

Electrical and Computer Engineering

The Department of Electrical and Computer Engineering at Johns Hopkins is committed to providing a rigorous educational experience that prepares students for further study and successful careers, and is dedicated to research that contributes to fundamental knowledge in both analytical and experimental aspects of the field. The mission of our undergraduate programs is to provide a stimulating and flexible curriculum in fundamental and advanced topics in electrical and computer engineering, basic sciences, mathematics, and humanities, in an environment that fosters development of analytical, computational, and experimental skills and that involves students in design projects and research experiences. At the graduate level, our mission is to provide advanced training that prepares master's graduates to work at the forefront of knowledge in their chosen specialty, and prepares doctoral students for original research that will advance the frontiers of knowledge in their chosen areas.

The department focuses its teaching and research programs in three major areas: (1) computer engineering; (2) systems, communications, and signal processing; and (3) solid state and quantum electronics.

The faculty offers undergraduate courses at both the introductory and intermediate levels in these areas, and graduate courses leading to research topics at the forefront of current knowledge. Guided individual study projects available for undergraduates provide opportunities for student participation in activities in the department and in the research programs of the faculty. In the graduate program, original research in close association with individual faculty members is emphasized.

The Faculty

Andreas G. Andreou, Professor: Micro and nanosystems technologies, sensory information processing, neural computation.

William R. Brody, Professor (President, The Johns Hopkins University): medical imaging, magnetic resonance imaging.

Gert Cauwenberghs, Professor: Mixed-signal VLSI systems, neural computation, machine learning.

Frederic M. Davidson, Professor: quantum optics, optical coherence, optical communications.

Virantha N. Ekanayake, Assistant Professor: VLSI, micro-architecture, compilers, asynchronous circuit design.

Ralph R. Etienne-Cummings, Associate Professor, Director of Computer Engineering Program: Mixed-signal VLSI, computational sensors, robotics, neuromorphic engineering.

John Goutsias, Professor: Signal and image processing, modeling and computational analysis of cellular processes, bioinformatics.

Pablo A. Iglesias, Professor: Robust control, systems biology, mathematical modeling of biological systems.

Frederick Jelinek, Julian Sinclair Smith Professor of Electrical and Computer Engineering (Director, Center for Language and Speech Processing): speech recognition, statistical methods of natural language processing, and information theory.

Richard I. Joseph, Jacob Suter Jammer Professor of Electrical Engineering: electromagnetic theory, nonlinear wave propagation, solitons.

Jin U. Kang, Associate Professor: Opto-electronics, nonlinear optics, fiber optics and lasers.

Alexander E. Kaplan, Professor: "Extreme" nonlinear optics: super-powerful laser interactions with matter.

Sanjeev P. Khudanpur, Assistant Professor: information theory, statistical language modeling.

Jacob B. Khurgin, Professor: Quantum electronics, nonlinear optics.

Gerard G. L. Meyer, Professor (Chair): Parallel computing, computational methods, fault-tolerant computing.

Jerry L. Prince, William B. Kouwenhoven Professor: Image processing and computer vision with application to medical imaging.

Wilson J. Rugh, Edward J. Schaefer Professor of Electrical Engineering: linear and nonlinear system theory, control theory.

Paul Sotiriadis, Assistant Professor: Circuit theory and design, dynamical systems, information theory, signal processing.

Trac Duy Tran, Associate Professor: Filter banks, wavelets, multirate systems and applications.

Howard L. Weinert, Professor: statistical signal and image processing.

Joint, Part-Time, Visiting, and Emeritus Appointments

Paul Bottomley, Professor (Radiology): Magnetic resonance imaging, metabolic MRI.

William J. Byrne, Associate Research Professor: Large vocabulary continuous speech recognition.

Gregory Chirikjian, Professor (Mechanical Engineering): Robotics, computational biology, statistics of biological macromolecules.

A. Brinton Cooper III, Associate Research Professor: Error control coding, coded wireless and optical communication.

Christopher Diehl, Assistant Research Professor (Senior Professional Staff APL): Machine learning, computer vision, sensor networks.

James D. Franson, Professor (Principal Professional Staff APL): Quantum optics and quantum computing.

Donald Geman, Professor (Applied Mathematics and Statistics): Computer vision, computational biology, statistical learning.

Robert E. Glaser, Lecturer: Advanced digital logic systems.

Willis Gore, Professor Emeritus

Moise H. Goldstein Jr., Professor Emeritus

Gregory Hager, Professor (Computer Science): robotics, vision-based interaction, and visual tracking.

Robert E. Jenkins, Senior Lecturer: Digital systems, spacecraft systems and space technology.

Mark N. Martin, Assistant Research Professor and Senior Professional Staff APL: Low power VLSI, CMOS device physics, radiations effects.

Michael I. Miller, Hershel L. Seder Professor of Biomedical Engineering (Director, Center for Imaging Science): image understanding and computer vision, medical imaging and computational anatomy.

Nael Osman, Assistant Professor (Radiology): Image and multi-dimensional signal processing, medical imaging.

C. Harvey Palmer Jr., Professor Emeritus

Louis J. Podrazik, Lecturer: Parallel computer architectures and algorithms, fault tolerant design.

Theodore O. Poehler, Research Professor (Vice Provost for Research): Quantum electronics, solid state physics.

Philippe Pouliquen, Lecturer: Optoelectronic, mixed signal, low power VLSI, CAD tools for VLSI.

Izhak Shafran, Assistant Research Scientist: Large vocabulary continuous speech recognition.

Raymond Sova, Assistant Research Professor (Principal Professional Staff APL): Laser communications, R-F photonics.

Kim Strohhahn, Assistant Research Professor (Principal Professional Staff APL): Radiation hardened electronics.

Matthias Stuber, Associate Research Professor, (Radiology): High resolution coronary MRI, MR myocardial tagging, high field MRI.

Nitish Thakor, Professor (Biomedical Engineering): Biomedical instrumentation sensors and VLSI systems, neuroengineering.

Michael E. Thomas, Research Professor (Principal Professional Staff APL): Propagation of light, applied spectroscopy and lasers.

Benjamin Tsui, Professor (Radiology): Image reconstruction, quantitative SPECT and PET imaging, structural X-ray analysis.

James West, Research Professor: electroacoustics, physical acoustics, and architectural acoustics.

Raimond Winslow, Professor (Biomedical Engineering): Systems biology and bioinformatics.

Current Research Activities

Computer Engineering

Computer engineering research activities include work on computer structures (with emphasis on microprocessors), parallel and distributed processing, fault-tolerant computing, analysis of algorithms, and VLSI analog architectures for machine vision, associative processing, and micropower computing.

Systems, Communications, and Signal Processing

Current research in systems and control includes the development of analysis and design techniques for nonlinear systems; optimization methods in filtering, estimation, and control; efficient implementation and analysis of iterative algorithms on specialized computing structures; design and analysis of robust linear control algorithms, and H-infinity control theory. Research in speech processing involves work in all aspects of language or speech science and technology, with fundamental studies under way in areas such as language modeling, pronunciation modeling, natural language processing, neural auditory processing, acoustic processing, optimality theory, and language acquisition. Image analysis efforts currently concern statistical analysis of restoration and reconstruction algorithms, development of statistical image models for image restoration and segmentation, geometric modeling for object detection and estimation, morphological image analysis, and magnetic resonance imaging. There is opportunity for joint work in image analysis with faculty in the Department of Radiology, School of Medicine.

Solid State and Quantum Electronics

Current research activities include work in the theory of nonlinear waves, optical communications, and quantum well devices. Other areas of interest involve the study of the nonlinear interactions of light with matter and single elementary particles, X-ray sources and lasers, optical bi-stability, radiation protection, laser beam control and steering, the nonlinear optics of semiconductors, nonlinear

optics of biological objects as well as research on sub-femtosecond pulses and devices based on single atoms. Semiconductor device studies include optical detectors, VLSI circuit design and modeling and microwave devices and circuits. Study of a laser radar and RF photonics is also being pursued. Theoretical and experimental studies involving linear optical properties of various materials and passive remote sensing of the atmosphere are being investigated.

Facilities

The department maintains extensive facilities for teaching and research in Barton Hall and The Stieff Building. The two main teaching labs (Electrical Engineering Lab and Computer Engineering Lab) make extensive use of state-of-the-art design environments such as CADENCE, Xilinx Tools, TI DSP systems, VHDL, and Verilog. In addition, the department includes the computational sensory-motor system lab, the control systems design lab, the parallel computing and imaging lab, the photonics and optoelectronics lab, the semiconductor microstructures lab, and the sensory communication and microsystem lab, adaptive and the sensory communication microsystem lab.

Undergraduate Programs

The Department of Electrical and Computer Engineering offers two bachelors degree programs: one in Electrical Engineering and one in Computer Engineering (with the close collaboration of the Computer Science Department). Each program is described on the following page.

Bachelor of Science in Electrical Engineering Mission and Educational Objectives

The faculty of the Electrical Engineering Program at Johns Hopkins is committed to providing a rigorous educational experience that prepares students for further study and to professionally and ethically practice engineering in a competitive global environment. The mission of the program is to provide a stimulating and flexible curriculum in fundamental and advanced topics in electrical engineering, basic sciences, mathematics, and humanities, in an environment that fosters development of analytical, computational, and experimental skills and that involves students in design projects and research experiences; and to provide our electrical engineering graduates with the tools, skills and competencies necessary to understand and apply today's technologies and become leaders in developing and deploying tomorrow's technologies.

The Electrical Engineering Program's educational objectives are to educate students who, after

graduation, will be successful engineers in industry, government laboratories and other organizations, or advanced students in the best graduate programs. In these endeavors, they will:

- apply their understanding of the fundamental scientific, engineering, and professional principles at the foundation of Computer Engineering.
- apply advanced mathematical, computational and experimental techniques to respond to technological demands in an economical and efficient manner.
- contribute to society as broadly educated, articulate, and ethical citizens who are at ease in multidisciplinary teams.
- strive to continually update and renew their knowledge throughout their careers in order to meet the needs of a rapidly changing world.

Students graduating with a B.S. in Electrical Engineering will have demonstrated the ability to:

- understand advanced mathematics, probability and statistics, basic science, and computer science, and apply this knowledge to electrical engineering disciplines.
- design, conduct, evaluate and report experiments, including analysis and statistical interpretation of data.
- identify, formulate and solve electrical engineering problems.
- use basic concepts and modern engineering tools (laboratory instrumentation and computer hardware and software) to design electrical engineering systems, components and processes to meet specifications, taking into account cost, safety, environmental and socio-political constraints.
- communicate effectively and work on multidisciplinary teams.
- be aware of professional and ethical responsibilities, and contemporary issues, and appreciate the societal, economic, and environmental impacts of engineering.
- enter professional practice or graduate school with the recognition of the need for life-long learning and the ability to pursue it.

Each student and faculty adviser must consider these objectives in planning a set of courses and projects that will satisfy degree requirements. The sample programs and the program checklist are provided in a separate advising manual and illustrate course selections that will help students meet the program objectives.

Faculty and others will assess student performance to ensure that our educational objectives

are met. Students will have opportunities to assess their own educational progress and achievements in several ways, including exit interviews and alumni surveys. Through regular review processes, including Academic Council departmental reviews, visits by the departmental external advisory board, course evaluations, and ABET visits, students will have opportunities to discuss their educational experiences and expectations. The outcomes of these assessment processes will be used by the faculty to improve the content and delivery of the educational program.

The success of each student's program will depend on effective faculty advising. Every undergraduate student in the Electrical Engineering Program must follow a program approved by the faculty adviser. The faculty adviser must be a member of the Electrical and Computer Engineering faculty.

Requirements for the Bachelor of Science in Electrical Engineering

The Bachelor of Science degree in Electrical Engineering requires a minimum of one hundred and twenty-six (126) credits that must include:

- *Forty-five (45) credits of ECE courses including Circuits (520.213), Signals and Systems (520.214), Fields, Matter and Waves I (520.219), one (1) introductory laboratory course (520.345, 520.349 or 520.372), and at least six (6) credits of advanced laboratory, design intensive, or senior design project courses from those given in the attached advising check-list. Up to six (6) credits of Computer Science courses may be used to satisfy the 45-credit requirement. A GPA of at least 2.0 must be maintained in ECE courses. Courses in this group may not be taken Pass/Fail.*
- *Six (6) credits of engineering courses from School of Engineering departments other than ECE or Mathematical Sciences or General Engineering. Students must complete enough of the approved non-ECE advanced design labs so that they have at least twelve (12) credits of combined ECE and non-ECE advanced laboratory, design intensive, or senior design project courses. Courses in this group may not be taken Pass/Fail.*
- *Twenty (20) credits of mathematics courses taken from the Mathematics Department or the Mathematical Sciences Department. Students must take Calculus II (110.109), Calculus III (110.202), Linear Algebra (110.201), Differential Equations (110.302), and Probability and Statistics (550.310/311) or Introduction to Probability (550.420). Courses in this group may not be taken Pass/Fail. Elementary or precalculus courses such as 110.105 or 550.111-112 are not acceptable. (Calculus I may be waived*

through an examination taken during freshman orientation. If not waived, it must be taken as a prerequisite to Calculus II.)

- *Sixteen (16) credits of basic sciences (physics, chemistry, biology, earth and planetary sciences), which must include General Physics (171.101-102), General Physics Laboratory (173.111-112), and Introductory Chemistry (030.101). Courses in this group may not be taken Pass/Fail.*
- *At least six (6), three-credit courses in humanities and social sciences. The humanities and social sciences courses are one of the strengths of the academic programs at Johns Hopkins. They represent opportunities for students to appreciate some of the global and societal impacts of engineering, to understand contemporary issues, and to exchange ideas with scholars in other fields. Some of the courses will help students to communicate more effectively, to understand economic issues, or to analyze problems in and an increasingly international world. The selection of courses should not consist solely of introductory courses, but should have both depth and breadth. Typically, this means that students should take at least three (3) courses in a specific area with at least one of them at an advanced level.*
- *A programming language requirement must be met by taking Introduction to Java (600.107) or Introduction to Programming in C/C++ (600.109).*
- *Two (2) writing intensive (W) courses (at least 3 credits each) are required. The writing intensive courses may not be taken Pass/Fail and require a C- or better grade. Students may wish to consider a course in Technical Communications to fulfill one of the W requirements.*

Additional details concerning advising and degree requirements are in the *Electrical Engineering Advising Manual*. The B.S. in Electrical Engineering is accredited by the Engineering Commission of the Accreditation Board for Engineering and Technology (ABET).

The sample program shown has an emphasis on systems and communications aspects of electrical engineering. Other sample programs can be found in the advising manual.

Freshman Year (30 credits)

110.108-109	Calculus I, II	8
171.101-102	Physics I, II	8
173.111-112	Physics Lab I, II	2
520.137	Intro to ECE	3
520.142	Digital System Fundamentals	3
H/S Electives		<u>6</u>
	Total	30

Sophomore Year (34 credits)

110.202 Calculus III	4
110.201 Linear Algebra	4
030.101 Chemistry I	3
520.213 Circuits	4
520.214 Signals and Systems	4
520.219 Fields, Matter & Waves I	3
600.109 Intro Programming in C/C++	3
Non-ECE Engineering Elective	3
H/S Electives	<u>6</u>
Total	34

Junior Year (32 credits)

110.302 Differential Equations	4
550.310 Probability and Statistics	4
520.372 Programmable Device Lab	3
520.345 ECE Laboratory	3
Basic Science Elective	3
520.353 Control Systems	3
Non-ECE/MathSci Engineering Elective	3
Elective	3
H/S Electives	<u>6</u>
Total	32

Senior Year (31 credits)

520.498-499 Senior Design Project	6
520.435 Digital Signal Processing	4
ECE Signals/Systems/Comm. Electives	6
ECE Advanced Lab/Design Elective	6
Elective	3
Non-ECE/MathSci Engineering Electives	<u>6</u>
Total	31

**Bachelor of Science in Computer Engineering
Mission and Educational Objectives**

The Computer Engineering program at Johns Hopkins is supported by faculty in the Department of Electrical and Computer Engineering and the Department of Computer Science, who are committed to providing a rigorous educational experience that prepares students for further study and to professionally and ethically practice engineering in a competitive global environment. The mission of the program is to provide students with a broad, integrated education in the fundamentals and advanced topics in computer engineering, basic sciences, mathematics, and humanities in an environment that fosters the development of analytical, computational, and experimental skills, and that involves students in design projects and research experiences; and to provide our computer engineering graduates with the tools, skills and competencies necessary to understand and apply today's technologies and become leaders in developing and deploying tomorrow's technologies.

From this mission statement, the Computer Engineering faculty has determined educational objectives for the B.S. in Computer Engineering Program. Consistent with Johns Hopkins' long-standing emphasis on the individual, the Computer Engineering program will provide a high-quality educational experience that is tailored to the needs and interests of each student. In addition, each student's program of study is planned in consultation with a faculty adviser to enable graduates of the program to educate students who, after graduation, will be successful engineers in industry, government laboratories and other organizations, or advanced students in the best graduate programs. In these endeavors, they will:

- apply their understanding of the fundamental scientific, engineering, and professional principles at the foundation of Computer Engineering.
- apply advanced mathematical, computational and experimental techniques to respond to technological demands in an economical and efficient manner.
- contribute to society as broadly educated, articulate, and ethical citizens who are at ease in multidisciplinary teams.
- strive to continually update and renew their knowledge throughout their careers in order to meet the needs of a rapidly changing world.

Students graduating with a B.S. in Computer Engineering will have demonstrated the ability to

- understand advanced and discrete mathematics, probability and statistics, basic science, and computer science, and apply this knowledge to computer engineering disciplines.
- design, conduct, evaluate and report experiments, including analysis and statistical interpretation of data.
- identify, formulate and solve computer engineering problems.
- use basic concepts and modern engineering tools (laboratory instrumentation and computer hardware and software) to design computer engineering systems, components and processes to meet specifications, taking into account cost, safety, environmental and socio-political constraints.
- communicate effectively and work on multidisciplinary teams.
- be aware of professional and ethical responsibilities, and contemporary issues, and appreciate the societal, economic, and environmental impacts of engineering.

- enter professional practice or graduate school with the recognition of the need for life-long learning and the ability to pursue it.

Each student and faculty adviser must consider these objectives in planning a set of courses and projects that will satisfy degree requirements. The sample programs and the program checklist included in this advising manual illustrate course selections that will help students meet the program objectives.

Faculty and others will assess student performance to ensure that our educational objectives are met. Students will have opportunities to assess their own educational progress and achievements in several ways, including exit interviews and alumni surveys. Through regular review processes, including Academic Council departmental reviews, visits by the departmental external advisory board, course evaluations, and ABET visits, students will have opportunities to discuss their educational experiences and expectations. The outcomes of these assessment processes will be used by the faculty to improve the content and delivery of the educational program.

The success of each student's program will depend on effective faculty advising. Every undergraduate student in the Computer Engineering Program must follow a program approved by a faculty adviser. The faculty adviser must be a member of the program committee that supervises the Computer Engineering Program. The current faculty members in the program committee are:

Department of Electrical and Computer Engineering

Andreas G. Andreou, Professor and Director of
Computer Engineering Program
Gert Cauwenberghs, Professor
Ralph Etienne-Cummings, Associate Professor
Gerard Meyer, Professor and Chair

Department of Computer Science

Yair Amir, Associate Professor
Gerald Masson, Professor
Lawrence Wolff, Professor

Requirements for the Bachelor of Science in Computer Engineering

The Bachelor of Science degree in Computer Engineering requires a minimum of 126 credits, which must include the following:

- *Forty-two (42) credits in Computer Engineering*, which must include:
 - a. *Fifteen (15) credits of Electrical and Computer Engineering courses*, which must include

Digital System Fundamentals (520.142), and Circuits (520.213).

- b. *Fifteen (15) credits of Computer Science courses* which must include Introduction to Programming in JAVA (600.107) or Introduction to Programming in C/C++ (600.109), Data Structure (600.226) and Computer System Fundamentals (600.333).
- c. *The program must also contain a substantial advanced laboratory and design experience component, appropriate for the student's interests.* This requirement can be met by taking twelve (12) credits of advanced laboratory, design intensive, or senior design project courses from those given in the attached advising checklist. At least six (6) of these twelve credits must be from ECE or CS courses.

A GPA of at least 2.0 must be maintained in Computer Engineering courses. Courses in this category may not be taken Pass/Fail.

- *Six (6) credits of engineering courses from School of Engineering departments other than Computer Science, ECE, Mathematical Sciences, or General Engineering.* Students must complete enough of the approved non-CS/ECE advanced design labs so that they have at least twelve (12) credits of advanced laboratory, design intensive, or senior design project courses. Courses in this group may not be taken Pass/Fail.
- *Twenty-four (24) credits in mathematics courses taken from the Mathematics Department or the Mathematical Sciences Department.* Calculus II (110.109), Calculus III (110.202), Linear Algebra (110.201) or Linear Algebra and Differential Equations (550.291), Discrete Mathematics (550.171), Probability and Statistics (550.310/311) or Introduction to Probability (550.420) must be taken. Elementary or precalculus courses such as 110.105 or 550.111-112 are not acceptable. (Calculus I may be waived through an examination taken during freshman orientation. If not waived, it must be taken as a prerequisite to Calculus II.) Courses in this category may not be taken Pass/Fail.
- *Sixteen (16) credits of basic sciences* (physics, chemistry, biology, earth and planetary sciences), which must include General Physics (171.101-102), General Physics Laboratory (173.111-112), and Introductory Chemistry (030.101). Courses in this category may not be taken Pass/Fail.
- *At least six (6), three-credit courses in humanities and social sciences.* The humanities and social sciences courses are one of the strengths of the academic programs at Johns Hopkins. They represent opportunities for students to appreciate some

of the global and societal impacts of engineering, to understand contemporary issues, and to exchange ideas with scholars in other fields. Some of the courses will help students to communicate more effectively, to understand economic issues, or to analyze problems in an increasingly international world. The selection of courses should not consist solely of introductory courses but should have both depth and breadth. Typically, this means that students should take at least three (3) courses in a specific area with at least one of them at an advanced level.

- *At least two (2) writing intensive (W) courses are required (at least 3 credits each).* These courses may not be taken Pass/Fail and require a grade of C- or better. Students may wish to consider a course in Technical Communications to fulfill one of the W requirements.

This program fulfills the general distribution requirements of the University. The remaining credits are electives to be selected by the student in consultation with and approval by the faculty adviser. It should be noted that there is a University rule stating that no more than eighteen (18) D or D+ credits can be counted towards the total credit requirements for a degree.

The 42 credits of computer engineering courses must include the following:

- 18 credits in Electrical and Computer Engineering
- 18 credits in Computer Science
- 6 additional credits of either ECE or CS

The program must also contain a substantial advanced laboratory and design experience appropriate to the student's interests. This requirement can be met by either twelve (12) credits of advanced laboratory or design intensive courses or six (6) credits of advanced laboratory or design intensive courses and one year of a Senior Design Project (520.498-499).

A GPA of at least 2.0 must be maintained in Computer Engineering courses.

Additional details concerning advising and degree requirements are in the *Computer Engineering Advising Manual*. The B.S. in Computer Engineering is accredited by the Engineering Commission of the Accreditation Board for Engineering and Technology (ABET).

The sample program shown has an emphasis on hardware/device aspects of computer engineering. Other sample programs can be found in the advising manual.

Freshman Year (30 credits)

110.108-109 Calculus I, II	8
171.101-102 Physics I, II	8
173.111-112 Physics Lab I, II	2
520.137 Intro to ECE	3
520.142 Digital Systems Fundamentals	3
600.109 Introduction to C/C++	3
H/S Elective	<u>3</u>
	30

Sophomore Year (35 credits)

110.202 Calculus III	4
550.291 Linear Algebra and Differential Equations	4
030.101 Intro to Chemistry	3
600.226 Data Structures	3
520.213 Circuits	4
520.214 Signals and Systems	4
520.216 Intro to VLSI	3
600.271 Automata and Computation Theory	3
600.118 Intermediate Programming C/C++	4
H/S Elective	<u>3</u>
	35

Junior Year (32 credits)

550.171 Discrete Math	4
600.318 Operating Systems	4
600.334 Computer System Architecture	3
600.333 Computer System Fundamentals	3
520.372 Programmable Device Lab	3
520.345 ECE Lab	3
Science Elective	3
520.349 Microprocessor Laboratory	3
H/S Elective	<u>6</u>
	32

Senior Year (32 credits)

550.310 Intro. to Probability and Statistics	4
520.448 Electronic Design Laboratory	3
520.491 CAD of Digital VLSI Systems	3
520.490 Digital VLSI	3
520.495 Microfabrication Lab	3
520.424 FPGA Synthesis Lab	3
Non-ECE/ECE/MathSci Engineering Electives	6
H/S Elective	<u>6</u>
	31

Bachelor of Arts Degree

To meet the requirements for the B.A. degree, the program must include:

- *Eighteen (18) credits of humanities and social sciences courses.*
- *Four writing-intensive (W) courses must be included.*

- *Twenty (20) credits of mathematics or mathematical statistics courses.* Typically these include Calculus I (110.108), Calculus II (110.109), and Calculus III (110.202) or equivalent, and Linear Algebra (110.201). Elementary or pre-calculus courses such as 110.105 or 550.111-112 are not acceptable.
- *Thirty (30) credits of ECE courses.* Three credits of computer science courses may be counted toward this 30-credit requirement.
- *Additional credits* giving a total of at least 120 credits.
- Additional information on academic policies and degree requirements, including academic ethics, may be found in the *Undergraduate Academic Manual* of The Johns Hopkins University. Students are urged to read the credit requirements, under the credit requirements section, in the academic manual section of the Compendium.

The student should be aware that the B.A. degree program *is not accredited by the Accreditation Board for Engineering and Technology (ABET).*

Bachelor's/Master's Program

At the end of their sophomore year, students who are majors in electrical and computer engineering may apply for admission to a concurrent bachelor's/master's program which combines a B.S. in Electrical Engineering with a master of science in engineering. If accepted, they must take at least two courses per semester that satisfy the requirements of the M.S.E. program.

Graduate Programs

Every graduate student in the Department of Electrical and Computer Engineering must follow a program approved by a faculty adviser in the department. The adviser assigned to the student upon admission may be changed, subject to the approval of the new adviser. Additional details are in the department's *Graduate Student Advising Manual*.

Requirements for the M.S.E. Degree

The department has M.S.E. degree programs for both full-time and part-time students. A student who has completed a program of study similar to that required for the B.S. in Electrical Engineering degree must complete the following requirements for the M.S.E. degree:

- At least eight one-semester graduate-level courses approved by the student's adviser.
- One of the following: (1) an original master's essay, (2) a special project report, or (3) two additional one-semester graduate courses.

Ph.D. in Electrical and Computer Engineering

The department admits students into the Ph.D. program directly. Most students working toward the Ph.D. degree are full-time, although a part-time program can be arranged subject to the university residency requirement. A guiding principle behind the department's requirements for the Ph.D. degree is that performance in research, as distinct from course work, should be the primary criterion for assessing the student's progress.

Requirements for the Ph.D. Degree

University requirements for the Ph.D. degree are listed under Academic Information for Graduate Students (see page 48). In addition, the department requires satisfactory completion of the Ph.D. departmental examination and the University Graduate Board oral examination, preparation of a preliminary research proposal, a departmental seminar presentation, and an oral dissertation defense.

The departmental examination is offered twice yearly. Each faculty member prepares a set of questions, and the student must select and complete the sets of questions of three faculty members. This examination must be passed before the beginning of the fifth semester of full-time graduate study. After passing the examination, the student can be accepted by a faculty member who will oversee the student's research. This research sponsor then guides the remainder of the student's program leading to the Ph.D. degree.

The University Graduate Board oral examination is administered by a panel consisting of the research sponsor, another faculty member in Electrical and Computer Engineering, and three faculty members from other departments. This examination must be taken within one year of passing the departmental examination.

In the course of research leading to the Ph.D. degree, the student must submit a preliminary research proposal to the department, and present a departmental seminar. Finally, a public dissertation defense will be conducted before a panel of readers consisting of at least three Electrical and Computer Engineering faculty members. Further details concerning M.S.E. and Ph.D. degree requirements are published in a manual for graduate students in Electrical and Computer Engineering.

Financial Aid

Financial aid is available for candidates of high promise. Teaching assistantships normally consist of a stipend commensurate with the teaching or grading duties assigned. Research assistantships are available on sponsored research projects directed by members of the faculty.

Undergraduate Courses

520.137 (E,Q) Introduction to Electrical and Computer Engineering

An introductory course covering the principles of electrical engineering including sinusoidal wave forms, electrical measurements, digital circuits, and applications of electrical and computer engineering. Laboratory exercises, the use of computers, and a design project are included in the course. Open to freshman Engineering majors and any Arts and Sciences majors.

Tran 3 credits fall

520.142 (E,Q) Digital System Fundamentals

Number systems and computer codes, switching functions, minimization of switching functions, Quine-McCluskey method, sequential logic, state tables, memory devices, analysis and synthesis of synchronous sequential devices.

Meyer 3 credits spring

520.213 (E,Q) Circuits

An introductory course on electric circuits covers analysis techniques in time and frequency domains, transient and steady state response, and operational amplifiers. Prerequisites: Differential and Integral Calculus 110.108-109.

Weinert 4 credits fall, summer

520.214 (E,Q) Signals and Systems

An introduction to discrete-time and continuous-time signals and systems covers representation of signals and linear time-invariant systems and Fourier analysis. Prerequisites: Calculus III 110.202 and Circuits 520.213.

Rugh 4 credits spring;

Weinert 4 credits summer

520.216 (E) Introduction to VLSI

This course teaches the basics of switch-level digital CMOS VLSI design. This includes creating digital gates using MOS transistors as switches, laying out a design using CAD tools, and checking the design for conformance to the Scalable CMOS design rules. Prerequisite: 520.142 and 520.213.

Pouliquen 3 credits spring

520.219-220 (E) Fields, Matter, and Waves

Vector analysis, electrostatic fields in vacuum and material media, stationary currents in conducting media, magnetostatic fields in vacuum and material media. Maxwell's equations and time-dependent electric and magnetic fields, electromagnetic waves and radiation, transmission lines, wave guides, applications. Prerequisites: 110.108-109, 171.101-102. Co-requisite: 110.202.

Joseph 3 credits

520.345 Electrical and Computer Engineering Laboratory

This course consists of 11 one-week laboratory experiments intended to provide an introduction to analog and digital circuits commonly used in engineering. Topics include phase and frequency response, transistors, oper-

ational amplifiers, filters, and other analog circuits. The experiments are done using computer controlled digital oscilloscopes, function generators, and power supplies. Prerequisites: 171.101-102, 520.213.

Kang 3 credits fall

520.349 Microprocessor Laboratory

This course introduces the student to the programming of computers at the machine level. General concepts relevant to microcontrollers are presented, including memory access, numerical representations, programming models, and coding techniques. Prerequisites: 520.142 or equivalent and programming competence in a high-level language such as BASIC or PASCAL.

Glaser 3 credits fall

520.353 (E,Q) Control Systems

Modeling, analysis, and an introduction to design for feedback control systems. Topics include state equation and transfer function representations, stability, performance measures, root locus methods, and frequency response methods (Nyquist, Bode). Prerequisites: 520.214 and 110.201 or 550.291.

Rugh 3 credits fall

520.372 Programmable Device Laboratory

The use of programmable memories (ROMs, EPROMs, and EEPROMs) as circuit elements (as opposed to storage of computer instructions) is covered, along with programmable logic devices (PALs and GALs). These parts permit condensing dozens of standard logic packages (TTL logic) into one or more off-the-shelf components. Students design and build circuits using these devices with the assistance of CAD software. Topics include programming EEPROMs; using PLDs as address decoders; synchronous sequential logic synthesis for PLDs; and PLD-based state machines. Prerequisites: 520.142 and 520.345.

Glaser 3 credits spring

520.401 (E) Basic Communication

This course covers the principles of modern analog and digital communication systems. Topics include amplitude modulation formats (DSB, SSC VSB), exponential modulation formats (PM, FM), superheterodyne receivers, digital representation of analog signals, sampling theorem, pulse code modulation formats (PCM, DPCM, DM, spread-spectrum), signals with additive Gaussian noise, maximum likelihood receiver design, matched filtering, and bit error rate analyses of digital communication systems. Prerequisite: 520.214.

Davidson 3 credits

520.407 (E) Introduction to the Physics of Electronic Devices

This course is designed to develop and enhance the understanding of the basic physical processes taking place in the electronic and optical devices and to prepare students for taking classes in semiconductor devices and circuits, optics, lasers, and microwaves devices, as

well as graduate courses. Both classical and quantum approaches are used. Specific topics include theory of molecular bonding; basics of solid state theory; mechanical, transport, magnetic, and optical properties of the metals; semiconductors; and dielectrics. Prerequisites: 171.101-102, 520.219.

Khurgin 3 credits fall

520.410 (E) Fiber Optics and Devices

This course covers light propagation in fiber optic light guides, integrated optic wave guides, photodetectors, and the photon nature of light. Topics include light propagation in step-index and graded-index optical fibers, dielectric slab waveguides, photodetectors, photon shot noise, and photodetector signal-to-noise ratios. Prerequisites: 520.214, 520.219-220 or equivalent.

Kang 3 credits spring

520.413 (E) Introduction to Photonics

This course is an introduction-level course for students interested in opto-electronics. It covers the basics behind the optical devices used in communication, information storage, and display. The course begins with the in-depth review of principles of geometrical optics and imaging including the cameras, microscopes, and telescopes. The physical optical phenomena of interference, diffraction, and polarization of light are then studied, as well as the theory of the light propagation in optical waveguides. Based on this background various devices for modulation, switching, scanning, and demultiplexing of light are then described. Prerequisites: 520.219-220 or equivalent.

Khurgin 3 credits

520.414 (E) Image Processing and Analysis I

The course covers fundamental methods for the processing and analysis of images and describes standard and modern techniques for the understanding of images by humans and computers. Topics include elements of visual perception, sampling and quantization, image transforms, image enhancement, color image processing, image restoration, image segmentation, and multiresolution image representation. Laboratory exercises demonstrate key aspects of the course. Prerequisite: 520.214.

Goutsias 3 credits fall

520.415 (E) Image Processing and Analysis II

This course is a continuation of 520.414. It covers fundamental methods for the processing and analysis of images and describes standard and modern techniques for the understanding of images by morphological image processing and analysis, image representation and description, image recognition and interpretation. Laboratory exercises demonstrate key aspects of the course. Prerequisite: 520.414.

Goutsias 3 credits spring

520.419 (E,Q) Theory and Design of Iterative Algorithms

An introduction to the study of the structure, behavior, and design of iterative algorithms. Topics include problem formulations, algorithm description and classification, the deterministic iterative (DI) schema, doubling

schema, cluster point sets, periodic points, DI schemas without stop rule, the monotonic DI schema, contractive and affine maps, bounded and Cauchy sequences, asymptotically regular sequences, monotonic sequences. Prerequisites: 110.201, 110.202.

Meyer 3 credits

520.422 (E) Computer Architecture

A study of the structure and organization of classical von Neuman uniprocessor computers. Topics include a brief history of modern machines starting from the Turing computer model, instruction sets, addressing, RISC versus CICS, traps and interrupt handling, twos complement arithmetic, adders and ALUs, CSA's Booth's algorithm, multiplication and division, control unit design, microprogramming, dynamic versus static linking, memory systems and the memory hierarchy, paging segmentation, cache hardware, cache organizations, and replacement policies. Prerequisite: 520.213.

Jenkins 3 credits fall

520.424 (E,Q) FPGA Synthesis Laboratory

An advanced laboratory course in the application of FPGA technology to information processing, using VHDL synthesis methods for hardware development. The student will use commercial CAD software for VHDL simulation and synthesis, and implement their systems in programmable XILINX 20,000 gate FPGA devices. The lab will consist of a series of digital projects demonstrating VHDL design and synthesis methodology, building up to final projects at least the size of an 8-bit RISC computer. Projects will encompass such things as system clocking, flip-flop registers, state-machine control, and arithmetic. The students will learn VHDL methods as they proceed through the lab projects, and prior experience with VHDL is not a prerequisite. Prerequisites: 520.142, 520.345, 520.349 or 520.372, 600.333-334 or 520.422 or equivalent advanced competence in computer systems.

Jenkins 3 credits fall

520.425 (E) FPGA Projects Laboratory

Laboratory course for FPGA based senior projects. Students will work in teams to complete a design project that makes use of embedded FPGAs. The projects will make use of the Spartan2 XSA boards and other resources from the FPGA Synthesis lab course. Possible projects include: A 16 or 32 bit RISC processor with student designed ISA architecture, assembler, and mini operating system; or a Spartan2 emulation of an existing microprocessor such as an 8051, an optical communication system to transmit stereo music using various modulation schemes for comparison (This would include FM or AM and at least one digital scheme such as FSK); or a digital receiver for commercial AM or FM radio. Students are expected to complete a demonstration and produce a poster session final report. Prerequisites: 520.424 and senior status, no exceptions.

Jenkins 3 credits spring.

520.426 (E,N) Parallel Processing Systems

An introduction to parallel hardware/software computing structures. Pipelining and vector machines, structures

and algorithms for array processors, multiprocessor architectures and control, data flow machines, and VLSI parallel computing structures.

Jenkins 3 credits spring

520.428 (E,Q) Introduction to Algorithms for Parallel Computers

An introduction to the design and analysis of algorithms for implementation on advanced multiple computer architectures. Efficient techniques for vector, shared memory, and distributed memory machines. Classical parallel algorithms studied include parallel prefix, sorting, and message routing on specific architectures using MPI. Numerical linear algebra primitives: solution of structured linear systems, including bidiagonal, tridiagonal, triangular systems; LU, QR, FFT factorizations. Algorithm/ architecture mappings and tradeoffs. Prerequisites: basic computer architecture and a course in computer programming.

Podrazik 3 credits fall

520.429 (E) Principles of Parallel Programming

Programming models and languages for current computing platforms. Computational models include shared and distributed memory multiprocessors. Essential techniques of message-passing parallel programming will be based upon MPI (Message Passing Interface); shared memory programming will use the OpenMP standard. Other parallel language extensions will be studied, including Split-C and UPC (unified parallel C). Programming projects will be given for the IBM SP parallel computer and other available departmental multicomputers. Prerequisite: 520.428 Introduction to Algorithms for Parallel Computers and proficiency in programming in the C language.

Podrazik 3 credits spring

520.430 Parallel Optimization

Optimization problems and their analysis including primal and dual formulations. Optimality conditions and their relationship to algorithm synthesis. Survey of both unconstrained and constrained optimization algorithms in the context of developing algorithms suitable for implementation on parallel computers. Unconstrained techniques include gradient descent, conjugate-gradient, Quasi-Newton and Newton's Method, their parallel implementations and algorithm variants. A survey of parallel algorithms for constrained optimization will be presented, including feasible set, projection and interior point methods. Various applications will be studied throughout the class to supplement the theory. Prerequisite: a course in advanced calculus and a course in linear algebra (a previous course in optimization or parallel processing is not required).

Podrazik 3 credits fall

520.432 (E) Medical Imaging Systems

An introduction to the physics, instrumentation, and signal processing methods used in general radiography, X-ray computed tomography, ultrasound imaging, magnetic resonance imaging, and nuclear medicine. The primary focus is on the methods required to reconstruct images within each modality, with emphasis on the resolution,

contrast, and signal-to-noise ratio of the resulting images. Prerequisite: 520.214. Co-listed as 580.472.

Prince 3 credits spring

520.435 (E) Digital Signal Processing

Methods for processing discrete-time signals. Topics include signal and system representations, z-transforms, sampling, discrete Fourier transforms, fast Fourier transforms, digital filters. Prerequisite: 520.214.

Weinert 4 credits

520.443 Digital Multimedia Coding and Processing

An introduction to the coding and processing of digital multimedia. The course covers current popular techniques for processing, storage, and delivery of media such as speech, audio, images and video. The emphasis will be on the theoretical basis as well as efficient implementations. Topics include transform and subband coding, motion estimation and compensation, international compression standards (AC3, JPEG, MPEG, H.263, HDTV), and emerging techniques. Prerequisites: 520.435, C/C++ programming and Matlab are required.

Tran 3 hours

520.447 (E,Q) Introduction to Information Theory and Coding

This course will address some basic scientific questions about systems that store or communicate information. Mathematical models will be developed for (1) the process of error-free data compression leading to the notion of entropy, (2) data (e.g., image) compression with slightly degraded reproduction leading to rate-distortion theory and (3) error-free communication of information over noisy channels leading to the notion of channel capacity. It will be shown how these quantitative measures of information have fundamental connections with statistical physics (thermodynamics), computer science (string complexity), economics (optional portfolios), probability theory (large deviations), and statistics (Fisher information, hypothesis testing). Prerequisite: 550.310.

Khudanpur 3 credits fall

520.448 Electronics Design Laboratory

An advanced laboratory course in which teams of students design, build, test, and document application specific information processing microsystems. Semester long projects range from sensors/actuators, mixed signal electronics, embedded microcomputers, algorithms and robotics system design. Demonstration and documentation of projects are important aspects of the evaluation process. Prerequisites: 520.216, 520.345 or equivalent. Recommended: 600.333, 600.334, 520.349, 520.372, 520.490 or 520.491.

Staff 3 credits spring

520.450 Advanced Microprocessor Laboratory

The course covers the interfacing of microprocessors to memory and peripherals. Topics include input/output ports, timer operations, interrupt handling, serial communication, digital to analog and analog to digital conversions, and EEPROM programming. Student work is primarily software with some hardware hookup. Prerequisite:

sites: 520.349 or programming competence in 8080 or Z-80 assembly language and an understanding of logic gates.

Glaser 3 credits spring

520.454 (E,Q) Control Systems Design

Classical and modern control systems design methods. Topics include formulation of design specifications, classical design of compensators, state variable and observer based feedback. Computers are used extensively for design, and laboratory experiments are included. Prerequisites: 520.353, 110.201.

Iglesias 3 credits spring

520.457 (E,Q) Basic Quantum Mechanics for Engineers

Basic principles of quantum mechanics for engineers. Topics include the quantum theory of simple systems, in particular atoms and engineered quantum wells, the interaction of radiation and atomic systems, and examples of application of the quantum theory to lasers and solid-state devices. Prerequisites: 171.101-102, 520.219-220.

Kaplan 3 credits fall

520.460 (E) Introduction to Error Control Coding

Designs of error control codes and their decoders for digital communication systems are presented in an algebraic framework. Rate, minimum distance, and error correction and detection capabilities of linear block codes are presented. Generator and parity check matrices are introduced and decoders are developed. Families of cyclic codes are presented, including BCH and Reed-Solomon codes and their decoders. Performance analyses of error control codes demonstrate the contribution of coding to communications and provide bases upon which to compare codes. Prerequisites: probability and statistics 550.310 and competence in linear algebra.

Cooper 3 credits fall

520.465 Digital Communications

This course introduces the basic tools and topics of modern digital communication beginning with the mathematical representation and spectral properties of random signals and a basic introduction to the detection of real and complex signals in the presence of noise. Memoryless modulation and demodulation schemes are thoroughly studied for the Gaussian channel, and measures of performance are developed. Topics in wireless communication will be introduced. Prerequisites: 520.401, 550.310 or 550.420.

Cooper 3 credits spring

520.481 (E) Microwaves and High Speed Circuits

This course will introduce key concepts important to Microstrip circuits and will include: Propagation of waves in transmission lines with emphasis on microstrip circuits and design and analysis of couplers, matching circuits, amplifiers, filters, oscillators and high speed digital circuits. Extensive use is made of CAD tools. Prerequisites: 520.219-220.

Edwards 3 credits spring

520.482 (E) Introduction to Lasers

This course covers the basic principles of laser oscillation. Specific topics include propagation of rays and Gaussian beams in lenslike media, optical resonators, spontaneous and stimulated emission, interaction of optical radiation and atomic systems, conditions for laser oscillation, homogeneous and inhomogeneous broadening, gas lasers, solid state lasers, Q-switching and mode locking of lasers.

Staff 3 credits

520.484 (E) Optoelectronics Lab

This laboratory course involves designing and building optoelectronic circuits. Namely, laser diode drivers (CW and pulsed), oscillators, low-noise amplifier circuits, photodetector biasing circuits, and active filters will be designed, built, and tested. Prerequisites: 520.345 and permission of instructor.

Kang 3 credits spring

520.485 (E) Advanced Semiconductor Devices

This course is designed to develop and enhance the understanding of the operating principles and performance characteristics of the modern semiconductor devices used in high speed optical communications, optical storage, and information display. The emphasis is on device physics and fabrication technology. The devices include heterojunction bipolar transistors, high mobility FET's, semiconductor lasers, laser amplifiers, light-emitting diodes, solar cells, and others.

Khurgin 3 credits

520.491 CAD of Digital VLSI Systems

An introductory course in which students, manually and through computer simulations, design digital CMOS integrated circuits and systems. The design flow covers transistor, physical, and behavioral level descriptions, using SPICE, Layout, and VerilogHD1 VLSI CAD tools. After design computer verification, students can fabricate and test their semester-long class projects. Prerequisites: 520.142, 520.216, or equivalent. Recommended: 600.333, 600.334, 520.349 or 520.372.

Etienne-Cummings 3 credits fall

520.492 Mixed-Signal VLSI Systems

Silicon models of information and signal processing functions, with implementation in mixed analog and digital CMOS integrated circuits. Aspects of structured design, scalability, parallelism, low-power consumption, and robustness to process variations. Topics include digital-to-analog and analog-to-digital conversion, delta-sigma modulation, bioinstrumentation, and adaptive neural computation. The course includes a VLSI design project. Prerequisite: 520.491 or equivalent.

Cauwenberghs 3 credits spring

520.493 (E) Analog Integrated Circuits

The course will cover the basics of the theory and the design of wireless telecommunication circuits. Circuit blocks such as oscillators, phase locked loops, mixers, filters, R.F. and broadband amplifiers, modulators and demodulators as well as bias and support circuits such as band-gap voltage references will also be discussed. The

emphasis will be on bipolar transistor circuit design. The course will have weekly lectures, design and simulation assignments using CAD tools, and a small number of laboratory assignments. Prerequisites: 520.214 and 520.216.
Sotiriadis 3 credits

520.495 Microfabrication Laboratory

This laboratory course is an introduction to the principles of microfabrication for microelectronics, sensors, MEMS, and other synthetic microsystems that have applications in medicine and biology. Course comprises of laboratory work and accompanying lectures that cover silican oxidation, aluminum evaporation, photoresist deposition, photolithography, plating, etching, packaging, design and analysis CAD tools, and foundry services. Co-listed as 580.495 and 530.495. Permission of the instructor is required. Due to the popularity of this course registration is first come, first serve to undergraduates with senior standing only.

Andreou/Wang 4 credits fall

420.496-497 VLSI Design and Prototyping Workshop

Hands-on laboratory where students individually complete the design, layout, and testing of a VLSI circuit implementing a system-on-chip. Examples include CMOS computational imagers, video and speech coders, pattern recognition processors, and biointerfaces. Both semesters need to be completed in order to receive course credit. Chips are fabricated through MOSIS at the end of the first semester, and experimentally characterized in the second. Coursework includes in-class presentation of design and measured results. Pre-/co-requisites: 520.491, 520.492, or 520.493.

Cauwenberghs 3 credits

520.498-499 (E) Senior Design Project

Capstone design project, in which a team of students engineers a system and evaluates its performance in meeting design criteria and specifications. Example application areas are microelectronic information processing, image processing, speech recognition, control, communications, and biomedical instrumentation. The design needs to demonstrate creative thinking and experimental skills, and needs to draw upon knowledge in basic sciences, mathematics, and engineering sciences. Interdisciplinary participation, such as by biomedical engineering, mechanical engineering, and computer science majors, is strongly encouraged.

Staff 3 credits

520.501-502 Independent Study

Individual, guided study under the direction of a faculty member in the department. The program of study or research, including the credit to be assigned, must be worked out in advance between the student and the faculty member involved. May be taken either term by freshmen or sophomores.

Staff 1-3 credits 501-fall 502-spring

520.503-504 Independent Study

Individual study, including participation in research, under the guidance of a faculty member in the depart-

ment. The program of study or research time required, and credit assigned must be worked out in advance between the student and the faculty member involved. May be taken either term by juniors or seniors.

Staff 1-3 credits 503-fall 504-spring

520.505 Summer Independent Research

Independent study or research over the summer under the direction of a faculty member in the department. The program of research, including the credit to be assigned, must be worked out in advance between the student and the faculty member involved.

Staff 1-3 credits

520.545-546 Research

Independent study or research over the summer under the direction of a faculty member in the department. The program of research, including the credit to be assigned, must be worked out in advance between the student and the faculty member involved.

Staff 1-3 credits 545-fall, 546-spring

520.550 Electrical and Computer Engineering Internships

Staff 1-3 credits

520.574 Research (Intersession)

520.576 Independent Study (Intersession)

520.590 Senior Design Project (Summer)

520.595 Independent Study (Summer)

520.596 Independent Research

520.597 Research (Summer)

520.599 ECE Internships (Summer)

Graduate Courses

520.601 Introduction to Linear Dynamical Systems

A beginning graduate course in linear, time-invariant systems. Topics include state-equation representations, input-output representations, response properties, controllability, observability, realization theory, stability, and linear feedback. Prerequisites: undergraduate courses in control systems and linear algebra.

Rugh 3 hours

520.603 Electromagnetic Waves and Radiating Systems

Representation of the electromagnetic field: Maxwell's equations, potentials, boundary conditions, stress and energy, harmonic waves. Radiation, the antenna boundary value problems. Cavity resonators, theory of waveguides, refraction. Scattering by objects without edges, diffraction by obstacles with edges. Special topics.

Joseph 3 hours

520.604 Computational Electromagnetics

Various approximate techniques for solving Maxwell's equations are of vital importance to microwave and optical engineers. The three main computational approaches

in use today (Moment Method, Geometrical Theory of Diffraction, and Finite Difference-Time Domain) are developed.

Joseph, Thomas

520.605-606 Introduction to Solid State Physics

An introduction to solid state physics for advanced undergraduate and graduates students in physical science and engineering. Topics include crystal structure of solids: band theory; thermal, optical, and electronic properties; transport and magnetic properties of metals, semiconductors, and insulators; and superconductivity. The concepts and applications of solid state principles in modern electronic, optical, and structural materials are discussed. Prerequisite: quantum mechanics or permission of instructor.

Khurgin 3 hours

520.608 Image Reconstruction and Restoration

This course covers the principles and methods used to reconstruct images from remotely sensed data and to restore images from blurred and noisy observations. General variational and stochastic regularization methods for ill-posed inverse problems are covered. Those specific methods used in imaging problems, where the amount of data is typically huge, are presented in detail. Synthetic aperture radar and X-ray computed tomography serve as motivating examples throughout the course, and specific details for reconstruction and restoration within these applications are covered. Prerequisite: 520.651.

Prince 3 hours spring

520.610 Computational Functional Genomics

This class provides an introduction to mathematical and computational techniques for functional genomics, a growing area of research in cell biology and genetics whose objective is to understand the biological function of genes and their interactions. Computational functional genomics focuses on the problems of collecting, processing, and analyzing data related to genome-wide patterns of gene expression with the objective to discover mechanisms by which a cell's gene expression is coordinated. This has become feasible with the development of DNA microarray technology, which allows the simultaneous measurement of gene expression levels of thousand of genes. Several topics will be covered in this class. These include an introduction to cell biology (cells, genome, DNA, transcription, translation, control of gene expression, DNA and RNA manipulation), DNA microarray technology and experimental design, processing and analysis of microarray data (data reduction and filtering, clustering), and computational models for genetic regulatory networks (Boolean networks, Bayesian networks, ODE-based networks). Prerequisite: working knowledge of elementary probability and statistics. Co-listed with 580.610.

Goutsias 3 hours spring

520.614 Linear System Theory

A second course in state-variable representations for linear systems, with emphasis on multi-input, multi-output, nonstationary systems. Topics include solution properties,

periodic systems, stability concepts, controllability, observability, and realization theory.

Staff 3 hours

520.615 Linear Control Theory

A continuation of 520.614, with emphasis on basic properties of linear control problems. Topics include polynomial and rational fraction descriptions, stabilization, characterization of stabilizing controllers, and geometric approaches. Prerequisite: 520.614.

Staff 3 hours

520.617 Sampled Data Control

This course deals with multivariable, linear continuous-time plants connected to a discrete-time controller through ideal sample and hold circuitry. Topics include effects of sampling, intersample behavior, input-output stability, lifting and fast discretization. Prerequisite: undergraduate work on discrete-time control.

Iglesias 3 hours

520.619 Optical Communications

Fundamentals of direct and coherent (heterodyne) detection optical communication receivers. Topics include Poisson nature of photon detection; estimation and detection for photon counting receivers; marked, filtered, and doubly stochastic Poisson processes; and information theory for the photon communication channel.

Davidson 3 hours

520.621 Introduction to Nonlinear Systems

Nonlinear systems analysis techniques; phase-plane, limit cycles, harmonic balance, expansion methods, describing function. Liapunov stability. Popov criterion. Prerequisite: 520.601 or equivalent.

Staff 3 hours

520.623 Optical Propagation, Backgrounds, and Sensing

This course presents a unified perspective on optical propagation in linear media. A basic background is established using electromagnetic theory, spectroscopy, and quantum theory. Properties of the optical field and propagation media gases, liquids, and solids and their interaction are developed. Basic formulas on absorption line-strength and shape and Rayleigh scattering are developed and applied to atmospheric transmission, seawater propagation, optical windows, optical fibers, and remote sensing. A survey of experimental techniques and hardware is presented. Computer codes are discussed and demonstrated. Prerequisites: A course on electromagnetic theory and elementary quantum mechanics.

Thomas 3 hours fall

520.630 Introduction to the Calculus of Variations and Optimal Control

An introduction to standard results of variational calculus in the context of minimization problems in n-dimensional Euclidean space. The application of convexity concepts to such problems. Classical minimization problems and the Euler-Lagrange equations. The last part of the course introduces optimal control problems and the Pontryagin principle. Prerequisite: 110.405.

Rugh 3 hours

520.633 Introduction to Robust Control

An introduction to the robust analysis and control of linear systems. Topics include time and frequency response; norm characterizations of robustness and performance; deterministic and stochastic noise models; robust stability and performance; and optical control.

Iglesias 3 hours fall

520.636 Feedback Control in Biological Signaling Pathways

Signal transduction pathways in biological systems need to be precisely regulated. This control is done through feedback regulatory loops. In this course we formulate mathematical models of signaling pathways and analyze their behavior using engineering control theory. Prerequisites: Differential Equations, Control Theory.

Iglesias 3 hours fall

520.644 Pattern Theory: From Representation to Inference

This course examines the metric pattern theory of Ulf Grenander in which shapes and patterns are studied as random processes on graphs. The course begins with the study of Markov processes on directed acyclic graphs including Markov chains and branching processes, and on random fields on regular lattices. Moving to the continuum, we examine Gaussian random fields, second order representation theory, and random processes in space time, as well as random processes of geometric shape through Gaussian fields on manifolds. Numerous examples will be examined in image understanding and image analysis. Co-listed as 580.744.

Miller 3 hours spring

520.645 Adaptive Filtering

An introduction to the basic principles, mathematical theory, algorithmic design, and practical implementation of linear adaptive filters. Topics include adaptive least-mean-square and recursive-least-square algorithms, adaptive lattice structures, fast finite-precision implementations, and behavioral analysis. Prerequisite: 520.435.

Tran 3 hours fall/alternate years

520.646 Wavelets and Filter Banks

This course serves as an introduction to wavelets, filter banks, multirate signal processing, and time-frequency analysis. Topics include wavelet signal decompositions, bases and frames, QMF filter banks, design methods, fast implementations, and applications. Prerequisite: 520.435 DSP, C/C++ & Matlab programming experience, 110.201 Undergraduate Linear Algebra.

Tran 3 hours spring

520.651 Random Signal Analysis

A course covering second-order properties of random processes with applications in estimation and detection. A foundation course for further work in stochastic systems, signal processing, and communications. Prerequisites: elementary courses in probability, signals, and linear systems.

Staff 3 hours fall

520.652 Filtering and Smoothing

A course on least-squares estimation of random processes generated by linear systems. Topics include projections, square-root algorithms, initial and boundary value models. Prerequisite: 520.651.

Weinert 3 hours spring

520.653 Fundamental Non-linear Optics

Kaplan 3 hours

520.655 Foundations of Digital Communications

This course presents the theory of modulation and detection in digital communications. The optimum receiver for the Gaussian channel is presented. Classes of modulation schemes are studied, and the performance of each is compared with theoretical limits. How to deal with signal distortion caused by frequency selectivity is examined, and receivers for signals experiencing amplitude fading due to receiver and transmitter motion are discussed. Prerequisites: 520.651.

Cooper 3 hours

520.666 Information Extraction from Speech and Text

Introduction to statistical methods of speech recognition (automatic transcription of speech) and understanding. The course is a natural continuation of 600.465 but is independent of it. Topics include elementary information theory, hidden Markov models, efficient hypothesis search methods, statistical decision trees, the estimation-maximization (EM) algorithm, maximum entropy estimation, finite state transducers, context-free grammars, parsing, and the Baum, CYK, and Viterbi algorithms. Weekly assignments and several programming projects. Prerequisites: 550.310 or equivalent, expertise in C or C++ programming. Co-listed with 050.666 and 600.666.

Khudanpur/Jelinek 3 hours spring

520.673 Magnetic Resonance in Medicine

The course is an introduction to the field of magnetic resonance imaging. All of the basic principles of magnetic resonance imaging that are necessary to understand current literature are covered. Topics include: Bloch equations, imaging principles, excitation, image contrast mechanisms and instrumentation. Prerequisites: 520.214 or 580.222. Co-listed with 580.673.

Atalar 3 hours

520.674 Information Theoretic Methods in Statistics

Applications of information theory to probability theory and statistics will be discussed: entropy, mutual information and K-L divergence, data compression and channel coding, information geometry, maximum entropy methods, the E-M algorithm and alternating minimization, Sanov's theorem and large deviations, redundancy, MDL and universal data compression. Prerequisite: 550.420 or equivalent.

Khudanpur 3 hours spring

520.678 Automatic Speech Processing and Recognition

Introduction to core modeling techniques for automatic speech recognition (ASR). The course will examine a range of algorithms, including pattern recognition,

search techniques, acoustic modeling, and language modeling techniques. In addition, it will also delve into normalization of features and speaker adaptations. Students will build and test algorithms using public domain speech recognition software. Prerequisite: 520.651.

Shafran 3 hours spring

520.691 Optoelectronic VLSI

Advanced course on the design and analysis of integrated optoelectronic systems, such as CMOS imagers, active pixel sensors, CMOS and BiCMOS high speed OE receiver and transmitter arrays, CMOS compatible liquid crystal (LC) arrays. The course will address issues at the device, circuit, and architecture level. There will be weekly paper assignments, lectures, and projects including a final project to be fabricated through the MOSIS foundry. Prerequisite: 520.495 or permission of instructor.

Andreou 3 hours

520.725 Medical Microsystems

Fundamental and advanced fabrication processes for integrating diverse materials (including silicon) into microstructures and microdevices. Micropatterning, moulding, sensing, and actuation technologies. Research concepts and applications of microsystems at the molecular, cellular, and medical systems level. Applications such as DNA microarrays, drug and gene delivery, microsensors and actuators for research, microstructures for implants and microdevices for prostheses. Prerequisites: 580.471 or 580.495. Undergraduates by permission. Co-listed as 580.725.

Staff 3 hours

520.727-728 Quantum Electronics

Interaction or radiation with free and bound electrons, perturbation theory, density operator, and quantum statistics. An introduction to laser theory and nonlinear optics. Prerequisite: a 400 level course in Schroedinger wave equation quantum mechanics.

Kaplan 3 hours

520.735 Sensory Information Processing

Analysis of information processing in biological sensory organs and in engineered microsystems using the mathematical tools of communication theory. Natural or synthetic structures are modeled as microscale communication networks implemented under physical constraints, such as size and available energy resources and are studied at two levels of abstraction. At the information processing level we examine the functional specification, while at the implementation level we examine the physical specification and realization. Both levels are characterized by Shannon's channel capacity, as determined by the channel bandwidth, the signal power, and the noise power. The link between the information processing level and the implementation level of abstraction is established through first principles and phenomenological otherwise, models for transformations on the signal, constraints on the system, and noise that degrades the signals. Prerequisite: permission of instructor.

Andreou 3 hours

520.736 Seminar on Control and Systems Biology

This weekly seminar will focus on research issues in the use of control theory to study biological signal transduction pathways. The purpose of this course is to provide the students with background in research areas in computational, mathematical and systems biology. Each week, the participants will be assigned selected papers in these areas. While one student will lead the discussion, all students will be expected to have read the papers and to contribute to the discussion. Prerequisites: 520/580.636 or permission of instructor.

Iglesias 1.5 hours

520.738 Advanced Electronics Design Lab

This course is the graduate expansion of the 520.448 Electronic Design Lab, which is an advanced laboratory course in which teams of students design, build, test and document application specific information processing microsystems. Semester long projects range from sensors/actuators, mixed signal electronics, embedded microcomputers, algorithms and robotics systems design. Demonstration and documentation of projects are important aspects of the evaluation process. For this graduate expansion, all projects will be based on recently published research from IEEE Transactions. The students will be required to fully research, analyze, implement and demonstrate their chosen topic. The emphasis will be on VLSI microsystems, although other topics will also be considered. Prerequisite: graduate standing.

Etienne-Cummings 3 hours

520.745 Solid State Electronics

An introduction to the physical principles and operational characteristics of semiconductor devices. Topics will include semiconductor physics, junctions devices, MOS devices, surface effects, and defect models.

Staff 3 hours

520.746 Seminar on Medical Image Analysis

This weekly seminar will focus on research issues in medical image analysis, including image segmentation, registration, statistical modeling, and applications. It will also include selected topics relating to medical image acquisition, especially where they relate to analysis. The purpose of the course is to provide the participants with a thorough background in current research in these areas, as well as to promote greater awareness and interaction between multiple research groups within the university. The format of the course is informal. It will meet weekly for approximately one hour. Students will read selected papers. All students will be assumed to have read these papers by the time the paper is scheduled for discussion. Individual students will be assigned on a rotating basis to lead the discussion on particular papers or sections of papers. Co-listed as 600.746.

Taylor/Prince 1 credit

520.748 Seminar on Advanced Topics in MRI Research

This course builds on the Magnetic Resonance in Medicine course (520/580.473) and introduces current applications. The students will be exposed to existing research topics and become aware of the need for engineering

knowledge for the research. Topics covered include, but are not limited to, new imaging methods, signal and image processing, RF coil design, and challenging applications, such as imaging of the heart. Prerequisite 520/580.473 or permission of instructor. Co-listed with 580.748 .

Osman/Atalar 2 hours

520.753 Seminar on Optical Communication

A seminar devoted to advanced research topics on optical communications systems and devices. Prerequisite: 520.619.

Davidson 3 hours

520.760 Seminar on Geometric Control Theory

Topics include local/global decompositions of nonlinear control systems using smooth distributions on a manifold, the control Lie algebra, controlled invariant distributions, applications to disturbance decoupling and noninteracting control, and feedback linearization techniques. Prerequisites: 520.614, elementary background in differential topology or differential geometry, or permission of instructor.

Rugh 3 hours

520.761-762 Seminar on Large-Scale Analog Computation

Research seminar devoted to current research in the engineering of large-scale integrated analog systems. Topics include models for vision and auditory processing as well as implementation constraints and limitations.

Andreou 3 hours

520.763 Seminar on Solid State, Quantum Electronics and Nonlinear Optics

Research seminar on current research in the area of interaction of light with matter.

Kaplan 1.5 hours

520.765 Nonlinear Waves and Interactions in Optics and Electrodynamics

Nonlinear phenomena in optics and electrodynamics and their applications are discussed, with emphasis on the basic theory (classical and quantum) of the phenomena.

Kaplan 3 hours

520.766 Seminar in Error Control Coding

A seminar on new and emerging developments in error control coding will meet weekly to review and discuss those developments in seminar format. Participants will select topics from a suggested list or from areas of their own specific interest for presentation. An introductory knowledge of error control coding, such as is found in any major textbook, will be needed for satisfactory participation.

Cooper 2 hours

520.771-772 Advanced Integrated Circuits

Study of devices, circuits, and design methodology for analog computing systems, both MOS and bipolar. Students will use CAD tools to design and test circuits fabricated through the MOSIS service with special emphasis on integrated sensors and sensory systems and on micro-power integrated circuits for biomedical devices and instrumentation.

Andreou/Cauwenberghs 3 hours

520.773 Advanced Topics in Fabrication and Microengineering

Graduate-level course on topics that relate to microsystem integration of complex functional units across different physical scales from nano to micro and macro. Topics will include emerging fabrication technologies, micro-electromechanical systems, nanolithography, nanotechnology, soft lithography, self-assembly, and soft materials. Discussion will also include biological systems as models of microsystem integration and functional complexity. Prerequisite: permission of instructor required.

Andreou

520.774 Kernel Machine Learning

Statistical learning theory and kernel based pattern recognition. Topics include kernel methods, large margin classifiers, support vector machines, regularization networks, Gaussian processes, sparse approximation, and applications in vision and speech. Assignments include a class project and presentation of original work. Co-listed as 600.774.

Cauwenberghs 3 hours alternate years

520.776 Learning on Silicon

Silicon models of adaptive neural computation. Topics include online learning architecture, on-chip and chip-in-the-loop learning, support vector "machines" in silicon, analog and mixed-signal adaptive VLSI circuits, and technology directions. Students in groups will design and implement a learning machine on a chip fabricated through the MOSIS foundry.

Cauwenberghs 3 credits 1+ hours

520.778 Advanced Topics on Circuit Information Processing and Dynamics (Seminar)

There is vast number of important and challenging problems in modeling, optimizing, and designing circuits and complex circuit systems, that involve an extensive use of information, communication, optimization, control, and systems dynamics theory. The seminar intends to expose the students to the beauty of such interdisciplinary problems. Participating students are expected to have a fair graduate-level background in circuits and applied mathematics. Permission of instructor is required.

Sotiradis 3 hours

520.779 Advanced Topics in Spoken Language Systems

Research seminar devoted to the analysis of spoken language systems. Participants will discuss speech processing and language modeling themes in current language engineering literature. Laboratory projects of mutual interest to instructor and students may be undertaken. Registration by permission only.

Staff 1-3 hours fall

520.800 Independent Study

Individual, guided study under the direction of a faculty member in the department. May be taken either term by graduate students.

520.801-802 Dissertation Research

520.809-810 Special Studies

Individual study in an area of mutual interest to a student and a faculty member in the department.