# Department of Electrical and Computer Engineering

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The Electrical and Computer Engineering Department offers major programs leading to the bachelor of science in electrical engineering or the bachelor of science in electrical and computer engineering, as well as required and elective courses for students majoring in other fields.

Electrical and computer engineering includes the broad range of design, construction, and operation of electrical components, circuits, and systems as well as the science and technology of design, construction, and implementation of the software and hardware components of modern computing systems and computer-controlled equipment. This includes sustainable energy and electric power, signal and image processing, embedded systems, control systems, nanotechnology and integrated circuits, antennas, RF and communication systems, and all phases of the transmission of information.

Laboratories are an important part of most undergraduate courses in the electrical and computer engineering program. Use of appropriate laboratory equipment, design tools, and components demonstrates fundamental concepts of the courses and acquaints students with methods and tools they may use after graduation. The department has five teaching laboratories that support courses in electric circuits, electronics, systems, logic design, and RF and communication. In addition, the program has a laboratory dedicated to senior design projects. All laboratories are supported by the facilities of the Engineering Computing Center.

## Requirements for the Majors

**Major in Electrical Engineering**

In addition to fulfilling the undergraduate Core Curriculum for the bachelor of science degree, students majoring in electrical engineering must fulfill the following major requirements and complete a minimum of 190 units. For every required engineering and science course, if an associated laboratory is listed following the course description, then that laboratory is also required to fulfill the major requirements.

**English**

* ENGL 181

**Mathematics and Natural Science**

* MATH 11, 12, 13, 14
* AMTH 106 (or MATH 22) and AMTH 108
* CHEM 11 or 11T
* PHYS 31, 32, 33
* PHYS 34 or MATH 51
* One from CHEM 12, BIOL 1A, PHYS 113 or 121, MATH 53, 105 or 123

**Engineering**

* ENGR 1
* COEN 10 (or demonstrated equivalent programming proficiency)
* COEN 11, COEN 12
* MECH 121
* ELEN 20, 21, 50, 100, 104, 110, 115, 120, 192, 194, 195, 196

**Technical Electives**

Five undergraduate ELEN 100-level elective courses. One course must be selected from at least four of the following five areas:

* IC Design: ELEN 116, 117, 151, 152, 153, 156
* Systems: ELEN 118, 130, 133, 134, 160, 161, 167
* RF and Communication: ELEN 105, 141, 142, 144
* Power Systems: ELEN 164, 183, 184
* Digital and Embedded Systems: ELEN 121, 122, 123, 124, 127, 180

Additional electives may be substituted, with the approval of the advisor, including first-year graduate-level electrical engineering coursework.

**Professional Development**

A professional development experience selected from one of the following options:

* Four or more units in a study abroad program that does not duplicate other coursework
* Cooperative education experience with enrollment in ELEN 188 and ELEN 189
* 2 units in ENGR 110 (Community-Based Engineering Design)
* Preparation for graduate study in electrical engineering with completion of 2 or more additional units of upper-division or graduate-level courses
* Completion of an approved minor or second major in any field of engineering or science
* Completion of 10 or more units in the combined bachelor of science and master of science program
* 2 units of Peer education experience
* 2 units of undergraduate research, ELEN 199

## Major in Electrical and Computer Engineering

In addition to fulfilling the undergraduate Core Curriculum for the bachelor of science degree, students majoring in electrical and computer engineering must fulfill the following major requirements and complete a minimum of 190 units. For every required engineering and science course, if an associated laboratory is listed following the course description, then that laboratory is also required to fulfill the major requirements.

**English**

* ENGL 181

**Mathematics and Natural Science**

* MATH 11, 12, 13, 14, 51, 53
* CSCI 163A
* AMTH 106 (or MATH 22) and AMTH 108
* PHYS 31, 32, 33
* One course selected from CHEM 11 or 12, BIOL 1A, PHYS 34, 113 or 121, MATH 105 or 123

**Engineering**

* ENGR 1
* COEN 10, 11, 12, and 177
* ELEN 20, 21, 50, 100, 115, 120, 121, 122, 133, 142, 192, 194, 195, 196

**Technical Electives**

Three undergraduate ELEN 100-level elective courses approved by an academic advisor. At least one must be selected from (ELEN 123, 124, 127). With advisor approval at most one may be selected from COEN courses. ELEN 188 and 189 may not be used as technical electives.

Additional electives may be substituted, with the approval of the advisor from first-year graduate-level engineering coursework

**Professional Development**

A professional development experience selected from one of the following options:

* 4 or more units in a study abroad program that does not duplicate other coursework
* Cooperative education experience with enrollment in ELEN 188 and ELEN 189
* 2 units in ENGR 110 (Community-Based Engineering Design)
* Preparation for graduate study in either electrical and computer engineering or computer science and engineering with completion of 2 or more additional units of upper-division or graduate-level courses
* Completion of an approved minor or second major in any field of engineering or science
* Completion of 10 or more units in the combined bachelor of science and master of science program
* 2 units of Peer education experience
* 2 units of undergraduate research, ELEN 199

## Requirements for the Minors

**Minor in Electrical Engineering**

Students must fulfill the following requirements for a minor in electrical engineering:

* ELEN 21, 21L, 50, 50L, 115, 115L
* Two courses selected from ELEN 100, 104, and 110, including their associated laboratory courses
* Three upper-division ELEN lecture courses (ELEN 100-level courses, excluding ELEN 188, 189, 192, 194, 195, and 196)
* Work completed to satisfy these requirements for the minor must include at least two courses beyond any free electives or other courses required to earn the bachelor’s degree in the student’s primary major

**Minor in Electrical and Computer Engineering**

* ELEN 21, 21L, 50, 50L, 120, 120L
* Two courses selected from ELEN 122, 133, and 142, including their associated laboratory courses
* Three additional upper-division Electrical and Computer Engineering lecture courses (ELEN 121, 122, 123, 124, 127, 133, 142, 153, 161)
* Work completed to satisfy these requirements for the minor must include at least two courses beyond any free electives or other courses required to earn the bachelor's degree in the student's primary major

## Combined Bachelor of Science and Master of Science Program

The Department of Electrical and Computer Engineering offers a combined degree program leading to the bachelor of science in either major and a master of science in electrical and computer engineering. This program is open to majors with an approved grade point average in electrical and computer engineering, mathematics, and physics courses. Under the combined degree program, an undergraduate student begins taking courses required for a master’s degree before completing the requirements for the bachelor’s degree and typically completes the requirements for a master of science in electrical and computer engineering within a year of obtaining the bachelor’s degree. Undergraduate students interested in the combined degree program are required to apply for the program between February of their junior year and December of their senior year.

Students in this program will receive their bachelor’s degree after satisfying the full undergraduate degree requirements. To earn the master’s degree, students must fulfill all the requirements for the degree, including the completion of 46 units of coursework beyond that applied to their bachelor’s degree. No course can be used to satisfy requirements for both the bachelor’s degree and the master’s degree. However, completion of 10 or more units of coursework in electrical and computer engineering taken for the master’s degree satisfies the professional development requirement of the undergraduate program.

The program of studies for the master’s degree may include up to 20 units of electrical and computer engineering upper-division elective coursework excluding ELEN 188 and 189. These undergraduate units can count toward a master’s degree only if a grade of “B” or better is earned. Students who do not complete the combined degree program within six years of entering the University will automatically be transferred to the regular master’s degree program. Although six years is the maximum timeframe for completing the combined degree, full-time students enrolling in February of their junior year normally complete both degrees within five years.

## Electrical and Computer Engineering Laboratories

The Electromagnetics and Communications Laboratory provides a full range of modern RF measurement capabilities up to 22 GHz, including a number of vector network analyzers, spectrum analyzers, and antenna measurement systems. This lab also includes complete production facilities for prototyping printed microwave circuits and antennas. Further, the lab has extensive computer-aided design and simulation capability, including both commercial packages and research-grade in-house solvers. In both research and teaching, connections between physical hardware measurements and computer simulations are stressed.

The Cybersecurity Laboratory provides various research projects in different aspects of cybersecurity including hardware, network, internet of things (IoT), mobile, etc. The Cybersecurity Laboratory supports both graduate and undergraduate student research. This lab has the following facilities for experiments, tests, and data collection and analysis: Oscilloscopes, Logic Analyzers, Thermal Chamber, FPGAs, microcontrollers, hacking tools, and more.

The IC Design and Technology Laboratory is dedicated to teaching and research topics on electronic materials and devices, integrated circuit design, and IC manufacturing technologies. Current research topics include modeling complex electronic devices using variational methodologies, materials and device characterizations, fabrication and experimental studies of photovoltaic devices, emission free smart infrastructure, and optimizing energy infrastructure.

The Complex Systems and Control Laboratory provides an experimental environment for students in the area of control system engineering. The lab includes computer-controlled DC motors. These motors provide students with a range of qualitative and quantitative experiments such as inverted pendulum for learning the utility and versatility of feedback in computer-controlled systems.

The Latimer Energy Laboratory (LEL) supports a very wide range of activities relating to solar energy, more specifically photovoltaics (PV) and management of renewable energy sources, from K-12 outreach through graduate engineering. The laboratory focuses on two major directions: 1) measurement and characterization of different renewable energy sources; and 2) integration of renewable energy into the electric grid. The lab has instrumentation such as pyranometers, VIS-IR spectrometers, metallurgical microscopes, source meters, grid simulator software and related computers.

The Thermal and Electrical Nanoscale Transport (TENT) Laboratory provides teaching and research facilities for modeling, simulation, and characterization of devices and circuits in the nanoscale. Ongoing research topics include silicon heterostructures; thin dielectric;, high-frequency device and circuit parameter extraction; carbon nanostructures used as electrical interconnect and thermal interface materials; and compact modeling of transistors and interconnects for large-scale circuit simulation. This laboratory is located inside NASA Ames Research Center in Moffett Field, California, and was established to conduct, promote, and nurture nanoscale science and technology, interdisciplinary research, and education activities at the University.

The Information Processing and Machine Learning Laboratory supports research in theoretical algorithm development in digital signal processing, adaptive and nonlinear signal processing, machine learning, and deep learning. Application areas include speech, audio, image and video processing for computer vision, communications, biological testing and diagnostics, artificial intelligence (AI), Voice-over-IP networking. The lab supports student research in algorithms and real-time implementations on Graphical Processing Units (GPUs), digital signal processors (DSPs) and field programmable gate arrays (FPGAs). Laboratory equipment includes digital oscilloscopes, video cameras and wireless LAN networking equipment.

The Image and Video Processing Laboratory supports graduate student research on algorithms and implementations for image analysis, computer vision, image reconstruction and super-resolution, and stereo imaging. Laboratory equipment includes cameras for image acquisition and computational resources, including FPGAs and GPUs, for real-time testing.

## Lower-Division Courses

### 20. Emerging Areas in Electrical and Computer Engineering

Introduction to new frontiers in electrical and computer engineering. Hands-on activities and visits to research and production facilities in Silicon Valley companies to learn how the fundamentals of electrical and computer engineering are enabling new emerging technologies. (2 units)t

### 21. Introduction to Logic Design

Boolean functions and their minimization. Combinational circuits: adders, multipliers, multiplexers, decoders. Sequential logic circuits: latches and flip-flops, registers, counters. Memory. Busing. Programmable logic. Use of industry quality CAD tools for schematic capture and HDL in conjunction with FPGAs. Also listed as COEN 21. Corequisite: ELEN 21L. (4 units)

### 21L. Logic Design Laboratory

Laboratory for ELEN 21. Also listed as COEN 21L. Corequisite: ELEN 21. (1 unit)

### 49. Fundamentals of Electricity for Civil Engineers

Transducers. Motors, generators and efficiency. DC and AC circuits. One and three-phase power systems. Sources of electricity. Hydroelectric power, generation, and pumps. Electrical diagrams and schematics. (4 units)

### 50. Electric Circuits I

Physical basis and mathematical models of circuit components and energy sources. Circuit theorems and methods of analysis are applied to DC and AC circuits. Corequisite: ELEN 50L, PHYS 33. (4 units)

### 50L. Electric Circuits I Laboratory

Laboratory for ELEN 50. Corequisite: ELEN 50. (1 unit)

## Upper-Division Courses

### 100. Electric Circuits II

Continuation of ELEN 50. Sinusoidal steady state and phasors, transformers, resonance, Laplace analysis, transfer functions. Frequency response analysis. Bode diagrams. Switching circuits. Prerequisite: ELEN 50 with a grade of C- or better, or PHYS 70. Corequisite: ELEN 100L, AMTH 106. (4 units)

### 100L. Electric Circuits II Laboratory

Laboratory for ELEN 100. Corequisite: ELEN 100. (1 unit)

### 104. Electromagnetics I

Vector analysis and vector calculus. The laws of Coulomb, Lorentz, Faraday, and Gauss. Dielectric and magnetic materials. Energy in electric and magnetic fields. Capacitance and inductance. Maxwell’s equations. Wave equation. Poynting vector. Wave propagation and reflection in transmission lines. Radiation. Prerequisites: PHYS 33 and ELEN 50 with a grade of C- or better. Corequisite: ELEN 104L. (4 units)

### 104L. Electromagnetics I Laboratory

Laboratory for ELEN 104. Corequisite: ELEN 104. (1 unit)

### 105. Electromagnetics II

In-depth study of several areas of applied electromagnetics such as transmission lines circuits including microstrip and strip lines, Smith Chart and bounce diagram, magnetic circuits, antennas and antenna arrays. Prerequisite: ELEN 104. Corequisite: ELEN 105L. (4 units)

### 105L. Electromagnetics II Laboratory

Laboratory for ELEN 105. Corequisite: ELEN 105. (1 unit)

### 110. Linear Systems

Signals and system modeling. Laplace transform. Transfer function. Convolution. Discrete systems. Frequency analysis. Fourier series and transform. Filtering. State-Space models. Prerequisite: ELEN 100. Corequisite: ELEN 110L. (4 units)

### 110L. Linear Systems Laboratory

Laboratory for ELEN 110. MATLAB laboratory/problem sessions. Corequisite: ELEN 110. (1 unit)

### 112. Modern Network Synthesis and Design

Approximation and synthesis of active networks. Filter design using positive and negative feedback biquads. Sensitivity analysis. Fundamentals of passive network synthesis. Design project. Prerequisite: ELEN 110. Corequisite: ELEN 112L. (4 units)

### 112L. Modern Network Synthesis and Design Laboratory

Laboratory for ELEN 112. Corequisite: ELEN 112. (1 unit)

### 115. Electronic Circuits I

Study of basic principles of operation, terminal characteristics, and equivalent circuit models for diodes and transistors. Analysis and design of diode circuits, transistor amplifiers, and inverter circuits. Prerequisite: ELEN 50 with a grade of C- or better. Corequisite: ELEN 115L. (4 units)

### 115L. Electronic Circuits I Laboratory

Laboratory for ELEN 115. Corequisite: ELEN 115. (1 unit)

### 116. Analog Integrated Circuit Design

Design and analysis of multistage analog amplifiers. Study of differential amplifiers, current mirrors and gain stages. Frequency response of cascaded amplifiers and gain-bandwidth considerations. Concepts of feedback, stability, and frequency compensation. Prerequisite: ELEN 115. Corequisite: ELEN 116L. (4 units)

### 116L. Analog Integrated Circuit Design Laboratory

Laboratory for ELEN 116. Corequisite: ELEN 116. (1 unit)

### 117. Advanced Analog Integrated Circuits

Design and analysis of BJT and MOSFET analog ICs. Study of analog circuits such as comparators, sample/hold amplifiers, and switched capacitor circuits. Architecture and design of analog to digital and digital to analog converters. Reference and biasing circuits. Study of noise and distortion in analog ICs. Prerequisite: ELEN 116. Corequisite: ELEN 117L. (4 units)

### 117L. Advanced Analog Integrated Circuits Laboratory

Laboratory for ELEN 117. Corequisite: ELEN 117. (1 unit)

### 118. Fundamentals of Computer-Aided Circuit Simulation

Introduction to algorithms and principles used in circuit simulation packages (such as SPICE). Formulation of equations for linear and nonlinear circuits. Detailed study of the three different types of circuit analysis (AC, DC, and transient). Discussion of computational aspects, including sparse matrices, Newton’s method, numerical integration, and parallel computing. Applications to electronic circuits, active filters, and CMOS digital circuits. Course includes a number of design projects in which simulation software is written in MATLAB and verified using SPICE. Prerequisites: ELEN 21, with a grade of C- or better; ELEN 100 and 115. Corequisite: ELEN 118L. (4 units)

### 118L. Fundamentals of Computer-Aided Circuit Simulation Laboratory

Laboratory for ELEN 118. Corequisite: ELEN 118. (1 unit)

### 119. Current Topics in Electrical and Computer Engineering

Subjects of current interest. May be taken more than once if topics differ. (4 units)

### 120. Microprocessor System Design

Design and analysis of microprocessor-based systems. ARM architecture and Assembly Language programming. Integration of digital and analog input/output devices. Interrupts and Timers, Bus timing analysis, ADC and DAC, Waveform synthesis, Serial communication, Displays. Embedded computing platforms. Prerequisites: A grade of C- or better in (COEN-21 or ELEN-21 and in COEN-11). Co-requisite: ELEN 120L. (4 units)

### 120L. Microprocessor System Design Laboratory

Laboratory for ELEN 120. Lab projects based on an embedded computer module to practical applications that reinforce class concepts and provide some opportunities for creative design. Prerequisites : A grade of C- or better in ELEN 21 and COEN 11. Co-requisite: ELEN 120

Co-requisite: ELEN 120. (1 unit)

### 121. Real-Time Embedded Systems

Computing systems that measure, control, and interact. Real-time principles (multitasking, scheduling, synchronization), interfacing sensors, actuators and peripherals, implementation trade-offs, development environments, embedded software (file systems, drivers, libraries, software re-use, concurrency), buffered communications, Real-time multimedia. Prerequisites: A grade of C- or better in ELEN-120. Co-requisite: ELEN 121L. (4 units)

### 121L. Real-Time Embedded Systems Laboratory

Laboratory for ELEN 121. Co-requisite: ELEN 121. (1 unit)

### 122. Computer Architecture

Application of logic design concepts to computer architecture. Computation state machines. Computer instruction definition and formatting, the use of opcodes and operands. Memory, and how it is used to store instructions and data. Instruction execution, control transfer. Application of critical path concepts and pipelining. Hazards. Caches. Hardware support for virtual memory. Prerequisites: A grade of C- or better in either COEN or ELEN 21. Co-requisite: ELEN 122L. (4 units)

### 122L. Computer Architecture Laboratory

Laboratory for ELEN 122. Co-requisite: ELEN 122. (1 unit)

### 123. Mechatronics

Introduction to behavior, design, and integration of electromechanical components and systems. Review of appropriate electronic components/circuitry, mechanism configurations, and programming constructs. Use and integration of sensors, microcontrollers, and actuators. Also listed as COEN 123 and MECH 143. Prerequisite: ELEN 50 with a grade of C- or better and COEN 11 or 44. Corequisite: ELEN 123L. (4 units)

### 123L. Mechatronics Laboratory

Laboratory for ELEN 123. Also listed as COEN 123L and MECH 143L. Corequisite: ELEN 123. (1 unit)

### 127. Advanced Logic Design

Contemporary design of finite-state machines as system controllers using FPGA devices. Minimization techniques, performance analysis, and modular system design. HDL simulation and synthesis. Also listed as COEN 127. Prerequisite: ELEN 21 with a grade of C- or better. Corequisites: ELEN 127L. (4 units)

### 127L. Advanced Logic Design Laboratory

Laboratory for ELEN 127. Design, construction, and testing of controllers from verbal specs. Use of CAD design tools. Also listed as COEN 127L. Corequisite: ELEN 127. (1 unit)

### 130. Control Systems

Applications of control systems in engineering. Principle of feedback. Performance specifications: transient and steady-state response. Stability. Design of control systems by frequency and root locus methods. Computer-controlled systems. State-variable feedback design. Problem sessions. Prerequisite: ELEN 110. Corequisite: ELEN 130L. (4 units)

### 130L. Control Systems Laboratory

Laboratory for ELEN 130. Corequisite: ELEN 130. (1 unit)

### 131. Introduction to Robotics

Overview of robotics: control, artificial intelligence, and computer vision. Components and structure of robots. Kinematics and dynamics of robot manipulators. Servo-control design, PID control. Trajectory planning, obstacle avoidance. Sensing and vision. Robot intelligence and task planning. Prerequisite: ELEN 110. Corequisite: ELEN 131L. (4 units)

### 131L. Introduction to Robotics Laboratory

Laboratory for ELEN 131. Corequisite: ELEN 131. (1 unit)

### 133. Digital Signal Processing

Discrete signals and systems. Difference equations. Convolution summation. Z-transform, transfer function, system response, stability. Digital filter design and implementation. Frequency domain analysis. Discrete Fourier transform and FFT. Audio, video, and communication applications. Prerequisites: ELEN 110 or both ELEN 50 with a grade of C- or better, and COEN 19. Corequisite: ELEN 133L. (4 units)

### 133L. Digital Signal Processing Laboratory

Laboratory for ELEN 133. Laboratory for real-time processing. Corequisite: ELEN 133. (1 unit)

### 134. Applications of Signal Processing

Current applications of signal processing. Topics may vary. Example topics include Speech Coding, Speech Recognition, and Biometrics. Prerequisite: ELEN 133, MATLAB. Corequisite: ELEN 134L. (4 units)

### 134L. Applications of Signal Processing Laboratory

Laboratory for ELEN 134. Corequisite: ELEN 134. (1 unit)

### 139. Special Topics in Signals and Systems

Subjects of current interest. May be taken more than once if topics differ. (4 units)

### 141. Communication Systems

Modulation and demodulation of analog and digital signals. Baseband to passband conversion. Random processes, Signal-to-noise ratios and Bandwidth Considerations Prerequisites: ELEN 110 and AMTH 108. Corequisite: ELEN 141L. (4 units)

### 141L. Communication Systems Laboratory

Laboratory for ELEN 141. Corequisite: ELEN 141. (1 unit)

### 142. Communications and Networking

Networking in different media. Effects of the media on data rate. Error detection and correction. Routing algorithms. Collision and retransmission in networks. Prerequisite: AMTH 108 with a grade of C- or better; or its equivalent. Co-requisite: ELEN 142L. (4 units)

### 142L. Communications and Networking Laboratory

Laboratory for ELEN 142. Corequisite: ELEN 142. (1 unit)

### 144. Microwave Circuit Analysis and Design

The fundamental characteristics of passive and active electrical components. Parasitics, models, and measurements. Modeling of circuit interconnects . Study of crosstalk in high-speed digital circuits, matching circuits, power dividers and microwave filters. Prerequisite: ELEN 105. Corequisite: ELEN 144L. (4 units)

### 144L. Microwave Circuit Analysis and Design Laboratory

Laboratory for ELEN 144. Corequisite: ELEN 144. (1 unit)

### 151. Device Electronics for IC Design

Properties of materials, crystal structure, and band structure of solids. Carrier statistics and transport; p-n junction electrostatics, I-V characteristics, equivalent circuits. Metal-semiconductor contacts, Schottky diodes. MOS field-effect transistors, bipolar junction transistors. This course covers the essential device concepts necessary for analog, digital, and/or mixed signal circuit design. Credit not allowed for both ELEN 151 and ELEN 267. Prerequisite or corequisite: ELEN 104. Corequisite: ELEN 151L. (4 units)

### 151L. Device Electronics Laboratory

Laboratory for ELEN 151. Corequisite: ELEN 151. (1 unit)

### 152. Semiconductor Devices and Technology

Continuation of MOS field-effect transistors, bipolar junction transistors, heterojunctions. Principles of silicon IC fabrication processes. Bulk and epitaxial crystal growth, thermal oxidation, diffusion, ion implantation. Process simulation for basic devices. Prerequisite: ELEN 151. Corequisite: ELEN 152L. Cross-listed as ELEN 276. (4 units)

### 152L. Semiconductor Devices and Technology Laboratory

Laboratory for ELEN 152. Corequisite: ELEN 152. (1 unit)

### 153. Digital Integrated Circuit Design

Introduction to VLSI design and methodology. Study of basic principles, material properties, fabrication, operation, terminal characteristics, and equivalent circuit models for CMOS digital integrated circuits. Study of CMOS combinational and sequential integrated circuits and technology scaling. Physical design and layout principles. Interconnect modeling. Semiconductor memories. Use of state-of-the-art CAD tools. Prerequisites: ELEN/COEN 21 and ELEN 50 with a grade of C- or better. Corequisite: ELEN 153L. (4 units)

### 153L. Digital Integrated Circuit Design Laboratory

Laboratory for ELEN 153. Corequisite: ELEN 153. (1 unit)

### 156. Introduction to Nanotechnology

Introduction to the field of nanoscience and nanotechnology. Properties of nanomaterials and devices. Nanoelectronics: from silicon and beyond. Measurements of nanosystems. Applications and implications. Laboratory experience is an integral part of the course. Also listed as MECH 156. Prerequisites: PHYS 33 and either PHYS 34 or MECH 15. Corequisite: ELEN 156L. (4 units)

### 156L. Introduction to Nanotechnology Laboratory

Laboratory for ELEN 156. Also listed as MECH 156L. Corequisite: ELEN 156. (1 unit)

### 160. Chaos Theory, Metamathematics, and the Limits of Science: An Engineering Perspective on Religion

Limitations of science are examined in the framework of nonlinear system theory and metamathematics. Strange attractors, bifurcations, and chaos are studied in some detail. Additional topics include an introduction to formal systems and an overview of Godel’s theorems. The mathematical background developed in the course is used as a basis for exploring the relationship between science, aesthetics, and religion. Particular emphasis is placed on the rationality of faith. Also listed as ELEN 217. Prerequisites: AMTH 106 (or an equivalent course in differential equations), and a basic familiarity with MATLAB. Corequisite: ELEN 160L. (4 units)

### 160L. Chaos Theory, Metamathematics, and the Limits of Knowledge: A Scientific Perspective on Religion Laboratory

Laboratory for ELEN 160. Corequisite: ELEN 160. (1 unit)

### 161. Information, Quantum Computing, and Complexity: The Beauty of Nature and the Nature of Beauty

Beauty is examined from an interdisciplinary perspective, taking into account insights from mathematics, physics, engineering, neuroscience, and psychology, as well as philosophy, art history, and theology. Technical topics include information theory, quantum computing, fractal geometry, complex systems, cellular automata, Boolean networks, and set theory. Prerequisite: AMTH 106 (or equivalent). Familiarity with basic concepts in probability theory is expected, as is some experience with MATLAB. Corequisite: ELEN 161L. (4 units)

### 161L. Information, Quantum Computing, and Complexity: The Beauty of Nature and the Nature of Beauty Laboratory

Laboratory for ELEN 161. Corequisite: ELEN 161. (1 unit)

### 164. Introduction to Power Electronics

Power and efficiency computations, rectifiers, power devices, DC-to-DC converters, AC-to-DC converters, and DC-to-AC inverters. Prerequisite: ELEN 115. Corequisite: ELEN 164L. (4 units)

### 164L. Introduction to Power Electronics Laboratory

Laboratory for ELEN 164. Corequisite: ELEN 164. (1 unit)

### 167. Medical Imaging Systems

Overview of medical imaging systems including sensors and electrical interfaces for data acquisition; mathematical models of the relationship of structural and physiological information to sensor measurements, resolution, and accuracy limits; conversion process from electronic signals to image synthesis. Analysis of the specification and interaction of the functional units of imaging systems and the expected performance. Focus on MRI, CT, and ultrasound. Also listed as BIOE 167, BIOE 267. Prerequisite: BIOE 162 or ELEN 110 or MECH 142. (4 units)

### 180. Introduction to Information Storage

Storage hierarchy. Design of memory and storage devices, with a particular emphasis on magnetic disks and storage-class memories. Error detection, correction, and avoidance fundamentals. Disk arrays. Storage interfaces and buses. Network attached and distributed storage, interaction of economy, and technological innovation. Also listed as COEN 180. Prerequisites: ELEN 21 or COEN 21, and COEN 20; COEN 122 is recommended. (4 units)

### 182. Energy Systems Design

Introduction to alternative energy systems with emphasis on those utilizing solar technologies; system analysis including resources, extraction, conversion, efficiency, and end-use; project will design power system for a house off or on grid making best use of renewable energy; system design will include power needs, generation options, storage, back-up power. Prerequisite: ELEN 50. (4 units)

### 183. Power Systems Analysis

Analysis, design, and optimization of power systems for traditional and renewable power generation. Balanced three phase circuits. Transformers and transmission lines. Prerequisite: ELEN 100 or PHYS 12. Corequisite: ELEN 183L. (4 units)

### 183L. Power Systems Analysis Laboratory

Laboratory for ELEN 183. Corequisite: ELEN 183. (1 unit)

### 184. Power System Stability and Control

Examine power system stability and power system control, including load frequency control, economic dispatch, and optimal power flow. Also listed as ELEN 231. Prerequisites: ELEN 183 or equivalent. (4 units)

### 188. Co-op Education

Practical experience in a planned program designed to give students practical work experience related to their academic field of study and career objectives. Satisfactory completion of the assignment includes preparation of a summary report on co-op activities. P/NP grading. May be taken twice. May not be taken for graduate credit. (2 units)

### 189. Co-op Technical Report

Credit given for a technical report on a specific activity such as a design or research project, etc., after completing the co-op assignment. Letter grades based on content and presentation quality of report. May be taken twice. May not be taken for graduate credit. Prerequisite: ELEN 188. Approval of department co-op advisor required. (2 units)

### 192. Introduction to Senior Design Project

Junior preparation for senior project. An introduction to project requirements and participation in the coordination of the senior conference. Tentative project selection. (2 units)

### 194. Design Project I

Specification of an engineering project, selected with the mutual agreement of the student and the project advisor. Complete initial design with sufficient detail of target specification. Incorporation of relevant engineering standards and appropriate realistic constraints. Initial draft of the project report. Corequisite: ENGL 181. (2 units)

### 195. Design Project II

Implementation, construction, and testing of the project, system, or device. Sustainability analysis. Demonstration of project and formal design review. Prerequisite: ELEN 194. (2 units)

### 196. Design Project III

Continued design, implementation, and testing of the project, system, or device to improve function and add capability. Reliability analysis. Formal public presentation of results. Final report. Prerequisite: ELEN 195. (1 unit)

### 199. Directed Research/Reading

Investigation of an approved engineering problem and preparation of a suitable project report. Open to electrical and computer engineering majors only. (1–6 units)