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, control, 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, Control, 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.

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 (http://e-catalog.jhu.edu/departments-program-requirements-and-courses/engineering/computer-science)). Each program is described below. Both degree programs are accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Bachelor of Science in Electrical Engineering

Mission

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.

**Educational Objectives**

The Program Educational Objectives (PEOs) for electrical engineering (EE) at the Johns Hopkins University describe what EE graduates are expected to attain within a few years of graduation. The PEOs are determined in consultation with the Electrical and Computer Engineering External Advisory Committee and approved by the ECE faculty.

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.

**Outcomes**

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

• An ability to apply knowledge of mathematics, science, and engineering

• An ability to design and conduct experiments, as well as to analyze and interpret data

• An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

• An ability to function on multidisciplinary teams

• An ability to identify, formulate, and solve engineering problems

• An understanding of professional and ethical responsibility

• An ability to communicate effectively

• The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

• A recognition of the need for, and an ability to engage in life-long learning

• A knowledge of contemporary issues

• An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

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 Name</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</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.219</td>
<td>Fields, Matter &amp; Waves</td>
<td>3</td>
</tr>
<tr>
<td>Choose one of the following:</td>
<td></td>
<td></td>
</tr>
<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 I</td>
<td></td>
</tr>
<tr>
<td>EN.520.372</td>
<td>Programmable Device Lab</td>
<td></td>
</tr>
<tr>
<td>Advanced laboratory, design intensive, or senior design project courses</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Total Credits</td>
<td></td>
<td>20</td>
</tr>
</tbody>
</table>

* 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 Name</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>or AS.110.211</td>
<td>Honors Multivariable Calculus</td>
<td></td>
</tr>
<tr>
<td>AS.110.201</td>
<td>Linear Algebra</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.212</td>
<td>Honors Linear Algebra</td>
<td></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>
</tbody>
</table>
or EN.550.420 Introduction to Probability

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</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>AS.171.101 General Physics: Physical Science Major I</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.107 General Physics for Physical Sciences Majors (AL)</td>
<td></td>
</tr>
<tr>
<td>AS.171.102 General Physics: Physical Science Majors II</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.108 General Physics for Physical Science Majors (AL)</td>
<td></td>
</tr>
<tr>
<td>AS.173.111 General Physics Laboratory I</td>
<td></td>
</tr>
<tr>
<td>AS.173.112 General Physics Laboratory II</td>
<td>1</td>
</tr>
</tbody>
</table>

Total Credits 10

- 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.171.111 General Physics Laboratory I and AS.173.112 General Physics Laboratory II. Courses in this group 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.

- A programming language requirement must be met by taking or EN.600.120 Intermediate Programming.

- Two (2) writing intensive courses (at least 3 credits each) are required. The writing intensive courses may not be taken Satisfactory/Unsatisfactory and require a C- or better grade. Students may wish to consider a course in Technical Communications to fulfill one of the writing intensive requirements. The course EN.661.315 Culture of the Engineering Profession, is recommended by the ECE Faculty as a writing intensive course.


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

Freshman Credits

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.108 Calculus I</td>
<td>4</td>
</tr>
</tbody>
</table>

Sophomore Credits

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.202 or .211 Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.201 or .212 Linear Algebra</td>
<td>4</td>
</tr>
<tr>
<td>AS.030.101 Introductory Chemistry I</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.213 Circuits</td>
<td></td>
</tr>
<tr>
<td>EN.520.214 Signals &amp; Systems</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.219 Fields, Matter &amp; Waves</td>
<td>3</td>
</tr>
<tr>
<td>EN.600.107 Introductory Programming in Java</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.216 Introduction To VLSI</td>
<td>3</td>
</tr>
<tr>
<td>H/S Electives</td>
<td>6</td>
</tr>
</tbody>
</table>

Junior Credits

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.302 Diff Equations/Applic</td>
<td>4</td>
</tr>
<tr>
<td>EN.550.310 Probability &amp; Statistics for the Physical and Information Sciences &amp; Engineering</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.372 Programmable Device Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.345 Electrical &amp; Computer Engineering Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>Basic Science Elective</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.353 Control Systems</td>
<td>3</td>
</tr>
<tr>
<td>Non-ECE/MathSci Engineering Elective</td>
<td>3</td>
</tr>
<tr>
<td>Elective</td>
<td>3</td>
</tr>
<tr>
<td>H/S Electives</td>
<td>6</td>
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</table>

Senior Credits

<table>
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<tr>
<th>Course</th>
<th>Credits</th>
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<tbody>
<tr>
<td>EN.520.498 &amp; EN.520.499 Senior Design Project</td>
<td>6</td>
</tr>
<tr>
<td>EN.520.435 Digital Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>ECE Signals/Systems/Comm. Electives</td>
<td>6</td>
</tr>
<tr>
<td>ECE Advanced Lab/Design Elective</td>
<td>6</td>
</tr>
<tr>
<td>Elective</td>
<td>3</td>
</tr>
<tr>
<td>Non-ECE/MathSci Engineering Electives</td>
<td>6</td>
</tr>
</tbody>
</table>

Total Credits: 122
Bachelor of Science in Computer Engineering

Mission

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.

Educational Objectives

The Program Educational Objectives (PEOs) for computer engineering (CE) at the Johns Hopkins University describe what CE graduates are expected to attain within a few years of graduation. The PEOs are determined in consultation with the Electrical and Computer Engineering External Advisory Committee and approved by the ECE faculty.

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.

Outcomes

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

- An ability to apply knowledge of mathematics, science, and engineering
- An ability to design and conduct experiments, as well as to analyze and interpret data
- An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- An ability to function on multidisciplinary teams
- An ability to identify, formulate, and solve engineering problems
- An understanding of professional and ethical responsibility
- An ability to communicate effectively
- The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- A recognition of the need for, and an ability to engage in life-long learning
- A knowledge of contemporary issues
- An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

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:
  - Electrical and Computer Engineering courses (15 credits)
    EN.520.142 Digital Systems Fundamentals 3
    EN.520.213 Circuits 4
  - Fifteen (15) credits of Electrical and Computer Engineering courses, which must include EN.520.142 Digital Systems Fundamentals, and.
  - 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).
  - 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 courses from School 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 Linear Algebra and Differential 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 Introduction 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</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.108 Calculus I</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.109 Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.171.101 or .107 General Physics:Physical Science Major I</td>
<td>4</td>
</tr>
<tr>
<td>AS.171.102 or .108 General Physics: Physical Science Majors II</td>
<td>4</td>
</tr>
<tr>
<td>AS.173.111 General Physics Laboratory I</td>
<td>1</td>
</tr>
<tr>
<td>AS.173.112 General Physics Laboratory II</td>
<td>1</td>
</tr>
<tr>
<td>EN.520.137 Introduction To Electrical &amp; Computer Engineering</td>
<td>3</td>
</tr>
</tbody>
</table>

### Sophomore

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.202 or .211 Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>EN.550.291 Linear Algebra and Differential Equations</td>
<td>4</td>
</tr>
<tr>
<td>AS.030.101 Introductory Chemistry I</td>
<td>3</td>
</tr>
<tr>
<td>EN.600.226 Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.213 Circuits</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.214 Signals &amp; Systems</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.216 Introduction To VLSI</td>
<td>3</td>
</tr>
<tr>
<td>EN.600.271 Automata &amp; Computation Theory</td>
<td>3</td>
</tr>
<tr>
<td>EN.600.120 Intermediate Programming</td>
<td>4</td>
</tr>
</tbody>
</table>

### Junior

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

### Senior

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

Total Credits: 124

### 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...
Requirements for the M.S.E. Degree

A student who has completed a program of study similar to that following requirements for the M.S.E. degree:

• Thirty (30) credits of ECE courses. Three credits of computer science courses may be counted toward this 30-credit requirement.
• Additional credits giving a total of at least 120 credits.
• Additional information on academic policies and degree requirements, including academic ethics, may be found in the Undergraduate Academic Manual of The Johns Hopkins University. Students are urged to read the credit requirements, under the credit requirements section, in the academic manual section of the Compendium.

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

Bachelor’s/Master’s Program

At the end of their sophomore year, students who are majors in electrical and computer engineering may apply for admission to the combined 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.

Master of Science in Engineering (M.S.E.) Degree

The department offers a comprehensive and flexible Master of Science in Engineering (M.S.E.) degree program that includes courses from several areas of Electrical and Computer Engineering. In addition, the following specialized M.S.E. tracks are offered: 1) Communications, 2) Control Systems, 3) Language and Speech Processing, 4) Microsystems and Computer Engineering, and 3) Photonics and Optoelectronics.

Requirements for the M.S.E. Degree

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:

• Eight one-semester graduate (400-799) courses approved by the advisor must be satisfactorily completed. At least five of these courses must come from the full-time ECE Department (520.XXX) but cannot include Independent Study, Dissertation Research, ECE Seminar or Special Studies.
• Further depth of understanding must be demonstrated by either satisfactorily completing two additional one-semester graduate (400-799) courses approved by the advisor (one of which must come from the full-time ECE Department (520.XXX), or by writing an M.S.E. thesis acceptable to a member of our faculty, or by completing a special project acceptable to a member of our faculty and writing the corresponding report.
• A course (including independent study) is satisfactorily completed if a grade of A, B, C, or P is obtained. No more than one C grade can be counted toward the requirements and a D or F or second C grade results in probation. A second D or F or a third C grade results in termination from our program.
• Students may transfer in up to two courses from outside JHU. These courses must have been completed after the undergraduate degree was conferred and not applied to a degree elsewhere.
• Every graduate course designated Independent Study, Dissertation Research, or Special Studies counted toward the M.S.E. degree must include a written report. A copy of the report will become part of the student’s permanent file.
• Every student must register for a minimum of two semesters as a full-time resident graduate student (this rule does not apply to students in the concurrent B.S./M.S.E. program). Full-time resident M.S.E. students must satisfactorily complete at least three graduate courses per semester for credit.
• Every student must be registered in the semester that degree requirements are met; this includes students who have no courses remaining in which to enroll but must resolve coursework for which an “Incomplete” grade was assigned and those who must complete other academic requirements, such as a language or computing requirement (these students may apply for Nonresident Status).
• Every student must earn the M.S.E. degree within five consecutive academic years (ten semesters). Only semesters during which a student has a university-approved leave of absence are exempt from the ten semester limit; otherwise, all semesters from the beginning of the student’s graduate studies – whether the student is resident or not – count toward the ten semester limit.
• Every student must complete training on academic ethics.
• Every student must complete training on the responsible and ethical conduct of research, if applicable (Please see the WSE Policy on the Responsible Conduct of Research).

Doctor of Philosophy (Ph.D.) Degree

Graduate study in Electrical and Computer Engineering is oriented toward the Ph.D. degree, with emphasis on scholarship and research rather than formal course work. Our Ph.D. program is designed to be easily tailored to the needs and interests of individual students. There are no lists of required courses. The program is directed at independent, highly motivated individuals who desire to work closely with faculty members at the forefront of research in a variety of scientific areas, such as:

• Computational and Biomorphic Systems
• Computational Systems Biology and Bioinformatics
• Computer Engineering
• Control Systems
• Image Processing and Analysis
• Integrated Circuits and Microsystems
• Language and Speech Processing
• Photonics and Optoelectronics
• Signal Processing

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/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 advisor 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 advisor, another faculty member in Electrical and Computer Engineering, and three faculty members from other departments. This examination must be taken before the end of the sixth semester.

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

Financial Aid

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

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

Faculty

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

Director of Undergraduate Programs
Trac D. Tran
Filter banks, wavelets, multirate systems and applications.

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.

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

Hynek Hermansky
Julian S. Smith Professor: 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.

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

Alexander E. Kaplan

Jacob B. Khurgin
Quantum electronics, nonlinear optics.

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

T.E. (Ed) Schlesinger
Professor and Benjamin T. Tome Dean: solid state electronic and optical devices, nanotechnology, and information storage systems.

Howard L. Weinert
Fast compact algorithms and software for extracting signals from noise

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

Sanjeev P. Khudanpur
Information theory, statistical language modeling.

Assistant Professors
Amy C. Foster
Silicon photonics, nonlinear optics, nanophotonics, integrated biophotonics.

Mark A. 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.

**Joint, Part-Time, Visiting, and Emeritus Appointments**

Emad M. Boctor
Assistant Professor (Radiology): image-guided intervention, ultrasound imaging, elasticity, and thermal imaging.

Paul A. Bottomley
Russell H. Morgan Professor (Radiology): magnetic resonance imaging, metabolic MRI.

Sang (Peter) Chin
Assistant Research Professor: compressive sensing, novel signal processing, game theory, extremal graph theory, differential geometry, and quantum computing and verification.

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

Glenn A. Coppersmith
Assistant Research Scientist.

Richard V. Cox
Research Professor/Director, Human Language Technology Center of Excellence.

Frederic M. Davidson
Professor Emeritus

Yamac Dikmelik
Assistant Research Scientist.

Eric C. 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.

Israel Gannot
Associate Research Professor.

Dennice F. Gayme
Assistant Professor (Mechanical Engineering): dynamics and control of nonlinear, networked and spatially distributed systems. Applications include: the electric power grid, wall turbulence and wind farms.

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

Robert E. Glaser
Lecturer: advanced digital logic systems.

Moise H. Goldstein Jr.
Professor Emeritus.

Willis Gore
Professor Emeritus.

Gregory D. Hager
Professor and Chair (Computer Science): vision, robotics, human-machine systems, computer-integrated medicine.

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.

Xingde Li
Professor (Biomedical Engineering): Endomicroscopy technologies, nanobiophotonics and molecular imaging, early detection.

Elliot R. McVeigh
Massey Professor and Director (Biomedical Engineering): imaging.

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

C. Harvey Palmer Jr.
Professor Emeritus.

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

Philippe O. Pouliquen
Assistant Research Professor: optoelectronic, mixed signal, low power VLSI, CAD tools for VLSI.

Carey E. Priebe

Arman Rahmim
Assistant Professor (Radiology).

Charbel Rizk
Associate Research Scientist.

Wilson J. Rugh
Edward J. Schaefer Professor Emeritus.

Nitish V. Thakor
Professor (Biomedical Engineering): medical instrumentation, medical micro and nanotechnologies, neurological instrumentation, signal processing, computer applications.

Benjamin M. W. Tsui
EN.520.120. Introduction to Model Rocketry.
Model rocketry is only the small cousin of space rocketry, but it shares many interesting aspects with its real-world counterpart. This course aims to explore the different parts of this sport, with an emphasis on how engineering principles are employed in practice. Classes will cover both practical and theoretical topics such as model rocket construction and design (recovery devices, glide recovery, multistage rockets), stability, aerodynamics, altitude prediction and determination. Some familiarity with a programming language (possibly Matlab) is required for the assignments.
Instructor(s): R. Tron
Area: Engineering.

EN.520.137. Introduction To Electrical & Computer Engineering.
An introductory course covering the principles of electrical engineering including sinusoidal wave forms, electrical measurements, digital circuits, and applications of electrical and computer engineering. Laboratory exercises, the use of computers, and a design project are included in the course.
Instructor(s): T. Tran
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.142. Digital Systems Fundamentals.
Number systems and computer codes, switching functions, minimization of switching functions, Quine - McCluskey method, sequential logic, state tables, memory devices, analysis, and synthesis of synchronous sequential devices.
Instructor(s): G. Meyer; P. Julian
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.150. Light, Image and Vision.
This course is designed for beginning undergraduate students and covers the principle of optics and imaging from the human vision perspective. The topics for the course include the basic principles and properties of light, imaging and image formation, optical imaging and display systems, and human vision. The course include bio-weekly labs that allows students to implement and experience the concepts learned during the lectures.
Instructor(s): J. Kang
Area: Engineering.

EN.520.211. ECE Engineering Team Project.
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): R. Etienne Cummings
Area: Engineering.

EN.520.212. ECE Engineering Team Project (Freshmen and Sophomores).
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; J. West; R. Etienne Cummings
Area: Engineering.
EN.520.213. Circuits.
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.

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;Prerequisite: EN.520.213
Instructor(s): M. Elhilali
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.216. Introduction To VLSI.
This course teaches the basics of switch-level digital CMOS VLSI design. This includes creating digital gates using MOS transistors as switches, laying out a design using CAD tools, and checking the design for conformance to the Scalable CMOS design rules. Recommended: EN.520.213.
Prerequisites: EN.520.142 and recommended: 520.213
Instructor(s): A. Andreou
Area: Engineering.

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;Prerequisites: AS.171.101 and AS.171.102 and AS.110.109 Pre/Co-Requisite: AS.110.202
Instructor(s): M. Foster
Area: Engineering, Natural Sciences.

EN.520.220. Fields, Matter & Waves.
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.

A study of the structure and organization of classical von Neuman uniprocessor computers. Topics include a brief history of modern machines starting from the Turing computer model, instruction sets, addressing, RISC versus CICS, traps and interrupt handling, twos complement arithmetic, adders and ALUs, CSA’s Booth’s algorithm, multiplication and division, control unit design, microprogramming, dynamic versus static linking, memory systems and memory hierarchy, paging segmentation, cache hardware, cache organizations, and replacement policies.
Prerequisites: EN.520.142
Instructor(s): P. Pouliquen
Area: Engineering.

EN.520.240. Introduction to Mechatronics.
Introduction to Mechatronics is mostly hands-on, interdisciplinary design class consisting of lectures about key topics in mechatronics, and lab activities aimed at building basic professional competence. After completing the labs, the course will be focused on a final mini-project for the remainder of the semester. This course will encourage and emphasize active collaboration with classmates. Each team will plan, design, manufacture and/or build, test, and demonstrate a robotic system that meets the specified objectives.
Instructor(s): C. Rizk
Area: Engineering.

This course provides an introduction to the science and engineering of renewable energy technologies. The class will begin with an overview of today’s energy landscape and proceed with an introduction to thermodynamics and basic heat engines. Specific technologies to be discussed include photovoltaics, fuel cells and hydrogen, biomass, wind power and energy storage. The class should be accessible to those from a variety of science and engineering disciplines. Recommended Course Background: Introductory Physics and Calculus.
Instructor(s): S. Thon
Area: Engineering.

EN.520.315. Introduction to Information Processing of Sensory Signals.
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.520.345. Electrical & Computer Engineering Laboratory.
This course consists of 11 one-week laboratory experiments intended to provide an introduction to analog and digital circuits commonly used in engineering. Topics include phase and frequency response, transistors, operational amplifiers, filters, and other analog circuits. The experiments are done using computer controlled digital oscilloscopes, function generators, and power supplies.
Prerequisites: 171.101-102 and EN.520.213
Instructor(s): A. Foster; S. Ramesh
Area: Engineering.

EN.520.349. Microprocessor Lab I.
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.520.353. Control Systems.
Modeling, analysis, and an introduction to design for feedback control systems. Topics include state equation and transfer function representations, stability, performance measures, root locus methods, and frequency response methods (Nyquist, Bode).
Prerequisites: Prereqs: EN.530.343 AND EN.520.214
Instructor(s): D. Tarraf
Area: Engineering.
EN.520.372. Programmable Device Lab.
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 (PLDs 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
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): R. Glaser
Area: Engineering.

EN.520.391. CAD Design of Digital VLSI Systems I (Juniors).
An introductory course in which students, manually and through computer simulations, design digital CMOS integrated circuits and systems. The design flow covers transistor, physical, and behavioral level descriptions, using SPICE, Layout, and Verilog HDL VLSI CAD tools. After design computer verification, students can fabricate and test their semester-long class projects. Juniors Only. Recommended Course Background: EN.520.142, EN.520.216 or equivalent; Corequisite: EN600.333, EN.600.334, EN.520.349 or EN.520.372
Instructor(s): R. Etienne Cummings
Area: Engineering.

EN.520.401. Basic Communication.
This course covers the principles of modern analog and digital communication systems. Topics include: amplitude modulation formats (DSB, SSC VSB), exponential modulation formats (PM, FM) , superheterodyne receivers, digital representation of analog signals, sampling theorem, pulse code modulation formats (PCM, DPCM, DM, spread-spectrum), signals with additive Gaussian noise, maximum likelihood receiver design, matched filtering, and bit error rate analyses of digital communication systems.
Prerequisites: Prereqs: EN.520.214 AND EN.550.310 or equivalent.
Instructor(s): F. Davidson
Area: Engineering.

EN.520.402. Digital Communications.
This is a first course in digital communications. Topics covered are sampling theorem, representation and reconstruction of analog signals from sampled values, quantization noise, pulse code modulation, delta modulation, digital waveform encoding, signal space descriptions of binary and M-ary signaling schemes (BPSK, QAM, FSK, PAM, PSK), optimal receivers, effects of additive Gaussian noise on bit error rates, digital transmission through band-limited channels, and multicarrier transmission systems (OFDM). System concepts will be emphasized through implementation with TIMS hardware. This course is a replacement for EN.520.401 and EN.520.465 and can not be taken by students who have taken these courses.
Prerequisites: (EN.520.214) AND (EN.550.310 OR EN.550.311 OR EN.550.420 OR equivalent);EN.520.401 AND EN.520.465.
This course is a replacement for EN.520.401 and EN.520.465 and can not be taken by students who have taken these courses.
Instructor(s): F. Davidson
Area: Engineering, Natural Sciences.

EN.520.403. Introduction to Optical Instruments.
This course is intended to serve as an introduction to optics and optical instruments that are used in engineering, physical, and life sciences. The course covers first basics of ray optics with the laws of refraction and reflection and goes on to description of lenses, microscopes, telescopes, and imaging devices. Following that basics of wave optics are covered, including Maxwell equations, diffraction and interference. Operational principles and performance of various spectrometric and interferometric devices are covered including both basics (monochromatic, Fabry-Perot and Michelson interferometers), and advanced techniques of near field imaging, laser spectroscopy, Fourier domain spectroscopy, laser Radars and others.
Instructor(s): J. Khurgin
Area: Engineering.

EN.520.407. Introduction to the Physics of Electronic Devices.
This course is designed to develop and enhance the understanding of the basic physical processes taking place in the electronic and optical devices and to prepare students for taking classes in semiconductor devices and circuits, optics, lasers, and microwaves devices, as well as graduate courses. Both classical and quantum approaches are used. Specific topics include theory of molecular bonding; basics of solid state theory; mechanical, transport, magnetic, and optical properties of the metals; semiconductors; and dielectrics.
Instructor(s): J. Khurgin
Area: Engineering.

EN.520.410. Fiber Optics & 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.
Instructor(s): F. Davidson
Area: Engineering.

EN.520.414. Image Processing & Analysis.
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 multisolution 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.
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.520.416. Processing of Audio and Visual Signals.
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.520.419. Iterative Algorithms.
An introduction to the study of the structure, behavior and design of iterative algorithms. Topics include problem formulations, algorithm description and classification, the deterministic iterative (DI) schema, doubling schema, cluster point sets, periodic points, DI schemas without stop rule, the monotonic DI schema, contractive and affine maps, bounded and Cauchy sequences, asymptotically regular sequences, monotonic sequences.
Prerequisites: AS.110.201-202.
Instructor(s): G. Meyer
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.424. FPGA Synthesis Lab.
An advanced laboratory course in the application of FPGA technology to information processing, using VHDL synthesis methods for hardware development. The student will use commercial CAD software for VHDL simulation and synthesis, and implement their systems in programmable XILINX 20,000 gate FPGA devices. The lab will consist of a series of digital projects demonstrating VHDL design and synthesis methodology, building up to final projects at least the size of an 8-bit RISC computer. Projects will encompass such things as system clocking, flip-flop registers, state-machine control, and arithmetic. The students will learn VHDL methods as they proceed through the lab projects, and prior experience with VHDL is not a prerequisite.
Prerequisites: 520.142 and 520.345. Recommended Courses: 600.333 (Computer System Fundamentals) or 520.349 (Microprocessor Lab)
Instructor(s): P. Pouliquen
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.425. FPGA Senior Projects Laboratory.
Laboratory course for FPGA based senior projects. Students will work in teams to complete a design project that makes use of embedded FPGAs. The projects will make use of the Spartan2 XSA boards and other resources from the FPGA Synthesis lab course. Possible projects include: A 16 or 32 bit RISC processor with student designed ISA architecture, assembler, and mini operating system; or a Spartan2 emulation of an existing microprocessor such as an 8051, an optical communication system to transmit stereo music using various modulation schemes for comparison (This would include FM or AM and at least one digital scheme such as FSK); or a digital receiver for commercial AM or FM radio. Students are expected to complete a demonstration and produce a poster session final report. Senior status, no exceptions.
Prerequisites: Prereq: 520.424 and senior status,
Instructor(s): R. Jenkins
Area: Engineering.

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. Pouliquen
Area: Engineering.

EN.520.432. Medical Imaging Systems.
An introduction to the physics, instrumentation, and signal processing methods used in general radiography, X-ray computed tomography, ultrasound imaging, magnetic resonance imaging, and nuclear medicine. The primary focus is on the methods required to reconstruct images within each modality, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Co-listed as EN.580.472
Prerequisites: EN.580.222 OR EN.520.214
Instructor(s): J. Prince
Area: Engineering.

EN.520.433. Medical Image Analysis.
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.
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.
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.

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.
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.
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.; Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): R. Etienne Cummings.

EN.520.450. Advanced Micro-Processor Lab.
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 eZ8 microcontrollers. Upon completion, students can use these flash-based chips as elements in other project courses. Recommended Course Background: EN.520.349
**Prerequisites:** Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): R. Glaser.

EN.520.452. Advanced ECE Engineering Team Project.
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. (Juniors and Seniors)
Instructor(s): R. Etienne Cummings
Area: Engineering.

EN.520.453. Advanced ECE Engineering Team Project.
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.
**Prerequisites:** Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): J. Kang; J. West; R. Etienne Cummings
Area: Engineering.

EN.520.454. Control Systems Design.
Classical and modern control systems design methods. Topics include formulation of design specifications, classical design of compensators, state variable and observer based feedback. Computers are used extensively for design, and laboratory experiments are included.
Instructor(s): P. Iglesias
Area: Engineering, Natural Sciences.

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.

EN.520.459. Quantum Mechanics for Engineering.
This course will describe some of the basic ideas in and early development of quantum mechanics. This course is intended for students without any previous background in this subject. A description of some of the fundamental ideas in Quantum Mechanics will be offered from a practical point of view and from a perspective that should be useful to engineers who want to understand how these concepts manifest in materials and devices. Topics include the Schrodinger Wave Equation and the concept of a wave function, quantization in atoms and engineered semiconductor heterostructures, the interaction of radiation and atomic systems, and examples of the application of quantum theory in lasers and electronic solid-state devices. Recommended background for this course includes freshmen-year physics (including fundamentals of electricity and magnetism) and sophomore-year mathematics (including partial derivatives, basic differential equations, and fundamentals of linear algebra).
Instructor(s): T. Schlesinger
Area: Engineering, Quantitative and Mathematical Sciences.
EN.520.460. The Art of Error Control Coding.
Error control coding is the study and practice of detecting and/or correcting errors that occur in the transmission of digital information over a noisy communication channel, the transferal of information to and from memory and mass storage in a computer, or in any other application where random processes corrupt information. The student will study encoders and decoders for the most important codes in current use and will confront realistic problems in the use of coding. The course will comprise lectures, discussions, and projects.
Prerequisites: (EN.550.310 OR EN.550.311 OR EN.550.420 or equivalent) AND (AS.110.201 or equivalent)
Instructor(s): A. Cooper
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.465. Digital Communications I.
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
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.473. Magnetic Resonance in Medicine.
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
Area: Engineering, Natural Sciences.

EN.520.482. Introduction to Lasers.
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.
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.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): J. Kang.

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.520.491. CAD Design of Digital VLSI Systems I (Seniors/Grads).
Seniors and Graduate Students Only
Instructor(s): R. Etienne Cummings
Area: Engineering.

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.
Instructor(s): P. Pouliquen
Area: Engineering.

EN.520.495. Microfabrication Laboratory.
This laboratory course is an introduction to the principles of microfabrication for microelectronics, sensors, MEMS, and other synthetic microsystems that have applications in medicine and biology. Course comprises of laboratory work and accompanying lectures that cover silicon oxidation, aluminum evaporation, photoresist 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.
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.
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): Staff
Area: Engineering.

EN.520.501. Independent Study-Freshmen-Sophomores.
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.
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.
Instructor(s): A. Andreou.

EN.520.503. Independent Study-Juniors-Seniors.
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.
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.520.545. Research.
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): Staff.

EN.520.548. Independent Research.
Instructor(s): S. Thon.

Instructor(s): J. Kang; T. Tran.

EN.520.572. Electrical & Computer Engineering Internship-Intersession.

EN.520.574. Research-Intersession.

EN.520.576. Independent Study.
Instructor(s): R. Etienne Cummings.

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

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

EN.520.599. Internship-Summer.
Instructor(s): F. Davidson; G. Meyer; 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): P. Iglesias.

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.520.613. Advanced Topics in Optical Medical Imaging.
The course will review the recent advances in photonics technologies for medical imaging and sensing. The course is designed for graduate students with a background in optics and engineering. The main topics for the course are: Light Source and Devices for Biomedical Imaging; Fluorescence, Raman, Rayleigh Scatterings; Optical Endoscopy and Virtual biopsy; Novel imaging contrast dyes, nanoparticles, and optical clearing reagents; Label-free optical technologies in clinical applications; Neurophotonics and Optogenetics.
Instructor(s): J. Kang.

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.
Area: Engineering.

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 mafs.
Instructor(s): G. Meyer.
EN.520.621. Introduction To Nonlinear Systems.
Nonlinear systems analysis techniques: phase-plane, limit cycles, harmonic balance, expansion methods, describing function, Liapunov stability. Popov criterion. Recommended Course Background: EN.520.601 or equivalent.
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. 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.520.631. 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): T. Tran.

EN.520.632. Extraction of Signals from Noise.
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.520.646. Waves & 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): T. Tran.

EN.520.651. Compressed Sensing and Sparse Recovery.
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.520.652. Extraction of Signals from Noise.
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.520.673. Magnetic Resonance in Medicine.
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.

EN.520.678. Biomedical Photonics.
This course will cover the basic optics principles including geometric, beam and wave description of light. The course will also cover the basic generation and detection techniques of light and the principles of optical imaging and spectroscopy. The general basis is established, and students will focus on commonly employed optical techniques and tools for biomedical research including various optical microscopy technologies, fiber optics, Raman spectroscopy, Fluorescence lifetime, FRAT, FRET and FCS. The recent development in tissue optics, biomedical optical imaging/spectroscopy techniques (such as OCT, multiphoton fluorescence and harmonics microscopy, Structured Illumination, light scattering, diffuse light imaging and spectroscopy, optical molecular imaging, photo-acoustic imaging) will also be discussed. Representative biomedical applications of translational biomedical photonics technologies will be integrated into the corresponding chapters.
Instructor(s): X. Li
Area: Engineering.

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.520.701. 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.520.738. 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): R. Etienne Cummings.

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.

EN.520.763. Seminar on Solid State, Quantum Electronics and Nonlinear Optics.
Research Seminar on current research in the area of interaction of light with matter.
Instructor(s): A. Kaplan
Area: Engineering, Natural Sciences.

Instructor(s): A. Andreou.

EN.520.772. Advanced Integrated Circuits.

EN.520.773. Advanced Topics In Microsystem 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; J. Wang.

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 neuromechanics, 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): L. Whitcomb; N. Cowan; P. Kazanzides; R. Etienne Cummings; R. Vidal.

Materials Science Engineering

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.
Prerequisites: 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.
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.530.682. Haptic Applications. An introduction to the required theoretical and practical background in the design and development of haptic applications. Haptic technology enables users to touch and/or manipulate virtual or remote objects in simulated environments or tele-operation systems. This course aims to cover the basics of haptics through lectures, lab assignments, a term project, and readings on current topics in haptics. Through lab assignments, students learn to create haptic-enabled virtual environments using software development toolkits and a haptic device. Students will be required to complete a project with approval of the instructor. Recommended course background: ME, CS, and ECE graduate and senior undergraduate students who are being enthusiastic to learn about haptics and knowledgeable in basic C++ programming. Students with experience with other programming languages (Python, Java, etc.) should be able to self-tutor themselves to complete lab assignments. Instructor(s): M. Zadeh.

Biomedical Engineering
EN.580.107. Immunoengineering: A New Frontier. What therapy could cure debilitating diseases such as cancer, HIV, allergies, diabetes, Alzheimers, or influenza? Engineers and Immunologists are attempting to create this with your body's own immune system. Understanding how these therapies work, how they might work in the future, and how to apply engineering principles to enhance these therapies will be the focus of this course. Instructor(s): A. Kosmides; J. Hickey Area: Engineering.

EN.580.472. Medical Imaging Systems. An introduction to the physics, instrumentation, and signal processing methods used in general radiography, X-ray computed tomography, ultrasound imaging, magnetic resonance imaging, and nuclear medicine. The primary focus is on the methods required to reconstruct images within each modality, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Cross-listed with Neuroscience and Electrical and Computer Engineering (EN.520.432). Prerequisites: EN.580.222 OR EN.520.214 Instructor(s): J. Prince Area: Engineering.

EN.580.483. Nuclear Medicine Imaging. This course provides an intermediate-level introduction to the instrumentation, image processing and reconstruction methods used in planar nuclear medicine imaging, single-photon emission computed tomography (SPECT) and positron emission tomography (PET). Topics include radioactive decay, nuclear medicine instrumentation including radiation detectors and associated electronics, analytic and statistical iterative tomographic reconstruction, imaging physics, and image quality in the context of these three modalities. This course will be taught at the School of Medicine Campus. Recommended Course Background: EN.520.432/EN.580.472 and EN.520.434/EN.580.473 Instructor(s): A. Rahnim; B. Tsui; E. Frey; Y. Du 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.600.479. Representation Learning. Often the success of a machine learning project depends on the choice of features used. Machine learning has made great progress in training classification, regression and recognition systems when "good" representations, or features, of input data are available. However, much human effort is spent on designing good features which are usually knowledge-based and engineered by domain experts over years of trial and error. A natural question to ask then is "Can we automate the learning of useful features from raw data?" Representation learning algorithms such as principal component analysis aim at discovering better representations of inputs by learning transformations of data that disentangle factors of variation in data while retaining most of the information. The success of such data-driven approaches to feature learning depends not only on how much data we can process but also on how well the features that we learn correlate with the underlying unknown labels (semantic content in the data). This course will focus on scalable machine learning approaches for learning representations from large amounts of unlabeled, multi-modal, and heterogeneous data. We will cover topics including deep learning, multi-view learning, dimensionality reduction, similarity-based learning, and spectral learning. Students may receive credit for 600.479 or 600.679 but not both. [Analysis or Applications] Required course background: machine learning or basic probability and linear algebra. Prerequisites: If you have completed EN.600.679 you may not enroll in EN.600.479. Instructor(s): R. Arora Area: Engineering.
EN.600.679. **Representation Learning.**
Graduate level version of 600.479. Students may receive credit for 600.479 or 600.679 but not both. [Analysis or Applications] Required course background: machine learning or basic probability and linear algebra. Co-listed with EN.600.479

**Prerequisites:** If you have completed EN.600.479 you may not enroll in EN.600.679.
Instructor(s): R. Arora.