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 four major areas:

1. systems, communications, and signal processing;
2. photonics and optoelectronics;
3. integrated electronics and computer engineering; and
4. information extraction from acoustic and visual signals.

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.

Current Research Activities

Systems, Communications, and Signal Processing

Current research in systems and control includes the development of analysis, design and state estimation techniques for hybrid and 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 and hybrid control algorithms. There is also a significant effort in systems biology, particularly the analysis of signaling pathways in biological systems. 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.

Photonics and Optoelectronics

Current research activities include work in fiber optic sensors and endoscopic 3-D imaging devices for medical applications, 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.

Integrated Electronics and 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.

Facilities

The department maintains extensive facilities for teaching and research in Barton Hall and Hackerman Hall. 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 cellular signaling control 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.

Financial Aid

Financial aid is available for candidates of high promise. Research assistantships are available on sponsored research projects directed by members of the faculty.

The Department of Electrical and Computer Engineering offers two bachelor’s degree programs: one in Electrical Engineering and one in Computer Engineering (with the close collaboration of the Computer Science Department). Each program is described below.

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 to prepare them for what graduates are expected to attain within a few years of graduation. The educational objectives of the EE program are:

- Our graduates will become successful practitioners in engineering and other diverse careers.
- Some graduates will pursue advanced degree programs in engineering and other disciplines.

Students graduating with a B.S. in electrical engineering will have demonstrated the ability to:

- Understand calculus-based 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.
- 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 a set of skills to be successful.

Each student and faculty advisor 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 advisor. The faculty advisor 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 the following:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.520.213</td>
<td>Circuits</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.214</td>
<td>Signals &amp; Systems I</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.219</td>
<td>Fields, Matter &amp; Waves</td>
<td>3</td>
</tr>
</tbody>
</table>

Choose one of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.520.345</td>
<td>Electrical &amp; Computer Engineering Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.349</td>
<td>Microprocessor Lab</td>
<td></td>
</tr>
<tr>
<td>EN.520.372</td>
<td>Programmable Device Lab</td>
<td></td>
</tr>
</tbody>
</table>

Advanced laboratory, design intensive, or senior design project courses 6

Total Credits 20

* Six (6) credits of advanced laboratory, design intensive, or senior design project courses from those given in the degree planning checklist. 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 Satisfactory/Unsatisfactory.

**Six (6) credits of engineering courses from School of Engineering departments other than ECE or Applied Mathematics and Statistics or General Engineering (note: Entrepreneurship and Management courses in the Center for Leadership Education CANNOT be counted as “other engineering courses”). 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 Satisfactory/Unsatisfactory.**

**Mathematics Department or the Applied Mathematics and Statistics Department (20 credits)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.109</td>
<td>Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.202</td>
<td>Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.201</td>
<td>Linear Algebra</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.302</td>
<td>Diff Equations/Applic</td>
<td>4</td>
</tr>
<tr>
<td>EN.550.310/311</td>
<td>Probability &amp; Statistics for the Physical and Information Sciences &amp; Engineering</td>
<td>4</td>
</tr>
<tr>
<td>or EN.550.420</td>
<td>Intro To Probability</td>
<td></td>
</tr>
</tbody>
</table>

Total Credits 20

* Courses in this group may not be taken Pass/Fail. Elementary or precalculus courses such as AS.110.105 Introduction to Calculus or EN.550.111 Statistical Analysis I - EN.550.111 Statistical Analysis I 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.)

**Basic Sciences (16)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.171.101</td>
<td>General Physics: Physical Science Major I</td>
<td>4</td>
</tr>
</tbody>
</table>
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.

### 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 advisor to educate students to prepare them for what graduates are expected to attain within a few years of graduation. The educational objectives of the CE program are:

- Our graduates will become successful practitioners in engineering and other diverse careers.
- Some graduates will pursue advanced degree programs in engineering and other disciplines.

Students graduating with a B.S. in computer engineering will have demonstrated the ability to:

- understand calculus 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.
- 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 a set of skills to be successful.

Each student and faculty advisor 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 advisor.

**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:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>EN.520.142</td>
<td>Digital Systems Fundamentals</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.213</td>
<td>Circuits</td>
<td>4</td>
</tr>
</tbody>
</table>

  a. Fifteen (15) credits of Electrical and Computer Engineering courses, which must include EN.520.142 Digital Systems Fundamentals, and .

  b. Fifteen (15) credits of Computer Science courses which must include EN.600.120 Intermediate Programming, EN.600.226 Data Structures and Computer System Fundamentals (EN.600.233 Computer System Fundamentals).

  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 degree planning checklist in Section I.C. At least six (6) of these 12 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 Satisfactory/Unsatisfactory.

- **Six (6) credits of engineering departments other than Computer Science, ECE, Applied Mathematics and Statistics, or General Engineering (note: Entrepreneurship and Management courses in the Center for Leadership Education CANNOT be counted as “other engineering courses”). 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 Satisfactory/Unsatisfactory.

- **Twenty-four (24) credits in mathematics courses taken from the Mathematics Department or the Applied Mathematics and Statistics Department. AS.110.109 Calculus II (For Physical Sciences and Engineering), AS.110.202 Calculus III, AS.110.201 Linear Algebra or EN.550.291 Lin Alg & Diff Equations, EN.550.171 Discrete Mathematics, EN.550.310 Probability & Statistics for the Physical and Information Sciences & Engineering/EN.550.311 Probability and Statistics for the Biological Sciences and Engineering or EN.550.420 Intro To Probability must be taken. Elementary or precalculus courses such as AS.110.105 or EN.550.111-EN.550.112 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 Satisfactory/Unsatisfactory.

- **Sixteen (16) credits of basic sciences (physics, chemistry, biology, earth and planetary sciences), which must include AS.171.101 General Physics:Physical Science Major I-AS.171.102 General Physics: Physical Science Majors II, AS.173.111 General Physics Laboratory I-AS.173.112 General Physics Laboratory II, and AS.030.101 Introductory Chemistry I. Courses in this category may not be taken Satisfactory/Unsatisfactory.

- **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 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 writing intensive requirements.

Additional details concerning advising and degree requirements are in the Computer Engineering Advising Manual. The B.S. in Computer Engineering degree program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

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**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.108 &amp; AS.110.109</td>
<td>Calculus I</td>
<td>8</td>
</tr>
<tr>
<td>AS.171.101 &amp; AS.171.102</td>
<td>General Physics: Physical Science Major I</td>
<td>8</td>
</tr>
<tr>
<td>AS.173.111 &amp; AS.173.112</td>
<td>General Physics Laboratory I</td>
<td>2</td>
</tr>
<tr>
<td>EN.520.137</td>
<td>Introduction To Electrical &amp; Computer Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.142</td>
<td>Digital Systems Fundamentals</td>
<td>3</td>
</tr>
<tr>
<td>EN.600.107</td>
<td>Introductory Programming in Java</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>H/S Elective</td>
<td>3</td>
</tr>
</tbody>
</table>

**Sophomore**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.202</td>
<td>Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>EN.550.291</td>
<td>Lin Alg &amp; Diff Equations</td>
<td>4</td>
</tr>
<tr>
<td>AS.030.101</td>
<td>Introductory Chemistry I</td>
<td>3</td>
</tr>
<tr>
<td>EN.600.226</td>
<td>Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.213</td>
<td>Circuits</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.214</td>
<td>Signals &amp; Systems I</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.216</td>
<td>Introduction To VLSI</td>
<td>3</td>
</tr>
<tr>
<td>EN.600.271</td>
<td>Automata &amp; Computation Theory</td>
<td>3</td>
</tr>
<tr>
<td>EN.600.120</td>
<td>Intermediate Programming</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>H/S Elective</td>
<td>3</td>
</tr>
</tbody>
</table>

**Junior**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.550.171</td>
<td>Discrete Mathematics</td>
<td>4</td>
</tr>
<tr>
<td>EN.600.318</td>
<td>Operating Systems</td>
<td>4</td>
</tr>
<tr>
<td>EN.600.233</td>
<td>Computer System Fundamentals</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.372</td>
<td>Programmable Device Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.345</td>
<td>Electrical &amp; Computer Engineering Laboratory</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Science Elective</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.349</td>
<td>Microprocessor Lab I</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>H/S Elective</td>
<td>6</td>
</tr>
</tbody>
</table>

**Senior**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>EN.550.310</td>
<td>Probability &amp; Statistics for the Physical and Information Sciences &amp; Engineering</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.448</td>
<td>Electronics Design Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.491</td>
<td>CAD Design of Digital VLSI Systems I (Seniors/Grads)</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.492</td>
<td>Mixed-Mode VLSI Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.495</td>
<td>Microfabrication Laboratory</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.424</td>
<td>FPGA Synthesis Lab</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Non-ECE/ECE/MathSci Engineering Electives</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>H/S Elective</td>
<td>6</td>
</tr>
</tbody>
</table>

**Total Credits: 127**

**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 courses.
- Twenty (20) credits of mathematics or mathematical statistics courses. Typically these include AS.110.108 Calculus I, AS.110.109 Calculus II (For Physical Sciences and Engineering), and AS.110.202 Calculus III or equivalent, and AS.110.201 Linear Algebra. Elementary or pre-calculus courses such as AS.110.105 or EN.550.111-EN.550.112 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).

**Minor in Robotics**

A minor in Robotics is offered by the Laboratory for Computational Sensing and Robotics. Detailed information regarding this program can be found at: https://lcsr.jhu.edu/Robotics_Minor.

**Minor in Computer-Integrated Surgery**

A minor in Computer-Integrated Surgery is offered by the Department of Computer Science. Detailed information regarding this program can be found at: https://lcsr.jhu.edu/Education/Undergraduate/CISminor.

**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.

Every graduate student in the Department of Electrical and Computer Engineering must follow a program approved by a faculty advisor in the department. The advisor assigned to the student upon admission may be changed, subject to the approval of the new advisor. 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 advisor.
- One of the following:
  - an original master’s essay,
  - a special project report, or
  - 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 (http://e-catalog.jhu.edu/archive/2013-14/grad-students/academic-policies/#graduationanddegreecompletiontext). 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.

For current faculty and contact information go to http://www.ece-jhu.org/index.php/people

**Faculty**

**Chair**

Jin U. Kang  
Jacob Suter Jammer Professor: fiber optic devices and lasers, biophotonics, optical imaging and sensing.

**Director of Undergraduate Programs**

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

**Director of Graduate Programs**

Pablo A. Iglesias  
Edward J. Schaefer Professor: systems biology, mathematical modeling of biological systems, control theory.

**Professors**

Andreas G. Andreou  
CMOS devices and integrated circuits, bioelectronics, nanoelectronics, life science microsystems, natural and synthetic sensory systems, neural computation.

Ralph R. Etienne-Cummings  
Mixed-signal VLSI, computational sensors, robotics, neuromorphic engineering.

John Goutsias  
Signal and image processing, computational systems biology, bioinformatics, modeling and analysis of complex networked systems.

Hynek Hermansky  
Emulating and integrating human-like processing strategies into speech engineering systems; neural information processing; human sensory perception; speech and speaker recognition; speech coding and enhancement; and machine learning.

Alexander E. Kaplan  

Jacob B. Khurgin  
Quantum electronics, nonlinear optics.

Gerard G. L. Meyer  
Parallel computing, computational methods, fault tolerant computing.

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

Howard L. Weinert  
Statistical signal and image processing.

**Associate Professor**

Sanjeev P. Khudanpur
Information theory, statistical language modeling.

Assistant Professors

Mounya Elhilali
Biological basis of sound and speech perception, neural signal processing, computational neuroscience, cognitive neuromorphic engineering.

Amy Foster
Silicon photonics, nonlinear optics, nanophotonics, integrated biophotonics.

Mark Foster
Ultrafast and nonlinear optics, all-optical signal processing, ultrafast phenomena and measurement, nonlinear dynamics.

Danielle C. Tarraf
Systems and control theory, with emphasis on hybrid systems; network analysis and control; automata theory, algebra, and combinatorics as they apply in systems and control.

Susanna M. Thon
Renewable energy conversion and storage, photovoltaics, optoelectronics, nanoengineering and nanophotonics, and scalable fabrication.

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

Joint, Part-Time, Visiting, and Emeritus Appointments

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

Sang Peter Chin
Assistant Research Professor; Ph.D., MIT. compressive sensing, Novel Signal Processing, Game Theory, Extremal graph theory, Differential geometry, and Quantum computing and verification.

Glenn A. Coppersmith
Assistant Research Scientist, Ph.D., Northeastern University.

Noah Cowan
Associate Professor (Mechanical Engineering): robotics, computer vision and control, mobile robotics and legged locomotion, biomechanics and bio-inspired robotics.

Yamac Dikmelik
Assistant Research Scientist.

Eric Frey
Professor (Radiology): algorithms for computed tomography, small animal X-ray microcomputed tomography, quantitative PET, SPECT and nuclear medicine imaging, image evaluation, scatter compensation in SPECT, simultaneous dual isotope SPECT and Monte Carlo simulation of radiation transport.

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.

Gregory D. Hager
Professor and Chair, Computer Science; Ph.D., University of Pennsylvania. Computer vision and robotics, medical devices and human-machine systems.

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

Aren Jansen
Assistant Research Professor: automatic speech recognition, sparse representations and models, unsupervised/semi-supervised learning, geometric structure of speech sounds, computational modeling of speech perception, manifold learning algorithms, novel applications of machine learning techniques.

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

Richard I. Joseph
Jacob Suter Jammer Professor Emeritus.

Moise H. Goldstein Jr.
Professor Emeritus.

C. Harvey Palmer Jr.
Professor Emeritus.

Junghoon Lee
Assistant Research Professor: 3-D reconstruction algorithms from cone-beam projections, limited angle tomography, computer assisted surgery, computational structural biology, nonlinear optimization, statistical signal & image processing/inverse problems.

Xingde Li
Associate Professor (Biomedical Engineering): medical imaging and MRI.

Elliot R. McVeigh
Professor (Biomedical Engineering): cardiovascular MRI, image guided therapy, novel MRI methods.

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

Dzung L. Pham
Associate Professor (Radiology): homeomorphic brain image segmentation, neuroanatomical atlases in MIPAV, robust tissue classification, statistical characterization of brain tissue in MRI.

Theodore O. Poehler
Research Professor: quantum electronics, solid state physics.

Philippe Pouliquen
Assistant Research Scientist: optoelectronic, mixed signal, low power VLSI, CAD tolls for VLSI.

Carey Priebe
Professor (Applied Mathematics and Statistics): computational statistics, kernel and mixture estimates, statistical pattern recognition, statistical image analysis, statistical inference for high-dimensional and graph data.

Wilson J. Rugh
Edward J. Schaefer Professor Emeritus.

Nitish Thakor
Professor (Biomedical Engineering): medical instrumentation, medical micro and nanotechnologies, neurological instrumentation, signal processing, and neural prosthesis.

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

Benjamin M. W. Tsui
Professor (Radiology): quantitative SPECT, PET and CT imaging techniques, image reconstruction methods, computer simulation tools and methods in imaging, image quality assessment, small animal SPECT, PET and CT imaging techniques.

Rene Vidal
Professor (Biomedical Engineering): computer vision (human motion, dynamic scene reconstruction, multiple view geometry, omnidirectional vision), machine learning (generalized component analysis and geometric clustering), robotics (vision-based control), control (identification of hybrid systems).

R. Jacob Vogelstein
Assistant Research Professor (Senior Professional Staff APL) VLSI: systems, neuro-morphic engineering, neural prosthesis systems.

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

C. Roger Westgate
Professor Emeritus.

Raimond Winslow
Professor (Biomedical Engineering): applied statistical learning, computational cell biology, cardiac electrophysiology, grid-based computing and data sharing for collaborative science.

For current course information and registration go to https://isis.jhu.edu/classes/

Courses

**EN.520.137. Introduction To Electrical & Computer Engineering. 3 Credits.**
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.
Instructor(s): T. Tran
Area: Engineering, Quantitative and Mathematical Sciences.

**EN.520.142. Digital Systems Fundamentals. 3 Credits.**
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.
Instructor(s): G. Meyer
Area: Engineering, Quantitative and Mathematical Sciences.

**EN.520.211. ECE Engineering Team Project. 1 Credit.**
This course introduces the student to the basics of engineering team projects. The student will become a member of and participate in the different aspects of an ECE team project over several semesters.
(Freshmen and Sophomores)
Instructor(s): J. Kang
Area: Engineering.

**EN.520.212. ECE Engineering Team Project (Freshmen and Sophomores). 1 Credit.**
This course introduces the student to the basics of engineering team projects. The student will participate in an ECE engineering team project as a member. The student is expected to participate in the different aspects of the project over several semesters. (Freshmen and Sophomores)
Permission of instructor required.
Instructor(s): J. Kang
Area: Engineering.

**EN.520.213. Circuits. 4 Credits.**
An introductory course on electric circuit analysis. Topics include time domain and frequency domain analysis techniques, transient and steady-state response, and operational amplifiers.

**Prerequisites: AS.110.108 and AS.110.109**
Instructor(s): H. Weinert
Area: Engineering.

**EN.520.214. Signals & Systems I. 4 Credits.**
An introduction to discrete-time and continuous-time signals and systems covers representation of signals and linear time-invariant systems and Fourier analysis.

**Prerequisites: Corequisite: AS.110.202**
Instructor(s): M. Elhilali
Area: Engineering, Quantitative and Mathematical Sciences.

**EN.520.216. Introduction To VLSI. 3 Credits.**
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. Recommended: EN.520.213.

**Prerequisites: EN.520.142 and recommended: 520.213**
Instructor(s): A. Andreou
Area: Engineering.

**EN.520.219. Fields,Matter & Waves. 3 Credits.**
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: Co-req: AS.110.202**
Instructor(s): M. Foster
Area: Engineering, Natural Sciences.
EN.520.220. Fields, Matter & Waves. 3 Credits.
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: EN.520.219 or equivalent
Instructor(s): M. Foster
Area: Engineering, Natural Sciences.

EN.520.222. Computer Architecture. 3 Credits.
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 CISC, traps and interrupt handling, two’s complement arithmetic, adders and ALUs, CSA’s Booth’s algorithm, multiplication and division, control unit design, microprogramming, dynamic versus static linking, memory systems and memory hierarchy, paging segmentation, cache hardware, cache organizations, and replacement policies.
Prerequisites: EN.520.142
Instructor(s): R. Jenkins
Area: Engineering.

EN.520.315. Introduction to Information Processing of Sensory Signals. 3 Credits.
An introductory course to basic concepts of information processing of human communication signals (sounds, images) in living organisms and by machine. Recommended Course Background: EN.520.214 (or EN.580.222) or consent of the instructor.
Instructor(s): H. Hermansky
Area: Engineering.

EN.520.326. Introduction to Optical Instruments. 3 Credits.
This course introduces the student to the programming of microprocessors at the machine level. 68HC08, 8051, and eZ8 microcontrollers are programmed in assembly language for embedded control purposes. The architecture, instruction set, and simple input/output operations are covered for each family. Upon completion, students can use these flash-based chips as elements in other project courses. Recommended Course Background: EN.520.142 or equivalent.
Instructor(s): R. Glaser
Area: Engineering.

EN.520.335. Control Systems. 3 Credits.
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).
Instructor(s): D. Tarraf
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.372. Programmable Device Lab. 3 Credits.
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 (PLAs 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. Recommended Course Background: EN.520.142 and EN.520.345
Instructor(s): R. Glaser
Area: Engineering.

EN.520.391. CAD Design of Digital VLSI Systems I (Juniors). 3 Credits.
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.
Instructor(s): F. Davidson
Area: Engineering.

EN.520.401. Basic Communication. 3 Credits.
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.
Instructor(s): F. Davidson
Area: Engineering.

EN.520.403. Introduction to Optical Instruments. 3 Credits.
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.
Instructor(s): F. Davidson
Area: Engineering.
EN.520.407. Introduction to the Physics of Electronic Devices. 3 Credits.
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 microwave 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: AS.171.101 AND AS.171.102 AND EN.520.219
Instructor(s): J. Khurgin
Area: Engineering.

EN.520.410. Fiber Optics & Devices. 3 Credits.
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. Recommended Course Background: EN.520.214, EN.520.219-EN.520.220, or equivalent.
Instructor(s): F. Davidson
Area: Engineering.

EN.520.414. Image Processing & Analysis. 3 Credits.
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.
Prerequisites: EN.520.214.
Instructor(s): J. Goutsias
Area: Engineering.

EN.520.415. Image Process & Analysis II. 3 Credits.
This course 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.
Prerequisites: EN.520.414
Instructor(s): J. Goutsias
Area: Engineering.

EN.520.419. Iterative Algorithms. 3 Credits.
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: AS.110.201-202.
Instructor(s): G. Meyer
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.420. Theory & Design of Iterative Algorithms II. 3 Credits.
This course is a continuation of EN.520.419. It covers information on the non-deterministic schema and cyclic iterative schemas, Jacobsian, Hessians and Mean Value Theorems, spectral norm, convex sets and positive definite majs. Prerequisite: EN.520.419
Prerequisites: Prerequisite: EN.520.419
Instructor(s): G. Meyer
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.424. FPGA Synthesis Lab. 3 Credits.
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.
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.425. FPGA Senior Projects Laboratory. 3 Credits.
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. Senior status, no exceptions.
Prerequisites: Prereq: 520.424 and senior status,
Instructor(s): R. Jenkins
Area: Engineering.

EN.520.427. Product Design Lab. 3 Credits.
This project-based course is designed to help students learn how to turn their ideas into commercial products. In the first half of the course, emphasis will be placed on the product development process: student teams will gradually build up a complete "contract book" including a mission statement, competitive analysis, patent review, product specifications, system schematics, economic analysis, development schedule, etc. In the second half of the course, each team will be expected to implement its design and demonstrate a prototype of their product's core functionality. At the end of the semester, a final written report will be submitted in the form of a utility patent. Students are encouraged to take this course in conjunction with Electronic Design Lab (ECE 520.448) in the Spring semester and leverage the groundwork developed here to enable production of a fully functional and marketable prototype by the end of the academic year.
Instructor(s): P. Poulilquen
Area: Engineering.
EN.520.429. Principles of Parallel Programming. 3 Credits.
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. Students should be proficient in programming in the C language.
Instructor(s): L. Podrazik
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.432. Medical Imaging Systems. 3 Credits.
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. Co-listed as EN.580.472
Instructor(s): J. Prince
Area: Engineering.

EN.520.433. Medical Image Analysis. 3 Credits.
This course covers the principles and algorithms used in the processing and analysis of medical images. Topics include, interpolation, registration, enhancement, feature extraction, classification, segmentation, quantification, shape analysis, motion estimation, and visualization. Analysis of both anatomical and functional images will be studied and images from the most common medical imaging modalities will be used. Projects and assignments will provide students experience working with actual medical imaging data.
Prerequisites: EN.520.432 OR EN.580.472 OR EN.550.310 OR EN.550.311
Instructor(s): J. Prince
Area: Engineering.

EN.520.434. Modern Biomedical Imaging Instrumentation and Techniques. 3 Credits.
An intermediate biomedical imaging course covering modern biomedical imaging instrumentation and techniques as applied to diagnostic radiology and other biomedical applications. It includes recent advances in various biomedical imaging modalities, multi- modality imaging and molecular imaging. The course is team taught by experts in the respective fields and provides a broad based knowledge of modern biomedical imaging to prepare students for graduate studies and research in biomedical imaging. Also, the course will offer tours and practical experience with modern biomedical imaging equipments in clinical and research settings. Co-listed with EN.580.473
Prerequisites: EN.520.432 OR EN.580.472
Instructor(s): B. Tsui.

EN.520.435. Digital Signal Processing. 4 Credits.
Methods for processing discrete-time signals. Topics include signal and system representations, z- transforms, sampling, discrete Fourier transforms, fast Fourier transforms, digital filters.
Prerequisites: EN.520.214.
Instructor(s): H. Weinert
Area: Engineering.

EN.520.443. Digital Multimedia Coding and Processing. 3 Credits.
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. Recommended Course Background: EN.520.435, experience with Matlab and/or C/C++ programming.
Instructor(s): T. Tran
Area: Engineering.

EN.520.445. Audio Signal Processing. 3 Credits.
This course gives a foundation in current audio and speech technologies, and covers techniques for sound processing by processing and pattern recognition, acoustics, auditory perception, speech production and synthesis, speech estimation. The course will explore applications of speech and audio processing in human computer interfaces such as speech recognition, speaker identification, coding schemes (e.g. MP3), music analysis, noise reduction. Students should have knowledge of Fourier analysis and signal processing.
Instructor(s): M. Elhilali
Area: Engineering.

EN.520.447. Information Theory. 3 Credits.
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 (optimal portfolios), probability theory (large deviations), and statistics (Fisher information, hypothesis testing).
Instructor(s): S. Khudanpur
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.448. Electronics Design Lab. 3 Credits.
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. Recommended:
EN.600.333, EN.600.334, EN.520.349, EN.520.372, EN.520.490 or EN.520.491.
Prerequisites: EN.520.345 or equivalent Recommended: 600.333, 600.334, 520.216, 520.349, 520.372, 520.490 or 520.491.
Instructor(s): P. Pouliquen.

EN.520.450. Advanced Micro-Processor Lab. 3 Credits.
This course covers the usage of common microcontroller peripherals. Interrupt handling, timer operations, serial communication, digital to analog and analog to digital conversions, and flash ROM programming are done on the 68HC08, 8051, and eZB microcontrollers. Upon completion, students can use these flash-based chips as elements in other project courses. Recommended Course Background: EN.520.349
Instructor(s): R. Glaser.
**EN.520.452. Advanced ECE Engineering Team Project. 3 Credits.**
This course introduces the student to running an ECE engineering team project. The student will participate in the team project as a leading member and is expected to manage both the team members and the different aspects of the project over several semesters. Permission of the instructor is required for new team members. (Junior and Seniors) Instructor(s): J. Kang  
Area: Engineering.

**EN.520.453. Advanced ECE Engineering Team Project. 3 Credits.**
The course introduces the student to running an engineering team project. The student will participate in the ECE engineering team project as a leading member. The student is expected to participate in the different aspects of the project over several semesters and manage both team members and the project. (Juniors and Seniors) Permission of instructor is required. Instructor(s): J. Kang  
Area: Engineering.

**EN.520.454. Control Systems Design. 3 Credits.**
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 exercises are included.  
Prerequisites: EN.520.353 AND AS.110.201  
Area: Engineering, Natural Sciences.

**EN.520.457. Basics of Wave and Quantum Mechanics. 3 Credits.**
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. Recommended Course Background: AS.171.101-AS.171.102 and EN.520.219-EN.520.220  
Instructor(s): A. Kaplan  
Area: Engineering, Natural Sciences.

**EN.520.465. Digital Communications I. 3 Credits.**
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. Recommended Course Background: EN.520.401, EN.550.310 or EN.550.420  
Instructor(s): F. Davidson  
Area: Engineering, Quantitative and Mathematical Sciences.

**EN.520.466. Digital Communication II. 3 Credits.**
Achieving reliable and efficient digital communications over noisy channels is studied. Shannon’s Noisy Channel Coding Theorem provides the basis and the goal. Bounds on code performance in noisy channels are developed. Important block and convolutional codes and codes on graphs are examined jointly with their respective decoders.  
Prerequisites: EN.520.401 AND AS.110.201  
Instructor(s): A. Hammons  
Area: Engineering, Quantitative and Mathematical Sciences.

**EN.520.473. Magnetic Resonance in Medicine. 3 Credits.**
This course provides a wide-ranging introduction to the physics and principles of magnetic resonance imaging (MRI). Topics include the resonance phenomenon, relaxation, signal formation, spatial localization, image contrast, hardware, signal processing, and image reconstruction. MATLAB simulation exercises will demonstrate key aspects of MRI and a laboratory component using the clinical MRI systems at the School of Medicine will reinforce concepts learned in class. Textbook “Principles of Magnetic Resonance Imaging” by D. Nishimura (from www.lulu.com) should be obtained before the start of the course. Recommended Course Background: (EN.520.434 or EN.580.473) or (EN.520.432 or EN.580.472). Co-listed with EN.580.476 and EN.580.673.  
Instructor(s): D. Herzka; P. Bottomley; W. Edelstein  
Area: Engineering, Natural Sciences.

**EN.520.481. Microwaves and High Speed Circuits. 3 Credits.**
Instructor(s): C. Westgate  
Area: Engineering.

**EN.520.482. Introduction to Lasers. 3 Credits.**
This course covers the basic principles of laser oscillation. Specific topics include propagation of rays and Gaussian beams in lens-like 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.  
Prerequisites: EN.520.219 AND EN.520.220  
Instructor(s): J. Khurgin  
Area: Engineering, Natural Sciences.

**EN.520.483. Bio-Photonics Laboratory. 3 Credits.**
This laboratory course involves designing a set of basic optical experiments to characterize and understand the optical properties of biological materials. The course is designed to introduce students to the basic optical techniques used in medicine, biology, chemistry and material sciences.  
Instructor(s): J. Khurgin.

**EN.520.485. Advanced Semiconductor Devices. 3 Credits.**
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, detectors, solar cells and others.  
Instructor(s): J. Khurgin  
Area: Engineering, Natural Sciences.

**EN.520.487. Intro To MEMS. 3 Credits.**
Area: Engineering, Natural Sciences.

**EN.520.491. CAD Design of Digital VLSI Systems I (Seniors/Grads). 3 Credits.**
Seniors and Graduate Students Only  
Instructor(s): P. Pouliquen  
Area: Engineering.
EN.520.492. Mixed-Mode VLSI Systems. 3 Credits.
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. Recommended Course Background: EN.521.491 or equivalent.
Area: Engineering.

EN.520.495. Microfabrication Laboratory. 4 Credits.
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 silicon oxidation, aluminum evaporation, photore sist deposition, photolithography, plating, etching, packaging, design and analysis CAD tools, and foundry services. Seniors only or Perm. Req’d. Co-listed as EN.580.495 & EN.530.495
Instructor(s): A. Andreou; J. Wang
Area: Engineering, Natural Sciences.

EN.520.498. Senior Design Project. 3 Credits.
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 micro-electronic 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. Instructor permission required.
Instructor(s): Staff
Area: Engineering.

EN.520.499. Senior Design Project. 3 Credits.
Capstone design project, in which a team of students engineer a system and evaluate 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.
Instructor(s): A. Andreou; J. Kang; J. Prince; J. West
Area: Engineering.

EN.520.501. Independent Study-Freshmen-Sophomores. 3 Credits.
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. Instructor permission required.
Instructor(s): A. Andreou; J. Kang; J. Prince.

EN.520.502. Indep Study - Fresh/Soph. 0 - 3 Credit.
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.

EN.520.503. Independent Study-Juniors-Seniors. 3 Credits.
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 juniors or seniors. Instructor permission required.
Instructor(s): Staff.

EN.520.504. Independent Study - Juniors/Seniors. 0 - 3 Credit.
Individual study, including participation in research, under the guidance of a faculty member in the department. 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.
Instructor(s): Staff.

EN.520.515. Processing of Audio and Visual Signals. 3 Credits.
This course consists of two parts. The lecture component of this course is covered by attending EN.520.315. Concurrently, on the more advanced graduate level, there is an additional requirement of critical analysis of the material covered, and the hands-on homework complementing the lectures. Recommended Course Background: EN.520.214 (or EN.580.222) or consent of the instructor.
Instructor(s): H. Hermansky
Area: Engineering.

EN.520.545. Research. 3 Credits.
Instructor Approval Required. 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.
Instructor(s): A. Andreou; F. Davidson; J. West; P. Iglesias; T. Tran.

EN.520.548. Independent Research. 0 - 3 Credit.
Instructor(s): Staff.

EN.520.550. Electrical Engineering - Internship. 0 - 3 Credit.
Instructor(s): J. Kang; T. Tran.

EN.520.595. Independent Study. 3 Credits.
Instructor(s): A. Andreou; J. Kang; J. West; R. Etienne Cummings.

EN.520.597. Research-Summer. 3 Credits.
Instructor(s): F. Davidson; J. West; P. Iglesias; R. Etienne Cummings; T. Tran.

EN.520.599. Internship-Summer. 1 Credit.
Instructor(s): F. Davidson; J. Kang; M. Miller.

Seminar for Electrical & Computer Engineering; required of all doctoral students who have not passed the qualifying exam. Repeatable course.
Instructor(s): P. Iglesias
Area: Engineering, Natural Sciences.

EN.520.601. Introduction to Linear Systems Theory.
A beginning graduate course in multi-input multi-output, linear, time-invariant systems. Topics include state-space and input-output representations; solutions and their properties; multivariable poles and zeros; reachability, observability and minimal realizations; stability; system norms and their computation; linearization techniques. Recommended Course Background: Undergraduate courses in control systems and linear algebra.
Instructor(s): D. Tarraf.
EN.520.608. Image Reconstruction & 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 will be 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 will serve as motivating examples throughout the course, and specific details for reconstruction and restoration within these applications are covered. Recommended Course Background: EN.520.651.

EN.520.610. Comput Funct 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. Topics covered: 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). Co-listed with EN.580.610. Students should have working knowledge of elementary probability and statistics.
Instructor(s): J. Goutsias.

EN.520.611. Ultrafast Optical Phenomena.
This course will give an introduction to the field of ultrafast phenomena which studies processes in nature and engineering occurring on the shortest of time scales. Topics will include the complex representation of ultrafast optical signals, nonlinear optics, pulse propagation effects resulting from dispersion and nonlinearities, the fundamentals of ultrafast sources including mode locking and amplification, ultrafast measurement techniques, and the wide range of cutting-edge applications of ultrafast sources.
Area: Engineering, Natural Sciences.

EN.520.612. Advanced 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. Recommended Course Background: EN.520.214, EN.520.219-EN.520.220 or equivalent.
Area: Engineering.

EN.520.618. Hybrid Systems.
This graduate level seminar style class focuses on the emerging field of hybrid systems. Topics covered include mathematical models of hybrid systems, analysis and controller synthesis techniques, and model complexity reduction.
Prerequisites: EN.520.601 OR EN.530.616 OR EN.580.616
Instructor(s): D. Tarraf
Area: Engineering.

EN.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.
Instructor(s): F. Davidson.

This course covers information on the non-deterministic schema and cyclic iterative schemas, Jacobians, Hessians and Mean Value Theorems, spectral norm, convex sets and positive definite majs.

EN.520.621. Introduction To Nonlinear Systems.
Instructor(s): P. Iglesias
Area: Engineering, Natural Sciences.

By employing fundamental concepts from diverse areas of research, such as statistics, signal processing, biophysics, biochemistry, cell biology, and epidemiology, this course introduces a multidisciplinary and rigorous approach to the modeling and computational analysis of complex interaction networks. Topics to be covered include: overview of complex nonlinear interaction networks and their applications, graph-theoretic representations of network topology and stoichiometry, stochastic modeling of dynamic processes on complex networks and master equations, Langevin, Poisson, Fokker-Plank, and moment closure approximations, exact and approximate Monte Carlo simulation techniques, time-scale separation approaches, deterministic and stochastic sensitivity analysis techniques, network thermodynamics, and reverse engineering approaches for inferring network models from data.
Instructor(s): J. Goutsias.

EN.520.624. Integrated Photonics.
This course gives an introduction to integrated photonics. Topics include: material platforms, fabrication approaches, devices and device operation, numerical modeling, nonlinear processes, and applications. Devices discussed include waveguides, resonators, sensors, modulators, detectors, lasers and amplifiers. Recommended Course Background: EN.520.219-EN.520.220, EN.520.495, or equivalent.
Instructor(s): A. Foster
Area: Engineering, Natural Sciences.

EN.520.627. Photovoltaics and Energy Devices.
This course provides an introduction to the science of photovoltaics and related energy devices. Topics covered include basic concepts in semiconductor device operation and carrier statistics; recombination mechanisms; p-n junctions; silicon, thin film, and third generation photovoltaic technologies; light trapping; and detailed balance limits of efficiency. Additionally, thermophotovoltaics and electrical energy storage technologies are introduced. A background in semiconductor device physics (EN.520.485, or similar) is recommended.
Instructor(s): S. Thon.
EN.520.633. Intro To Robust Control.
The subject of this course is robust analysis and control of multivariable systems. Topics include system analysis (small gain arguments, integral quadratic constraints); parametrization of stabilizing controllers; $\mathcal{H}_\infty$ optimization based robust control design; and LTI model order reduction (balanced truncation, Hankel reduction). Recommended Course Background: EN.520.601 or EN.530.616 or EN.580.616
Instructor(s): D. Tarraf
Area: Engineering, Natural Sciences.

EN.520.636. Signaling Pathways.
Instructor(s): P. Iglesias.

EN.520.646. Wavelets & 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. Recommended Course Background: EN.520.435, AS.110.201, C/C++ and Matlab programming experience.
Instructor(s): T. Tran.

EN.520.648. Compressed Sensing and Sparse Recovery.
Sparsity has become a very important concept in recent years in applied mathematics, especially in mathematical signal and image processing, as in inverse problems. The key idea is that many classes of natural signals can be described by only a small number of significant degrees of freedom. This course offers a complete coverage of the recently emerged field of compressed sensing, which asserts that, if the true signal is sparse to begin with, accurate, robust, and even perfect signal recovery can be achieved from just a few randomized measurements. The focus is on describing the novel ideas that have emerged in sparse recovery with emphasis on theoretical foundations, practical numerical algorithms, and various related signal processing applications. Recommended Course Background: Undergraduate linear algebra and probability.
Instructor(s): S. Khudanpur.

EN.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. Recommended Course Background: elementary courses in probability, signals, and linear systems.
Instructor(s): S. Khudanpur.

EN.520.652. Filtering & Smoothing.
Random Signal Analysis, or equivalent, plus some background in linear algebra and matrix theory. This course is intended to give students an opportunity to do directed research in algorithm development that culminates in a MATLAB program. Students will learn about extracting signals from noise using statistical and non-statistical models. Topics include Kalman filtering, smoothing, interpolation (upsampling), spline fitting, and the numerical linear algebra issues that impact these problems. Emphasis is on fast, compact, stable algorithms. The grade is based on the term project and occasional homework. There are no examinations. Class attendance is mandatory.
Prerequisites: Some background in linear algebra, matrix theory, random signals, and MATLAB.
Instructor(s): H. Weinert.

EN.520.666. Information Extraction.
Introduction to statistical methods of speech recognition (automatic transcription of speech) and understanding. The course is a natural continuation of EN.600.465 but is independent of it. Topics include elementary information theory, hidden Markov models, the Baum and Viterbi algorithms, efficient hypothesis search methods, statistical decision trees, the estimation-maximization (EM) algorithm, maximum entropy estimation and estimation of discrete probabilities from sparse data for acoustic and language modeling. Co-listed as EN.600.666.
Recommended Course Background: EN.550.310 and EN.600.120 or equivalent, expertise in C or C++ programming.
Instructor(s): S. Khudanpur.

EN.520.671. Brain Computer Interfaces.
In this course, students will learn state-of-the-art techniques in Brain-Computer Interfaces (BCI) through readings and hands-on work with multi-channel electroencephalographic (EEG) neural recording systems. The class will meet once a week to review a paper or book chapter about BCI technologies, but the bulk of the work will be conducted in the lab, where each student team will be provided with an EEG hardware/software package and design, develop and demonstrate a BCI application. A competition will be held at the end of the semester to judge the best and most innovative projects. There are no formal prerequisites, but students are expected to be proficient in software programming (C and Matlab), signal processing, machine learning and experimental design. Knowledge of neuroscience is not required but may be useful. Grad students only. Graded on a Satisfactory/ Unsatisfactory basis.
Instructor(s): F. Tenore; R. Vogelstein
Area: Engineering, Natural Sciences.

EN.520.673. Magnetic Resonance/Medic.
This course provides a wide-ranging introduction to the physics and principles of magnetic resonance imaging (MRI). Topics include the resonance phenomenon, relaxation, signal formation, spatial localization, image contrast, hardware, signal processing, and image reconstruction. MATLAB simulation exercises will demonstrate key aspects of MRI and a laboratory component using the clinical MRI systems at the School of Medicine will reinforce concepts learned in class. Textbook "Principles of Magnetic Resonance Imaging" by D. Nishimura (from www.lulu.com) should be obtained before the start of the course. Recommended Course Background: (EN.520.434 or EN.580.473) or (EN.520.432 or EN.580.472). Co-listed with EN.580.476 and EN.580.673.
Instructor(s): D. Herzka; P. Bottomley; W. Edelstein.

EN.520.680. Speech and Auditory Processing by Humans and Machines.
This graduate level seminar focuses on works that are relevant to building advanced systems for information extraction from auditory signals. It loosely compliments and expands on the lecture material from the graduate course EN.520.515. Participants will take turns in presenting and critically discussing selected topics, with an aim of using this knowledge in their research projects. When available, guest speakers may at times contribute or substitute for the presentation of the participants. Recommended Course Background: Completion or concurrent participation in EN.520.515 or consent of the instructor.
Instructor(s): H. Hermansky.

EN.520.682. Computational & Systems Neuroscience.
Instructor(s): M. Elhilali.

EN.520.691. Optoelectronic Microsystems.
EN.520.701. Current Topics in Language and Speech Processing. This biweekly seminar will cover a broad range of current research topics in human language technology, including automatic speech recognition, natural language processing and machine translation. The Tuesday seminars will feature distinguished invited speakers, while the Friday seminars will be given by participating students. A minimum of 75% attendance and active participation will be required to earn a passing grade. Grading will be S/U.
Instructor(s): S. Khudanpur.

EN.520.702. Current Topics in Language and Speech Processing. This biweekly seminar will cover a broad range of current research topics in human language technology, including automatic speech recognition, natural language processing and machine translation. The Tuesday seminars will feature distinguished invited speakers, while the Friday seminars will be given by participating students. A minimum of 75% attendance and active participation will be required to earn a passing grade. Cross-listed with Computer Science. Grading will be S/U.
Instructor(s): S. Khudanpur
Area: Engineering.

EN.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.
Instructor(s): A. Andreou.

EN.520.736. Seminar on Control in 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: EN.520.636 OR EN.580.636 or permission of instructor
Instructor(s): P. Iglesias.

EN.520.738. Advanced Electronic Lab Design. This course is the graduate expansion of the EN.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. Open to graduate students only.
Instructor(s): P. Poulouqen.

EN.520.744. Seminar in CISST. Current research topics in computer integrated surgery, presented primarily by pre-eminent invited speakers in the field.

EN.520.746. Seminar: 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 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 1.5 hours. Students will read selected papers and will be assigned on a rotating basis to lead the discussion. Co-listed as EN.600.746.
Instructor(s): J. Prince.

EN.520.761. Large Scale Analog Compt. Instructor(s): A. Andreou; R. Etienne Cummings.

EN.520.762. 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.
Instructor(s): A. Andreou; R. Etienne Cummings
Area: Engineering.

Instructor(s): A. Kaplan
Area: Engineering, Natural Sciences.

EN.520.771. Advanced Integrated Circuits. Instructor(s): A. Andreou; R. Etienne Cummings.

EN.520.772. Advanced Integrated Circuits.

EN.520.773. Advanced Topics In Microsytem Fabrication. 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. Perm. Req’d.
Instructor(s): A. Andreou.
EN.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.
Instructor(s): Staff.

EN.520.801. Dissertation Research.

EN.520.802. Dissertation Research.
Instructor(s): Staff.

EN.520.809. Special Studies.
Individual study in an area of mutual interest to a student and a faculty member in the department. Permission of Instructor required.

EN.520.810. Special Studies.
Individual study in an area of mutual interest to a student and a faculty member in the department.
Instructor(s): M. Thomas; R. Jenkins; R. Joseph.

EN.520.890. Independent Study-Summer.
Instructor(s): Staff.

Cross Listed Courses

General Engineering

EN.500.745. Seminar in Computational Sensing and Robotics.
Seminar series in robotics. Topics include: Medical robotics, including computer-integrated surgical systems and image-guided intervention. Sensor based robotics, including computer vision and biomedical image analysis. Algorithmic robotics, robot control and machine learning. Autonomous robotics for monitoring, exploration and manipulation with applications in home, environmental (land, sea, space), and defense areas. Biorobotics and biomechanics, including devices, algorithms and approaches to robotics inspired by principles in biomechanics and neuroscience. Human-machine systems, including haptic and visual feedback, human perception, cognition and decision making, and human-machine collaborative systems. Cross-listed Mechanical Engineering, Computer Science, Electrical and Computer Engineering, and Biomedical Engineering.
Instructor(s): Staff.

Materials Science Engineering

EN.510.314. Electron Prop-Material. 3 Credits.
Fourth of the Introduction to Materials Science series, this course is devoted to a study of the electronic, optical and magnetic properties of materials. Lecture topics include electrical and thermal conductivity, thermoelectricity, transport phenomena, dielectric effects, piezoelectricity, and magnetic phenomena. Recommended Course Background: EN.510.311 and EN.510.202 or another programming course or permission of instructor.
Instructor(s): T. Poehler
Area: Engineering, Natural Sciences.

EN.510.418. Electronic and Photonic Processes and Devices. 3 Credits.
This course is intended for advanced undergraduates and graduate students and will cover the fundamentals and properties of electronic and optical materials and devices. Subject matter will include a detailed and comprehensive discussion of the physical processes underlying modern electronic and optical devices. Detailed descriptions of modern semiconductor devices such as lasers and detectors used in optical communications and information storage and processing will be presented. Also listed as EN.510.618/EN.510.418.
Instructor(s): T. Poehler
Area: Engineering, Natural Sciences.

An introduction to solid state physics for advanced undergraduates and graduate 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. The concepts of solid state principles in modern electronic, optical, and structural materials are discussed. Cross-listed with Electrical and Computer Engineering.
Instructor(s): T. Poehler.

Basic solid state physics principles applied to modern electronic, optical, and structural materials. Topics discussed will include magnetism, superconductivity, polymers, nano-structured materials, electronic effects, and surface physics. For advanced undergraduates and graduate students in physical science and engineering. Recommended Course Background: EN.510.611
Instructor(s): T. Poehler.

EN.510.618. Electronic and Photonic Processes and Devices.
This course is intended for advanced undergraduates and graduate students and will cover the fundamentals and properties of electronic and optical materials and devices. Subject matter will include a detailed and comprehensive discussion of the physical processes underlying modern electronic and optical devices. Detailed descriptions of modern semiconductor devices such as lasers and detectors used in optical communications and information storage and processing will be presented. Also listed as EN.510.618/EN.510.418.
Instructor(s): T. Poehler.

Mechanical Engineering

EN.530.616. Introduction to Linear Systems.
This course examines linear, discrete- and continuous-time, and multi-input-output systems in control and related areas. Least squares and matrix perturbation problems are considered. Topics covered include state-space models, stability, controllability, observability, transfer function matrices, realization theory, feedback compensators, state feedback, optimal regulation, observers, observer-based compensators, measures of control performance, and robustness issues using singular values of transfer functions. ME EN.530.616 can be used to fulfill the requirement of BME EN.580.616 or ECE EN.520.601.
Instructor(s): N. Cowan.

Biomedical Engineering

EN.580.472. Topics in Medical Imaging Systems. 3 Credits.
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. Cross-listed with Neuroscience and Electrical and Computer Engineering (EN.520.432).
Instructor(s): J. Prince
Area: Engineering.
**EN.580.616. Introduction to Linear Dynamical Systems.**
This course examines linear, discrete- and continuous-time, and multi-input-output systems in control and related areas. Least squares and matrix perturbation problems are considered. Topics covered include state-space models, stability, controllability, observability, transfer function matrices, realization theory, feedback compensators, state feedback, optimal regulation, observers, observer-based compensators, measures of control performance, and robustness issues using singular values of transfer functions. BME EN.580.616 can be used to fulfill the requirement of ME EN.530.616 or ECE EN.520.601.
Instructor(s): S. Sarma.

**Computer Science**

**EN.600.604. Current Topics in Language & Speech Processing.**
CLSP seminar series, for any students interested in current topics in language and speech processing.
Instructor(s): S. Khudanpur.