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 five major areas:

1. controls, networks and systems;
2. image and signal processing;
3. acoustics, speech and language processing;
4. microsystems and computer engineering, and
5. photonics and physical electronics.

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

Current Research Activities

Control, Networks, and Systems
Current research in control, networks, and systems includes the design and analysis of robust control algorithms; design, analysis, and performance evaluation of distributed control algorithms for networked dynamical systems; real-time optimization of dynamical systems; multi-time scale optimization decomposition of networked systems. Application domains include systems and synthetic biology, particularly the analysis of signaling pathways in biological systems; power systems, including multi-timescale market design and co-optimization, distributed control design for frequency regulation, real-time congestion management, and low inertia power system control; information networks, including the design of clock synchronization algorithms, and joint congestion control and multi-path routing for data networks.

Image and Signal Processing
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, magnetic resonance imaging, ultrasound imaging, and photoacoustic imaging. There is opportunity for joint work in image analysis and signal processing with faculty in the Department of Radiology and various other departments within the School of Medicine.

Acoustics, Speech and Language Processing
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. Research starting at the materials used for transduction of acoustic signals, through signal processing involved in extract relevant information from the acoustic signatures, and leading to the interpretation of the information to extract meaning and/or translating between languages.

Microsystems 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, VLSI analog architectures for machine vision, associative processing, and micropower computing, alternative computation systems and devices, applied neuroscience, hardware-friendly algorithms and MEMS.

Photonics and Physical Electronics
Current research activities include work in fiber optic sensors and endoscopic 3-D imaging devices for medical applications, secure optical communications, and semiconductor optoelectronics. Other areas of interest involve the study of the nonlinear interactions of light with matter, laser beam control and steering, and plasmonics. Semiconductor device studies include optical detectors, photovoltaics, silicon photonics, nanophotonics, quantum cascade lasers, high power III-Nitride electronic devices, VLSI circuit design and modeling and microwave devices and circuits. Study of a laser radar and RF photonics is also being pursued. Theoretical and experimental studies involving linear optical properties of various materials and passive remote sensing of the atmosphere are being investigated.

Facilities
The department maintains extensive facilities for teaching and research in Barton Hall, Hackerman Hall, Wyman, and Maryland 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.

Undergraduate Programs
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:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

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

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

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

Requirements for the Bachelor of Science in Electrical Engineering

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

Forty-five (45) credits of ECE courses including the following: *

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.520.123</td>
<td>Computational Modeling for Electrical and 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.520.214</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.219</td>
<td>Introduction to Electromagnetics</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.230</td>
<td>Mastering Electronics</td>
<td>2</td>
</tr>
<tr>
<td>EN.520.231</td>
<td>Mastering Electronics Laboratory (Mastering Electronics Lab)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Advanced laboratory, design intensive, or senior design project courses</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Total Credits</td>
<td>23</td>
</tr>
</tbody>
</table>

Six (6) credits of engineering courses (with an E designation) from KSAS or 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.

Six (6) credits of engineering courses (with an E designation) from KSAS or 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>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.109</td>
<td>Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.202</td>
<td>Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.211</td>
<td>Honors Multivariable Calculus</td>
<td>4</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>4</td>
</tr>
<tr>
<td>AS.110.302</td>
<td>Differential Equations and Applications</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.310/311</td>
<td>Probability &amp; Statistics</td>
<td>4</td>
</tr>
<tr>
<td>or EN.553.420</td>
<td>Introduction to Probability</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Total Credits</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 Precalculus or EN.553.111 Statistical Analysis I - are not acceptable.

**Basic Sciences (16)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.171.101</td>
<td>General Physics: Physical Science Major I</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.107</td>
<td>General Physics for Physical Sciences Majors (AL)</td>
<td></td>
</tr>
<tr>
<td>AS.171.102</td>
<td>General Physics: Physical Science Major II</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.108</td>
<td>General Physics for Physical Sciences Majors (AL)</td>
<td></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>AS.030.101</td>
<td>Introductory Chemistry I</td>
<td>3</td>
</tr>
</tbody>
</table>

Total Credits: 13

- 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 Major 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 five (5), three-credit courses in humanities and social sciences, plus two (2) additional credits in EN.660.400 Practical Ethics for Future Leaders and one (1) credit EN.520.404 Engineering solutions in a global, economic, environmental, and societal context. ECE students beginning prior to Fall 2018 will be permitted to fulfill this requirement by six (6), three credit courses, or by the guidelines provided above. 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 or theme, with at least one of them at an advanced level (300 level or higher).
- A programming language requirement must be met by taking EN.601.220 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).

The sample program below is very general. Sample programs with an emphasis on Signals, Systems, and Communications or Photonics and Optoelectronics can be found in the advising manual.
1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

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

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

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

Requirements for the Bachelor of Science in Computer Engineering

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

- Forty-two (42) credits in Computer Engineering, which must include:

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.520.123 Computational Modeling for Electrical and Computer Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.142 Digital Systems Fundamentals</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.214 Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>EN.520.230 Mastering Electronics</td>
<td>2</td>
</tr>
<tr>
<td>EN.520.231 Mastering Electronics Laboratory</td>
<td>2</td>
</tr>
</tbody>
</table>

- a. Fifteen (15) credits of Electrical and Computer Engineering courses, which must include EN.520.123 Computational Modeling for Electrical and Computer Engineering, EN.520.142 Digital Systems Fundamentals, EN.520.214 Signals and Systems, EN.520.230 Mastering Electronics, and EN.520.231 Mastering Electronics Laboratory.
b. *Fifteen (15) credits of Computer Science courses* which must include EN.601.220 Intermediate Programming, EN.601.226 Data Structures. Either EN.601.229 Computer System Fundamentals or EN.520.225 Advanced Digital Systems can be taken to fulfill this requirement.

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 (with an E designation) from KSAS or 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.553.291 Linear Algebra and Differential Equations, EN.553.171 Discrete Mathematics, EN.553.310 Probability & Statistics/EN.553.311 Probability and Statistics for the Biological Sciences and Engineering or EN.553.420 Introduction to Probability must be taken. Elementary or precalculus courses such as AS.110.105 or EN.553.111-EN.553.112 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 Major II, AS.173.111 General Physics Laboratory I AS.173.112 General Physics Laboratory II, and AS.030.101 Introductory Chemistry I. Courses in this category may not be taken Satisfactory/Unsatisfactory.

- At least five (5), three-credit courses in humanities and social sciences, plus two (2) additional credits in EN.660.400 Practical Ethics for Future Leaders and one (1) credit EN.520.404 Engineering solutions in a global, economic, environmental, and societal context. CEE students beginning prior to Fall 2018 will be permitted to fulfill this requirement by six (6), three credit courses, or by the guidelines provided above. 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 or theme, with at least one of them at an advanced level (300 level or higher).

- 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.

- *At least fifteen (15) credits of Computer Science courses, which must include EN.601.220 Intermediate Programming, EN.601.226 Data Structures, and EN.601.229 Computer System Fundamentals.* (NOTE: You can count either EN.601.229 Computer System Fundamentals or EN.520.225 Advanced Digital Systems as a CE required course.) If you take EN.500.112 Gateway Computing: JAVA it will count as a CS credit even though it has a general engineering number (EN.500.XXX). Please register for the ECE section of Gateway Computing. If you take a different section, you will be required to take a supplemental summer/inter session course (Java Bootcamp) to count this towards CS/ECE requirements.

Please note that all EAC ABET accredited programs require 45 credits of engineering coursework. The credit requirement for this program is met by combining major course work (42 credits) along with “other engineering” course work (3 credits of the additional 6 credits required by ECE). 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](http://www.abet.org).

The sample program shown is very general. Other sample programs with a focus in Microsystems, Computer Integrated Surgery, Software, or Robotics can be found in the advising manual.

<table>
<thead>
<tr>
<th>Freshman</th>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.109</td>
<td>Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
<td>EN.601.220 Intermediate Programming</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sophomore</th>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.201</td>
<td>Linear Algebra</td>
<td>4</td>
<td>AS.110.202 Calculus III or 211</td>
<td>4</td>
</tr>
<tr>
<td>AS.030.101</td>
<td>Introductory Chemistry I</td>
<td>3</td>
<td>EN.601.226 Data Structures</td>
<td>4</td>
</tr>
</tbody>
</table>
To meet the requirements for the B.A. degree, the program must include:

- Eighteen (18) credits of humanities and social sciences courses.
- Four writing intensive courses.
- Twenty (20) credits of mathematics or mathematical statistics courses. Typically these include AS.110.108 Calculus I, AS.110.109 Calculus II (For Physical Sciences and Engineering), and AS.110.202 Calculus III or equivalent, and AS.110.201 Linear Algebra. Elementary or pre-calculus courses such as AS.110.105 or EN.553.111-EN.553.112 are not acceptable.

- A programming language requirement must be met by taking EN.601.220 Intermediate Programming or EN.500.112 Gateway Computing: JAVA. If you take EN.500.112 Gateway Computing: JAVA it will count as a CS credit even though it has a general engineering number (EN.500.XXX). Please be sure to register for the ECE section of Gateway Computing. If you take a different section, you will be required to take a supplemental summer/ intersession course to count this towards ECE requirements. This cannot be taken as a Pass/fail.
- 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/.

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.

Graduate Programs
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 D or F or second C grade results in probation. A second D or F or a third C grade results in termination from our program.

• Students may transfer in up to two courses from outside JHU. These courses must have been completed after the undergraduate degree was conferred, not applied to a degree elsewhere, and must be approved in advance by the department.

• 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 fulltime 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**

The Ph.D. in Electrical and Computer Engineering is oriented with an emphasis on scholarship and research rather than formal coursework. 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.

Jacob B. Khurgin
Quantum electronics, nonlinear optics.

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

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

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

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.

Amy 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.

Sanjeev P. Khudanpur
Information theory, statistical language modeling.

Assistant Professors
Muyinatu A. Lediju Bell
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.

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

Vishal Patel
Signal & image processing, computer vision, machine learning biometrics, biomedical image analysis

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

Archana Venkataraman
Functional neuroimaging (fMRI, EEG), machine learning & probabilistic inference, network modeling of the brain, integration of imaging, genetics and behavioral data.

Joint, Part-Time, Visiting, and Emeritus Appointments
Emad M. Boctor
Assistant Professor (Radiology): image-guided intervention, ultrasound imaging, elasticity, and thermal imaging.

Paul A. Bottomley
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
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

Nicholas Durr
Assistant Professor (Biomedical Engineering): endoscopy, medical devices, in-vivo diagnostics, microscopy, surgical guidance, ocular imaging, cytometry, global health, clinical translation, commercial translation.

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.

Gene Yevgeny Fridman
Assistant Professor (Otolaryngology): neural prostheses, vestibular and cochlear implants, medical instrumentation.

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.

Moise H. Goldstein Jr.
Professor Emeritus.

Willis Gore
Professor Emeritus.

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

Richard I. Joseph
Jacob Suter Jammer Professor Emeritus.

Pedro M. Julian
Associate Professor: theory and applications of circuits and systems, nonlinear computational architectures, sensory and neuromorphic processors, low power VLSI systems.

Alexander E. Kaplan
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.

Gerard G.L. Meyer
Professor Emeritus.

Michael I. Miller
Professor and Director (Biomedical Engineering): computational anatomy, medical imaging, image understanding.

C. Harvey Palmer Jr.
Professor Emeritus.

Dzung L. Pham
Adjunct 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. Pribe

Arman Rahmim
Associate 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 Professor: integrated system-on-chip sensors; integrated photonics, controls, autonomous systems, UAV platforms, and sensors; biomimetic devices for medical applications.

Wilson J. Rugh
Edward J. Schaefer Professor Emeritus.

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.

Sridevi V. Sarma
Associate Professor (Biomedical Engineering) Research Interests: Computational neuroscience, estimation and control theory, applications to disorders of the central nervous system and brain machine interfaces.

J. Webster Stayman
Assistant Professor (Biomedical Engineering) Research Interests: Medical imaging, device design and optimization, adaptive imaging, task-based acquisition, reconstruction, and estimation theory.

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

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

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, medical learning, signal processing.

Shinji Watanabe
Associate Research Professor (Center for Language & Speech Processing) Research Interests: Speech Recognition, Speech Enhancement, Deep Learning, Spoken Language Processing.

C. Roger Westgate
EN.520.123. Computational Modeling for Electrical and Computer Engineering. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): N. Dehak
Area: Engineering
NA.

EN.520.137. Introduction To Electrical & Computer Engineering. 3.0 Credits.
An introductory course covering the principles of electrical engineering including sinusoidal waveforms, 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): T. Tran
Area: Engineering, Quantitative and Mathematical Sciences
NA.

EN.520.142. Digital Systems Fundamentals. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): P. Julian
Area: Engineering, Quantitative and Mathematical Sciences
NA.

EN.520.150. Light, Image and Vision. 3.0 Credits.
This course is designed for beginning undergraduate students and covers the principles 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 includes bio-weekly labs that allows students to implement and experience the concepts learned during the lectures.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Kang
Area: Engineering
NA.

EN.520.211. ECE Engineering Team Project. 1.0 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)
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Kang; J. West; S. Ramesh
Area: Engineering
NA.

EN.520.212. ECE Engineering Team Project (Freshmen and Sophomores). 1.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Rizk; J. Kang; J. West; S. Ramesh
Area: Engineering
NA.

EN.520.214. Signals and Systems. 4.0 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: (AS.110.107 OR AS.110.109); AS.110.202 can be taken while taking EN.520.214
Corequisites: NA
Instructor(s): M. Elhilali
Area: Engineering, Quantitative and Mathematical Sciences
NA.

EN.520.216. Introduction To VLSI. 3.0 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
Corequisites: NA
Instructor(s): R. Etienne Cummings
Area: Engineering
NA.
EN.520.219. Introduction to Electromagnetics. 3.0 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: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): M. Foster
Area: Engineering, Natural Sciences
NA.

EN.520.220. Electromagnetic Waves. 3.0 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
Corequisites: NA
Instructor(s): M. Foster
Area: Engineering, Natural Sciences
NA.

EN.520.222. Computer Architecture. 3.0 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, twos complement arithmetic, adders and ALUs, CSA's Booth's algorithm, multiplication and division, control unit design, microprogramming, dynamic versus static linking, memory systems and memory hierarchy, paging segmentation, cache hardware, cache organizations, and replacement policies.
Prerequisites: EN.520.142
Corequisites: NA
Instructor(s): P. Pouliquen
Area: Engineering
NA.

EN.520.225. Advanced Digital Systems. 3.0 Credits.
Students are introduced to Hardware Description Languages (HDL) through the assembly of virtual versions of the digital parts used in the previous semester's Digital Systems Fundamentals. From this point on, new components called modules are created as needed to implement larger digital circuits. Increasingly complex digital systems are then created through stages such as desktop calculators, and culminating in the design of microcontrollers and microprocessors. The hardware used for the digital systems designed is a custom board containing a Field Programmable Gate Array (FPGA). This board is configured using software on the student's computer, but is designed to be standalone. That is, once configured, it no longer needs to be connected to any host computer. The architecture of these complex digital systems starts with Finite State Machines (FSM). Hierarchical FSMs are then covered, followed by traditional two and three bus microprocessor architectures and digital signal processors.
Prerequisites: EN.520.142
Corequisites: NA
Instructor(s): P. Pouliquen
Area: Engineering
NA.

EN.520.230. Mastering Electronics. 2.0 Credits.
With this course, students will have a solid understanding of basic and fundamental electronic concepts and rules including resistive circuits, loop and node analysis, capacitor/inductor circuits, and transient analysis. Students will be able to build, design, and simulate a wide range of electronic devices; the class will focus on building and designing audio devices. Class lectures cover the fundamental concepts of electronics, followed by laboratory exercises that demonstrate the basic concepts. Students will learn to simulate circuits using SPICE. A final project is required. Prereqs: Physical Science Majors II (AS.171.102); General Physics Laboratory (AS.173.112).
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;
( AS.110.108 AND AS.110.109 ) AND (( AS.171.102 OR AS.171.108 ) AND AS.173.112 )
Corequisites: EN.520.231
Instructor(s): A. Foster; S. Ramesh
Area: Engineering
NA.

EN.520.231. Mastering Electronics Laboratory. 2.0 Credits.
With this course, students will have a solid understanding of basic and fundamental electronic concepts and rules including resistive circuits, loop and node analysis, capacitor/inductor circuits, and transient analysis. Students will be able to build, design, and simulate a wide range of electronic devices; the class will focus on building and designing audio devices. Class lectures cover the fundamental concepts of electronics, followed by laboratory exercises that demonstrate the basic concepts. Students will learn to simulate circuits using SPICE. A final project is required.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;
( AS.110.108 AND AS.110.109 ) AND (( AS.171.102 OR AS.171.108 ) AND AS.173.112 )
Corequisites: EN.520.230 Mastering Electronics
Instructor(s): A. Foster; S. Ramesh
Area: Engineering
NA.
EN.520.250. Leading Innovation Design Team. 1.0 Credit.
Project design course that Complements and/or Builds on Core Knowledge Relevant to Electrical & Computer Engineering with emphasis on multidisciplinary projects. All Projects will be sponsored, have clearly defined objectives, and must yield a Tangible Result at Completion. Project duration can vary between a minimum of 2 semesters and a maximum of 5 years. This course will afford the students the opportunity to use their creativity to innovative and to master critical skills such as: customer/user discovery and product specifications; concept development; trade study; systems engineering and design optimization; root cause; and effective team work. The students will also experience first hand the joys and challenges of the professional world. The course will be actively managed and supervised to represent the most effective industry practices with the instruction team, including guest speakers, providing customized lectures, technical support, and guidance. In addition, the students will have frequent interactions with the project sponsor and their technical staff. Specific projects will be listed on ece.jhu.edu. Students must take the class as a graded course. S/U is not an option. For additional info, see link below: https://engineering.jhu.edu/ ece/undergraduate-studies/leading-innovation-design-team/
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Corequisites: NA
Instructor(s): C. Rizk
Area: Engineering
NA.

EN.520.251. Leading Innovation Design Team. 1.0 Credit.
Project design course that Complements and/or Builds on Core Knowledge Relevant to Electrical & Computer Engineering with emphasis on multidisciplinary projects. All Projects will be sponsored, have clearly defined objectives, and must yield a Tangible Result at Completion. Project duration can vary between a minimum of 2 semesters and a maximum of 5 years. This course will afford the students the opportunity to use their creativity to innovative and to master critical skills such as: customer/user discovery and product specifications; concept development; trade study; systems engineering and design optimization; root cause; and effective team work. The students will also experience first hand the joys and challenges of the professional world. The course will be actively managed and supervised to represent the most effective industry practices with the instruction team, including guest speakers, providing customized lectures, technical support, and guidance. In addition, the students will have frequent interactions with the project sponsor and their technical staff. Specific projects will be listed on ece.jhu.edu. Students must take the class as a graded course. S/U is not an option. For additional info, see link below: https://engineering.jhu.edu/ ece/undergraduate-studies/leading-innovation-design-team/
Prerequisites: Students may receive credit for only one of the following courses; EN.520.251, EN.520.463 OR EN.520.663.;Laboratory Safety Introductory Course available in MyLearning prior to registration. The course is accessible from the Education tab through the portal my.jh.edu. Please note that this requirement is not applicable to new students registering for their first semester at Hopkins.
Corequisites: NA
Instructor(s): C. Rizk
Area: Engineering
NA.

EN.520.302. Internet of Things Project Lab. 3.0 Credits.
In this course the student configures, programs, and tests microprocessor modules with wireless interconnectivity for embedded monitoring and control purposes. Several different platforms are explored and programmed in high level languages (HLL). Upon completion, students can use these devices as elements in other project courses. Recommended Course Background: HLL programming and digital logic familiarity; Advanced Microprocessor Lab is a plus.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): R. Glaser
Area: Engineering
NA.

EN.520.315. Intro. to Bio-Inspired Processing of Audio-Visual Signals. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): H. Hermansky
Area: Engineering
NA.

EN.520.340. Introduction to Mechatronics. 3.0 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.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): I. Sekyonda
Area: Engineering
NA.

EN.520.344. Introduction to Digital Signal Processing. 3.0 Credits.
Introduction to digital signal processing, sampling and quantization, discrete time signals and systems, convolution, Z-transforms, transfer functions, fast Fourier transform, analog and digital filter design, A/D and D/A converters, and applications of DSP.
Prerequisites: EN.520.214
Corequisites: NA
Instructor(s): V. Patel
Area: Engineering
NA.
EN.520.349. Microprocessor Lab I. 3.0 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. The lab is open 24/7 and students can still take the class if they are unable to meet during lab time.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): R. Glaser
Area: Engineering
NA.

EN.520.353. Control Systems. 3.0 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: EN.520.214 OR EN.530.343 OR EN.580.222
Corequisites: NA
Instructor(s): E. Mallada Garcia
Area: Engineering
NA.

EN.520.370. Introduction to Renewable Energy Engineering. 3.0 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.
Prerequisites: (AS.171.101 OR AS.171.107) AND AS.110.109
Corequisites: NA
Instructor(s): S. Thon
Area: Engineering, Natural Sciences
NA.

EN.520.372. Programmable Device Lab. 3.0 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 (PALs and GALs). These parts permit condensing dozens of standard logic packages (TTL logic) into one or more off-the-shelf components. Students design and build circuits using these devices with the assistance of CAD software. Topics include programming EEPROMs; using PLDs as address decoders; synchronous sequential logic synthesis for PLDs; and PLD-based state machines. Recommended Course Background: EN.520.142 and EN.520.345
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Corequisites: NA
Instructor(s): R. Glaser
Area: Engineering
NA.

EN.520.385. Signals, Systems & Inference. 3.0 Credits.
This course builds on the fundamentals of signal processing to explore state space models and random processes. Topics include LTI systems, feedback, probabilistic models, signal estimation, random processes, power spectral density and hypothesis testing.
Prerequisites: (EN.580.222 OR EN.520.214) AND EN.550.310 AND AS.110.201
Corequisites: NA
Instructor(s): A. Venkataraman
Area: Engineering
NA.

EN.520.403. Introduction to Optical Instruments. 3.0 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.
Corequisites: NA
Instructor(s): J. Khurgin
Area: Engineering
NA.

EN.520.404. Engineering solutions in a global, economic, environmental, and societal context. 1.0 Credit.
Students will examine ECE based case studies and will apply decision making theory and leadership theory as it relates to information, communication, healthcare, and energy. The course aims to examine technology as it transitions from old to new, from impossible to possible. It will also evaluate the new hazards that these new technologies may have on the world. The students will have to quantify the good and the bad of each solution and weigh their contribution to Environment, Economy, society and Healthcare. The group will present these case studies to their classmates, justifying the solutions and answers to the ethical dilemmas they faced, and explain the impact of their decisions from an economic, environmental, and global perspective.
Prerequisites: NA
Corequisites: EN.660.400
Instructor(s): I. Gannot
Area: Humanities
NA.
EN.520.407. Introduction to the Physics of Electronic Devices. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Khurgin
Area: Engineering
NA.

EN.520.412. Machine Learning for Signal Processing. 3.0 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: Student may earn credit for EN.520.612 or EN.520.412, but not both.;AS.110.201 AND EN.550.310 AND EN.520.435
Corequisites: NA
Instructor(s): N. Dehak
Area: Engineering
NA.

EN.520.414. Image Processing & Analysis. 3.0 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 OR EN.580.222 OR (EN.580.243 AND EN.580.246)
Corequisites: NA
Instructor(s): J. Goutsias
Area: Engineering
NA.

EN.520.415. Image Process & Analysis II. 3.0 Credits.
This course covers fundamental methods for the processing and analysis of images and describes standard and modern techniques for the understanding of images by morphological image processing and analysis, image representation and description, image recognition and interpretation.
Prerequisites: Students may earn credit for EN.520.615 or EN.520.415, but not both.;EN.520.414
Corequisites: NA
Instructor(s): J. Goutsias
Area: Engineering
NA.

EN.520.417. Computation for Engineers. 3.0 Credits.
Designing algorithms in a finite precision environment that are accurate, fast, and memory efficient is a challenge that many engineers must face. This course will provide students with the tools they need to meet this challenge. Topics include floating point arithmetic, rounding and discretization errors, problem conditioning, algorithm stability, solving systems of linear equations and least-squares problems, exploiting matrix structure, interpolation, finding zeros and minima of functions, computing Fourier transforms, derivatives, and integrals. Matlab is the computing platform. Background in linear algebra, matrices, digital signal processing, Matlab.
Prerequisites: NA
Corequisites: NA
Instructor(s): H. Weinert
Area: Engineering
NA.

EN.520.424. FPGA Synthesis Lab. 3.0 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 must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): P. Pouliquen
Area: Engineering, Quantitative and Mathematical Sciences
NA.
EN.520.427. Design of Biomedical Instruments and Systems. 3.0 Credits.
The purpose of this course is to teach the students principles of product design for the biomedical market. From an idea to a product and all the stages in-between. The course material will include identification of the need, market survey, patents. Funding sources and opportunities, Regulatory requirements, Reimbursement codes, Business models. Integration of the system into the clinical field. system connectivity. Medical information systems. Medical standards (DICOM, HL-7, ICD, Medical information bus). How to avoid mistakes in system design and in system marketing. Entrepreneurship. The course participants will be divided to groups of 2-3 students each. Each group will be acting as a start-up company throughout the whole semester. Each group will need to identify a need. This can be done by meeting and interviewing medical personnel, at the Johns Hopkins Medical campus or other hospitals, clinics, HMOs, assisted living communities or other related to the medical world. The proposed medical instrument or system can be a combination of instrument and software. Each week, there will be a lecture devoted to the principal subjects mentioned above. Afterwards the students will present their ideas and progress to all class participants. There will be an open discussion for each of the projects. The feedback from class will help the development of the product. Each presentation, document, survey or paper will be kept in the course cloud which will have a folder for each of the groups. The material gathered in this folder will be built gradually throughout the semester. Eventually it will become the product blueprint. At the last week of the semester, the groups will present their product to a panel of experts involved with the biotech industry, in order to “convince” them to invest in their project. Previous years’ projects are listed in this website: (https://jhuecepdl.bitbucket.io).
Prerequisites: NA
Corequisites: NA
Instructor(s): I. Gannot; S. Ramesh
Area: Engineering
NA.

EN.520.432. Medical Imaging Systems. 3.0 Credits.
This course provides students with 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 from a signals and systems perspective, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Students will additionally engage in hands-on activities to reconstruct medical images from raw data.
Prerequisites: EN.520.214 OR EN.580.222 OR (EN.580.243 AND EN.580.246)
Corequisites: NA
Instructor(s): M. Bell
Area: Engineering
NA.

EN.520.433. Medical Image Analysis. 3.0 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.550.310 OR EN.550.311 OR EN.560.348
Corequisites: NA
Instructor(s): J. Prince
Area: Engineering
NA.

EN.520.434. Modern Biomedical Imaging Instrumentation and Techniques. 3.0 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: Students may not have taken EN.520.634
Corequisites: NA
Instructor(s): B. Tsui
Area: NA
NA.

EN.520.435. Digital Signal Processing. 3.0 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.
Corequisites: NA
Instructor(s): H. Weinert
Area: Engineering
NA.

EN.520.438. Deep Learning. 3.0 Credits.
Deep Learning is emerging as one of the most successful tools in machine learning for feature learning and classification. This course will introduce students to the basics of Neural Networks and expose them to some cutting-edge research. In particular, this course will provide a survey of various deep learning-based architectures such as autoencoders, recurrent neural networks and convolutional neural networks. We will discuss merits and drawbacks of available approaches and identify promising avenues of research in this rapidly evolving field. Various applications related to computer vision and biometrics will be studied. The course will include a project, which will allow students to explore an area of Deep Learning that interests them in more depth.
Prerequisites: EN.520.435 AND EN.601.220 AND EN.553.420
Corequisites: NA
Instructor(s): V. Patel
Area: Engineering
NA.
EN.520.445. Audio Signal Processing. 3.0 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.
Corequisites: NA
Instructor(s): M. Elhilali
Area: Engineering
NA.

EN.520.447. Information Theory. 3.0 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).
Prerequisites: EN.553.310 OR EN.553.420 OR EN.553.311; Students can earn credit for either EN.520.447 or EN.520.647, but not both.
Corequisites: NA
Instructor(s): J. Prince
Area: Engineering, Quantitative and Mathematical Sciences
NA.

EN.520.448. Electronics Design Lab. 3.0 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 microprocessors, 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.520.214, EN.520.216, EN.520.349, EN.520.372, EN.520.490 or EN.520.491.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): P. Julian
Area: NA
NA.

EN.520.450. Advanced Micro-Processor Lab. 3.0 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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): R. Glaser
Area: NA
NA.

EN.520.452. Advanced ECE Engineering Team Project. 3.0 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. (Juniors and Seniors)
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Corequisites: NA
Instructor(s): J. Kang; J. West; S. Ramesh
Area: Engineering
NA.

EN.520.453. Advanced ECE Engineering Team Project. 3.0 Credits.
The course introduces the student to running an ECE 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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): C. Rizk; J. West; S. Ramesh
Area: Engineering
NA.

EN.520.454. Control Systems Design. 3.0 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.
Corequisites: NA
Instructor(s): P. Iglesias
Area: Engineering
NA.
EN.520.459. Quantum Mechanics for Engineering. 3.0 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 freshmen-year physics (including fundamentals of electricity and magnetism) and sophomore-year mathematics (including partial derivatives, basic differential equations, and fundamentals of linear algebra).

Prerequisites: NA
Corequisites: NA
Instructor(s): T. Schlesinger
Area: Engineering, Quantitative and Mathematical Sciences NA.

EN.520.460. The Art of Error Control Coding. 3.0 Credits.
Error control coding is the study and practice of detecting and/or correcting errors that occur in the transmission of digital information over a noisy communication channel, the transferal of information to and from memory and mass storage in a computer, or in any other application where random processes corrupt information. The student will study encoders and decoders for the most important codes in current use and will confront realistic problems in the use of coding. The course will comprise lectures, discussions, and projects.

Prerequisites: NA
Corequisites: NA
Instructor(s): A. Cooper
Area: Engineering, Quantitative and Mathematical Sciences NA.

EN.520.462. Leading Innovation Design Team. 3.0 Credits.
Project design course that Complements and/or Builds on Core Knowledge Relevant to Electrical & Computer Engineering with emphasis on multidisciplinary projects. All Projects will be sponsored, have clearly defined objectives, and must yield a Tangible Result at Completion. Project duration can vary between a minimum of 2 semesters and a maximum of 5 years. This course will afford the students the opportunity to use their creativity to innovative and to master critical skills such as: customer/user discovery and product specifications; concept development; trade study; systems engineering and design optimization; root cause; and effective team work. The students will also experience first-hand the joys and challenges of the professional world. The course will be actively managed and supervised to represent the most effective industry practices with the instruction team, including guest speakers, providing customized lectures, technical support, and guidance. In addition, the students will have frequent interactions with the project sponsor and their technical staff. Specific projects will be listed on ece.jhu.edu

Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Corequisites: NA
Instructor(s): C. Rizk
Area: Engineering NA.

EN.520.463. Leading Innovation Design Team. 3.0 Credits.
Project design course that Complements and/or Builds on Core Knowledge Relevant to Electrical & Computer Engineering with emphasis on multidisciplinary projects. All Projects will be sponsored, have clearly defined objectives, and must yield a Tangible Result at Completion. Project duration can vary between a minimum of 2 semesters and a maximum of 5 years. This course will afford the students the opportunity to use their creativity to innovative and to master critical skills such as: customer/user discovery and product specifications; concept development; trade study; systems engineering and design optimization; root cause; and effective team work. The students will also experience first-hand the joys and challenges of the professional world. The course will be actively managed and supervised to represent the most effective industry practices with the instruction team, including guest speakers, providing customized lectures, technical support, and guidance. In addition, the students will have frequent interactions with the project sponsor and their technical staff. Specific projects will be listed on ece.jhu.edu

Prerequisites: Students may receive credit for only one of the following courses; EN.520.251, EN.520.463 OR EN.520.663. Laboratory Safety Introductory Course available in MyLearning prior to registration. The course is accessible from the Education tab through the portal my.jh.edu. Please note that this requirement is not applicable to new students registering for their first semester at Hopkins.
Corequisites: NA
Instructor(s): C. Rizk
Area: Engineering NA.

EN.520.471. Speech Technologies Reading Group. 1.0 Credit.
Reading group that explores novel algorithms and papers on speech technologies

Prerequisites: NA
Corequisites: NA
Instructor(s): N. Dehak
Area: NA

EN.520.473. Magnetic Resonance in Medicine. 3.0 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.

Prerequisites: NA
Corequisites: NA
Instructor(s): M. Schar; P. Bottomley
Area: Engineering, Natural Sciences NA.
EN.520.482. Introduction To Lasers. 3.0 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
Corequisites: NA
Instructor(s): J. Khurgin
Area: Engineering, Natural Sciences
NA.

EN.520.483. Bio-Photonics Laboratory. 3.0 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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): J. Kang
Area: NA
NA.

EN.520.485. Advanced Semiconductor Devices. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Khurgin
Area: Engineering, Natural Sciences
NA.

EN.520.486. Physics of Semiconductor Electronic Devices. 3.0 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.
Corequisites: NA
Instructor(s): J. Khurgin
Area: NA
NA.

EN.520.491. CAD Design of Digital VLSI Systems I (Juniors/Seniors). 3.0 Credits.
Juniors and Seniors Only.
Prerequisites: Student may take EN.520.491 or EN.520.691, but not both; AS.110.109 AND AS.171.102 AND EN.520.142 AND EN.520.142 AND ( EN.520.230 OR ( EN.520.213 AND EN.520.345 OR EN.520.216 ) )
Corequisites: NA
Instructor(s): R. Etienne Cummings
Area: Engineering
NA.

EN.520.492. Mixed-Mode VLSI Systems. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): P. Pouliquen
Area: Engineering
NA.

EN.520.495. Microfabrication Laboratory. 4.0 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.
Corequisites: NA
Instructor(s): A. Andreou; J. Wang
Area: Engineering, Natural Sciences
NA.

EN.520.498. Senior Design Project. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: Engineering
NA.
EN.520.499. Senior Design Project. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): A. Venkataraman
Area: Engineering
NA.

EN.520.502. Indep Study - Fresh/Soph. 0.0 - 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): A. Cooper; M. Bell
Area: Engineering
NA.

EN.520.503. Independent Study-Juniors-Seniors. 3.0 Credits.
Individual, guided study under the direction of a faculty member in the department. The program of study or research, including the credit to be assigned, must be worked out in advance between the student and the faculty member involved. May be taken either term by juniors or seniors. Instructor permission required.
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

EN.520.504. Independent Study - Juniors/Seniors. 0.0 - 3.0 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.
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

EN.520.506. ECE Undergraduate Research. 1.0 - 3.0 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.
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

EN.520.516. ECE Group Undergraduate Research. 1.0 - 3.0 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.
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

EN.520.550. Electrical Engineering - Internship. 0.0 - 3.0 Credits.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Kang; T. Tran
Area: NA
NA.

EN.520.595. Independent Study. 3.0 Credits.
NA
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

EN.520.597. Research - Summer. 3.0 Credits.
NA
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

EN.520.599. Internship - Summer. 1.0 Credit.
NA
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): F. Davidson; G. Meyer; J. Kang; M. Miller
Area: NA
NA.
EN.520.600. Electrical & Computer Engineering Seminar. 1.0 Credit.
Seminar for Electrical & Computer Engineering; required of all doctoral students who have not passed the qualifying exam. Repeatable course.
Prerequisites: NA
Corequisites: NA
Instructor(s): P. Iglesias
Area: Engineering, Natural Sciences
NA.

EN.520.601. Introduction to Linear Systems Theory. 3.0 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. Students cannot take EN.520.601 if they have already taken the equivalent courses EN.530.616 OR EN.580.616
Prerequisites: NA
Corequisites: NA
Instructor(s): P. Iglesias
Area: NA
NA.

EN.520.603. Introduction to Optical Instruments. 3.0 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: NA
Corequisites: NA
Instructor(s): J. Khurgin
Area: Engineering
NA.

EN.520.612. Machine Learning for Signal Processing. 3.0 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.553.310, and EN.520.435.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): N. Dehak
Area: Engineering
NA.

EN.520.613. Advanced Topics in Optical Medical Imaging. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Kang
Area: NA
NA.

EN.520.614. Image Processing & Analysis. 3.0 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. Recommended Prerequisite: EN.520.214 or equivalent
Prerequisites: Students may earn credit for EN.520.614 or EN.520.414, but not both.
Corequisites: NA
Instructor(s): J. Goutsias
Area: Engineering
NA.

EN.520.615. Image Processing & Analysis II. 3.0 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.
Corequisites: NA
Instructor(s): J. Goutsias
Area: Engineering
NA.

EN.520.616. Processing of Audio and Visual Signals. 3.0 Credits.
This course consists of two parts. The lecture component of this course is covered by attending EN.520.315. Concurrently, on the more advanced graduate level, there is an additional requirement of critical analysis of the material covered, and the hands-on homework complementing the lectures. Recommended Course Background: EN.520.214 (or EN.580.222) or consent of the instructor.
Prerequisites: NA
Corequisites: NA
Instructor(s): H. Hermansky
Area: NA
NA.
EN.520.617. Computation for Engineers. 3.0 Credits.
Designing algorithms in a finite precision environment that are accurate, fast, and memory efficient is a challenge that many engineers must face. This course will provide students with the tools they need to meet this challenge. Topics include floating point arithmetic, rounding and discretization errors, problem conditioning, algorithm stability, solving systems of linear equations and least-squares problems, exploiting matrix structure, interpolation, finding zeros and minima of functions, computing Fourier transforms, derivatives, and integrals. Matlab is the computing platform.
Prerequisites: NA
Corequisites: NA
Instructor(s): H. Weinert
Area: Engineering
NA.

EN.520.618. Hybrid Systems. 2.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): D. Tarraf
Area: Engineering
NA.

EN.520.621. Introduction To Nonlinear Systems. 3.0 Credits.
Nonlinear systems analysis techniques: phase-plane, limit cycles, harmonic balance, expansion methods, describing function, Liapunov stability, Popov criterion. Recommended Course Background: EN.520.601 or equivalent.
Prerequisites: NA
Corequisites: NA
Instructor(s): P. Iglesias
Area: Engineering, Natural Sciences
NA.

EN.520.622. Principles of Complex Networked Systems. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Goutsias
Area: NA
NA.

EN.520.623. Medical Image Analysis. 3.0 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: Student may earn credit for 520.433 or 520.623, but not both.
Corequisites: NA
Instructor(s): J. Prince
Area: NA
NA.

EN.520.624. Integrated Photonics. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): A. Foster
Area: Engineering, Natural Sciences
NA.

EN.520.627. Photovoltaics and Energy Devices. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Thon
Area: NA
NA.

EN.520.628. Satellite Communication System. 3.0 Credits.
This course presents the fundamentals of satellite communications link design and an in-depth treatment of practical considerations. Existing commercial, civil, and military systems are described and analyzed. Topics include satellite orbits, link analysis, antenna and payload design, interference and propagation effects, modulation techniques, coding, multiple access, and Earth station design. The impact of new technology on future systems in this dynamic field is discussed. Recommended Course Background: Communication Systems Engineering or equivalent or permission of the instructor.
Prerequisites: NA
Corequisites: NA
Instructor(s): N. Mosavi
Area: NA
NA.
EN.520.629. Networked Dynamical Systems. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): E. Mallada Garcia
Area: NA

EN.520.631. Ultrasound and Photoacoustic Beamforming. 3.0 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 pre-clinical data. The course will culminate with student projects to design and implement a new beamformer derived from the principles taught in class.
Prerequisites: NA
Corequisites: NA
Instructor(s): M. Bell
Area: NA

EN.520.632. Medical Imaging Systems. 3.0 Credits.
This course provides students with 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 from a signals and systems perspective, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Students will additionally engage in hands-on activities to reconstruct medical images from raw data.
Prerequisites: NA
Corequisites: NA
Instructor(s): M. Bell
Area: Engineering
NA.

EN.520.633. Intro To Robust Control. 3.0 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
Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: Engineering
NA.

EN.520.634. Modern Biomedical Imaging Instrumentation and Techniques. 3.0 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.520.432 or EN.580.472
Prerequisites: Students may not have taken EN.520.434.
Corequisites: NA
Instructor(s): B. Tsui
Area: NA
NA.

EN.520.635. Digital Signal Processing. 3.0 Credits.
Methods for processing discrete-time signals. Topics include signal and system representations, z-transforms, sampling, discrete Fourier transforms, fast Fourier transforms, digital filters. Audits are not permitted.
Prerequisites: Students may earn credit for EN.520.635 or EN.520.435, but not both.
Corequisites: NA
Instructor(s): H. Weinert
Area: Engineering
NA.

EN.520.636. Feedback Control in Biological Signaling Pathways. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): P. Iglesias
Area: NA
NA.
EN.520.638. Deep Learning. 3.0 Credits.
Deep Learning is emerging as one of the most successful tools in machine learning for feature learning and classification. This course will introduce students to the basics of Neural Networks and expose them to some cutting-edge research. In particular, this course will provide a survey of various deep learning-based architectures such as autoencoders, recurrent neural networks and convolutional neural networks. We will discuss merits and drawbacks of available approaches and identify promising avenues of research in this rapidly evolving field. Various applications related to computer vision and biometrics will be studied. The course will include a project, which will allow students to explore an area of Deep Learning that interests them in more depth.
Recommended Course Background: EN.520.435, EN.601.220, and EN.553.420
Prerequisites: NA
Corequisites: NA
Area: Engineering

EN.520.644. FPGA Synthesis Lab. 3.0 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 must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): P. Pouliquen
Area: Engineering, Quantitative and Mathematical Sciences

EN.520.645. Audio Signal Processing. 3.0 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.
Corequisites: NA
Instructor(s): M. Elhilali
Area: Engineering

EN.520.646. Wavelets & Filter Banks. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): T. Tran
Area: NA

EN.520.647. Information Theory. 3.0 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).
Prerequisites: Students can earn credit for either 520.447 or 520.647, not both.
Corequisites: NA
Instructor(s): J. Prince
Area: Engineering

EN.520.648. Compressed Sensing and Sparse Recovery. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): T. Tran
Area: NA

EN.520.649. Introduction to Radar Systems. 3.0 Credits.
This course introduces the fundamental concepts of the modern radar system architecture and design. Topics include the major subsystems and functions of a typical radar, the radar range equation and its different forms, radar cross section, signal to noise ratio, and radar modes. We will also discuss antennas, propagation, pulse compression, detection, tracking and many other general radar topics.
Prerequisites: NA
Corequisites: NA
Instructor(s): W. Montlouis
Area: NA

EN.520.651. Random Signal Analysis. 4.0 Credits.
The content for EN.520.651 has been revised with greater emphasis on graphical models, parameter estimation and posterior inference. Topics include probability theory, random variables/vectors, hypothesis testing, parameter estimation, directed and undirected graphical models, the EM algorithm, deterministic and stochastic approximations for EM, Markov chains and random sequences. Additional material may be covered as appropriate. The class is theoretical in nature; new concepts are presented via formula derivations and example problems. Homework assignments may require familiarity with Matlab (or an equivalent computational software).
Prerequisites: NA
Corequisites: NA
Instructor(s): A. Venkataraman
Area: NA

EN.520.652. Filtering and Smoothing. 3.0 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.
Corequisites: NA
Instructor(s): H. Weinert
Area: NA

EN.520.654. Control Systems Design. 3.0 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.
Corequisites: NA
Instructor(s): P. Iglesias
Area: Engineering

EN.520.657. Design of Biomedical Instruments and Systems. 3.0 Credits.
The purpose of this course is to teach the students principles of product design for the biomedical market. From an idea to a product and all the stages in-between. The course material will include identification of the need, market survey, patents. Funding sources and opportunities, Regulatory requirements, Reimbursement codes, Business models. Integration of the system into the clinical field. system connectivity. Medical information systems. Medical standards (DICOM, HL-7, ICD, Medical information bus). How to avoid mistakes in system design and in system marketing. Entrepreneurship. The course participants will be divided to groups of 2-3 students each. Each group will be acting as a start-up company throughout the whole semester. Each group will need to identify a need. This can be done by meeting and interviewing medical personnel, at the Johns Hopkins Medical campus or other hospitals, clinics, HMOs, assisted living communities or other related to the medical world. The proposed medical instrument or system can be a combination of instrument and software. Each week, there will be a lecture devoted to the principal subjects mentioned above. Afterwards the students will present their ideas and progress to all class participants. There will be an open discussion for each of the projects. The feedback from class will help the development of the product. Each presentation, document, survey or paper will be kept in the course cloud which will have a folder for each of the groups. The material gathered in this folder will be built gradually throughout the semester. Eventually it will become the product blueprint. At the last week of the semester, the groups will present their product to a panel of experts involved with the biotech industry, in order to “convince” them to invest in their project. Previous years’ projects are listed in this website: (https://jhuecepdl.bitbucket.io).
Prerequisites: NA
Corequisites: NA
Instructor(s): I. Gannot; S. Ramesh
Area: Engineering

EN.520.660. The Art of Error Control Coding. 3.0 Credits.
Error control coding is the study and practice of detecting and/or correcting errors that occur in the transmission of digital information over a noisy communication channel, the transferal of information to and from memory and mass storage in a computer, or in any other application where random processes corrupt information. The student will study encoders and decoders for the most important codes in current use and will confront realistic problems in the use of coding. The course will comprise lectures, discussions, and projects.
Prerequisites: NA
Corequisites: NA
Instructor(s): A. Cooper
Area: Engineering, Quantitative and Mathematical Sciences

NA.
EN.520.662. Leading Innovation Design Team. 3.0 Credits.
Project design course that Complements and/or Builds on Core Knowledge Relevant to Electrical & Computer Engineering with emphasis on multidisciplinary projects. All Projects will be sponsored, have clearly defined objectives, and must yield a Tangible Result at Completion. Project duration can vary between a minimum of 2 semesters and a maximum of 5 years. This course will afford the students the opportunity to use their creativity to innovative and to master critical skills such as: customer/user discovery and product specifications; concept development; trade study; systems engineering and design optimization; root cause; and effective team work. The students will also experience first-hand the joys and challenges of the professional world. The course will be actively managed and supervised to represent the most effective industry practices with the instruction team, including guest speakers, providing customized lectures, technical support, and guidance. In addition, the students will have frequent interactions with the project sponsor and their technical staff. Specific projects will be listed on ece.jhu.edu

Prerequisites: NA
Corequisites: NA
Instructor(s): C. Rizk
Area: NA
NA.

EN.520.663. Leading Innovation Design Team. 3.0 Credits.
Project design course that Complements and/or Builds on Core Knowledge Relevant to Electrical & Computer Engineering with emphasis on multidisciplinary projects. All Projects will be sponsored, have clearly defined objectives, and must yield a Tangible Result at Completion. Project duration can vary between a minimum of 2 semesters and a maximum of 5 years. This course will afford the students the opportunity to use their creativity to innovative and to master critical skills such as: customer/user discovery and product specifications; concept development; trade study; systems engineering and design optimization; root cause; and effective team work. The students will also experience first-hand the joys and challenges of the professional world. The course will be actively managed and supervised to represent the most effective industry practices with the instruction team, including guest speakers, providing customized lectures, technical support, and guidance. In addition, the students will have frequent interactions with the project sponsor and their technical staff. Specific projects will be listed on ece.jhu.edu

Prerequisites: NA
Corequisites: NA
Instructor(s): C. Rizk
Area: NA
NA.

EN.520.666. Information Extraction. 3.0 Credits.
Introduction to statistical methods of speech recognition (automatic transcription of speech) and understanding. The course is a natural continuation of EN.601.465 but is independent of it. Topics include elementary probability theory, hidden Markov models, and n-gram models using maximum likelihood, Bayesian and discriminative methods, and deep learning techniques for acoustic and language modeling. Recommended Course Background: EN.550.310 AND EN.600.120 or equivalent, expertise in Matlab or Python programming.

Prerequisites: NA
Corequisites: NA
Instructor(s): S. Watanabe
Area: NA
NA.

EN.520.667. Dynamic Implicit Surfaces. 3.0 Credits.
Course will cover dynamic implicit surfaces that arise in a number of modeling situations where the boundary is implicit. We will discuss a number of techniques used to generate these models, including level set methods and the phase field approach.

Prerequisites: NA
Corequisites: NA
Instructor(s): P. Iglesias
Area: NA
NA.

EN.520.671. Speech Technologies Reading Group. 1.0 Credit.
Reading Group that explores novel algorithms and papers on speech technologies

Prerequisites: NA
Corequisites: NA
Instructor(s): L. Garcia Perera
Area: NA
NA.

EN.520.673. Magnetic Resonance in Medicine. 3.0 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.

Prerequisites: NA
Corequisites: NA
Instructor(s): M. Schar; P. Bottomley
Area: NA
NA.
EN.520.678. Biomedical Photonics. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): X. Li
Area: Engineering
NA.

EN.520.680. Speech and Auditory Processing by Humans and Machines. 3.0 Credits.
The course relevant to building advanced systems for information extraction from speech and auditory signals. It introduces some relevant historical efforts for information processing of speech and audio signals and basic concepts of human auditory perception and human production and perception of speech. The main goal of the course is in implementation of relevant knowledge of human speech information processing in engineering systems for information extraction from speech signals, emphasizing power of the modern data-guided machine learning techniques. Basic knowledge of signal processing is assumed and the previous completion of the EN.520.445 or EN.520.645 is beneficial.
Prerequisites: EN.520.445 OR EN.520.645
Corequisites: NA
Instructor(s): H. Hermansky
Area: NA
NA.

EN.520.682. Introduction to Lasers. 3.0 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
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Khurgin
Area: NA
NA.

EN.520.683. Bio-Photonics Laboratory. 3.0 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
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): J. Kang
Area: NA
NA.

EN.520.686. Physics of Semiconductor Electronic Devices. 3.0 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.
Corequisites: NA
Instructor(s): J. Khurgin
Area: Engineering
NA.

EN.520.691. CAD Design of Digital VLSI Systems I (Grad). 3.0 Credits.
Graduate students only.
Prerequisites: Student may take EN.520.491 or EN.520.691, but not both.
Corequisites: NA
Instructor(s): R. Etienne Cummings
Area: Engineering
NA.

EN.520.692. Mixed-Mode VLSI Systems. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): P. Pouliquen
Area: NA
NA.

EN.520.700. Masters Research. 3.0 - 10.0 Credits.
Independent research for masters students
Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.
**EN.520.701. Current Topics in Language and Speech Processing. 1.0 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. Grading will be S/U.

**Prerequisites:** NA  
**Corequisites:** NA  
**Instructor(s):** J. Trmal  
**Area:** NA  

**EN.520.702. Current Topics in Language and Speech Processing. 1.0 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.

**Prerequisites:** NA  
**Corequisites:** NA  
**Instructor(s):** J. Trmal  
**Area:** NA  

**EN.520.735. Sensory Information Processing. 3.0 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.

**Prerequisites:** NA  
**Corequisites:** NA  
**Instructor(s):** A. Andreou  
**Area:** NA  

**EN.520.738. Advanced Electronic Lab Design. 3.0 Credits.**

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

**Prerequisites:** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.

**Corequisites:** NA  
**Instructor(s):** P. Julian  
**Area:** NA  

**EN.520.744. Advanced Topics in Signal Processing and Applied Machine learning for Next Generation Radar. 3.0 Credits.**

**Prerequisites:** NA  
**Corequisites:** NA  
**Instructor(s):** W. Montlouis  
**Area:** NA  

**EN.520.746. Seminar: Medical Image Analysis. 1.0 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.601.856.

**Prerequisites:** NA  
**Corequisites:** NA  
**Instructor(s):** J. Prince; R. Taylor  
**Area:** NA  

**EN.520.762. Emerging Models of Computation. 3.0 Credits.**

Advanced seminar course with topics in emerging models of computation. This year (Spring 2019) the course focuses on neurotrophic machine learning, event-based spike based processing and neural computation. The students will learn and use Brian and PyNN for a project in the class. (Permission of instructor required)

**Prerequisites:** NA  
**Corequisites:** NA  
**Instructor(s):** A. Andreou  
**Area:** Engineering  

**NA.**
EN.520.771. Advanced Integrated Circuits. 1.0 Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): A. Andreou
Area: NA
NA.

EN.520.773. Advanced Topics In Microsystem Fabrication. 4.0 Credits.
Graduate-level course on topics that relate to microsystem integration of complex functional units across different physical scales from nano to micro and macro. 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. 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. Required.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): J. Wang
Area: NA
NA.

EN.520.774. Advanced Topics in Electrical and Computer Engineering. 3.0 Credits.
Course content varies by instructor and topic. The major focus of this course is to train graduate students in developing or increasing research ability related to new and advanced concepts in electrical engineering. For example, these concepts may include advanced techniques in signal processing and communications, high performance computing, real-time computing and advanced parallel system architectures.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): W. Montlouis
Area: NA
NA.

EN.520.788. Biomedical Photonics II. 3.0 Credits.
This course serves as the continuation of 580.678(520.678) (Biomedical Photonics Part 1). It will cover the advanced topics on biomedical photonics, including (but not limited to) light scattering (Rayleigh and Mie scattering), photon diffusion, polarization (birefringence), fluorescence, lifetime measurements, confocal microscopy, optical coherence tomography, nonlinear microscopy, and super-resolution microscopy. Representative biomedical applications of some of these technologies will be integrated into the relevant chapters. If the lab space becomes available, we will also offer a hand-on lab section (optional) for students to design and build an imaging instrument. Recommended Background: Biomedical Photonics (580.678/520.678), or equivalent background on optics.
Prerequisites: NA
Corequisites: NA
Instructor(s): X. Li
Area: NA
NA.

EN.520.800. Independent Study. 1.0 - 3.0 Credits.
Individual, guided study under the direction of a faculty member in the department. May be taken either term by graduate students.
Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

EN.520.801. Dissertation Research. 3.0 - 20.0 Credits.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

EN.520.802. Dissertation Research. 3.0 - 20.0 Credits.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

EN.520.890. Independent Study-Summer. 1.0 - 3.0 Credits.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

Cross Listed Courses
General Engineering
EN.500.112. Gateway Computing: JAVA. 3.0 Credits.
This course introduces fundamental programming concepts and techniques, and is intended for all who plan to develop computational artifacts or intelligently deploy computational tools in their studies and careers. Topics covered include the design and implementation of algorithms using variables, control structures, arrays, functions, files, testing, debugging, and structured program design. Elements of object-oriented programming, algorithmic efficiency and data visualization are also introduced. Students deploy programming to develop working solutions that address problems in engineering, science and other areas of contemporary interest that vary from section to section.
Course work involves significant programming. Attendance and participation in class sessions are expected.
Prerequisites: Students may not have earned credit in courses: EN.500.113 OR EN.500.114 OR EN.510.202 OR EN.520.123 OR EN.530.112 OR EN.580.200 OR EN.601.107.
Corequisites: NA
Instructor(s): I. Sekyonda; S. More
Area: Engineering
NA.
EN.500.745. Seminar in Computational Sensing and Robotics. 1.0 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. Biorobotics and neuromechanics, including devices, algorithms and approaches to robotics inspired by principles in biomechanics and neuroscience. Human-machine systems, including haptic and visual feedback, human perception, cognition and decision making, and human-machine collaborative systems. Cross-listed Mechanical Engineering, Computer Science, Electrical and Computer Engineering, and Biomedical Engineering.
Prerequisites: NA
Corequisites: NA
Instructor(s): L. Whitcomb; P. Kazanzides
Area: NA
NA.

Materials Science Engineering
EN.510.611. Solid State Physics. 3.0 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): T. Poehler
Area: NA
NA.

EN.510.612. Solid State Physics. 3.0 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
Prerequisites: NA
Corequisites: NA
Instructor(s): T. Poehler
Area: NA
NA.

Mechanical Engineering
EN.530.421. Mechatronics. 3.0 Credits.
Students from various engineering disciplines are divided into groups of two to three students. These groups each develop a microprocessor-controlled electromechanical device, such as a mobile robot. The devices compete against each other in a final design competition. Topics for competition vary from year to year. Class instruction includes fundamentals of mechanism kinematics, creativity in the design process, an overview of motors and sensors, and interfacing and programming microprocessors.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module; EN.530.420 OR EN.520.240 or permission of the instructor.
Corequisites: NA
Instructor(s): J. Brown
Area: Engineering
NA.

EN.530.616. Introduction to Linear Systems Theory. 3.0 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. Students cannot take EN.530.616 if they have already taken the equivalent courses EN.520.601 OR EN.580.616.
Prerequisites: Students cannot take EN.530.616 if they have already taken EN.520.601 OR EN.580.616.
Corequisites: NA
Instructor(s): N. Cowan
Area: NA
NA.

Biomedical Engineering
EN.580.472. Medical Imaging Systems. 3.0 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
Corequisites: NA
Instructor(s): M. Bell
Area: Engineering
NA.
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 601.479 or 601.679 but not both. [Analysis or Applications] Required course background: machine learning or basic probability and linear algebra.

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