

# 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 the 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 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. Speech and language processing;
4. Microsystems and computer engineering, and
5. Solid State Electronics and Photonics

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 systems 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, learning, 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 an 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.

### Speech and Language Processing

Research in speech processing involves work in all aspects of language or speech science and technology, with fundamental studies underway 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 extracting 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 intelligence and sensory processing, associative processing, and micropower computing, alternative computation systems and devices, applied neuroscience, hardware-friendly algorithms, and MEMS.

### Solid State Electronics & Photonics

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. The study of 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 (Microprocessor & FPGA Lab and the Biophotonics 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: a BS in Electrical Engineering, and a BS in Computer Engineering (with the close collaboration of the Computer Science Department (<https://e-catalogue.jhu.edu/engineering/computer-science/>)). Students learn the fundamentals of electrical, computer and digital systems, data structures, and circuits, with an emphasis on hands-on experience to complement the theoretical. The BS degrees in both Electrical Engineering and Computer Engineering are accredited by the Engineering Accreditation Commission of ABET, [www.abet.org](http://www.abet.org) (<http://>

www.abet.org/), under the General Criteria and the Program Criteria for Electrical, Computer, Communications, Telecommunication(s) and similarly Named Engineering Programs.

### Graduate Programs

Graduate students work closely with their faculty advisors to design a plan based on their needs and interests. Our faculty understand industry demands a broad skill set coupled with research and design experience, and our curriculum offers the opportunity to meld theory and practice. Students are required to take at least five classes in ECE and an additional three courses in other engineering disciplines. Students have three options for completing their degree requirements: taking two additional courses; completing a master's essay/thesis; or completing a project. Additional details can be found in the department's Graduate Student Advising Manual.

## Combined Undergraduate/ Graduate 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 permits the student to complete their B.S. in electrical engineering while also working on their requirements towards their master of science in electrical engineering. In order to qualify, students must maintain a GPA of 3.5 or higher. The latest deadline to apply for this program is the end of their second to last semester. The application process is explained at <https://engineering.jhu.edu/ece/academics/undergraduate-studies/combined-bachelors-masters/>.

## Programs

- Computer Engineering, Bachelor of Science (<https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/electrical-computer-engineering/computer-engineering-bachelor-science/>)
- Electrical and Computer Engineering, Master of Science in Engineering (<https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/electrical-computer-engineering/electrical-computer-master-science-engineering/>)
- Electrical and Computer Engineering, PhD (<https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/electrical-computer-engineering/electrical-computer-engineering-phd/>)
- Electrical Engineering, Bachelor of Arts (<https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/electrical-computer-engineering/electrical-engineering-bachelor-arts/>)
- Electrical Engineering, Bachelor of Science (<https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/electrical-computer-engineering/electrical-engineering-bachelor-science/>)
- Energy, Minor (<https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/electrical-computer-engineering/energy-minor/>)

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

## Courses

### EN.520.123. Computational Modeling for Electrical and Computer Engineering. 3 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. Recommended courses: Calculus I (AS.110.106 OR AS.110.108) AND Physics I (AS.171.101 OR AS.171.105 OR AS.171.107 OR EN.530.123) Area: Engineering

### EN.520.137. Introduction To Electrical & Computer Engineering. 3 Credits.

An introductory course covering the principles of electrical engineering including sinusoidal wave forms, electrical measurements, digital circuits, and applications of electrical and computer engineering. Laboratory exercises, the use of computers, and a design project are included in the course.

**Prerequisite(s):** AS.110.106 OR AS.110.108

Area: Engineering, Quantitative and Mathematical Sciences

### EN.520.142. Digital Systems Fundamentals. 3 Credits.

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

Area: Engineering, Quantitative and Mathematical Sciences

### EN.520.150. Light, Image and Vision. 3 Credits.

This course is designed for beginning undergraduate students and covers the principle of optics and imaging from the human vision perspective. The topics for the course include the basic principles and properties of light, imaging and image formation, optical imaging and display systems, and human vision. The course include bio-weekly labs that allows students to implement and experience the concepts learned during the lectures.

Area: Engineering

**EN.520.151. ECE Ideation and Design Lab (First Year). 1 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](http://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/>

**Prerequisite(s):** 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.  
Area: Engineering

**EN.520.211. ECE Engineering Team Project. 1 Credit.**

This course introduces the student to the basics of engineering team projects. The student will become a member of and participate in the different aspects of an ECE team project over several semesters. (Freshmen and Sophomores)  
Area: Engineering

**EN.520.212. ECE Engineering Team Project (Freshmen and Sophomores). 1 Credit.**

This course introduces the student to the basics of engineering team projects. The student will participate in an ECE engineering team project as a member. The student is expected to participate in the different aspects of the project over several semesters. (Freshmen and Sophomores)Permission of instructor required.  
Area: Engineering

**EN.520.214. Signals and Systems. 4 Credits.**

An introduction to discrete-time and continuous-time signals and systems covers representation of signals and linear time-invariant systems and Fourier analysis.  
**Prerequisite(s):** (AS.110.107 OR AS.110.109);AS.110.202 or AS.110.211, prereq can be taken while taking EN.520.214  
Area: Engineering, Quantitative and Mathematical Sciences

**EN.520.216. Introduction To VLSI. 3 Credits.**

This course teaches the basics of switch-level digital CMOS VLSI design. This includes creating digital gates using MOS transistors as switches, laying out a design using CAD tools, and checking the design for conformance to the Scalable CMOS design rules.  
**Prerequisite(s):** (AS.110.107 OR AS.110.109) AND (AS.171.102 OR AS.171.104) AND EN.520.230 AND EN.520.231 AND EN.520.142  
Area: Engineering

**EN.520.219. Introduction to Electromagnetics. 3 Credits.**

Vector analysis, electrostatic fields in vacuum and material media, stationary currents in conducting media, magnetostatic fields in vacuum and material media. Maxwell's equations and time-dependent electric and magnetic fields, electromagnetic waves and radiation, transmission lines, wave guides, applications.

**Prerequisite(s):** 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.110.109 AND (AS.171.102 OR AS.171.104 OR AS.171.108) AND AS.173.112;AS.110.202 may be taken prior to or while enrolled in EN.520.219.

Area: Engineering, Natural Sciences

**EN.520.220. Electromagnetic Waves. 3 Credits.**

Maxwell's equations and time-dependent electric and magnetic fields, electromagnetic waves and radiation, transmission lines, impedance matching networks, waveguides, antennas, and applications.

**Prerequisite(s):** EN.520.219  
Area: Engineering, Natural Sciences

**EN.520.225. Advanced Digital Systems. 3 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 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.

**Prerequisite(s):** EN.520.142  
Area: Engineering

**EN.520.230. Mastering Electronics. 3 Credits.**

With this course, students will have a solid understanding of basic and fundamental electronic concepts and rules and will be able to build and design a wide range of electronic devices. Class lectures cover the fundamental concepts of electronics, followed by laboratory exercises that demonstrate the basic concepts. Topics include phase and frequency response, transistors, operational amplifiers, filters, and other analog circuits. The experiments are done using computer controlled digital oscilloscopes, function generators, and power supplies. Additionally, a project will be completed during the final few weeks of classes. Text book: The Bare Essentials of Electrical Engineering Maryam Al-Othman, John Cole, and Dimitri Peroulis.

**Prerequisite(s):** 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.110.107 OR AS.110.109) AND (AS.171.102 OR AS.171.108 OR AS.171.106) AND (AS.173.112 OR AS.173.116)

**Corequisite(s):** EN.520.231  
Area: Engineering

**EN.520.231. Mastering Electronics Laboratory. 2 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.

**Prerequisite(s):** 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.110.107 OR AS.110.109) AND (AS.171.102 OR AS.171.108) AND (AS.173.111 AND AS.173.112)

**Corequisite(s):** EN.520.230 Mastering Electronics  
Area: Engineering

**EN.520.232. Mastering Electronics II. 3 Credits.**

With this course, students will further develop their understanding of circuit and electronic concepts and rules and will be able to build and design a wide range of electronic devices. Class lectures cover advanced design concepts of analog CMOS integrated circuits, followed by laboratory exercises that reinforce the concepts. Topics include 2nd order circuits, phase and frequency response, transistors, operational amplifiers, noise, feedback, Bode diagrams, and frequency compensation. The experiments are done using computer controlled digital oscilloscopes, function generators, and power supplies. Additionally, a project will be completed during the final few weeks of classes.

**Prerequisite(s):** (AS.110.107 OR AS.110.109) AND (EN.500.112 OR EN.500.113 OR EN.500.114) AND (EN.520.230 AND EN.520.231)

**Corequisite(s):** EN.520.233 must be taken at the same time as EN.520.232.

Area: Engineering

**EN.520.233. Mastering Electronics II Lab. 2 Credits.**

For much of the semester, students will be performing a new lab experiment each week. During each student's scheduled lab section, they will be expected to attend in person and demonstrate the operation and theory behind a functioning circuit based on the corresponding lecture material from Mastering Electronics I. The student will be graded based on their functioning circuit, their experimental results, and their demonstration of its operation during their scheduled laboratory period. Each lab will have a prelab component to prepare students for practical applications as well as a supplemental lesson to begin each lab. Students will work in pairs on circuit development but are asked questions and graded individually. Each lab assignment contains a series of "checkoffs." These are tasks, questions, circuits, and data collections throughout the lab. Completion of a checkoff entails demonstrating successful operation and answering a set of verbal questions administered by the Lab Instructor or TA. Students are encouraged to collaborate with their classmates both in the lab and with instructors during their office hours.

**Prerequisite(s):** (AS.110.107 OR AS.110.109) AND (AS.171.102 OR AS.171.104 OR AS.171.108) AND (EN.500.112 OR EN.500.113 OR EN.500.114) AND (EN.520.230 AND EN.520.231)

**Corequisite(s):** Students must register for EN.520.232 concurrently.  
Area: Engineering

**EN.520.241. Introduction to Mechatronics: Sensing, Processing, Learning and Actuation. 3 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.

**Prerequisite(s):** 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.520.230 AND EN.520.231

Area: Engineering

**EN.520.250. Leading Innovation Design Team. 1 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](https://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/>

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class.

Area: Engineering

**EN.520.251. ECE Ideation and Design Lab. 1 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](http://ece.jhu.edu)

**Prerequisite(s):** Laboratory Safety Introductory Course available in MyLearning prior to registration. The course is accessible from the Education tab through the portal [my.jh.edu](http://my.jh.edu). Please note that this requirement is not applicable to new students registering for their first semester at Hopkins.

**Corequisite(s):** Student can take EN.520.463, EN.520.663, and EN.520.251, but not in the same semester

Area: Engineering

**EN.520.302. Internet of Things Project Lab. 3 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 courses to have taken prior to this class: (AS.110.109 OR AS.110.107) AND (AS.171.102 OR AS.171.104 OR AS.171.108) AND EN.500.113 AND (520.225 ADS or 601.229 CSF) AND EN.520.142 AND EN.520.230 AND EN.520.231 AND EN.520.450

**Prerequisite(s):** 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.

Area: Engineering

**EN.520.315. Intro. to Bio-Inspired Processing of Audio-Visual Signals. 3 Credits.**

An introductory course to basic concepts of information processing of human communication signals (sounds, images) in living organisms and by machine. Recommended Course Background: EN.520.214 (or EN.580.222) or consent of the instructor.

Area: Engineering

**EN.520.344. Introduction to Digital Signal Processing. 3 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

**Prerequisite(s):** EN.520.214 OR EN.580.242 OR EN.580.246

Area: Engineering

**EN.520.349. Microprocessor Lab I. 3 Credits.**

This course introduces the student to the programming of microprocessors at the machine level. 68HC08, 8051, and eZ8 microcontrollers are programmed in assembly language for embedded control purposes. The architecture, instruction set, and simple input/output operations are covered for each family. Upon completion, students can use these flash-based chips as elements in other project courses. Recommended Course Background: EN.520.142 or equivalent. The lab is open 24/7 and students can still take the class if they are unable to meet during lab time.

**Prerequisite(s):** 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.

Area: Engineering

**EN.520.353. Control Systems. 4 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). Recommended courses to have taken: EN.553.291 OR EN.553.385 OR AS.110.201

**Prerequisite(s):** EN.520.214 OR EN.530.343 OR (EN.580.243 AND EN.580.246)

Area: Engineering

**EN.520.363. ECE Ideation and Design Lab. 3 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](http://ece.jhu.edu).

**Prerequisite(s):** 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.

Area: Engineering

**EN.520.370. Introduction to Renewable Energy Engineering. 3 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.

**Prerequisite(s):** (AS.171.101 OR AS.171.105 OR AS.171.107 OR EN.530.123) AND (AS.110.109 OR AS.110.107)

Area: Engineering, Natural Sciences

**EN.520.385. Signals, Systems, & Learning. 3 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.

**Prerequisite(s):** (EN.580.243 AND (EN.580.246[C] OR EN.520.214)) AND (EN.553.310 OR EN.553.311) AND AS.110.201

Area: Engineering

**EN.520.390. Music Signal Processing. 3 Credits.**

This course covers the principles and algorithms used in the processing and analysis of music. Topics include music representation, Fourier analysis of signals including both continuous and discrete representations, signal filtering, music synchronization, dynamic time warping, music structure analysis, chord recognition, tempo and beat tracking, tempograms, content-based audio retrieval, and music decomposition. Projects and assignments will be carried out in Matlab and/or Python. Students must have familiarity with music notation, structure, and instruments.

**Prerequisite(s):** (EN.520.214 OR EN.580.246) AND (EN.500.113 OR EN.500.133); AS.110.201 OR EN.553.291 OR EN.553.310 OR EN.553.311 OR EN.553.420 OR EN.553.421 - student can either have already completed this class or must be concurrently registered at the same time as this course.

Area: Engineering, Quantitative and Mathematical Sciences

**EN.520.403. Introduction to Optical Instruments. 3 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.

**Prerequisite(s):** AS.171.102 OR AS.171.108

Area: Engineering

**EN.520.404. Engineering solutions in a global, economic, environmental, and societal context. 1 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.

**Corequisite(s):** EN.660.400

Area: Humanities

**EN.520.407. Introduction to the Physics of Electronic Devices. 3 Credits.**

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

**Prerequisite(s):** AS.171.102 OR AS.171.104 OR AS.171.108

Area: Engineering

**EN.520.412. Machine Learning for Signal Processing. 3 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.

**Prerequisite(s):** Students can only take EN.520.412 OR EN.520.612, not both.; (AS.110.201 AND EN.553.310 AND EN.520.344) OR (AS.110.201 AND EN.553.311 AND EN.520.344) OR (AS.110.201 AND EN.553.420 AND EN.520.344) OR (AS.110.201 AND EN.553.421 AND EN.520.344)

Area: Engineering

**EN.520.414. Image Processing & Analysis. 3 Credits.**

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

**Prerequisite(s):** EN.520.214 OR EN.580.222 OR EN.580.243

Area: Engineering

**EN.520.415. Image Process & Analysis II. 3 Credits.**

This course is a continuation of EN.520.414. It covers fundamental methods for the processing and analysis of images and describes standard and modern techniques for the understanding of images by humans and computers. This second part focuses on nonlinear techniques for image processing and analysis, and more specifically techniques based on Mathematical Morphology. Topics include binary and grayscale morphological operators (erosions, dilations, openings, and closings), advanced morphological transformations (the discrete size transform, pattern spectrum, morphological skeletons), morphological filtering, morphological image reconstruction, morphological segmentation (SKIZ and the watershed transform), and morphological techniques for multi-resolution image analysis. Undergrad students only.

**Prerequisite(s):** EN.520.414; Students may only earn credit for EN.520.415 or EN.520.615, but not both.

Area: Engineering

**EN.520.417. Computation for Engineers. 3 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.

**Prerequisite(s):** (EN.553.291 OR EN.553.385 OR AS.110.201) AND (EN.520.214 OR EN.580.222 OR EN.580.243)

Area: Engineering

**EN.520.418. Modern Convex Optimization. 3 Credits.**

Convex optimization is at the heart of many disciplines such as machine learning, signal processing, control, medical imaging, etc. In this course, we will cover theory and algorithms for convex optimization. The theory part includes convex analysis, convex optimization problems (LPs, QPs, SOCPs, SDPs, Conic Programs), and Duality Theory. We will then explore a diverse array of algorithms to solve convex optimization problems in a variety of applications, such as gradient methods, sub-gradient methods, accelerated methods, proximal algorithms, Newton's method, and ADMM. A solid knowledge of Linear Algebra is needed for this course.

**Prerequisite(s):** (AS.110.201 OR AS.110.212 OR EN.553.291) AND (EN.500.113 OR EN.500.133 OR EN.540.382)

Area: Engineering

**EN.520.420. Bioelectricity from Neurons to Semiconductors. 3 Credits.**

In this course you will use the engineering concepts learned in Mastering Electronics (or equivalent) and mathematical tools to understand and analyze basic bioelectricity and circuit theory in the context of the mammalian nervous system. A second objective is to instill in you an appreciation for the similarities between electricity in biology and in silicon circuits, enabling you to begin interfacing the two in simple recording and stimulating experiments. A solid quantitative understanding of electric phenomenon in the context of the biological system is essential for designing many devices for biomedical diagnosis, treatment, and beyond. This course will give you the theoretical framework you need to begin exploring electrophysiological devices with biomedical engineering applications.

**Prerequisite(s):** EN.520.230 AND EN.520.231

Area: Engineering

**EN.520.424. FPGA Synthesis Lab. 3 Credits.**

An advanced laboratory course in the application of FPGA technology to information processing, using VHDL synthesis methods for hardware development. The student will use commercial CAD software for VHDL simulation and synthesis, and implement their systems in programmable XILINX 20,000 gate FPGA devices. The lab will consist of a series of digital projects demonstrating VHDL design and synthesis methodology, building up to final projects at least the size of an 8-bit RISC computer. Projects will encompass such things as system clocking, flip-flop registers, state-machine control, and arithmetic. The students will learn VHDL methods as they proceed through the lab projects, and prior experience with VHDL is not a prerequisite. Recommended Course Background: EN.601.229 OR EN.520.225 OR EN.520.349

**Prerequisite(s):** 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.520.142 or equivalent.

Area: Engineering, Quantitative and Mathematical Sciences

**EN.520.427. Design of Advanced Instruments and Systems. 3 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://jhueceptl.bitbucket.io>).

**Prerequisite(s):** EN.520.231 Mastering Electronics or equivalent, or permission of instructor

Area: Engineering

**EN.520.432. Medical Imaging Systems. 3 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.

**Prerequisite(s):** EN.520.214 OR EN.580.222 OR (EN.580.243 AND EN.580.246)

Area: Engineering

**EN.520.433. Medical Image Analysis. 3 Credits.**

This course covers the principles and algorithms used in the processing and analysis of medical images. Topics include, interpolation, registration, enhancement, feature extraction, classification, segmentation, quantification, shape analysis, motion estimation, and visualization. Analysis of both anatomical and functional images will be studied and images from the most common medical imaging modalities will be used. Projects and assignments will provide students experience working with actual medical imaging data. Recommended to have taken 520.432 OR EN.580.472 and 520.414. This class for Undergraduates Only; Graduates register for EN.520.623

**Prerequisite(s):** EN.553.310 OR EN.553.311 OR EN.560.348 OR EN.553.420

Area: Engineering

**EN.520.438. Deep Learning. 3 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.

**Prerequisite(s):** (EN.520.635 OR EN.520.344) AND (EN.520.412 OR EN.520.612 OR EN.601.220) AND (EN.553.420 OR EN.553.421 OR EN.553.310 OR EN.553.311) OR EN.601.220 OR permission of instructor.

Area: Engineering

**EN.520.439. Machine Learning for Medical Applications. 3 Credits.**

In this course, students will actively learn the basic principles of artificial intelligence and machine learning techniques applied to medical applications, as well as medical concepts common in healthcare environments. Throughout the course, students will explore different types of bio-signals such as electroencephalograms, electrocardiograms, sound, medical imaging, and their associated processing methodologies. The primary objective is to give students the tools they need to be able to develop new artificial intelligence-related ideas in biomedical environments. At the end of the course, students will apply their newly acquired knowledge to complete a cumulative final project dealing with a real-world situation. Students are expected to be familiar with linear algebra. Python coding skills are recommended, as there will be one coding assignment every week.

**Prerequisite(s):** (EN.520.412 OR EN.520.612 OR EN.553.740 OR EN.601.475 OR EN.553.636 OR EN.553.436) AND (EN.520.443 OR EN.580.472) AND (EN.520.635 OR EN.520.344) AND (EN.500.113 OR EN.500.133 OR EN.540.382)

Area: Engineering

**EN.520.440. Machine Intelligence on Embedded Systems. 3 Credits.**

The second wave of AI is about statistical learning of low dimensional structures from high dimensional data. Inference is done using multilayer, data transforming networks using fixed point arithmetic with parameters that have limited precision known as Deep Neural Networks. In this course students will learn about Machine Learning and AI on embedded systems that have limited computational, storage and communication resources. Students are expected to be familiar with linear algebra and Python as well some familiarity with typical ML frameworks (TensorFlow, Keras e.t.c). A first course in ML is strongly advised. At the end of the course, students will apply their newly acquired knowledge to complete a final project with real world data for machine perception and cognition.

**Prerequisite(s):** EN.520.412 OR EN.520.612 OR EN.601.475 OR EN.601.675 OR EN.601.676 OR EN.601.482 OR EN.601.682 OR EN.601.486 OR EN.601.686 OR EN.520.439 OR EN.520.659 OR EN.520.650

Area: Engineering

**EN.520.445. Audio Signal Processing. 3 Credits.**

This course gives a foundation in current audio and speech technologies, and covers techniques for sound processing by processing and pattern recognition, acoustics, auditory perception, speech production and synthesis, speech estimation. The course will explore applications of speech and audio processing in human computer interfaces such as speech recognition, speaker identification, coding schemes (e.g. MP3), music analysis, noise reduction. Students should have knowledge of Fourier analysis and signal processing. It is recommended that students take EN.520.344 Digital Signal Processing prior to taking this class.

**Prerequisite(s):** EN.520.344 AND EN.520.432

Area: Engineering

**EN.520.447. Information Theory. 3 Credits.**

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

**Prerequisite(s):** Students can earn credit for either EN.520.447 or EN.520.647, but not both.; EN.553.310 OR EN.553.420 OR EN.553.421 OR EN.553.311

Area: Engineering, Quantitative and Mathematical Sciences

**EN.520.448. Electronics Design Lab. 3 Credits.**

An advanced laboratory course in which teams of students design, build, test and document application specific information processing microsystems. Semester long projects range from sensors/actuators, mixed signal electronics, embedded microcomputers, algorithms and robotics systems design. Demonstration and documentation of projects are important aspects of the evaluation process.

**Prerequisite(s):** 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.520.240 OR EN.520.340 OR EN.520.241 OR EN.520.230 OR EN.520.231) AND AS.110.109 AND (AS.171.102 OR AS.171.104) AND EN.520.142

**EN.520.450. Advanced Micro-Processor Lab. 3 Credits.**

This course covers the usage of common microcontroller peripherals. Interrupt handling, timer operations, serial communication, digital to analog and analog to digital conversions, and flash ROM programming are done on the 68HC08, 8051, and eZ8 microcontrollers. Upon completion, students can use these flash-based chips as elements in other project courses.

**Prerequisite(s):** 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.520.349

Area: Engineering



**EN.520.453. Advanced ECE Engineering Team Project. 3 Credits.**

The course introduces the student to running an engineering team project. The student will participate in the ECE engineering team project as a leading member. The student is expected to participate in the different aspects of the project over several semesters and manage both team members and the project. (Juniors and Seniors) Permission of instructor is required.

**Prerequisite(s):** 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.

Area: Engineering

**EN.520.454. Control Systems Design. 3 Credits.**

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

**Prerequisite(s):** (EN.553.291 OR EN.553.385 OR AS.110.201 or AS.110.212) AND EN.520.353

Area: Engineering

**EN.520.457. Quantum Mechanics for Engineering. 3 Credits.**

Basic principles of quantum mechanics for engineers. Topics include the quantum theory of simple systems, in particular atoms and engineered quantum wells, the interaction of radiation and atomic systems, and examples of application of the quantum theory to lasers and solid-state devices. Recommended Course Background: AS.171.101-AS.171.102 and EN.520.219-EN.520.220

Area: Engineering

**EN.520.462. Leading Innovation Design Team. 3 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](https://engineering.jhu.edu/ece/) For additional info, see: <https://engineering.jhu.edu/ece/undergraduate-studies/leading-innovation-design-team/>

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class.

Area: Engineering

**EN.520.463. ECE Ideation and Design Lab. 3 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](https://ece.jhu.edu)

**Prerequisite(s):** Laboratory Safety Introductory Course available in MyLearning prior to registration. The course is accessible from the Education tab through the portal [my.jh.edu](https://my.jh.edu). Please note that this requirement is not applicable to new students registering for their first semester at Hopkins.

**Corequisite(s):** Students can take 520.251 and 520.663, but not in the same semester as 520.463.

Area: Engineering

**EN.520.465. Machine Perception. 3 Credits.**

This course will cover topics such as Marr-Hildreth and Canny edge detectors, local representations (SIFT, LBP), Markov random fields and Gibbs representations, normalized cuts, shallow and deep neural networks for image and video analytics, shape from shading, Make 3D, stereo, and structure from motion.

**Prerequisite(s):** Students can only receive credit for EN.520.465 or EN.520.665, but not both.;(AS.110.202 OR AS.110.212) AND (EN.553.291 OR EN.553.385 OR AS.110.201) AND (EN.553.310 OR EN.553.311 OR EN.553.420 OR EN.553.421) AND EN.520.385

Area: Engineering

**EN.520.470. Infra-Red Sensing & Technologies. 3 Credits.**

Infrared technologies have evolved over the last sixty, primarily driven by defense applications and needs but have recently perforated into various non-defense markets. It remains critical to many military systems and increasing to autonomous systems in general. This course is intended as an overview of the various technologies that make up an infrared sensor system, it will include some historical perspectives as well as the state of the art and will emphasize the various tradeoffs involved in designing a system for particular applications. In particular, it will cover the following topics that represent the main components: optics, detectors, readout integrated circuits (ROIC) including digital designs, the various wavelength (SWIR, MWIR, LWIR), testing and calibration, image and signal processing, and applications. The course structure will involve lectures, labs, and final project. Lectures will involve guest speakers that are subject matter experts on the various topics.

Area: Engineering

**EN.520.482. Introduction To Lasers. 3 Credits.**

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

**Prerequisite(s):** AS.171.102 OR AS.171.108

Area: Engineering, Natural Sciences

**EN.520.483. Bio-Photonics Laboratory. 3 Credits.**

This laboratory course involves designing a set of basic optical experiments to characterize and understand the optical properties of biological materials. The course is designed to introduce students to the basic optical techniques used in medicine, biology, chemistry and material sciences. Recommended course background: EN.520.150 and 520.219

**Prerequisite(s):** 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.171.102 OR AS.171.108) AND AS.173.112 AND AS.110.202

**EN.520.485. Advanced Semiconductor Devices. 3 Credits.**

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

Area: Engineering, Natural Sciences

**EN.520.486. Physics of Semiconductor Electronic Devices. 3 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.

**Prerequisite(s):** Students may earn credit for EN.520.486 or EN.520.686, but not both.;AS.171.102 OR AS.171.108

Area: Engineering, Natural Sciences

**EN.520.487. Clinical Diagnostic Devices and Methods. 3 Credits.**

This is an upper level project oriented course. The purpose of this course is to teach the students technical aspects of clinical diagnostic devices and methods in a real life setting. The course material will include application of the fundamentals that they had learned in their previous electronics and programming classes to design medical devices and methods. The first part of the course will involve teaching of the foundation for medical devices and methods. After learning the foundation material, the course participants will be divided to groups of 2-3 students each. Each group will need to identify a requirement or problem. This can be done by interacting with medical personnel at the HU Bayview Hospital, JHU School of Medicine or other institutes. After learning the foundations and identifying the requirement or problem, the students will develop a device or find a solution to the problem. The medical device or method developed by the student can be an instrument, software or a combination of instrument and software.

**Prerequisite(s):** (EN.500.112 OR EN.500.113 OR EN.500.114) AND EN.520.230 AND EN.520.231

Area: Engineering

**EN.520.491. CAD Design of Digital VLSI Systems I (Juniors/Seniors). 3 Credits.**

Juniors and Seniors Only.

**Prerequisite(s):** Student may take EN.520.491 or EN.520.691, but not both.;AS.110.109 AND (AS.171.102 OR AS.171.104 OR AS.171.108) AND EN.520.142 AND EN.520.142 AND ( EN.520.230 OR ( EN.520.213 AND EN.520.345 OR EN.520.216 ) )

Area: Engineering

**EN.520.492. Mixed-Mode VLSI Systems. 3 Credits.**

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

**Prerequisite(s):** EN.520.491

Area: Engineering

**EN.520.495. Microfabrication Laboratory. 4 Credits.**

This laboratory course is an introduction to the principles of microfabrication for microelectronics, sensors, MEMS, and other synthetic microsystems that have applications in medicine and biology. Course comprises of laboratory work and accompanying lectures that cover silicon oxidation, aluminum evaporation, 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

**Prerequisite(s):** AS.171.102 OR AS.171.108

Area: Engineering, Natural Sciences

**EN.520.497. Data Communications and Networking. 3 Credits.**

This course provides a comprehensive overview of computer and data communication networks, with emphasis on analysis and modeling. Basic communications principles are reviewed as they pertain to communication networks.

**Prerequisite(s):** Students may take EN.520.697 or EN.520.497, but not both.;EN.520.214

Area: Engineering

**EN.520.498. Senior Design Project. 3 Credits.**

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

**Prerequisite(s):** (EN.553.291 OR EN.553.385 OR AS.110.201) AND (AS.110.202 OR AS.110.212) AND (AS.171.102 OR AS.171.108) AND EN.601.220 AND EN.520.142 AND EN.520.214 AND EN.520.230 AND EN.520.231

Area: Engineering

**EN.520.504. ECE Undergraduate Independent Study. 1 - 3 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.

**Prerequisite(s):** You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration, Online Forms.

**EN.520.506. ECE Undergraduate Research. 1 - 3 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.

**Prerequisite(s):** You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration, Online Forms.

**EN.520.516. ECE Group Undergraduate Research. 1 - 3 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.

**Prerequisite(s):** You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration, Online Forms.

**EN.520.520. Artificial Intelligence In Medicine Reading Group. 1 Credit.**

Course Description: The course will consist of a reading group exploring novel algorithms and papers on artificial intelligence and machine learning in medical applications. In this course, students will analyze the latest techniques and trends in machine learning (ML) for medical applications. They will also actively discuss basic methodologies traditionally employed. Students are expected to be familiar with linear algebra and machine learning. The primary objective is to give students the tools they need to be able to understand new ideas and trends relating to the use of machine learning in biomedical environments and other fields.

**Prerequisite(s):** You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration, Online Forms.;EN.520.412 OR EN.520.612 OR EN.520.439  
Area: Engineering

**EN.520.571. Speech Technologies Reading Group. 1 Credit.**

Reading group that explores novel algorithms and papers on speech technologies

**Prerequisite(s):** You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration, Online Forms.

**EN.520.575. Intellectual Property Seminar for Engineering and Business Management. 3 Credits.**

This is an interdisciplinary seminar class introducing students to legal issues concerning intellectual property that are commonly faced by engineers and management in a technology company. The course will explore various topics relating to intellectual property, with an emphasis on patent law and trade secrets. Through reading assignments, discussions, and projects, students will gain a general understanding of intellectual property and other areas of technology law, and will develop strategies for identifying and solving problems that intertwine issues concerning technology, business management, and law. Students will be graded based upon class participation, short writing assignments, and quizzes. There will be a short writing assignment in place of a final exam.

**EN.520.603. Introduction to Optical Instruments. 3 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.

Area: Engineering

**EN.520.605. Advanced Optical and Optoelectronic Instruments and Devices. 3 Credits.**

This course is essentially as continuation of 520.403 course "Introduction to Optical Instruments" and it picks where that course ends. The course starts with deeper exploration of light propagation in dispersive and anisotropic media and goes on to study of polarization optics. Then electro-optic and acousto-optic effects and devices based on them are studied. A short review of nonlinear optics includes frequency conversion, multiphoton absorption, Raman and Brillouin scattering. Then we study light propagation in waveguides, starting with coupled mode theory. Integrated devices include modulators, filters, multiplexers-demultiplexers, and others. The last section of the course includes advanced concepts, such as plasmonics, metasurfaces, and Fourier Optics.

Area: Engineering

**EN.520.607. Introduction to the Physics of Electronic Devices. 3 Credits.**

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

**Prerequisite(s):** Students may earn credit for EN.520.607 or EN520.407 but not both.

Area: Engineering

**EN.520.612. Machine Learning for Signal Processing. 3 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.

**Prerequisite(s):** 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.;Credit may only be earned for EN.520.412 or EN.520.612.

Area: Engineering

**EN.520.613. Advanced Topics in Optical Medical Imaging. 3 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.

**EN.520.614. Image Processing & Analysis. 3 Credits.**

The course covers fundamental methods for the processing and analysis of images and describes standard and modern techniques for the understanding of images by humans and computers. Topics include elements of visual perception, sampling and quantization, image transforms, image enhancement, color image processing, image restoration, image segmentation, and multiresolution image representation. Laboratory exercises demonstrate key aspects of the course. Recommended Prerequisite: EN.520.214 or EN 580.222 or EN 580.243 or equivalent.

Area: Engineering

**EN.520.615. Image Processing & Analysis II. 3 Credits.**

This course is a continuation of EN.520.614. It 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. This second part focuses on nonlinear techniques for image processing and analysis, and more specifically techniques based on Mathematical Morphology. Topics include binary and grayscale morphological operators (erosions, dilations, openings, and closings), advanced morphological transformations (the discrete size transform, pattern spectrum, morphological skeletons), morphological filtering, morphological image reconstruction, morphological segmentation (SKIZ and the watershed transform), and morphological techniques for multi-resolution image analysis. Grad students only. Recommended course background EN.520.414 or EN.520.614.

**Prerequisite(s):** Students may only earn credit for EN.520.415 or EN.520.615, but not both.

Area: Engineering

**EN.520.617. Computation for Engineers. 3 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.

Area: Engineering

**EN.520.618. Modern Convex Optimization. 3 Credits.**

Convex optimization is at the heart of many disciplines such as machine learning, signal processing, control, medical imaging, etc. In this course, we will cover theory and algorithms for convex optimization. The theory part includes convex analysis, convex optimization problems (LPs, QPs, SOCPs, SDPs, Conic Programs), and Duality Theory. We will then explore a diverse array of algorithms to solve convex optimization problems in a variety of applications, such as gradient methods, sub-gradient methods, accelerated methods, proximal algorithms, Newton's method, and ADMM. A solid knowledge of Linear Algebra is needed for this course.

Area: Engineering

**EN.520.620. Bioelectricity from Neurons to Semiconductors. 3 Credits.**

In this course you will use the engineering concepts learned in Mastering Electronics (or equivalent) and mathematical tools to understand and analyze basic bioelectricity and circuit theory in the context of the mammalian nervous system. A second objective is to instill in you an appreciation for the similarities between electricity in biology and in silicon circuits, enabling you to begin interfacing the two in simple recording and stimulating experiments. A solid quantitative understanding of electric phenomenon in the context of the biological system is essential for designing many devices for biomedical diagnosis, treatment, and beyond. This course will give you the theoretical framework you need to begin exploring electrophysiological devices with biomedical engineering applications.

Area: Engineering

**EN.520.621. Introduction To Nonlinear Systems. 3 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.

Area: Engineering, Natural Sciences

**EN.520.622. Principles of Complex Networked Systems. 3 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.

**EN.520.623. Medical Image Analysis. 3 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. **Prerequisite(s):** Student may earn credit for 520.433 or 520.623, but not both.;EN.520.432 OR EN.580.472 AND EN.550.310 OR EN.550.311

**EN.520.624. Integrated Photonics. 3 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.

Area: Engineering, Natural Sciences

**EN.520.627. Photovoltaics and Energy Devices. 3 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.

**EN.520.628. Satellite Communication System. 3 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.

**EN.520.629. Networked Dynamical Systems. 3 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.

**EN.520.631. Ultrasound and Photoacoustic Beamforming. 3 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 data. The course will culminate with student projects to design and implement a new beamformer derived from the principles taught in class. Recent projects have focused on the emerging use of deep learning to form a new class of ultrasound and photoacoustic images. Recommended background for students interested in deep learning projects: machine learning (EN.601.475), deep learning (EN.520.438/638 or EN.601.482/682), or equivalent.

**EN.520.632. Medical Imaging Systems. 3 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.

Area: Engineering

**EN.520.633. Intro To Robust Control. 3 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

Area: Engineering

**EN.520.635. Digital Signal Processing. 3 Credits.**

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

Area: Engineering

**EN.520.636. Feedback Control in Biological Signaling Pathways. 3 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.

**EN.520.637. Foundations of Reinforcement Learning. 3 Credits.**

The course will provide a rigorous treatment of reinforcement learning by building on the mathematical foundations laid by optimal control, dynamic programming, and machine learning. Topics include model-based methods such as deterministic and stochastic dynamic programming, LQR and LQG control, as well as model-free methods that are broadly identified as Reinforcement Learning. In particular, we will cover on and off-policy tabular methods such as Monte Carlo, Temporal Differences, n-step bootstrapping, as well as approximate solution methods, including on- and off-policy approximation, policy gradient methods, including Deep Q-Learning. The course has a final project where students are expected to formulate and solve a problem based on the techniques learned in class.

Area: Engineering

**EN.520.638. Deep Learning. 3 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: Recommended: Intermediate Programming & Probability/Statistics

**Prerequisite(s):** EN.520.435 OR EN.520.412 OR EN.520.612 or permission of instructor.

Area: Engineering

**EN.520.639. Communication Systems Engineering. 3 Credits.**

This course provides an overview of analog communications and presents the theory and applications relevant to modern digital communication systems. The course covers concepts in random signal analysis, lossless and lossy source coding, quantization, analog and digital modulation schemes, synchronization, channels characterization and capacity, optimum receivers, and adaptive equalization. We also discuss modern communication techniques related to adaptive antenna array signal processing and systems including SISO, SIMO, MISO and MIMO.

Area: Engineering

**EN.520.640. Machine Intelligence on Embedded Systems. 3 Credits.**

The second wave of AI is about statistical learning of low dimensional structures from high dimensional data. Inference is done using multilayer, data transforming networks using fixed point arithmetic with parameters that have limited precision known as Deep Neural Networks. In this course students will learn about Machine Learning and AI on embedded systems that have limited computational, storage and communication resources. Students are expected to be familiar with linear algebra and Python as well as some familiarity with typical ML frameworks (TensorFlow, Keras e.t.c). A first course in ML is strongly advised. At the end of the course, students will apply their newly acquired knowledge to complete a final project with real world data for machine perception and cognition.

**Prerequisite(s):** EN.520.412 OR EN.520.612 OR EN.601.475 OR EN.601.675 OR EN.601.676 OR EN.601.482 OR EN.601.486 OR EN.520.439 OR EN.520.659 OR EN.520.650

Area: Engineering

**EN.520.641. Neuromorphic Circuits and Systems. 3 Credits.**

This course covers the analysis, design and simulation of neuromorphic circuits and systems. It will begin with circuits from the advent of the neuromorphic engineering field, span through current designs and considerations, and culminate with a project that involves designing a novel version of such circuits. A good knowledge of VLSI design is required to complete this course.

**Prerequisite(s):** EN.520.491 OR EN.520.691 OR EN.520.492 OR EN.520.692.

Area: Engineering

**EN.520.644. FPGA Synthesis Lab. 3 Credits.**

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

**Prerequisite(s):** 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.

Area: Engineering, Quantitative and Mathematical Sciences

**EN.520.645. Audio Signal Processing. 3 Credits.**

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

Area: Engineering

**EN.520.646. Wavelets & Filter Banks. 3 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.

**EN.520.647. Information Theory. 3 Credits.**

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

**Prerequisite(s):** Students can earn credit for either 520.447 or 520.647, not both.

Area: Engineering

**EN.520.648. Compressed Sensing and Sparse Recovery. 3 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.

**EN.520.649. Introduction to Radar Systems. 3 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.

**EN.520.650. Machine Intelligence. 3 Credits.**

This course will cover the full range of topics studied in artificial intelligence, with emphasis on the "core competences" of intelligent systems - search, knowledge representation, reasoning under uncertainty, vulnerability, ethics and safety of intelligent systems. Recent applications in engineering and medicine will be highlighted.

Area: Engineering

**EN.520.651. Random Signal Analysis. 4 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). Audits not permitted.

**EN.520.653. Dynamics & Control of Modern Power Systems. 3 Credits.**

This course covers the fundamental theory of dynamic analysis and control of modern power systems. Topics include mathematical modeling of large-scale power systems, linear/nonlinear system theory (for example, Lyapunov stability, bifurcation), small- and large-disturbance analysis, and voltage stability and control. Furthermore, various emerging challenges and opportunities in future low-inertia power systems are discussed. Selective topics include inverter-based resources (IBRs), renewable generation, advanced control strategies, and smart grids technologies. There is an individual term project that focuses on a research question related to the class topics. The materials that are presented in the course are relatively dense in mathematical analysis and theory. Applications and software usage will be covered. Some unique perspectives are provided, such as bifurcation theory, trajectory sensitivities, and hybrid dynamics. There are also components tailored for the emerging transition that are novel and have not been offered in a classic power system dynamics course. Such new developments aim to address the pressing need in preparing students in the energy fields for analyzing future low-inertia smart grids. The materials covered in this course will complement the following two existing courses: EN.560.649 (01) Energy Systems EN.570.607 (01) Energy Policy and Planning Models. The course should be taken after the Energy Systems, or simultaneously. Recommended: Basic knowledge in calculus, electric circuits, and ordinary differential equations (ODE). One course in Control Systems (for example, EN.520.353 (01)), understand the concept of state space. Preferably one course in power system engineer/analysis (for example, EN.560.649 (01) Energy Systems). No required textbook

Area: Engineering

**EN.520.654. Control Systems Design. 3 Credits.**

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

Area: Engineering

**EN.520.656. Data Smoothing Using Machine Learning. 3 Credits.**

All measurements contain errors (noise). Before the measurements are used, they should be passed through a noise reduction filter. When the noise level is unknown, the filter can be designed using a machine learning method called cross-validation. This course will investigate algorithmic approaches to data smoothing using cross-validation. Students will complete several Matlab projects.

Area: Engineering

**EN.520.657. Design of Biomedical Instruments and Systems. 3 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://jhueceptl.bitbucket.io>).

Area: Engineering

**EN.520.659. Machine learning for medical applications. 3 Credits.**

In this course, students will actively learn the basic principles of artificial intelligence and machine learning techniques applied to medical applications, as well as medical concepts common in healthcare environments. Throughout the course, students will explore different types of bio-signals such as electroencephalograms, electrocardiograms, sound, medical imaging, and their associated processing methodologies. The primary objective is to give students the tools they need to be able to develop new artificial intelligence-related ideas in biomedical environments. At the end of the course, students will apply their newly acquired knowledge to complete a cumulative final project dealing with a real-world situation. Students are expected to be familiar with linear algebra. Python coding skills are recommended, as there will be one coding assignment every week. Recommended Course Background: EN.520.412 OR EN.520.612 OR Other machine learning backgrounds.

**Prerequisite(s):** EN.520.412 OR EN.520.612 OR EN.553.740 OR EN.601.475 OR EN.553.636 OR EN.553.436

Area: Engineering

**EN.520.662. Leading Innovation Design Team. 3 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](http://ece.jhu.edu)

**EN.520.663. ECE Ideation and Design Lab. 3 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](http://ece.jhu.edu)

**Prerequisite(s):** Laboratory Safety Introductory Course available in MyLearning prior to registration. The course is accessible from the Education tab through the portal [my.jh.edu](http://my.jh.edu). Please note that this requirement is not applicable to new students registering for their first semester at Hopkins.

Area: Engineering

**EN.520.665. Machine Perception. 3 Credits.**

This course will cover topics such as Marr-Hildreth and Canny edge detectors, local representations (SIFT, LBP), Markov random fields and Gibbs representations, normalized cuts, shallow and deep neural networks for image and video analytics, shape from shading, Make 3D, stereo, and structure from motion.

Area: Engineering

**EN.520.666. Information Extraction. 3 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.



**EN.520.680. Speech and Auditory Processing by Humans and Machines. 3 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.

**EN.520.682. Introduction to Lasers. 3 Credits.**

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

**EN.520.683. Bio-Photonics Laboratory. 3 Credits.**

This laboratory course involves designing a set of basic optical experiments to characterize and understand the optical properties of biological materials. The course is designed to introduce students to the basic optical techniques used in medicine, biology, chemistry and material sciences. Graduate version of EN.520.483

**Prerequisite(s):** 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.520.685. Advanced Semiconductor Devices. 3 Credits.**

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

**Prerequisite(s):** Students can only take EN.520.485 or EN.520.685, not both.

Area: Engineering, Natural Sciences

**EN.520.686. Physics of Semiconductor Electronic Devices. 3 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.

**Prerequisite(s):** Students may earn credit for EN.520.486 or EN.520.686, but not both.

Area: Engineering

**EN.520.687. Clinical Diagnostic Devices and Methods. 3 Credits.**

This is an upper level project oriented course. The purpose of this course is to teach the students technical aspects of clinical diagnostic devices and methods in a real life setting. The course material will include application of the fundamentals that they had learned in their previous electronics and programming classes to design medical devices and methods. The first part of the course will involve teaching of the foundation for medical devices and methods. After learning the foundation material, the course participants will be divided to groups of 2-3 students each. Each group will need to identify a requirement or problem. This can be done by interacting with medical personnel at the HU Bayview Hospital, JHU School of Medicine or other institutes. After learning the foundations and identifying the requirement or problem, the students will develop a device or find a solution to the problem. The medical device or method developed by the student can be an instrument, software or a combination of instrument and software.

Area: Engineering

**EN.520.691. CAD Design of Digital VLSI Systems I (Grad). 3 Credits.**

Graduate students only.

Area: Engineering

**EN.520.692. Mixed-Mode VLSI Systems. 3 Credits.**

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

**EN.520.697. Data Communications and Networking. 3 Credits.**

This course provides a comprehensive overview of computer and data communication networks, with emphasis on analysis and modeling. Basic communications principles are reviewed as they pertain to communication networks.

**Prerequisite(s):** Students may take EN.520.497 or EN.520.697, but not both.

Area: Engineering

**EN.520.698. Networks Meet Machine Learning: Methods and Applications. 3 Credits.**

This course teaches foundational knowledge about engineered networks. Topics to be covered include the mathematics of networks (derived from graph theory), data analysis, optimization and machine learning over networks. We will use examples of real-world networks to illustrate the inner workings of the taught methods. Students will learn about the ongoing research in the field, and ultimately apply their knowledge to conduct their own analysis of a real network as part of their final project.

**EN.520.738. Advanced Electronic Lab Design. 3 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.

**Prerequisite(s):** 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.520.773. Advanced Topics In Microsystem Fabrication. 4 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.

**Prerequisite(s):** 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.520.774. Advanced Topics in Electrical and Computer Engineering. 3 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.

**Prerequisite(s):** 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.520.800. ECE Graduate Independent Study. 1 - 3 Credits.**

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

**EN.520.802. ECE Dissertation Research. 3 - 20 Credits.**

Reading, research, or project work for advanced graduate students. Arranged individually between students and faculty.

**EN.520.803. Graduate Summer Research. 9 Credits.**

Reading, research, or project work for advanced graduate students. Arranged individually between students and faculty.

**EN.520.806. ECE Master's Research. 3 - 10 Credits.**

Independent research for masters students

**EN.520.807. Current Topics in Language and Speech Processing. 1 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.

**EN.520.820. Artificial Intelligence In Medicine Reading Group. 1 Credit.**

The course will consist of a reading group exploring novel algorithms and papers on artificial intelligence and machine learning in medical applications. In this course, students will analyze the latest techniques and trends in machine learning (ML) for medical applications. They will also actively discuss basic methodologies traditionally employed. Students are expected to be familiar with linear algebra and machine learning. The primary objective is to give students the tools they need to be able to understand new ideas and trends relating to the use of machine learning in biomedical environments and other fields.

**Prerequisite(s):** EN.520.612 OR EN.520.659 OR EN.520.439  
Area: Engineering

**EN.520.871. Speech Technologies Reading Group. 1 Credit.**

Reading Group that explores novel algorithms and papers on speech technologies

**EN.520.875. Intellectual Property Seminar for Engineering and Business Management. 3 Credits.**

This is an interdisciplinary seminar class introducing students to legal issues concerning intellectual property that are commonly faced by engineers and management in a technology company. The course will explore various topics relating to intellectual property, with an emphasis on patent law and trade secrets. Through reading assignments, discussions, and projects, students will gain a general understanding of intellectual property and other areas of technology law, and will develop strategies for identifying and solving problems that intertwine issues concerning technology, business management, and law. Students will be graded based upon class participation, short writing assignments, and quizzes. There will be a short writing assignment in place of a final exam.

**EN.520.890. Independent Study-Summer. 1 - 3 Credits.**

An independent course of study may be pursued under the direction of an adviser on those topics not specifically listed in the form of regular courses. Perm. Req'd. Graduate level students only.

**EN.520.895. Electrical & Computer Engineering Seminar. 1 Credit.**

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

## Cross Listed Courses

### Biomedical Engineering

#### EN.580.678. Biomedical Photonics I. 4 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.

**Prerequisite(s):** 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.

Area: Engineering

#### EN.580.788. Biomedical Photonics II. 4 Credits.

This course serves as the continuation of 580.678 (520.678), Biomedical Photonics I. 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. A hand-on lab section (optional) for students to design and build an imaging instrument, space permitting. No Audits.

### Center for Leadership Education

#### EN.660.345. Multidisciplinary Engineering Design 1. 3 Credits.

Students will work on teams with colleagues from different engineering disciplines to tackle a challenge for a clinical, community, or industry project partner. Through practicing a creative, human-centered design process, teams will understand the essential need behind the problem, prototype solutions, and test and refine their prototypes. In addition to project work, students will learn healthy team dynamics and how to collaborate among different working styles.

Area: Engineering

#### EN.660.346. Multidisciplinary Engineering Design 2. 3 Credits.

In this course, student teams continue their design projects from EN.660.345 with their project partners from industry, medicine, and the Baltimore community. Moving beyond the early design stages of their solution, teams will be introduced to product development tools such as risk analysis, specification creation, verification testing, and timeline management. They will continue to refine and test their prototypes in preparation for hand-off to their project partner at the end of the semester. As projects progress in technical depth, students have more opportunities to contribute expertise from their discipline while learning new skills from their peers and experts.

Area: Engineering

### Civil and Systems Engineering

#### EN.560.449. Energy Systems. 3 Credits.

This course revolves around the grid integration of renewable energy systems and operations of energy systems with renewables. The main emphasis is on grid level effects of renewable energy, particularly solar and wind power systems, and how these effects can be analyzed using mathematical modeling and modern software tools. The course begins with an introduction to basic power system concepts (transmission/distribution system modeling, power transformers, conventional and renewable generation technologies) along with power flow analysis and optimization. Following that, the course considers applications of optimal power flow and its variants to electricity market operations. An important component of this course is a guided project that will be carried out by students in small groups; each group will choose a real-world energy system to research and analyze and will present their findings at the end of the semester. Prior knowledge of circuits (including operations with complex numbers), linear algebra, calculus, and optimization is helpful, but not required. This course is co-listed with EN.560.649.

**Prerequisite(s):** AS.110.202

Area: Engineering, Quantitative and Mathematical Sciences

### Computer Science

#### EN.601.856. Seminar: Medical Image Analysis. 1 Credit.

This weekly seminar will focus on research issues in medical image analysis, including imagesegmentation, registration, statistical modeling, and applications. It will also include selected topics relating to medical image acquisition, especially where they relate to analysis. The purpose of the course is to provide the participants with a thorough background in current research in these areas, as well as to promote greater awareness and interaction between multiple research groups within the University. The format of the course is informal. Students will read selected papers. All students will be assumed to have read these papers by the time the paper is scheduled for discussion. But individual students will be assigned on a rotating basis to lead the discussion on particular papers or sections of papers. Co-listed with En.520.746.

### General Engineering

#### EN.500.113. Gateway Computing: Python. 3 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 homework involves significant programming. Attendance and participation in class sessions are expected.

**Prerequisite(s):** Students may only receive credit for one of the following courses: EN.500.112 OR EN.500.113 OR EN.500.114 OR EN.500.132 OR EN.500.133 OR EN.500.134

Area: Engineering

**EN.500.132. Bootcamp: Java. 1 Credit.**

This on-line course provides students who have already achieved a basic understanding of programming and computational thinking in one programming language with an opportunity to apply these skills in another programming language. Students will be expected to complete projects to demonstrate proficiency in the new language. Satisfactory/unsatisfactory only.

**Prerequisite(s):** Students can only take EN.500.112 OR EN.500.132, but not both.;EN.500.113 OR EN.500.114 OR EN.520.123 OR EN.601.220

Area: Engineering

**Mechanical Engineering****EN.530.421. Mechatronics. 3 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.

**Prerequisite(s):** 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 EN.520.340 or permission of the instructor.

Area: Engineering

**EN.530.616. Introduction to Linear Systems Theory. 3 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. No audit option, but contact the instructor if you want to informally sit in on the course.

**Prerequisite(s):** Recommended course background are undergraduate courses in linear algebra, differential equations, and an undergraduate level course in control systems. Students cannot take EN.530.616 if they have already taken EN.520.601 OR EN.580.616.

**Robotics****EN.620.745. Seminar in Computational Sensing and Robotics. 1 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.

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