ELECTRICAL AND COMPUTER ENGINEERING

http://www.ece.jhu.edu/

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 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.

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

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

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

Forty-five (45) credits of ECE courses including the following:*  
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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</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>
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<td>20</td>
</tr>
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</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>
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<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<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>
<tr>
<td>or EN.550.420</td>
<td>Introduction to Probability</td>
<td></td>
</tr>
<tr>
<td>Total Credits</td>
<td></td>
<td>20</td>
</tr>
</tbody>
</table>
* Courses in this group may not be taken Satisfactory/Unsatisfactory. 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)

programs can be found in the advising manual.

Communications aspects of electrical engineering. Other sample

Commission of ABET,

degree program is accredited by the Engineering Accreditation

Electrical Engineering Advising Manual. The B.S. in Electrical Engineering

Additional details concerning advising and degree requirements are in the

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

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>AS.110.108</td>
<td>Calculus I</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.109</td>
<td>Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.171.101 or 107</td>
<td>General Physics: Physical Science Major I</td>
<td>4</td>
</tr>
<tr>
<td>AS.171.102 or 108</td>
<td>General Physics: Physical Science Majors II</td>
<td>4</td>
</tr>
<tr>
<td>AS.173.111</td>
<td>General Physics Laboratory I</td>
<td>1</td>
</tr>
<tr>
<td>AS.173.112</td>
<td>General Physics Laboratory II</td>
<td>1</td>
</tr>
<tr>
<td>EN.520.137</td>
<td>Introduction To Electrical Computer Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.142</td>
<td>Digital Systems Fundamentals</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.213</td>
<td>Circuits</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.214</td>
<td>Signals Systems</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.219</td>
<td>Fields, Matter Waves</td>
<td>3</td>
</tr>
<tr>
<td>EN.500.107</td>
<td>Introductory Programming in Java</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.216</td>
<td>Introduction To VLSI</td>
<td>3</td>
</tr>
<tr>
<td>HS Electives</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Total Credits</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

- **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 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.600.107 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.

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

### 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
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 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:
  
  Educational and Computer Engineering courses (15 credits)
  
  EN.520.142 Digital Systems Fundamentals 3
  EN.520.213 Circuits 4

  a. Fifteen (15) credits of Electrical and Computer Engineering courses, which must include EN.520.142 Digital Systems Fundamentals, and...
  
  b. Fifteen (15) credits of Computer Science courses which must include EN.600.120 Intermediate Programming, EN.600.226 Data Structures and Computer System Fundamentals (EN.600.233 Computer System Fundamentals).
  
  c. The program must also contain a substantial advanced laboratory and design experience component, appropriate for the student’s interests.

  This requirement can be met by taking twelve (12) credits of advanced laboratory, design intensive, or senior design project courses from those given in the degree planning checklist in Section I.C. At least six (6) of these 12 credits must be from ECE or CS courses. A GPA of at least 2.0 must be maintained in Computer Engineering courses. Courses in this category may not be taken Satisfactory/Unsatisfactory.
  
  - Six (6) credits of engineering 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.
The sample program shown has an emphasis on hardware/device aspects of computer engineering. Other sample programs can be found in the advising manual. 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 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 Satisfactory/Unsatisfactory 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 credits giving a total of at least 120 credits.

**Freshman**

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<tr>
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<td>3</td>
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<td>EN.600.107</td>
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**Sophomore**

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<td>AS.110.202 or 211</td>
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<tr>
<td>EN.550.291</td>
<td>4</td>
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<tr>
<td>AS.030.101</td>
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<tr>
<td>EN.600.226</td>
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<td>EN.600.120</td>
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**Junior**

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<td>EN.550.171</td>
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<td>EN.600.318</td>
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<tr>
<td>EN.600.233</td>
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<tr>
<td>EN.520.372</td>
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<tr>
<td>EN.520.345</td>
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**Senior**

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<tr>
<td>EN.550.310</td>
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<td>EN.520.448</td>
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<tr>
<td>EN.520.491</td>
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<td>EN.520.495</td>
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<td>EN.520.424</td>
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**Total Credits: 126**

**Bachelor of Arts Degree in Electrical Engineering**

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

- Eighteen (18) credits of humanities and social sciences courses.
- Four writing intensive courses.
- Twenty (20) credits of mathematics or mathematical statistics courses. Typically these include AS.110.108 Calculus I, AS.110.109 Calculus II (For Physical Sciences and Engineering), and AS.210.202 Calculus III or equivalent, and AS.120.201 Linear Algebra. Elementary or pre-calculus courses such as AS.110.105 or EN.550.111-EN.550.112 are not acceptable.
- Thirty (30) credits of ECE courses. Three credits of computer science courses may be counted toward this 30-credit requirement.
- Additional credits giving a total of at least 120 credits.
- Additional information on academic policies and degree requirements can be found in the Undergraduate Academic Policies section of this catalog.

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

**Minor in Robotics**

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

Intermediate Programming

Automata Computation Theory

Introduction To VLSI

Signals Systems

Circuits

Data Structures

Introductory Chemistry I

Equations

Calculus III

Linear Algebra and Differential Equations

Probability Statistics for the Physical and Information Sciences Engineering

Electronics Design Lab

CAD Design of Digital VLSI Systems I (Juniors/Seniors)

Mixed-Mode VLSI Systems

Microfabrication Laboratory

FPGA Synthesis Lab

Non-ECE/ECE/MathSci Engineering Electives

H/S Elective
Minor in Computer-Integrated Surgery
A minor in Computer-Integrated Surgery is offered by the Laboratory for Computational Sensing and Robotics. Detailed information regarding this program can be found at: http://lcsr.jhu.edu/computer-integrated-surgery-minor/.

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) Image Processing, 5) Microsystems and Computer Engineering, 6) Photonics and Optoelectronics, and 7) Robotics.

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 C or D grade must be satisfactorily completed. At least five of these courses must come from the full-time ECE Department (520.XXX). No more than one C grade can be counted toward the requirements and a C or D grade must be satisfactorily completed. At least five of these courses must come from the full-time ECE Department (520.XXX).
- 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 C or D grade must be satisfactorily completed. At least five of these courses must come from the full-time ECE Department (520.XXX).
- 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 be enrolled in at least 9 credits to maintain full-time status (in fall/spring semesters).
- 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.

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

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

James West
Electroacoustics, physical acoustics, and architectural acoustics.

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
Muyinatu A. Lediju Bell (eff 7/1/16)
Ultrasound imaging, photoacoustic imaging, image quality improvements, advanced beamforming methods, light delivery systems, medical robotics, image-guided surgery, technology development, medical device design, clinical translation.

Najim Dehak
Speech processing and modeling; speaker and language recognition; audio segmentation; emotion recognition and health applications.

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.

Enrique Mallada
Networked dynamics, control, optimization, power networks.

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, nanoengineeering and nanophotonics, and scalable fabrication.

Archana Venkataraman (eff 8/1/16)
Functional neuroimaging (fMRI, EEG), machine learning & probabilistic inference, network modeling of the brain, integration of imaging, genetcs and behavioral data.

Joint, Part-Time, Visiting, and Emeritus Appointments
Emad M. Boctor

Electrical and Computer Engineering
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.

Noah J. Cowan
Associate Professor (Mechanical Engineering): navigation and control in biological systems; animal biomechanics and multisensory control; robotic systems, dynamics, and control; system identification of rhythmic systems; medical robotics.

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

Frederic M. Davidson
Professor Emeritus.

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.

Peter Gehlbach
Associate Professor (Ophthalmology): angiogenesis; diabetic retinopathy; microsurgical instrument development; gene therapy; macular degeneration.

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.

Richard I. Joseph
Jacob Suter Jammer Professor Emeritus.

Marin Kobilarov
Assistant Professor (Mechanical Engineering): dynamics and control motion planning reasoning under uncertainty robotics and aerospace.

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

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): 3D and spatiotemporal 4D tomographic image reconstruction algorithms; texture and shape analysis as applied to medical imaging (SPECT/PET); diffuse optical tomography (DOT) through the intact brain; cardiac and respiratory motion compensation methods; dynamic whole-body PET/CT parametric imaging; advanced quantitation methods for enhanced prognosis and treatment response assessment in cancer patients; adaptive multi-modality integration of anatomical (e.g. MRI or CT) information into functional (e.g. PET) image reconstruction; Monte Carlo simulation approaches, using high performance computing and mathematical anthropomorphic models; application of numerical observer studies as preliminary substitute for human observers for optimization and validation; modeling and incorporation of resolution degrading effects within image reconstruction tasks.

Charbel G. Rizk
Associate Research Scientist: integrated system-on-chip sensors; integrated photonics, controls, autonomous systems, UAV platforms, and sensors; biomimetic devices for medical applications.

Suchi Saria
Assistant Professor (Computer Science): machine learning; statistical inference; computational health informatics; probabilistic methods; time series models; information extraction in domains with structured and unstructured data (e.g., text, sensing devices, electronic health records, smart rooms); predictive modeling in healthcare.

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

Xiaoying Tang
Adjunct Assistant Professor: quantitative medical image analysis; neuroimaging; computational anatomy; computational neuroinformatics.

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

Rene Vidal
Professor (Biomedical Engineering): computer vision, biomedical imaging, machine learning, signal processing.

C. Roger Westgate
Professor Emeritus.

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

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

Courses

EN.520.123. Computational Modeling for Electrical and Computer Engineering. 3.00 Credits.
In this course, the students will acquire the skills of solving complex real world Electrical and Computer Engineering problems using computational modeling tools. This course will cover two aspects of solving those ECE problems. The first aspect consists of learning to map ECE tasks to mathematical models. The second aspect consists of introducing the students to the basic of computational algorithms needed to work with the models, and programming such algorithms in MATLAB.
Instructor(s): N. Dehak
Area: Engineering.

EN.520.137. Introduction to Electrical & Computer Engineering. 3.00 Credits.
An introductory course covering the principles of electrical engineering including sinusoidal wave forms, electrical measurements, digital circuits, and applications of electrical and computer engineering. Laboratory exercises, the use of computers, and a design project are included in the course.
Instructor(s): T. Tran
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.142. Digital Systems Fundamentals. 3.00 Credits.
Number systems and computer codes, switching functions, minimization of switching functions, Quine-McCluskey method, sequential logic, state tables, memory devices, analysis, and synthesis of synchronous sequential devices.
Instructor(s): P. Julian
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.150. Light, Image and Vision. 3.00 Credits.
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. 1.00 Credit.
This course introduces the student to the basics of engineering team projects. The student will become a member of and participate in the different aspects of an ECE team project over several semesters.
(Freshmen and Sophomores)
Instructor(s): A. Andreou; C. Rizk; J. Kang; J. West
Area: Engineering.

EN.520.212. ECE Engineering Team Project (Freshmen and Sophomores). 1.00 Credit.
This course introduces the student to the basics of engineering team projects. The student will participate in an ECE engineering team project as a member. The student is expected to participate in the different aspects of the project over several semesters. (Freshmen and Sophomores) Permission of instructor required.
Instructor(s): C. Rizk; J. Kang; J. West
Area: Engineering.

EN.520.213. Circuits. 4.00 Credits.
An introductory course on electric circuit analysis. Topics include time domain and frequency domain analysis techniques, transient and steady-state response, and operational amplifiers.
Prerequisites: AS.110.108 and AS.110.109
Instructor(s): B. Mohanty; H. Weinert
Area: Engineering.

EN.520.214. Signals & Systems. 4.00 Credits.
An introduction to discrete-time and continuous-time signals and systems covers representation of signals and linear time-invariant systems and Fourier analysis.
Prerequisites: Corequisite: AS.110.202; Prerequisite: EN.520.213
Instructor(s): M. Elhilali
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.216. Introduction To VLSI. 3.00 Credits.
This course teaches the basics of switch-level digital CMOS VLSI design. This includes creating digital gates using MOS transistors as switches, laying out a design using CAD tools, and checking the design for conformance to the Scalable CMOS design rules. Recommended: EN.520.213.
Prerequisites: EN.520.142 and recommended: 520.213
Instructor(s): A. Andreou
Area: Engineering.
EN.520.219. Fields, Matter & Waves. 3.00 Credits.
Vector analysis, electrostatic fields in vacuum and material media, stationary currents in conducting media, magnetostatic fields in vacuum and material media. Maxwell's equations and time-dependent electric and magnetic fields, electromagnetic waves and radiation, transmission lines, wave guides, applications.
Prerequisites: Co-req: AS.110.202; Prerequisites: ((AS.171.101 and AS.171.102) or (AS.171.101 and AS.171.108)) and AS.110.109 Pre/Co-Requisite: AS.110.202
Instructor(s): M. Foster
Area: Engineering, Natural Sciences.

EN.520.220. Fields, Matter & Waves. 3.00 Credits.
Magnetostatic fields in vacuum and material media. Maxwell's equations and time-dependent electric and magnetic fields, electromagnetic waves and radiation, transmission lines, wave guides, applications.
Prerequisites: EN.520.219 or equivalent
Instructor(s): M. Foster
Area: Engineering, Natural Sciences.

EN.520.222. Computer Architecture. 3.00 Credits.
A study of the structure and organization of classical von Neuman uniprocessor computers. Topics include a brief history of modern machines starting from the Turing computer model, instruction sets, addressing, RISC versus CICS, traps and interrupt handling, two's complement arithmetic, adders and ALUs, CSA's Booth's algorithm, multiplication and division, control unit design, microprogramming, dynamic versus static linking, memory systems and memory hierarchy, paging segmentation, cache hardware, cache organizations, and replacement policies.
Prerequisites: EN.520.142
Instructor(s): P. Pouliquen
Area: Engineering.

EN.520.240. Introduction to Mechatronics. 3.00 Credits.
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.

EN.520.270. Introduction to Renewable Energy Engineering. 3.00 Credits.
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. 3.00 Credits.
An introductory course to basic concepts of information processing of human communication signals (sounds, images) in living organisms and by machine. Recommended Course Background: EN.520.214 (or EN.580.222) or consent of the instructor.
Instructor(s): H. Hermansky
Area: Engineering.

EN.520.345. Electrical & Computer Engineering Laboratory. 3.00 Credits.
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: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): A. Foster, S. Ramesh
Area: Engineering.

EN.520.349. Microprocessor Lab I. 3.00 Credits.
This course introduces the student to the programming of microprocessors at the machine level. 68HC08, 8051, and eZ8 microcontrollers are programmed in assembly language for embedded control purposes. The architecture, instruction set, and simple input/output operations are covered for each family. Upon completion, students can use these flash-based chips as elements in other project courses.
Recommended Course Background: EN.520.142 or equivalent.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): R. Glaser
Area: Engineering.

EN.520.353. Control Systems. 3.00 Credits.
Modeling, analysis, and an introduction to design for feedback control systems. Topics include state equation and transfer function representations, stability, performance measures, root locus methods, and frequency response methods (Nyquist, Bode).
Prerequisites: Prerequisites: EN.520.343 AND EN.520.214
Instructor(s): E. Mallada Garcia
Area: Engineering.

EN.520.372. Programmable Device Lab. 3.00 Credits.
The use of programmable memories (ROMs, EPROMs, and EEPROMs) as circuit elements (as opposed to storage of computer instructions) is covered, along with programmable logic devices (PLAs and GALs). These parts permit condensing dozens of standard logic packages (TTL logic) into one or more off-the-shelf components. Students design and build circuits using these devices with the assistance of CAD software. Topics include programming EEPROMs; using PLDs as address decoders; synchronous sequential logic synthesis for PLDs; and PLD-based state machines. Recommended Course Background: EN.520.142 and EN.520.345.
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). 3.00 Credits.
An introductory course in which students, manually and through computer simulations, design digital CMOS integrated circuits and systems. The design flow covers transistor, physical, and behavioral level descriptions, using SPICE, Layout, and VerilogHD1 VLSI CAD tools. After design computer verification, students can fabricate and test their semester-long class projects. 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. 3.00 Credits.
This course covers the principles of modern analog and digital communication systems. Topics include: amplitude modulation formats (DSB, SSC VSB), exponential modulation formats (PM, FM), superheterodyne receivers, digital representation of analog signals, sampling theorem, pulse code modulation formats (PCM, DPCM, DM, spread-spectrum), signals with additive Gaussian noise, maximum likelihood receiver design, matched filtering, and bit error rate analyses of digital communication systems.
Prerequisites: Prereqs: EN.520.214 AND EN.550.310 or equivalent.
Instructor(s): Staff
Area: Engineering.

EN.520.402. Digital Communications. 3.00 Credits.
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): Staff
Area: Engineering, Natural Sciences.

EN.520.403. Introduction to Optical Instruments. 3.00 Credits.
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.
Prerequisites: Students may take EN.520.403 or EN.520.603, but not both.
Instructor(s): J. Khurgin
Area: Engineering.

EN.520.404. Digital Signal Processing. 3.00 Credits.
This course will focus on the use of machine learning theory and algorithms to model, classify and retrieve information from different kinds of real world complex signals such as audio, speech, image and video.
Prerequisites: Students may earn credit for EN.520.614 or EN.520.412, but not both.;AS.110.201 AND EN.550.310 AND EN.520.435
Instructor(s): N. Dehak
Area: Engineering.

EN.520.405. Image Processing & Analysis. 3.00 Credits.
The course covers fundamental methods for the processing and analysis of images and describes standard and modern techniques for the understanding of images by humans and computers. Topics include elements of visual perception, sampling and quantization, image transforms, image enhancement, color image processing, image restoration, image segmentation, and multiresolution image representation. Laboratory exercises demonstrate key aspects of the course.
Prerequisites: EN.520.214.; Students may earn credit for EN.520.614 or EN.520.414, but not both.
Instructor(s): J. Goutsias
Area: Engineering.

EN.520.407. Introduction to the Physics of Electronic Devices. 3.00 Credits.
This course is designed to develop and enhance the understanding of the basic physical processes taking place in the electronic and optical devices and to prepare students for taking classes in semiconductor devices and circuits, optics, lasers, and 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.520.419. Iterative Algorithms. 3.00 Credits.**
An introduction to the study of the structure, behavior and design of iterative algorithms. Topics include problem formulations, algorithm description and classification, the deterministic iterative (Di) schema, doubling schema, cluster point sets, periodic points, Di schemas without stop rule, the monotonic Di schema, contractive and affine maps, bounded and Cauchy sequences, asymptotically regular sequences, monotonic sequences.
**Prerequisites:** AS.110.201 AND AS.110.202
Instructor(s): G. Meyer
Area: Engineering, Quantitative and Mathematical Sciences.

**EN.520.424. FPGA Synthesis Lab. 3.00 Credits.**
An advanced laboratory course in the application of FPGA technology to information processing, using VHDL synthesis methods for hardware development. The student will use commercial CAD software for VHDL simulation and synthesis, and implement their systems in programmable XILINX 20,000 gate FPGA devices. The lab will consist of a series of digital projects demonstrating VHDL design and synthesis methodology, building up to final projects at least the size of an 8-bit RISC computer. Projects will encompass such things as system clocking, flip-flop registers, state-machine control, and arithmetic. The students will learn VHDL methods as they proceed through the lab projects, and prior experience with VHDL is not a prerequisite.
**Prerequisites:** 520.142 and 520.345. Recommended Courses: 500.333 (Computer System Fundamentals) or 520.349 (Microprocessor Lab); Students must have completed Lab Safety training prior to registering for this class; Students may take EN.520.624 or EN.520.644, but not both.
Instructor(s): P. Pouliquen
Area: Engineering, Quantitative and Mathematical Sciences.

**EN.520.425. FPGA Senior Projects Laboratory. 3.00 Credits.**
Laboratory course for FPGA based senior projects. Students will work in teams to complete a design project that makes use of embedded FPGAs. The projects will make use of the Spartan2 XSA boards and other resources from the FPGA Synthesis lab course. Possible projects include: A 16 or 32 bit RISC processor with student designed ISA architecture, assembler, and mini operating system; or a Spartan2 emulation of an existing microprocessor such as an 8051, an electrical 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): Staff
Area: Engineering.

**EN.520.427. Product Design Lab. 3.00 Credits.**
This project-based course is designed to help students learn how to turn their ideas into commercial products. In the first half of the course, emphasis will be placed on the product development process: student teams will gradually build up a complete contract book including a mission statement, competitive analysis, patent review, product specifications, system schematics, economic analysis, development schedule, etc. In the second half of the course, each team will be expected to implement its design and demonstrate a prototype of their product's core functionality. At the end of the semester, a final written report will be submitted in the form of a utility patent. Students are encouraged to take this course in conjunction with Electronic Design Lab (ECE 520.448) in the Spring semester and leverage the groundwork developed here to enable production of a fully functional and marketable prototype by the end of the academic year.
Instructor(s): P. Pouliquen
Area: Engineering.

**EN.520.432. Medical Imaging Systems. 3.00 Credits.**
An introduction to the physics, instrumentation, and signal processing methods used in general radiography, X-ray computed tomography, ultrasound imaging, magnetic resonance imaging, and nuclear medicine. The primary focus is on the methods required to reconstruct images within each modality, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Co-listed as EN.580.472
**Prerequisites:** Student may earn credit for EN.520.632 or EN.520.432, but not both.; EN.580.222 OR EN.520.214
Instructor(s): J. Prince
Area: Engineering.

**EN.520.433. Medical Image Analysis. 3.00 Credits.**
This course covers the principles and algorithms used in the processing and analysis of medical images. Topics include, interpolation, registration, enhancement, feature extraction, classification, segmentation, quantification, shape analysis, motion estimation, and visualization. Analysis of both anatomical and functional images will be studied and images from the most common medical imaging modalities will be used. Projects and assignments will provide students experience working with actual medical imaging data.
**Prerequisites:** EN.520.432 OR EN.580.472 OR EN.550.310 OR EN.550.311
Instructor(s): J. Prince
Area: Engineering.

**EN.520.434. Modern Biomedical Imaging Instrumentation and Techniques. 3.00 Credits.**
An intermediate biomedical imaging course covering modern biomedical imaging instrumentation and techniques as applied to diagnostic radiology and other biomedical applications. It includes recent advances in various biomedical imaging modalities, multi-modality imaging and molecular imaging. The course is team taught by experts in the respective fields and provides a broad based knowledge of modern biomedical imaging to prepare students for graduate studies and research in biomedical imaging. Also, the course will offer tours and practical experience with modern biomedical imaging equipments in clinical and research settings. Co-listed with EN.580.473
**Prerequisites:** EN.520.432 OR EN.580.472
Instructor(s): B. Tsui.
EN.520.435. Digital Signal Processing. 3.00 Credits.
Methods for processing discrete-time signals. Topics include signal and system representations, \( z \)-transforms, sampling, discrete Fourier transforms, fast Fourier transforms, digital filters.
Prerequisites: EN.520.214.; Students may receive credit for EN.520.435 or EN.520.635, but not both.
Instructor(s): H. Weinert
Area: Engineering.

EN.520.444. Audio Signal Processing. 3.00 Credits.
This course gives a foundation in current audio and speech technologies, and covers techniques for sound processing by processing and pattern recognition, acoustics, auditory perception, speech production and synthesis, speech estimation. The course will explore applications of speech and audio processing in human computer interfaces such as speech recognition, speaker identification, coding schemes (e.g. MP3), music analysis, noise reduction. Students should have knowledge of Fourier analysis and signal processing.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): M. Elhilali
Area: Engineering.

EN.520.447. Information Theory. 3.00 Credits.
This course will address some basic scientific questions about systems that store or communicate information. Mathematical models will be developed for (1) the process of error-free data compression leading to the notion of entropy, (2) data (e.g. image) compression with slightly degraded reproduction leading to rate-distortion theory and (3) error-free communication of information over noisy channels leading to the notion of channel capacity. It will be shown how these quantitative measures of information have fundamental connections with statistical physics (thermodynamics), computer science (string complexity), economics (optimal portfolios), probability theory (large deviations), and statistics (Fisher information, hypothesis testing).
Instructor(s): S. Khudanpur
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.448. Electronics Design Lab. 3.00 Credits.
An advanced laboratory course in which teams of students design, build, test and document application specific information processing microsystems. Semester long projects range from sensors/actuators, mixed signal electronics, embedded microcomputers, algorithms and robotics systems design. Demonstration and documentation of projects are important aspects of the evaluation process. Recommended: EN.600.333, EN.600.334, EN.520.349, EN.520.372, EN.520.490 or EN.520.491.
Prerequisites: EN.520.345 or equivalent Recommended: 600.333, 600.334, 520.216, 520.349, 520.372, 520.490 or 520.491.; Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): P. Julian; R. Etienne Cummings

EN.520.450. Advanced Micro-Processor Lab. 3.00 Credits.
This course covers the usage of common microcontroller peripherals. Interrupt handling, timer operations, serial communication, digital to analog and analog to digital conversions, and flash ROM programming are done on the 68HC08, 8051, and 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. 3.00 Credits.
This course introduces the student to running an ECE engineering team project. The student will participate in the team project as a leading member and is expected to manage both the team members and the different aspects of the project over several semesters. Permission of the instructor is required for new team members. (Junior and Seniors)
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): A. Andreou; C. Rizk; J. Kang; J. West
Area: Engineering.

EN.520.453. Advanced ECE Engineering Team Project. 3.00 Credits.
The course introduces the student to running an engineering team project. The student will participate in the ECE engineering team project as a leading member. The student is expected to participate in the different aspects of the project over several semesters and manage both team members and the project. (Juniors and Seniors) Permission of instructor is required.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): C. Rizk; J. Kang; J. West
Area: Engineering.

EN.520.454. Control Systems Design. 3.00 Credits.
Classical and modern control systems design methods. Topics include formulation of design specifications, classical design of compensators, state variable and observer based feedback. Computers are used extensively for design, and laboratory experiments are included.
Prerequisites: Students may earn credit for EN.520.654 or EN.520.454, but not both.
Instructor(s): P. Iglesias
Area: Engineering.

EN.520.457. Basics of Wave and Quantum Mechanics. 3.00 Credits.
Basic principles of quantum mechanics for engineers. Topics include the quantum theory of simple systems, in particular atoms and engineered quantum wells, the interaction of radiation and atomic systems, and examples of application of the quantum theory to lasers and solid-state devices. Recommended Course Background: AS.171.101-AS.171.102 and EN.520.219-EN.520.220
Instructor(s): A. Kaplan
Area: Engineering.

EN.520.459. Quantum Mechanics for Engineering. 3.00 Credits.
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 freshman-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.520.465. Digital Communications I. 3.00 Credits.
This course introduces the basic tools and topics of modern digital communication beginning with the mathematical representation and spectral properties of random signals and a basic introduction to the detection of real and complex signals in the presence of noise. Memoryless modulation and demodulation schemes are thoroughly studied for the Gaussian channel, and measures of performance are developed. Topics in wireless communication will be introduced. Recommended Course Background: EN.520.401, EN.550.310 or EN.550.420
Instructor(s): F. Davidson
Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.473. Magnetic Resonance in Medicine. 3.00 Credits.
This course provides a wide-ranging introduction to the physics and principles of magnetic resonance imaging (MRI). Topics include the resonance phenomenon, relaxation, signal formation, spatial localization, image contrast, hardware, signal processing, and image reconstruction. MATLAB simulation exercises will demonstrate key aspects of MRI and a laboratory component using the clinical MRI systems at the School of Medicine will reinforce concepts learned in class. Textbook Principles of Magnetic Resonance Imaging by D. Nishimura (from www.lulu.com) should be obtained before the start of the course. Recommended Course Background: (EN.520.434 or EN.580.473) or (EN.520.432 or EN.580.472), Co-listed with EN.580.476 and EN.580.673.
Instructor(s): Staff
Area: Engineering, Natural Sciences.

EN.520.482. Introduction to Lasers. 3.00 Credits.
This course covers the basic principles of laser oscillation. Specific topics include propagation of rays and Gaussian beams in lens-like media, optical resonators, spontaneous and stimulated emission, interaction of optical radiation and atomic systems, conditions for laser oscillation, homogeneous and inhomogeneous broadening, gas lasers, solid state lasers, Q-switching and mode locking of lasers.
Prerequisites: EN.520.219 AND EN.520.220
Instructor(s): J. Khurgin
Area: Engineering, Natural Sciences.

EN.520.483. Bio-Photonics Laboratory. 3.00 Credits.
This laboratory course involves designing a set of basic optical experiments to characterize and understand the optical properties of biological materials. The course is designed to introduce students to the basic optical techniques used in medicine, biology, chemistry and material sciences.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): J. Kang, S. Ramesh.

EN.520.485. Advanced Semiconductor Devices. 3.00 Credits.
This course is designed to develop and enhance the understanding of the operating principles and performance characteristics of the modern semiconductor devices used in high speed optical communications, optical storage and information display. The emphasis is on device physics and fabrication technology. The devices include heterojunction bipolar transistors, high mobility FET’s, semiconductor lasers, laser amplifiers, light-emitting diodes, detectors, solar cells and others.
Instructor(s): J. Khurgin
Area: Engineering, Natural Sciences.

EN.520.486. Physics of Semiconductor Electronic Devices. 3.00 Credits.
The course is designed to develop and enhance the understanding of the physical principles of modern semiconductor electronic and optoelectronic devices. The course starts with the basics of band structure of solid with emphasis on group IV and III-V semiconductors as well as two dimensional semiconductors like graphene. It continues with the statistics of carriers in semiconductors and continues to electronic transport properties, followed by optical properties. The course goes on to investigate the properties of two dimensional electronic gas. The second part of the course describes operational principles of bipolar and unipolar transistors, light emitting diodes, photodetectors, and quantum devices.
Prerequisites: Students may earn credit for EN.520.486 or EN.520.686, but not both.
Instructor(s): J. Khurgin.

EN.520.491. CAD Design of Digital VLSI Systems I (Juniors/Seniors). 3.00 Credits.
Juniors and Seniors Only. 
Prerequisites: Student may take EN.520.491 or EN.520.691, but not both.
Instructor(s): R. Etienne Cummings
Area: Engineering.

EN.520.492. Mixed-Mode VLSI Systems. 3.00 Credits.
Silicon models of information and signal processing functions, with implementation in mixed analog and digital CMOS integrated circuits. Aspects of structured design, scalability, parallelism, low power consumption, and robustness to process variations. Topics include digital-to-analog and analog-to-digital conversion, delta-sigma modulation, bioinstrumentation, and adaptive neural computation. The course includes a VLSI design project. Recommended Course Background: EN.521.491 or equivalent.
Instructor(s): P. Pouliquen
Area: Engineering.

EN.520.495. Microfabrication Laboratory. 4.00 Credits.
This laboratory course is an introduction to the principles of microfabrication for microelectronics, sensors, MEMS, and other synthetic microsystems that have applications in medicine and biology. Course comprises of laboratory work and accompanying lectures that cover silicon oxidation, aluminum evaporation, 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
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): A. Andreou; J. Wang
Area: Engineering, Natural Sciences.

EN.520.498. Senior Design Project. 3.00 Credits.
Capstone design project, in which a team of students engineers a system and evaluates its performance in meeting design criteria and specifications. Example application areas are micro-electronic information processing, image processing, speech recognition, control, communications, and biomedical instrumentation. The design needs to demonstrate creative thinking and experimental skills, and needs to draw upon knowledge in basic sciences, mathematics, and engineering sciences. Interdisciplinary participation, such as by biomedical engineering, mechanical engineering, and computer science majors, is strongly encouraged. Instructor permission required.
Instructor(s): Staff
Area: Engineering.
EN.520.499. Senior Design Project. 3.00 Credits.
Capstone design project, in which a team of students engineer a system and evaluate its performance in meeting design criteria and specifications. Example application areas are microelectronic information processing, image processing, speech recognition, control, communications and biomedical instrumentation. The design needs to demonstrate creative thinking and experimental skills, and needs to draw upon knowledge in basic sciences, mathematics and engineering sciences. Interdisciplinary participation, such as by biomedical engineering, mechanical engineering and computer science majors, is strongly encouraged.
Instructor(s): Staff
Area: Engineering.

EN.520.501. Independent Study-Freshmen-Sophomores. 3.00 Credits.
Individual, guided study under the direction of a faculty member in the department. The program of study or research, including the credit to be assigned, must be worked out in advance between the student and the faculty member involved. May be taken either term by freshmen or sophomores. Instructor permission required.
Instructor(s): A. Andreou, F. Davidson; J. Kang; J. Prince.

EN.520.502. Indep Study - Fresh/Soph. 0.00 - 3.00 Credits.
Individual, guided study under the direction of a faculty member in the department. The program of study or research, including the credit to be assigned, must be worked out in advance between the student and the faculty member involved.
Instructor(s): A. Andreou.

EN.520.503. Independent Study-Juniors-Seniors. 3.00 Credits.
Individual, guided study under the direction of a faculty member in the department. The program of study or research, including the credit to be assigned, must be worked out in advance between the student and the faculty member involved. May be taken either term by juniors or seniors.
Instructor(s): Staff.

EN.520.504. Independent Study - Juniors/Seniors. 0.00 - 3.00 Credits.
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.520.506. ECE Undergraduate Research. 1.00 - 3.00 Credits.
Independent research 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): N. Dehak; P. Iglesias.

EN.520.516. ECE Group Undergraduate Research. 1.00 - 3.00 Credits.
Independent research 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. This section has a weekly research group meeting that students are expected to attend.
Instructor(s): G. Meyer; J. Kang; M. Foster; S. Thon.

EN.520.545. Research. 1.00 - 3.00 Credits.
Instructor Approval Required. Independent study or research over the summer under the direction of a faculty member in the department. The program of research, including the credit to be assigned, must be worked out in advance between the student and the faculty member involved.
Instructor(s): D. Tarraf.

EN.520.548. Independent Research. 0.00 - 3.00 Credits.
Instructor(s): J. West; P. Iglesias; S. Thon.

EN.520.550. Electrical Engineering - Internship. 0.00 - 3.00 Credits.
Instructor(s): J. Kang; T. Tran.

EN.520.559. Independent Study. 0.00 - 3.00 Credits.
Instructor(s): A. Andreou; J. Kang; J. West; R. Etienne Cummings; T. Tran.

EN.520.597. Research-Summer. 3.00 Credits.
Instructor(s): Staff.

EN.520.599. Internship-Summer. 1.00 Credit.
Instructor(s): F. Davidson; G. Meyer; J. Kang; M. Miller.

EN.520.600. Electrical & Computer Engineering Seminar. 1.00 Credit.
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. 3.00 Credits.
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.520.603. Introduction to Optical Instruments. 3.00 Credits.
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.
Prerequisites: Students may take EN.520.403 or EN.520.603, but not both.
Instructor(s): J. Khurgin
Area: Engineering.

EN.520.611. Ultrafast Optical Phenomena. 3.00 Credits.
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.
Instructor(s): M. Foster
Area: Engineering, Natural Sciences.
EN.520.612. Machine Learning for Signal Processing. 3.00 Credits.
This course will focus on the use of machine learning theory and algorithms to model, classify and retrieve information from different kinds of real world complex signals such as audio, speech, image and video. Recommended Course Background: AS.110.201, EN.550.310, and EN.520.435.
Prerequisites: Students may earn credit for EN.520.412 or EN.520.612, but not both.
Instructor(s): N. Dehak
Area: Engineering.

EN.520.613. Advanced Topics in Optical Medical Imaging. 3.00 Credits.
The course will review the recent advances in photonics technologies for medical imaging and sensing. The course is designed for graduate students with a back ground 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.520.614. Image Processing & Analysis. 3.00 Credits.
The course covers fundamental methods for the processing and analysis of images and describes standard and modern techniques for the understanding of images by humans and computers. Topics include elements of visual perception, sampling and quantization, image transforms, image enhancement, color image processing, image restoration, image segmentation, and multiresolution image representation. Laboratory exercises demonstrate key aspects of the course.
Prerequisites: Students may earn credit for EN.520.614 or EN.520.414, but not both.
Instructor(s): J. Goutsias
Area: Engineering.

EN.520.615. Image Processing & Analysis II. 3.00 Credits.
The course covers fundamental methods for the processing and analysis of images and describes standard and modern techniques for the understanding of images by humans and computers. Topics include elements of visual perception, sampling and quantization, image transforms, image enhancement, color image processing, image restoration, image segmentation, and multiresolution image representation. Laboratory exercises demonstrate key aspects of the course. Grad students only.
Prerequisites: Students may earn credit for EN.520.615 or EN.520.415, but not both, EN.520.414 OR EN.520.614
Instructor(s): J. Goutsias
Area: Engineering.

EN.520.618. Hybrid Systems. 2.00 Credits.
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.
Instructor(s): D. Tarraf
Area: Engineering.

EN.520.620. Selected Topics in Theory of Iterative Algorithms. 3.00 Credits.
This course covers information on the non-deterministic schema and cyclic iterative schemas, Jacobians, Hessians and Mean Value Theorems, spectral norm, convex sets and positive definite majs.
Instructor(s): G. Meyer.

EN.520.621. Introduction To Nonlinear Systems. 3.00 Credits.
Instructor(s): P. Iglesias
Area: Engineering, Natural Sciences.

EN.520.622. Principles of Complex Networked Systems. 3.00 Credits.
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.520.623. Medical Imaging Analysis. 3.00 Credits.
Graduate version of 520.433. 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 AND EN.550.310 OR EN.550.311
Instructor(s): J. Prince.

EN.520.624. Integrated Photonics. 3.00 Credits.
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. 3.00 Credits.
This course provides an introduction to the science of photovoltaics and related energy devices. Topics covered include basic concepts in semiconductor device operation and carrier statistics; recombination mechanisms; p-n junctions; silicon, thin film, and third generation photovoltaic technologies; light trapping; and detailed balance limits of efficiency. Additionally, thermophotovoltaics and electrical energy storage technologies are introduced. A background in semiconductor device physics (EN.520.485, or similar) is recommended.
Instructor(s): S. Thon.
EN.520.629. Networked Dynamical Systems. 3.00 Credits.
Networks and dynamics are pervasive in our world today. Power systems, the Internet, social networks, and biological systems are only a few of the numerous scenarios in which objects or individuals can affect - and be affected by - other members of a large group. This course examines modeling, analysis and design of networked dynamical systems - i.e., dynamic entities interconnected by a network - as well as various applications of such systems in science and engineering. Topics covered include (algebraic) graph theory, basic models of networked dynamical systems, continuous-time and discrete-time distributed averaging (consensus), coordination algorithms (rendezvous, formation, flocking, and deployment), and distributed algorithm computation and optimization over networks. Some of the motivating applications that will be analyzed are robotic coordination, coupled oscillators, social networks, web PageRank, sensor networks, power grids, and epidemics. Recommended Course Background: Linear Algebra (AS.110.201), Control Systems (EN.520.353), or equivalents, basic Matlab skills, and sufficient mathematical maturity. Instructor(s): E. Mallada Garcia.

EN.520.631. Ultrasound and Photoacoustic Beamforming. 3.00 Credits.
This course will discuss basic principles of ultrasound and photoacoustic imaging and provide an in-depth analysis of the beamforming process required to convert received electronic signals into a usable image. We will cover basic beamforming theory and apply it to real clinical and preclinical data. The course will culminate with student projects to design and implement a new beamformer derived from the principles taught in class. Instructor(s): M. Bell.

EN.520.632. Medical Imaging Systems. 3.00 Credits.
An introduction to the physics, instrumentation, and signal processing methods used in general radiography, X-ray computed tomography, ultrasound imaging, magnetic resonance imaging, and nuclear medicine. The primary focus is on the methods required to reconstruct images within each modality, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Prerequisites: Student may earn credit for EN.520.632 or EN.520.432, but not both. Instructor(s): J. Prince Area: Engineering.

EN.520.633. Intro To Robust Control. 3.00 Credits.
The subject of this course is robust analysis and control of multivariable systems. Topics include system analysis (small gain arguments, integral quadratic constraints); parametrization of stabilizing controllers; $H_{\infty}$ optimization based robust control design; and LTI model order reduction (balanced truncation, Hankel reduction). Recommended Course Background: EN.520.601 or EN.530.616 or EN.580.616 Instructor(s): Staff Area: Engineering.

EN.520.635. Digital Signal Processing. 3.00 Credits.
Methods for processing discrete-time signals. Topics include signal and system representations, z-transforms, sampling, discrete Fourier transforms, fast Fourier transforms, digital filters. Prerequisites: Students may earn credit for EN.520.635 or EN.520.435, but not both. Instructor(s): H. Weinert Area: Engineering.

EN.520.636. Feedback Control in Biological Signaling Pathways. 3.00 Credits.
This course considers examples of the use of feedback control in engineering systems and looks for counterparts in biological signaling networks. To do this will require some knowledge of mathematical modeling techniques in biology, so a part of the course will be devoted to this. Instructor(s): P. Iglesias.

EN.520.644. FPGA Synthesis Lab. 3.00 Credits.
An advanced laboratory course in the application of FPGA technology to information processing, using VHDL synthesis methods for hardware development. The student will use commercial CAD software for VHDL simulation and synthesis, and implement their systems in programmable XILINX 20,000 gate FPGA devices. The lab will consist of a series of digital projects demonstrating VHDL design and synthesis methodology, building up to final projects at least the size of an 8-bit RISC computer. Projects will encompass such things as system clocking, flip-flop registers, state-machine control, and arithmetic. The students will learn VHDL methods as they proceed through the lab projects, and prior experience with VHDL is not a prerequisite. Prerequisites: Students may take EN.520.424 or EN.520.644, but not both. Instructor(s): P. Pouliquen Area: Engineering, Quantitative and Mathematical Sciences.

EN.520.645. Audio Signal Processing. 3.00 Credits.
This course gives a foundation in current audio and speech technologies, and covers techniques for sound processing by processing and pattern recognition, acoustics, auditory perception, speech production and synthesis, speech estimation. The course will explore applications of speech and audio processing in human computer interfaces such as speech recognition, speaker identification, coding schemes (e.g. MP3), music analysis, noise reduction. Students should have knowledge of Fourier analysis and signal processing. Prerequisites: Students make take EN.520.445 or EN.520.645, but not both. Instructor(s): M. Elhilali Area: Engineering.

EN.520.646. Wavelets & Filter Banks. 3.00 Credits.
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. 3.00 Credits.
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.520.544. Control Systems Design. 3.00 Credits.
Classical and modern control systems design methods. Topics include formulation of design specifications, classical design of compensators, state variable and observer based feedback. Computers are used extensively for design, and laboratory experiments are included. 
Prerequisites: Students may earn credit for EN.520.654 or EN.520.454, but not both.
Instructor(s): P. Iglesias
Area: Engineering.

EN.520.651. Random Signal Analysis. 4.00 Credits.
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): A. Venkataraman.

EN.520.652. Extraction of Signals from Noise. 3.00 Credits.
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.520.654. Control Systems Design. 3.00 Credits.
Classical and modern control systems design methods. Topics include formulation of design specifications, classical design of compensators, state variable and observer based feedback. Computers are used extensively for design, and laboratory experiments are included. 
Prerequisites: Students may earn credit for EN.520.654 or EN.520.454, but not both.
Instructor(s): P. Iglesias
Area: Engineering.

EN.520.666. Information Extraction. 3.00 Credits.
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.
Prerequisites: EN.550.310 AND EN.600.120 or equivalent, expertise in C or C++ programming.
Instructor(s): S. Khudanpur.

EN.520.678. Biomedical Photonics. 3.00 Credits.
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. After the basis is established, we will focus on some 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. 3.00 Credits.
This graduate level seminar focuses on works that are relevant to building advanced systems for information extraction from auditory signals. It loosely compliments and expands on the lecture material from the graduate course EN.520.515. Participants will take turns in presenting and critically discussing selected topics, with an aim of using this knowledge in their research projects. When available, guest speakers may at times contribute or substitute for the presentation of the participants. Recommended Course Background: Completion or concurrent participation in EN.520.515 or consent of the instructor.
Instructor(s): H. Hermansky.

EN.520.682. Introduction to Lasers. 3.00 Credits.
This course covers the basic principles of laser oscillation. Specific topics include propagation of rays and Gaussian beams in lens-like media, optical resonators, spontaneous and stimulated emission, interaction of optical radiation and atomic systems, conditions for laser oscillation, homogeneous and inhomogeneous broadening, gas lasers, solid state lasers, Q-switching and mode locking of lasers. Recommended Course Background: EN.520.219 and EN.520.220
Instructor(s): J. Khurgin.

EN.520.683. Bio-Photonics Laboratory. 3.00 Credits.
This laboratory course involves designing a set of basic optical experiments to characterize and understand the optical properties of biological materials. The course is designed to introduce students to the basic optical techniques used in medicine, biology, chemistry and material sciences. Graduate version of EN.520.483
Instructor(s): J. Kang; S. Ramesh.
EN.520.686. Physics of Semiconductor Electronic Devices. 3.00 Credits.
The course is designed to develop and enhance the understanding of
the physical principles of modern semiconductor electronic and opto-
electronic devices. The course starts with the basics of band structure
of solid with emphasis on group IV and III-V semiconductors as well
as two dimensional semiconductors like graphene. It continues with
the statistics of carriers in semiconductors and continues to electronic
transport properties, followed by optical properties. The course goes
on to investigate the properties of two dimensional electronic gas. The
second part of the course describes operational principles of bipolar and
unipolar transistors, light emitting diodes, photodetectors, and quantum
devices.
Prerequisites: Students may earn credit for EN.520.486 or EN.520.686,
but not both.
Instructor(s): J. Khurgin
Area: Engineering.

EN.520.691. CAD Design of Digital VLSI Systems I (Grad). 3.00 Credits.
Graduate students only.
Prerequisites: Student may take EN.520.491 or EN.520.691, but not both.
Instructor(s): R. Etiene Cummings
Area: Engineering.

EN.520.692. Mixed-Mode VLSI Systems. 3.00 Credits.
Silicon models of information and signal processing functions,
with implementation in mixed analog and digital CMOS integrated
circuits. Aspects of structured design, scalability, parallelism, low
power consumption, and robustness to process variations. Topics
include digital-to-analog and analog-to-digital conversion, delta-sigma
modulation, bioinstrumentation, and adaptive neural computation.
The course includes a VLSI design project. Recommended Course
Background: EN.521.491 or equivalent.
Instructor(s): P. Pouliluen.

EN.520.697. Advanced Electronic Lab Design. 3.00 Credits.
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
Area: Engineering.

EN.520.701. Current Topics in Language and Speech Processing. 1.00
Credit.
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.520.702. Current Topics in Language and Speech Processing. 1.00
Credit.
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. 3.00 Credits.
Analysis of information processing in biological sensory organs
and in engineered microsystems using the mathematical tools of
communication theory. Natural or synthetic structures are modeled
as microscale communication networks implemented under physical
constraints, such as size and available energy resources and are studied
at two levels of abstraction. At the information processing level we
examine the functional specification, while at the implementation level
we examine the physical specification and realization. Both levels are
characterized by Shannon's channel capacity, as determined by the
channel bandwidth, the signal power, and the noise power. The link
between the information processing level and the implementation level of
abstraction is established through first principles and phenomenological
otherwise, models for transformations on the signal, constraints on the
system, and noise that degrades the signals.
Instructor(s): A. Andreou.

EN.520.736. Advanced Electronic Lab Design. 3.00 Credits.
This course is the graduate expansion of the EN.520.448 Electronic
Lab, which is an advanced laboratory course in which teams of students design, build, test and document application
specific information processing microsystems. Semester long
projects range from sensors/actuators, mixed signal electronics,
embedded microcomputers, algorithms and robotics systems design.
Demonstration and documentation of projects are important aspects
of the evaluation process. For this graduate expansion, all projects
will be based on recently published research from IEEE Transactions.
The students will be required to fully research, analyze, implement
and demonstrate their chosen topic. The emphasis will be on VLSI
microsystems, although other topics will also be considered. Open to
graduate students only.
Instructor(s): P. Julian; R. Etiene Cummings.

EN.520.746. Seminar: Medical Image Analysis. 1.00 Credit.
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.520.773. Advanced Topics In Microsytem Fabrication. 1.00 Credit.
Graduate-level course on topics that relate to microsystem integration of
complex functional units across different physical scales from nano to
micro and macro. Topics will include emerging fabrication technologies,
micro-electromechanical systems, nanolithography, nanotechnology,
soft lithography, self-assembly, and soft materials. Discussion will also
include biological systems as models of microsystem integration and
functional complexity. Perm. Req’d.
Instructor(s): A. Andreou.
EN.520.800. Independent Study. 1.00 - 3.00 Credits.
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. 3.00 - 20.00 Credits.
EN.520.802. Dissertation Research. 3.00 - 20.00 Credits.
Instructor(s): Staff.

EN.520.809. Special Studies. 1.00 - 3.00 Credits.
Individual study in an area of mutual interest to a student and a faculty member in the department. Permission of Instructor required.
Instructor(s): A. Andreou; F. Davidson; J. Khurgin; N. Thakor; T. Tran.

EN.520.890. Independent Study-Summer. 1.00 - 3.00 Credits.
Instructor(s): Staff.

Cross Listed Courses

General Engineering
EN.500.745. Seminar in Computational Sensing and Robotics. 1.00 Credit.
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. Biobotics and neurorobotics, 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
EN.510.314. Electronic Properties of Materials. 3.00 Credits.
Fourth of the Introduction to Materials Science series, this course is devoted to a study of the electronic, optical and magnetic properties of materials. Lecture topics include electrical and thermal conductivity, thermoelectricity, transport phenomena, dielectric effects, piezoelectricity, and magnetic phenomena. This course contains computational modules; some prior knowledge of computer programming is needed. Recommended Course Background: EN.510.202 (Computation and Programming for Materials Scientists and Engineers) or equivalent.
Prerequisites: EN.510.311
Instructor(s): P. Searson
Area: Engineering, Natural Sciences.

EN.510.418. Electronic and Photonic Processes and Devices. 3.00 Credits.
This course is intended for advanced undergraduates and graduate students and will cover the fundamentals and properties of electronic and optical materials and devices. Subject matter will include a detailed and comprehensive discussion of the physical processes underlying modern electronic and optical devices. Detailed descriptions of modern semiconductor devices such as lasers and detectors used in optical communications and information storage and processing will be presented. Also listed as EN.510.618/EN.510.418.
Instructor(s): T. Poehler
Area: Engineering, Natural Sciences.

EN.510.611. Solid State Physics. 3.00 Credits.
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.

EN.510.612. Solid State Physics. 3.00 Credits.
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. 3.00 Credits.
This course is intended for advanced undergraduates and graduate students and will cover the fundamentals and properties of electronic and optical materials and devices. Subject matter will include a detailed and comprehensive discussion of the physical processes underlying modern electronic and optical devices. Detailed descriptions of modern semiconductor devices such as lasers and detectors used in optical communications and information storage and processing will be presented. Also listed as EN.510.618/EN.510.418.
Instructor(s): T. Poehler.

Mechanical Engineering
EN.530.682. Haptic Applications. 4.00 Credits.
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.580.472. Medical Imaging Systems. 3.00 Credits.
An introduction to the physics, instrumentation, and signal processing methods used in general radiography, X-ray computed tomography, ultrasound imaging, magnetic resonance imaging, and nuclear medicine. The primary focus is on the methods required to reconstruct images within each modality, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Cross-listed with Neuroscience and Electrical and Computer Engineering (EN.520.432).
Prerequisites: EN.580.222 OR EN.520.214
Instructor(s): J. Prince
Area: Engineering.
EN.580.483. Nuclear Medicine Imaging. 3.00 Credits.
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. Rahmim; B. Tsui; E. Frey; Y. Du
Area: Engineering.

Computer Science
EN.600.479. Representation Learning. 3.00 Credits.
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.600.479 you may not enroll in
EN.600.479.
Instructor(s): R. Arora
Area: Engineering.

EN.600.679. Representation Learning. 3.00 Credits.
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.