Systems—(Enroll in Engineering 209A.)

209B. Advanced Nonlinear Control—(Enroll in Engineering 209B.)

212. Integrated Circuit Fabrication Processes—For students interested in IC design and the influence of fabrication processes, or intending to pursue doctoral research involving use of Stanford's IC laboratory. Process simulators are used to illustrate concepts and provide a "virtual" lab experience. Topics: the fundamental 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: 112 or equivalent.
3 units, Aut (Plummer)

213. Heat Transfer in Microdevices—(Enroll in Mechanical Engineering 258.)

214. Analog Integrated Circuit Design—Analysis and design of MOS analog integrated circuits, emphasizing quantitative measures of performance, figures of merit, and circuit limitations. Evaluation of circuit performance by means of hand calculations and computer-aided circuit simulations. Design of operational amplifiers, broadband amplifiers, biasing circuits, and voltage references. Feedback amplifier design. Prerequisite: 113.
3 units, Aut (Lee)

216. Principles and Models of Semiconductor Devices—The fundamentals of carrier generation, transport, recombination, and storage in semiconductors. The physical principles of the operation of the p-n junction, metal semiconductor contact, bipolar junction transistor, MOS capacitor, MOS and junction field-effect transistors, and related devices such as CCDs and solar cells. First-order device models that reflect the physical principles and are useful for integrated circuit analysis and design. Prerequisites: 111, 112, or equivalent.
3 units, Aut (J. Harris)

217. Electron and Ion Beams for Semiconductor Processing—Focused and flood beams of electrons and ions are employed for processing semiconductor devices. The generation of such beams including thermionic emission, field-induced emission, first-order focusing, and glow discharge processes. The interactions of such beams with the target, including scattering in solids, the distribution of energy, heating, sputtering, beam-induced etching (including reactive-ion etching) and beam-induced deposition. Introduction to computer modeling of etching and deposition. Prerequisite: 212 or equivalent.
3 units, alternate years, given 2002-03

222. Applied Quantum Mechanics I—Introduction to quantum mechanics, with emphasis on applications in modern devices and systems. Topics: Schrödinger's equation, eigenfunctions and eigenvalues, operator approach to quantum mechanics, solutions of simple problems (including quantum wells, harmonic oscillators, simple periodic structures), tunneling, calculation techniques (including matrix diagonalization, perturbation theory, variational method), time-dependent perturbation theory (including application to optical absorption), fundamental postulates of quantum mechanics. Prerequisites: Physics 65 or 45 and 47 or equivalents; Mathematics 43 or equivalents.
3 units, Aut (Miller)

223. Applied Quantum Mechanics II—Continuation of 222, including more advanced topics: spin and identical particles, effective mass theory for semiconductors, annihilation and creation operators, density matrices, introductory quantum optics, and other topics in electronics, optoelectronics and optics. Prerequisite: 222.
3 units, Win (Miller)

228. Basic Physics for Solid State Electronics—Advanced undergraduate/graduate, introducing the physics underlying modern solid state materials and devices. Topics: the energy band theory of solids, energy bandgap engineering, classical kinetic theory, statistical mechanics,

equilibrium and non-equilibrium semiconductor statistics. Prerequisites: 112, Physics 70 or any course in Modern Physics.
3 units, Aut (Fan)

229B. Thin Film and Interface Microanalysis—(Enroll in Materials Science and Engineering 323.)

229D. Introduction to Magnetism and Magnetic Materials—(Enroll in Materials Science and Engineering 347.)

231. Lasers I—Introduction to lasers and how they 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; uses classical models for atomic transitions with little quantum mechanics background required. Prerequisites: electromagnetic theory to a level of at least 142, preferably 241, and some knowledge of atomic or modern physics such as Physics 57 or 130-131.
3 units, Aut (Feyer)

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, Win (Feyer)

234. Photonics Laboratory—Laboratory on photonics and fiber optics with a focus on communication and sensing. Experimental characterization of semiconductor lasers, optical fibers, photo detectors, receiver circuitry, fiber optic links, optical amplifiers, and optical sensors. Prerequisite: 142 or equivalent.
3 units, Aut, Win (Solgaard)

235. Guided Wave Optical Devices—Introduction to guided-wave optics, optical wave guide devices, and integrated optics. Review of wave propagation in layered media, slab wave guides, and optical fibers. Rectangular wave guides. Optical wave guide technology. Coupled-mode theory. Numerical analysis of complex wave guides. Photonic crystals. Physics and design of wave guide devices. Fiber sensors, wave guide gratings, wave guide modulators, directional couplers, ring filters. Prerequisite: working knowledge of electromagnetic theory to the level of 142 or equivalent.
3 units, Spr (Fan)

238. Electrical and Magnetic Properties of Solids—(Enroll in Materials Science and Engineering 209.)

241. Waves I—Introduction to waves and wave phenomena as they appear in different 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 common to diverse fields of application. 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, Aut (Tyler)

243. Semiconductor Optoelectronic Devices—Introduction to semiconductor optoelectronic devices for communications and other applications, covering operating principles and practical device features. Review of relevant semiconductor physics, and optical processes in semiconductors. Semiconductor heterostructures. Semiconductor 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, lasers (e.g., 222, 228, 231, or equivalents).
3 units, Win (J. Harris)

244. Communication Engineering Transmission Systems—Design of transmission systems for TV, telephone, and data-using satellites; microwave repeaters; mobile radio; and broadcast transmitters. Performance of FM, AM, SSB common digital schemes and spread-spectrum modulation, time, frequency, and code multiplexing. Emphasis is on link performance, capacity, total system design, and cost optimization. Current industry design problems and research results. Examples illustrate modern technologies providing service to rural populations. Prerequisite: senior or graduate standing in Electrical Engineering, or consent of instructor.
3 units, Aut (Lusignan)

245. Wireless Electromagnetic Design Laboratory—See 144.
3 units, Spr (Leeson)

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, wave guide, micro strip), 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 is application-system-component; individual components are modeled by Fields-Modes-Equivalent Network. Prerequisite: 142 or equivalent.
3 units, Aut (Leeson) alternate years, not given 2002-03

247. Introduction to Optical Fiber Communications—Components: optical fibers—step and graded index, multi- and single-mode fibers, attenuation and dispersion. Optical sources and transmitters: LED and laser. Single- and multi-mode lasers. Linewidth, RIN, chirp. Optical detectors and receivers: PIN and APD, quantum efficiency and responsivity, capacitance and bandwidth, integrating front end and transimpedance receivers. Systems: digital systems and bit-error-ratio, analog systems and signal-to-noise ratio. Quantum limit, equalization, noise, and sensitivity. Applications: digital trunking, TDM hierarchy, undersea cables, local area networks, analog links, subcarrier multiplexing, and video distribution. Advanced technologies: wavelength-division-multiplexing, coherent systems, optical amplifiers, semiconductor and fiber amplifiers; solitons. Prerequisites: 113, 142. Corequisite: 278.
3 units, Aut (Marhic)

248. Fundamentals of Noise Processes—Introduction to statistical processes and Fourier analysis: binomial, Gaussian, and Poisson distributions; time averaging vs. ensemble averaging; Parseval and Wiener-Khintchine theorems. Thermal noise and quantum noise: fluctuation-dissipation theorem, Johnson-Nyquist formula, zero-point fluctuation. Noise of junction devices, amplifiers and oscillators: van der Pol oscillator and parametric oscillator. Noise consideration of communication and weak force detection systems. Prerequisites: familiarity with basic device, circuits, and electromagnetism to the level of 111, 142.
3 units, Aut (Yamamoto)

249. Introduction to the Space Environment—Experimentation in the near-earth space environment using radio and other electromagnetic waves, and electric and magnetic instrumentation on space probes. Tools used: transmitters, antennas, receivers, sensors, radars, and displays. The earth's ionosphere, magnetosphere, and interplanetary space. The role of the sun, and the effects produced by changes in solar activity. Geoelectric and geomagnetic fields. Charged particle motion, trapped particles (Van Allen radiation), and the aurora. Applications to current experimental programs. Planning and execution of experiments. Prerequisites:

familiarity with electromagnetics at the level of 142 and senior or graduate standing.

3 units (Fraser-Smith) alternate years, not given 2002-03

251. Progress in Worldwide Telecommunications—(Enroll in Management Science and Engineering 237.)

252. Antennas for Telecommunications and Remote Sensing—Fundamental parameters. 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, alternate years, given 2002-03

254. Principles of Radar Systems—Analysis and design, emphasizing radars as systems. 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 undergraduate or graduate standing.

3 units, Win (Tyler, Zebker) alternate years, not given 2002-03

255. Radar Remote Sensing—(Enroll in Geophysics 265.)

256. Numerical Electromagnetics—The 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 indispersive 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, alternate years, given 2002-03

261. The Fourier Transform and Its Applications—The Fourier transform as a tool for solving physical problems. Fourier transform of discrete and continuous time signals, generalized transforms, and Fourier series. Convolutions and correlations, the Dirac delta function, Fourier transform theorems, measures of time duration and bandwidth, analysis of linear systems, sampling theorems, the discrete Fourier transform, and two-dimensional Fourier analysis. Prerequisite: previous exposure to Fourier series at the level of 102.

3 units, Aut (Nishimura)
Win (Hesselink)

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. Students create software to form images using these techniques using actual data. Prerequisites: 261. Recommended: 278, 279.

3 units, alternate years, given 2002-03

263. Introduction to Linear Dynamical Systems—Introduction to applied 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. Observability and least-squares state estimation. Prerequisite: exposure to basic linear algebra and matrices (as in Mathematics 103); differential equations and Laplace transforms (as in 102).

3 units, Aut (Boyd)

264. Digital Filtering—Introduction to modern digital signal processing techniques. Optimal design procedures for Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters. Theory of quantization noise. Discrete Fourier Transform and its applications. Interpolation and decimation techniques for A/D and D/A conversion. Subband filtering. Prerequisites: 103. Recommended: 261.

3 units, Aut (Widrow)

265. Signal Processing Laboratory—Designed for undergraduate and graduate students, applying 101, 102, 103 to real-world signal processing applications. Lab exercises use a programmable DSP to implement signal processing tasks. Topics: A/D conversion and quantization, filter design and implementation, spectral analysis, audio signal processing, rate conversion, digital data communication. Prerequisite: 103. Recommended: 261, Z-transform, discrete-time Fourier transform, IIR filters, FIR filters, sampling theorem, filter structures.

3 units, Win, Spr (Meng)

268. Introduction to Modern Optics—Geometrical optics: raymatrices, 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) alternate years, not given 2002-03

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: 112; familiarity with circuits, logic design, and digital system organization.

3 units, Aut (Staff)
Spr (Lu)

273. Digital Systems Engineering—Fundamental 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 affect on signaling, and methods for noise reduction; timing conventions; timing noise (skew and jitter), its affect 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: 121 or equivalent, 113 or equivalent.

3 units, Win (Dally)

274. Introduction to Cryptography and Computer Security—(Enroll in Computer Science 255.)

275. Logic Design—(Formerly 381.) Principles and techniques of logic design. Combinational circuit analysis (hazard detection); combinational circuit design including PLA, VLSI, and MSI techniques and testing techniques; IC logic families, flipflop properties, sequential circuit analysis and synthesis for fundamental and pulse mode circuits, design for testability techniques. Prerequisite: 121 or equivalent.

3 units, Aut, Win (McCluskey)

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, 278 or equivalent. Corequisite: 279 or equivalent.
3 units, Spr (Cox)

277. Stochastic Decision Models—(Enroll in Management Science and Engineering 251.)

278. Introduction to Statistical Signal Processing—Random variables, vectors, and processes; time averages, expectations, and laws of large numbers; stationarity, autocorrelation, and spectral analysis; mean square error estimation, detection, and linear filtering; independent increment, Gaussian, and Poisson random processes. Prerequisite: 177 or 178, and linear systems and Fourier transforms at the level of 102 or 261.
3 units, Aut (El Gamal)
Win (Prabhakar)

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: 104 or 261 and 178 or 278.
3 units, Spr (Goldsmith)

281. Embedded System Design Laboratory—Lectures on the architecture and design of microprocessor-based systems. Lab experiments use MicroChip PIC16C74 microcontroller evaluation board. Five-week individual design project. Lab. Prerequisites: 121, and 181 or 182 or equivalent experience in assembly language programming.
3 units, Aut (Gill)

282. Computer Architecture and Organization—The structure of systems using processors, memories, input/output (I/O) devices, and I/O interfaces as building blocks. Computer system instruction set design and implementation, including memory hierarchies and pipelining. Issues and tradeoffs involved in the design of computer system architectures with respect to the design of instruction sets. Prerequisite: 182.
3 units, Aut (Staff)
Spr (Olukoton)

283. Compilers—(Enroll in Computer Science 143.)

284. Introduction to Computer Networks—(Winter Quarter, enroll in Computer Science 244A.) Structure and components of computer networks; functions and services; packet switching; layered architectures; ISO's Open Systems Interconnections (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, IP); transport layer (UDP, TCP); application layer.
3-4 units, Aut (Tobagi)
Win (McKeown)

285. Programming Languages—(Enroll in Computer Science 242.)

286A. Operating Systems and Systems Programming—(Enroll in Computer Science 140.)

286B. Advanced Topics in Operating Systems—(Enroll in Computer Science 240.)

287. Introduction to Computer Graphics—(Enroll in Computer Science 248.)

288. Mathematical Methods for Robotics and Vision—(Enroll in Computer Science 205.)

289. Introduction to Computer Vision—(Enroll in Computer Science 223B.)

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 (Gray)

292. Special Seminars—Special seminars and experimental courses are given on topics of current interest by specialists in the field. Announcements are made one or two quarters prior to presentation. See *Time Schedule* and bulletins in the department office for current listing.
by arrangement

293A. Fundamentals of Energy Processes—For seniors and graduate students. Theory of modern energy conversion, transmission, and storage methods. Windmills. Heat engines: classical engines, ocean thermal energy converters, thermoelectric, thermionic, and radio-noise engines. Prerequisites: Physics 55, Mathematics 43, or equivalent.
3 units, Aut (da Rosa)

293B. Fundamentals of Energy Processes—For seniors and graduate students. Fuel cells. Production of hydrogen: electrolytic, chemical, thermolytic, photolytic. Hydrogen storage: hydrides. Insolation. Photoelectric converters; photo-thermovoltaic converters. Biomass: photosynthesis, production of methane and ethanol from vegetable matter. Prerequisites: Physics 55, Mathematics 43, or equivalent.
3 units, Win (da Rosa)

GRADUATE

300. Master's Thesis and Thesis Research—For students who wish to do independent work under the direction of a department faculty member as part of their master's degree program. Written thesis is required for final letter grade. The continuing grade 'N' is given in quarters prior to the thesis submission. (See 390 if a letter grade is not appropriate.)
by arrangement

310. Integrated Circuits Technology and Design Seminar—In-depth treatment of device structures, fabrication technologies, and circuit design issues in integrated circuits. Introduces current research topics in these areas. (AU)
1 unit, Aut (Lee, Wooley)

311. Advanced Integrated Circuit Fabrication—What are the practical and fundamental limits to the evolution of the technology of modern MOS and bipolar devices? How are modern devices and circuits fabricated and what future changes are likely? Advanced techniques and models of device and back-end (interconnect and contact) processing. Use of SUPREM and PISCES for process modeling. MOS and bipolar process integration. Prerequisites: 212, 216.
3 units, Spr (Saraswat)

312. Solid-State Sensors and Actuators—Surveys solid-state sensors and actuators, focusing on the use of integrated circuit fabrication technology for their realization. Categories of sensors and actuators are biological, chemical, mechanical, optical, thermal, etc. 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.
3 units, Win (Kovacs)

313. Digital MOS Integrated Circuits—Analysis and design of digital MOS integrated circuits. Device and circuit modeling considerations. Circuit performance evaluation by means of simple approximations and computer-aided circuit analysis. Transistor-level design techniques for implementing specific digital circuit functions. Logic and memory subsystem considerations. Adjunct to courses in VLSI architecture and layout. Prerequisite: 112 or equivalent.

3 units, Win (Horowitz)

314. RF Circuit Design—Design of RF integrated circuits for communications systems. Topics: the design of 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 high efficiency (e.g., class E, F) RF power amplifiers, coupling networks. Behavior and modeling of passive and active components at RF. Prerequisite: 214.

3 units, Win (Lee)

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, voltage references, operational amplifiers, gain blocks, and analog 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 (Wooley)

316. Advanced VLSI Devices—In modern VLSI technologies, MOS and bipolar device electrical characteristics are sensitive to structural details and therefore to fabrication techniques. How are VLSI devices and circuits fabricated and what future changes are likely? What are the implications for device electrical performance caused by fabrication techniques? Physical models for submicron structures, control of electrical characteristics (threshold voltage, breakdown voltage, current gain) in small structures, and alternative device structures for VLSI. Prerequisites: 212, 216, or equivalent.

3 units, Win (Saraswat)

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. The use of phase-shifting masks and other wavefront-engineering approaches. Extensive hands-on use of computer simulations of each of the above steps. Prerequisites: 141 or equivalent, 212 or equivalent, basic competence in computing.

3 units, Spr (Pease) alternate years, not given 2002-03

318. Logic Synthesis of VLSI Circuits—Solving logic design problems with CAD tools for VLSI circuits. Analysis and design of exact and heuristic algorithms for logic synthesis. Topics: representation and optimization of combinational logic functions (encoding problems, binary decision diagrams), representation and optimization of multiple-level networks (algebraic and Boolean methods, "don't care" set computation, timing verification, and optimization), modeling and optimization of sequential functions and networks (retiming), semicustom libraries and library binding. Prerequisites: familiarity with logic design, algorithm development, and programming.

3 units, Win (Simimic)

319. Computer-Aided System Design Laboratory—Computer-aided design of VLSI systems: theory and practice. Topics: modeling languages (e.g., Verilog), high-level synthesis and optimization methods (scheduling, binding, data-path, and control synthesis), design of systems with low-power consumption, and hardware/software co-design. Individual/group projects involve the use of CAD tools. Prerequisite: 318.

3 units, Spr (De Micheli)

320. Automatic Formal Verification Techniques—(Enroll in Computer Science 356.)

321. MEMS Design—Theory and practice of MEMS design, micromechanical fundamentals and CAD tools for definition, design, and layout of MEMS. Case studies of successful MEMS engineering projects. Emphasis is on physical understanding and elementary modeling, not numerical simulations. Students complete a MEMS design project: layout, evaluation strategy, and modeling. Prerequisite: 312 or equivalent.

3 units, Spr (Solgaard) alternate years, not given 2002-03

326. Organic Materials for Electronic and Photonic Devices—(Enroll in Materials Science and Engineering 343.)

327. Properties of Semiconductor Materials—Modern semiconductor devices and integrated circuits are based on the unique energy band, carrier transport, and optical properties of semiconductor materials. These physical properties can be chosen and optimized for operation of semiconductor devices. Emphasis is on the 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, alternate years, given 2002-03

328. Physics of Advanced Semiconductor Devices—The principles governing the operation of modern semiconductor devices. Underlying assumptions and approximations commonly made in analyzing devices. Emphasis is on the application of semiconductor physics to the development of advanced semiconductor devices (e.g., heterojunctions, HJ-bipolar transistors, HJ-FETs, nano structures, tunneling, single electron transistor and photonic devices). Use of ATLAS and MEDICI 2-D Poisson solvers for simulation of ultra-small devices. Examples are related to up-to-date device research.

3 units, Spr (Harris) alternate years, not given 2002-03

329. The Electronic Structure of Surfaces and Interfaces—Basic physical concepts and phenomena for surface science techniques probing the electronic structure of surfaces and interfaces. Microscopic and atomic models in understanding microstructures have technologically important applications, e.g., within semiconductor device technology and catalysis. The basic 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: 238 or consent of instructor; Physics 70 or equivalent.

3 units, alternate years, given 2002-03

335. Introduction to Information Storage Systems—Introduction to data storage technology from a system perspective. Discussions of magnetic disk recording: read and write processes, nonlinearities, inductive and magnetoresistive heads, thin film and particular media, noises, signal-to-noise ratio, error rate, RLL codes, error detection and correction, partial response and maximum likelihood (PRML) detection channel, servo, off-track performance, superparamagnetic effect. Introduction to alternative information storage technologies: CD-ROM, DVD, magneto-optic recording, holographic recording, flash memory, and magnetic RAM. Introduction to storage networks. Recommended: basic electromagnetism, binary algebra, probability, and Fourier transform.

3 units, Win (Wang)

338A. Quantum Optics and Measurements—(Enroll in Applied Physics 387.)

338B. Mesoscopic Physics and Nanostructures—(Enroll in Applied Physics 388.)

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, Spr (Miller) not given 2002-03

344. High Frequency Laboratory—Combination lecture/lab emphasizing the lab. Techniques in the 1MHz-1GHz range useful in designing and measuring oscillators, amplifiers, and mixers. Basic high frequency measurement techniques including s-parameter measurements, Amplifier Noise Figure; and oscillator phase noise. Lectures by the professor and experts from Lucent and Hewlett-Packard. (Two lectures, one lab weekly.) Enrollment limited to 20. Prerequisites: good understanding of transmission lines, Smith charts.

3 units, Aut (Cox)

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 (S. Harris)

347. Optical Methods in Engineering Science—The 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 is used for demonstrations and as a design tool. Prerequisite: 268 or 366, or equivalent.

3 units, Spr (Hesselink) alternate years, not given 2002-03

349. Advanced Modern Optics—Holography (basic principles, Bragg holography); photorefractive effect (physical principles and applications); wave matter interactions (polarization effects); vigorous coupled wave analysis. Prerequisite: 268 or 366, or equivalent.

3 units, alternate years, given 2002-03

350. Radioscience Seminar—Seminars by university and industrial researchers on 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. Student-faculty discussions. (AU)

1 unit, Aut (Zebker)
Win (Inan)
Spr (Fraser-Smith)

351. Digital Switching in Telecommunications—Switching fundamentals; space and time division switching; blocking probability analysis; rearrangeable networks; self-routing networks; ATM switching architectures; performance evaluation of ATM switches; network synchronization and signaling methods. Prerequisite: 374 or basic knowledge of telecom systems.

3 units, Spr (Narasimha)

352. Electromagnetic Waves in the Ionosphere and Magnetosphere—Magneto-ionic theory in multi-component media, signal dispersion, group ray velocity, wave polarization, refractive index surfaces, ray tracing, absorption, boundary effects, interpretation of natural phenomena (whistlers, VLF emissions), remote sensing in plasmas, communication, theory of wave-particle interactions in the magnetosphere. Prerequisite: 142 or equivalent.

3 units, alternate years, given 2002-03

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. Electromagnetic theory through standard graduate engineering topics. Partial differential equations, boundary value problems in rectangular and spherical coordinates. Prerequisites: 241 or equivalent, and partial differential equations, or consent of instructor.

3 units, alternate years, given 2002-03

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. Prerequisites: 254, 261. Recommended: 264, 278, 279.

3 units, alternate years, given 2002-03

356. Elementary Plasma Physics: Principles and Applications—Plasmas in nature and industry. Basic plasma characteristics. 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 cold plasmas. Waves in magnetized plasmas. Waves in warm plasmas. Electron and ion waves. MHD waves. Waves in hot plasmas. Landau damping. Nonlinear effects. Applications in industry and space science. Prerequisite: 142 or Physics 122.

3 units, Spr (Inan) alternate years, not given 2002-03

358A. Lasers Laboratory—(Enroll in Applied Physics 304.)

358B. Nonlinear Optics Laboratory—(Enroll in Applied Physics 305.)

359. Wireless Communication—Performance of digital modulation in fading and intersymbol interference; capacity of wireless channels, flat fading countermeasures (diversity, coding, and interleaving, adaptive modulation); multiple antenna systems; intersymbol interference countermeasures; equalization, multicarrier modulation, spread spectrum and RAKE receivers; multiple access and cellular systems.

3 units, Aut (Goldsmith)

360. Advanced Topics in Wireless Communications—Current research areas in wireless communications: new theoretical developments, system design issues, and implementation constraints. Possible topics: adaptive modulation and coding, OFDM, spread spectrum, multicarrier spread spectrum, smart antennas, multiuser detection, cellular system design, dynamic resource allocation, handoff and mobility management, access and channel assignment, system capacity, packet radio networks. Focus is on multiple access, cellular system design, and ad-hoc wireless networks. Prerequisites: 276, 359.

3 units, alternate years, given 2002-03

361A. Modern Control Design I—(Enroll in Engineering 207A.)

361B. Modern Control Design II—(Enroll in Engineering 207B.)

362. Applied Vision and Image Systems—(Enroll in Psychology 221.)

363. Linear Dynamic Systems—Continuation of 263. Optimal control and dynamic programming; linear quadratic regulator. More on Lyapunov theory and methods. Time-varying and periodic systems. Realization theory. Linear estimation and the Kalman filter. Examples and applications from digital filters, circuits, signal processing, and control systems. Prerequisites: 263 or equivalent, basic probability as in Statistics 116 or 278.
3 units, Win (Boyd) alternate years, not given 2002-03

364. Convex Optimization with Engineering Applications—Recognizing and solving convex optimization problems that arise in engineering. Convex sets, functions, and optimization problems. The basics of convex analysis and theory of convex programming: optimality conditions, duality theory, theorems of alternative, and applications. Least-squares, linear and quadratic programs, semidefinite programming, geometric programming, extremal volume, etc. Numerical algorithms for smooth unconstrained problems; interior-point and ellipsoid methods for constrained problems. Applications to signal processing, communications, control, analog and digital circuit design, computational geometry, statistics and mechanical engineering. Prerequisites: working knowledge of linear algebra (e.g., from 263), background in applications, and willingness to program in Matlab.
3 units, alternate years, given 2002-03

365. Vision and Image Processing—(Enroll in Psychology 267.)

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, given 2002-03

367A. Applications of the Fast Fourier Transform (FFT) in Digital Audio Signal Processing—(Enroll in Music 420.)

367B. Signal Processing Methods in Musical Acoustics—(Enroll in Music 421.)

367C. Perceptual Audio Coding—(Enroll in Music 422.)

368. Digital Image Processing—Topics: image acquisition and display, properties of the human visual system, color representations, sampling and quantization, point operations, linear image filtering and correlation, transforms and subband decompositions, nonlinear filtering, contrast and color enhancement, dithering and image restoration, image registration, and simple feature extraction and recognition tasks. Emphasis is on the general principles of image processing. Students write and investigate image processing algorithms in Matlab. Prerequisites: 261, 278.
3 units, Spr (Girod)

369A. Medical Imaging Systems I—Imaging internal structures within the body using high-energy radiation studied from a systems viewpoint. Modalities covered: x-ray, computerized tomography, and nuclear medicine. Analysis of existing and proposed systems in terms of resolution, modulation transfer function, detection sensitivity, noise, and potential for improved diagnosis. Prerequisite: 261.
3 units, Win (Nishimura) alternate years, not given 2002-03

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)

371. Advanced VLSI Circuit Design—Overview of important issues in high performance digital VLSI design. Focus is from a system perspective (a fast processor, DSP, etc.), CMOS, circuits. 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, 313, or consent of instructor. Recommended: knowledge of C and C-shells.
3 units, Spr (Horowitz)

372. Quantization and Data Compression—The theory and design of codes for quantization and signal compression systems (source coding systems), systems which convert analog or high bit rate digital signals to low bit rate signals while optimizing fidelity, subject to available communication and storage capacity. The theoretical and practical tradeoffs among bit rate, fidelity, and complexity in codes for quantization and compression. Topics: scalar quantization (PCM), transform and predictive codes, lossless (entropy) codes, vector quantizers designed using clustering and decision tree design algorithms, Bayes optimal prediction and classification, Shannon distortion-rate theory, and high rate (asymptotic) quantization theory. Prerequisites: 261, 278.
3 units (Gray) alternate years, given 2002-03

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. Prerequisites: 263, 264.
3 units, Win (Widrow)

373B. Adaptive Neural Networks—Adaptive threshold elements, feedforward layered networks, Madaline rules, back propagation, 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. Prerequisite: 373A.
3 units, Spr (Widrow)

374. Digital Transmission Systems in Telecommunications—Voice digitization: PCM, ADPCM, and LPC coding techniques. CELP speech coding in packet and cellular telephony. Time division multiplexing: synchronous, asynchronous, and pointer based (SONET/SDH) systems. Voice and video transmission over packet networks. Prerequisites: 261, 278, or equivalents.
3 units, Win (Narasimha)

375. Advanced Analysis of Feedback—For advanced students. The required mathematics and basic results in the analysis of linear and nonlinear feedback systems. Nonlinear ODEs, local and global stability, Lyapunov theory. Gains of operators, small gain theorems, loop transformations, circle criteria, Popov theorem. Passive and contractive operators, Kalman-Yacubovich theorem. Robustness of multivariable linear systems, stability of feedback systems, linear systems with nonlinear actuators and sensors, overflow and quantizer induced limit cycles in digital filters. Prerequisite: 263.
3 units (Boyd) alternate years, given 2002-03

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. Kolmogorov complexity, Shannon entropy. Rate distortion theory. Huffman coding and random coding. Unified treatment based on the asymptotic equipartition theorem. Prerequisite: 278 or Statistics 116, or equivalent.
3 units, Win (Gill)

SCHOOL OF ENGINEERING

376B. Information Theory—Rate distortion theory and Kolmogorov complexity. Information theory and statistics. Stein's Lemma. AEP. Information capacity of networks. Slepian-Wolf Theorem. Optimal investment and information theory. Maximum entropy and Burg's Theorem. Prerequisite: 376A.
3 units, alternate years, given 2002-03

377A. Dynamic Programming and Stochastic Control—(Enroll in Management Science and Engineering 351.)

377B. Neuro-Dynamic Programming and Reinforcement Learning—(Enroll in Management Science and Engineering 339.)

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: 103, 278.
3 units

379B. Digital Communication II—Capacity calculation, cut-off rates, Viterbi Detection, partial-response methods, convolutional codes, trellis and turbo codes, low-density parity check codes, shaping codes, encoder/decoder complexity. Prerequisites: 278, 379A.
3 units (Cioffi) alternate years, given 2002-03

379C. Advanced Digital Communication—Topics: transmit optimization for channels with intersymbol interference, combined equalization and coding, line coding design and analysis, discrete multitone (DMT), vector modulation, generalized DFE.
3 units, Spr (Cioffi) alternate years, not given 2002-03

380. Seminar on Computer Systems—Current research in the design, implementation, analysis, and use of computer systems ranging from integrated circuits to operating systems and programming languages. (AU)
1 unit, Aut, Win, Spr (Allison, Wharton)

381A. Database System Implementation—(Enroll in Computer Science 346.)

381B. Transaction Processing and Distributed Databases—(Enroll in Computer Science 347.)

383. Advanced Compiling Techniques—(Enroll in Computer Science 243.)

384A. Internet Protocols and Standards—Local area networks protocol standards: MAC Addressing; IEEE 802.1 bridging protocols (transparent bridging, virtual LANs). Internet protocol standards: the Internet Protocol (IPv4, IPv6, ICMP); routing protocols for interior gateways (RIP, OSPF) and exterior gateways (EGP, BGP, Policy routing); IP multicast (IGMP, DVMRP, CBT, MOSPF, PIM). Asynchronous Transfer Mode (ATM); interworking with ATM. Prerequisite: 284.
3 units, Win (Tobagi)

384B. Multimedia Communication Over the Internet—Multimedia applications and requirements. Multimedia traffic generation and characterization: audio compression, image and video compression standards (JPEG, H.261, MPEG-2 and H.263). Advances in networking technologies and protocols for multimedia applications: LAN technologies; broadband services to the home including ADSL, cable modems, hybrid fiber-coax (HFC), and wireless Internet protocols including IP multicast, resource reservation protocols (ST2+, RSVP). Differentiated services in the Internet. Real-time transport protocol (RTP), RTP profiles and payload formats. Audio-video conferencing standards: the Internet architecture (SDP, SAP, SIP); ITU recommendations H. 320 and H. 323. Data conferencing standards: ITU recommendation T.120. Real-time streaming protocol (RTSP). Prerequisites: 284 or Computer Science 244A. Recommended: 384A.
3 units, Spr (Tobagi)

384D. Projects in Computer Networks—(Enroll in Computer Science 344.)

384S. Network Architectures and Performance Engineering—(Same as Management Science and Engineering 334.) Introduction to the modeling and control methodologies used in network performance engineering: Markov chains and stochastic modeling, queuing networks, stochastic simulation, dynamic programming, network optimization algorithms, large-scale distributed computation for networking operations, etc. The application of such methodologies to key design issues in high-performance network architectures for IP networking, wireless networks, and optical networks: 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, wavelength routing and topology design of optical networks, server placement and capacity management, etc. Prerequisites: 284 and basic understanding of probability.
3 units, Spr (Bambos)

384X,Y. Packet Switch Architectures I and II—The theory and practice of designing packet switches, such as Internet routers, Ethernet switches and ATM switches. Introduction: evolution of switches and routers. Output scheduling: motivation for providing bandwidth and delay guarantees; fairness; active queue management and packet dropping schemes. Switching: example architectures, performance metrics; unicast switching: blocking phenomena, connections with bipartite graph matching, practical algorithms; unicast switching with speedup; multicast switching. Address lookup: exact and longest prefix matches, performance metrics, hardware and software solutions. Packet classifiers: for firewalls and policy-based routing; graphical description; Theoretical complements: basic queuing models, graph matching algorithms, stability through Lyapunov functions, fluid models. Prerequisites: Computer Science 161, and EE284/CS244A. A familiarity with probability is assumed (for example, from 178, 278, or Statistics 116.)
3 units, Win, Spr (McKeown, Prabhakar)

385. Special Seminars in Computer Systems—Seminars on current research topics in computer systems are given occasionally and are usually announced one or two quarters in advance. See the *Time Schedule* and bulletins in department office for current listings.

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, and system reliability. Emphasis is on student presentations and Ph.D. thesis research.
1-4 units, Aut, Win (McCluskey)
Spr (Staff)

386A. Parallel Computer Architecture and Programming—(Enroll in Computer Science 315A.)

386B. Parallel Programming Project—(Enroll in Computer Science 315B.)

387. Error-Correcting Codes—Theory and implementation of 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: familiarity with discrete mathematics, elementary probability, and linear algebra.
3 units, Spr (Gill)

388. Programming Language Design—(Enroll in Computer Science 342.)

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.

by arrangement

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.

by arrangement

392. Special Seminars—Special seminars and experimental courses are given on topics of current interest by specialists in the field. Announcements are made one or two quarters prior to presentation. See the *Time Schedule* and bulletins in department office for current listings.

by arrangement

392A. Database System Principles—(Enroll in Computer Science 245.)

392B. Introduction to Image Sensors and Digital Cameras—Introduction to the design and analysis of image sensors and digital cameras. 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. Topics: photodetectors; CCD and CMOS passive and active sensor operation; noise and FPN analysis; spatial resolution and MTF; SNR and dynamic range; A/D conversion approaches; color interpolation, correction, and balance; and autofocus. A MATLAB camera simulator is used to explore various tradeoffs in camera design. Prerequisites: undergraduate level device, circuit, and system background, e.g., equivalent to 102, 111, 112, and 113; and some familiarity with noise analysis.

3 units, Spr (El Gamal)

392J. Digital Video Processing—The fundamentals of digital video processing. Spatio-temporal sampling, motion analysis, motion-compensated filtering, and general video processing operations including noise reduction, restoration, superresolution, frame-rate conversion, deinterlacing, and compression (frame-based and object-based methods). Advanced topics: video segmentation, digital television, and video libraries and databases (MPEG-7). Prerequisite: 368.

3 units, Win (Apostolopoulos, Wee) alternate years, not given 2002-03

392K. Genetic Algorithms and Genetic Programming—(Enroll in Computer Science 426.)

392L. Optical Fiber Communications Laboratory—Experimental techniques in optical fiber communications. Students investigate, experimentally, properties of key optical communications components: fibers, lasers, modulators, photodiodes, optical amplifiers, WDM multiplexers and demultiplexers, etc. Key optical communications systems techniques: eye diagrams and BER measurements. Prerequisites: 247, 348.

3 units, Spr (Kazovsky)

392M. Adaptive Communication Systems—Advanced communication design techniques for wireless and high-speed wireline applications. General and applied concepts in communication theory, concepts in digital communication receivers (adaptive antenna array and adaptive equalization). The practical aspects of advanced algorithms and systems for wireless digital communications of second and third generation: IS-136 and WCMDA. The ADSL and OFDM systems. Skills and level of problem solving enables students to contribute effectively to research and development in this area. Prerequisites: one graduate course in signal processing, communication systems and probability. Recommended: exposure to simulation platforms, e.g., MATLAB and Simulink.

3 units, given 2002-03

392P. Constrained Coding—Introduction to the theory and practice of constrained coding. Descriptions of several applications where constrained coding has been used: magnetic tape drives, optical disk drives, holographic recording, and a wireless communications application. Develop formal properties of constrained systems, capacity and code rate, finite-state encoders, and sliding-block decoders, culminating in the state-splitting code construction algorithm. Alternative models of encoding and code construction. Methods of integrating constrained codes with error-correction codes: concatenation with Reed-Solomon codes, reversed concatenation, turbo decoding, forbidden list codes, and spectral null codes. Prerequisites: elementary probability, linear algebra. Recommended: error-correction coding, information theory.

3 units, Aut (Marcus)

392Q. Mobile and Wireless Networks and Applications—(Enroll in Computer Science 444N.)

395. Electrical Engineering Instruction: Practice Teaching—Open to limited number of advanced graduate students in Electrical Engineering who plan to make teaching their career. Qualified students conduct a small section of an established course taught in parallel by an experienced instructor.

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

398A. Image Communication I—Principles and systems for digital image communication, emphasizing source coding for efficient storage and transmission of still and moving images. Part I of a two-course series covers fundamentals and still image communication techniques. Image acquisition and sampling, color systems. Lossless coding principles. Arithmetic coding, run-length coding. Facsimile coding. Extension to multilevel images. Lossy compression principles, scalar quantization, vector quantization. Lossless and lossy predictive coding. DPCM. Transform coding. Multiresolution coding, subband coding, and wavelets. EZW and SPIHT coding. Embedded image representations. Fractal image compression. Limits of human visual perception. Image quality measures. Watermarking and authentication of images. Standards: ITU-T T. 4, T. 6, GIF, JBIG, JPEG, JPEG-2000. Students investigate image compression algorithms in Matlab or C. Prerequisites: 261, 278.

3 units, Aut (Girod)

398B. Image Communication II—Principles and systems for digital image communication, emphasizing source coding for efficient storage and transmission of still and moving images. Part II of a two-course series covers digital video communication techniques. Digital studio standard. Interframe coding. Motion-compensated prediction. Motion-compensated hybrid coding. Motion estimation. Rate distortion analysis and optimization of video coding schemes. Motion-compensated interpolation and frame-rate conversion. Transcoding and compressed-domain watermarking. Scalable layered video representations. Error-resilient video coding. Synthetic-natural hybrid coding, model-based coding. Video indexing and retrieval. Applications: videotelephony, videoconferencing, digital TV broadcasting, Internet video streaming, wireless video. Standards: MPEG-1, MPEG-2, MPEG-4, MPEG-7, ITU-T H. 261, H. 263. Students investigate video compression algorithms in Matlab or C. Term project. Prerequisites: 261, 278. Recommended: 398A.

3 units, Win (Girod)

399. Topics in Computer Vision—(Enroll in Computer Science 328.)

400. Thesis and Thesis Research—Limited to students who have established candidacy for the degree of Engineer or Ph.D. A grade of 'S' indicates satisfactory work; no letter grade is assigned.

by arrangement

402A. Seminar: Topics in International Technology Management—High-tech entrepreneurship and innovation in E. Asia. Implications of the rise of startup companies for innovation systems in E. Asia, including related changes in university-industry relations, high tech R&D management, intellectual property laws and other regulation, foreign and domestic venture capital, international technology sharing (joint ventures), etc. Distinguished speakers from industry and government.

1 unit, Aut (Dasher)

402S. Topics in International Advanced Technology—Bioapplications of nanotechnologies. Nano-scale fabrication techniques, systems, and informatics, including BioMEMS and NEMS; molecular motors, sensors, DNA computing and related technologies. Focus is on applications such as biological and medical analysis, diagnostics, and pharmaceutical manufacturing. Distinguished speakers from industry and other research institutions.
1 unit, Aut (Dasher)

410. Integrated Circuit Fabrication Laboratory—Preference to students pursuing doctoral research programs in which the facilities of the IC lab are used. Laboratory fabrication of silicon gate NMOS or CMOS integrated circuits. Emphasis is on the practical aspects of IC fabrication, including silicon wafer cleaning, photolithography, etching, oxidation, diffusion, ion implantation, chemical vapor deposition, physical sputtering, and wafer testing. Prerequisites: 212, 216, consent of instructor.
3-4 units, Win (Saraswat)

414. Design of RF Integrated 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 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)

453. Geomagnetically Trapped Radiation—Charged particle trapping in planetary magnetic fields, and its importance in near-earth-space phenomena. The motion of charged particles in inhomogeneous magnetic and electric fields, adiabatic invariants, distribution functions and diffusion equation methods. Useful theorems for interpreting experimental data. Source and loss processes and the physical mechanisms responsible for producing trapped radiation at the earth and other planets. Prerequisite: 142.
3 units, Win (Walt) alternate years, not given 2002-03

478. Topics in Multi-User Information Theory—Selected topics in multi-user source and channel coding; source coding with side information, correlated sources, multiple access channel, broadcast channel, interference channel, relay channel. Capacity of wireless and optical channels. Prerequisite: 376A.
3 units, Spr (Elgamal) alternate years, not given 2002-03

479. Multiuser Digital Transmission Systems—Fundamental theoretical multiuser communications concepts (multiple access, broadcast, multiuser detection, crosstalk), matrix channel descriptions and optimized multiuser transmission, code-division multiple access concepts and implementations.
3 units, not given 2002-03

481A. Computer Graphics: Geometric Modeling—(Enroll in Computer Science 348A.)

481B. Computer Graphics: Image Synthesis Techniques—(Enroll in Computer Science 348B.)

482A. Advanced Computer Organization: Processor Microarchitecture—High performance computer design focusing on the microarchitecture of high-performance processors. Topics: pipelining, memory systems, out-of-order issue, branch prediction, and vector processors. Design project. Enrollment limited to 30. Prerequisites: 282, 382.
3 units, Spr (Dalley) alternate years, not given 2002-03

482B. Advanced Computer Organization: Interconnection Networks—High performance computer design focusing on interconnection networks used from processor-memory and processor-processor communication. Topics: network topology, routing methods, flow control, router microarchitecture, and performance analysis. Enrollment limited to 30. Prerequisites: 282, 382.
3 units (Dally) alternate years, given 2002-03

483. Topics in Compilers—(Enroll in Computer Science 343.)

484. Topics in Computer Graphics—(Enroll in Computer Science 448.)

485. Broad Area Colloquium for Artificial Intelligence, Geometry, Graphics, Robotics, and Vision—(Enroll in Computer Science 528.)

486. 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, given 2002-03

487. Digital Signal Processing Architectures and Systems—The design and implementation of signal processing systems. Survey of architectures and tools available to automate this task. Case studies in data communications, low power design, and video signal processing. Topics: DSP building blocks, architectures, programmable architectures, architecture design tools, video compression, wireless communication, and low-power design. Prerequisites: 271, basic DSP concepts, C programming language, and UNIX.
3 units, alternate years, given 2002-03

488. Testing Aspects of Computer Systems—The fundamental principles of testing computer systems and designing for testability. Failure and fault models. Deterministic and probabilistic techniques of test generation and testing. Techniques for testing memories and microprocessors. Design for testability. Prerequisite: 273.
3 units, alternate years, given 2002-03

489. Fault Tolerant Computing Systems—Basic considerations in the design of reliable computing systems. Concurrent checking techniques. Redundancy and evaluation methods. System considerations. Examples of specific system designs. Prerequisite: 282.
3 units, alternate years, given 2002-03

492. Special Seminars—Special seminars and experimental courses are given on topics of current interest by specialists in the field. Announcements are made one or two quarters prior to presentation. See the *Time Schedule* and bulletins in department office.
by arrangement

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.

45. Science and Technology in WW II and What Happened Afterward—(Same as Overseas Studies 128V.)
4 units, Win (Osgood)

This file has been excerpted from the *Stanford Bulletin, 2001-02*, pages 154-170. Every effort has been made to ensure accuracy; late changes (after print publication of the bulletin) may have been made here. Contact the editor of the *Stanford Bulletin* via email at arod@stanford.edu with changes, corrections, updates, etc.