ELECTRICAL ENGINEERING

Degree Types: MS, PhD

The Electrical Engineering (EE) (https://www.mccormick.northwestern.edu/electrical-computer/graduate/) division in the Department of Electrical and Computer Engineering (https://mccormick.northwestern.edu/electrical-computer/) offers programs leading to the MS and PhD degrees in EE. Areas of study include Solid-State, Photonic, and Quantum Technologies (design, analysis, and proof-of-concept development of solid-state and photonic devices and systems) and Signals and Systems (communication networks, signal processing, and control). When applying to the PhD or MS program (https://www.mccormick.northwestern.edu/electrical-computer/graduate/), students should specify EE as the division which will represent their major field of study.

EE faculty also participate in other graduate programs on campus. For details and contact information, see the respective web sites for each program:

- Master of Science in Information Technology (https://www.mccormick.northwestern.edu/information-technology/)
- Master of Science in Robotics (https://www.mccormick.northwestern.edu/robotics/)

Additional resources:

- Department website (https://mccormick.northwestern.edu/electrical-computer/)
- Program handbook(s)

Degrees Offered

- Electrical Engineering BS/MS (https://catalogs.northwestern.edu/tgs/electrical-engineering/electrical-engineering-bach-mast/)
- Electrical Engineering MS (https://catalogs.northwestern.edu/tgs/electrical-engineering/electrical-engineering-ms/)
- Electrical Engineering PhD (https://catalogs.northwestern.edu/tgs/electrical-engineering/electrical-engineering-phd/)

Electrical Engineering: MS

Learning objective(s)/Students should be able to…

- demonstrate mastery of one or more areas of electrical engineering through success in advanced coursework, and
- demonstrate an ability to work independently on projects or original research related to electrical engineering.

Electrical Engineering: PHD

Learning objective(s)/Students should be able to…

- demonstrate broad knowledge of electrical engineering and related areas, including how the current state of the art is being advanced, and
- complete a significant body of original research in electrical engineering, including publishing work in peer-reviewed journals, presenting work at conferences, and producing a dissertation which demonstrates how the student has advanced the field and become a leading researcher in the chosen area.

Electrical Engineering Courses

ELEC_ENG 302-0 Probabilistic Systems (1 Unit)
Introduction to probability theory and its applications. Axioms of probability, distributions, discrete and continuous random variables, conditional and joint distributions, correlation, limit laws, connection to statistics, and applications in engineering systems. May not receive credit for both ELEC_ENG 302-0 and any of the following: IEMS 202-0; MATH 310-1; STAT 320-1; ELEC_ENG 383-0, ELEC_ENG 385-0.
Corequisite: MATH 228-2 or equivalent.

ELEC_ENG 307-0 Communications Systems (1 Unit)
Analysis of analog and digital communications systems, including modulation, transmission, and demodulation of AM, FM, and TV systems. Design issues, channel distortion and loss, bandwidth limitations, additive noise.
Prerequisites: ELEC_ENG 222-0, ELEC_ENG 302-0 or equivalent.

ELEC_ENG 308-0 Applied Electromagnetics and Photonics (1 Unit)
Electromagnetic wave behavior and design of metallic, dielectric, and optical waveguides and antennas and antenna arrays. Electromagnetic wave fundamentals of wireless communications systems and radar techniques.
Prerequisite: ELEC_ENG 224-0.

ELEC_ENG 326-0 Electronic System Design I (1 Unit)
This fast-paced course will teach a student how to go from a project idea to a fully functional prototype implementation. This involves a printed circuit design using PCB CAD software, surface mount soldering, MCU programming, CAD design for 3D printing, and web design. This course has been approved as an Electrical Engineering Technical Elective to be included in the 2020-2021 Catalog. Current electrical engineering students can petition to use it as a technical elective.
Prerequisite: Students must have completed (ELEC_ENG 225-0 and COMP_SCI 211-0), or MECH_ENG 333-0, or graduate standing, or instructor consent.

ELEC_ENG 327-0 Electronic System Design II: Project (1 Unit)
This course puts to practice the knowledge gained in Electronic System Design I, and have students create a fully functional prototype implementation. This involves the same principles as in Electronic System Design I, but more independently, and with some design optimization. The course will also focus on team management and presentation skills, culminating in a project fair to the public. For a student with senior standing, this course can count towards the Design Degree Requirement in EE.
Prerequisite: ELEC_ENG 326-0 or instructor consent.

ELEC_ENG 331-0 Introduction to Computational Photography (1 Unit)
Fundamentals of digital imaging and modern camera architectures. Hands-on experience acquiring, characterizing, and manipulating data captured using a modern camera platform.
Prerequisite: COMP_SCI 150 or COMP_SCI 211 or Consent of Instructor.

ELEC_ENG 332-0 Introduction to Computer Vision (1 Unit)
Computer and biological vision systems, image formation, edge detection, image segmentation, texture, representation and analysis of two-dimensional geometric structures and of three-dimensional structures.
Prerequisites: COMP_SCI 212-0 or ELEC_ENG 302-0 or equivalent or graduate standing.

ELEC_ENG 333-0 Introduction to Communication Networks (1 Unit)
Data communication basics. Telephone, cellular, cable, and computer networks. Layered network architectures, models, and protocols. Switching, routing, flow control, and congestion control. Medium access

control, ARQ, and local area networks. Queuing models and network performance analysis.
Prerequisite: ELEC_ENG 302-0 or equivalent.

ELEC_ENG 334-0 Fundamentals of Blockchains and Decentralization (1 Unit)
This course is partly an introduction to the fundamentals of blockchains and decentralized applications and partly a springboard toward deeper understanding and further exploration. The course explains how blockchains work; teaches the underlying fundamentals of distributed consensus; provides hands-on experience through computer assignments; and also touches upon economic and policy issues.
Prerequisites: COMP_SCI 212-0 or ELEC_ENG 302-0 or equivalent or graduate standing and basic programming skills.

ELEC_ENG 353-0 Digital Microelectronics (1 Unit)
Logic families, comparators, A/D and D/A converters, combinational systems, sequential systems, solid-state memory, largescale integrated circuits, and design of electronic systems.
Prerequisites: COMP_ENG 203-0, ELEC_ENG 225-0.

ELEC_ENG 359-0 Digital Signal Processing (1 Unit)
Discrete-time signals and systems. Discrete-time Fourier transform, z-transform, discrete Fourier transform, digital filters.
Prerequisite: ELEC_ENG 222-0.

ELEC_ENG 360-0 Introduction to Feedback Systems (1 Unit)
Linear feedback control systems, their physical behavior, dynamical analysis, and stability. Laplace transform, frequency spectrum, and root locus methods. System design and compensation using PID and lead-lag controllers. Digital implementations of analog controllers.
Prerequisite: ELEC_ENG 222-0 or MECH_ENG 390-0 or BMD_ENG 309-0 or equivalent.

ELEC_ENG 363-0 Digital Filtering (1 Unit)
Recursive and nonrecursive digital filters, decimation and interpolation, A/D and D/A conversion as digital filtering problems. Implementation of nonrecursive filters via FFT, quantization problems (e.g., companding and limit cycles).
Prerequisite: ELEC_ENG 359-0.

ELEC_ENG 372-1 Robot Design Studio (1 Unit)
In this course, teams of students will design and build robots. For instance, teams may build robots inspired by the Summer Olympics: a robot that can perform on the uneven bars, that can skate a half-pipe, or or that can do flips on a BMX bike. The ultimate goal is to build a robust, elegant machine capable of performing exciting dynamic feats. Along the way, students will refine skills in mechatronics, electromechanical design, real-time programming, sensor selection and integration, motor/transmission design, and feedback control.
Prerequisite: Consent of Instructor.

ELEC_ENG 372-2 Robot Design Studio (1 Unit)
In this course, teams of students will design and build robots. For instance, teams may build robots inspired by the Summer Olympics: a robot that can perform on the uneven bars, that can skate a half-pipe, or that can do flips on a BMX bike. The ultimate goal is to build a robust, elegant machine capable of performing exciting dynamic feats. Along the way, students will refine skills in mechatronics, electromechanical design, real-time programming, sensor selection and integration, motor/transmission design, and feedback control.
Prerequisite: ELEC_ENG 372-1.

ELEC_ENG 374-0 Introduction to Digital Control (1 Unit)
Discrete dynamics systems; discrete models of continuous systems feedback and digital controllers; analog-digital conversion; digital control design including PID, lead/lag, deadbeat, and mode-lmatching controllers.
Prerequisite: ELEC_ENG 360-0.

ELEC_ENG 378-0 Digital Communications (1 Unit)
Sampling and time-division multiplexing, baseband digital signals and systems. Coded pulse modulation, error control coding, digital modulation systems, information measure and source encoding, and introduction to spread spectrum communications.
Prerequisite: ELEC_ENG 302-0 or equivalent.

ELEC_ENG 379-0 Lasers and Coherent Optics (1 Unit)
Optical resonators; fundamental operation of lasers; mode-locking and Q-switching; optical propagation and diffraction; Gaussian beams; thin-lens imaging; optical signal processing.

ELEC_ENG 380-0 Wireless Communications (1 Unit)
Overview of existing and emerging wireless communications systems; interference, blocking, and spectral efficiency; radio propagation and fading models; performance of digital modulation in the presence of fading; diversity techniques; code-division multiple access.
Prerequisite: ELEC_ENG 378-0.

ELEC_ENG 381-0 Electronic Properties of Materials (1 Unit)
Fundamental properties of electrons in materials. Classical and quantum mechanical descriptions of free and bound electrons. Optical, electrical, thermal, and magnetic properties of materials. Microelectronic, optoelectronic, magnetic recording, superconductivity.
Prerequisite: ELEC_ENG 223-0 or consent of instructor.

ELEC_ENG 382-0 Photonic Information Processing (1 Unit)
Introduction to photonic information processing; coherent and incoherent light; electro-optic and acousto-optic modulation; optical signal processing; holography; optical storage.
Prerequisites: ELEC_ENG 222-0 and ELEC_ENG 224-0 or consent of instructor.

ELEC_ENG 383-0 Fiber-Optic Communications (1 Unit)
Semiconductor diode lasers, internal modulation, electro-optic modulation, coherent and incoherent detection, optical fibers and their properties, optical amplifiers, communication systems, optical networks.
Prerequisites: ELEC_ENG 223-0, ELEC_ENG 224-0.

ELEC_ENG 384-0 Solid State Electronic Devices (1 Unit)
Energy-band model for semiconductors; carrier statistics and transport; diodes, bipolar and field-effect transistors; integrated circuits, optoelectronic and heterojunction devices.
Prerequisite: ELEC_ENG 381-0 or consent of instructor.

ELEC_ENG 385-0 Optoelectronics (1 Unit)
Introduction to solid-state optoelectronic devices; display devices, laser diodes, photodetectors, and light modulators; optical waveguides and fibers; system application of optoelectronic devices.
Prerequisite: ELEC_ENG 381-0 or consent of instructor.

ELEC_ENG 387-0 Advanced Digital Systems Design with FPGAs (1 Unit)
This course covers the systematic design of advanced digital systems using field programmable gate arrays (FPGAs). The course presents a top-down design methodology, where students learn how to translate software applications in high-level level languages (such as C/C++) into SystemVerilog models to run on FPGAs. The course focuses on designing real-time high-performance computing applications using industry-standard methodologies, with an emphasis on simulation-based verification and debugging.

ELEC_ENG 388-0 Nanotechnology (1 Unit)
Physics and fabrication of photonic and electronic devices. Physics of semiconductors: crystal structures, reciprocal lattice, elements of quantum mechanics, heterojunctions, quantum wells, and super-lattices. Bulk crystal, thin-film, and epitaxial growth technologies. Device

processing technologies: diffusion oxidation, ion implantation, annealing, etching, and photolithography.
Prerequisite: ELEC_ENG 223-0 or consent of instructor.

ELEC_ENG 389-0 Superconductivity and Its Applications (1 Unit)
Properties of materials in the superconducting state; charge flow dynamics of type II superconductors; highTc superconductors; applications for computers and high-frequency devices.
Prerequisite: ELEC_ENG 381-0 or consent of instructor.

ELEC_ENG 390-0 Introduction to Robotics (1 Unit)
Homogeneous vectors and planes; homogeneous transformation, position and orientation transformations, kinematics and inverse kinematic solutions of robot manipulators; Jacobian and inverse Jacobian relation; robot trajectory and task planning; dynamic formulation and computation of robot manipulators; robot programming and control systems.
Prerequisite: COMP_SCI 230-0.

ELEC_ENG 395-0 Special Topics in Electrical Engineering (1 Unit)
Topics suggested by students or faculty and approved by the department.

ELEC_ENG 401-0 Fundamentals of Electronic Devices (1 Unit)
Transport phenomena in semiconductors, theory of the p-n junction, biopolar and unipolar devices, general analysis of the metal-semiconductor and MIS structures, CCD, and MOSFET and biopolar transistors.
Prerequisite: ELEC_ENG 381-0 or ELEC_ENG 388-0.

ELEC_ENG 402-0 Advanced Electronic Devices (1 Unit)
Semiconductor optics, heterojunctions, quantum wells, superlattices, and resonant funneling. Field-effect and potential-effect devices. Hot-electron devices. Microwave devices.
Prerequisite: ELEC_ENG 381-0 or ELEC_ENG 384-0.

ELEC_ENG 403-0 Quantum Semiconductors (1 Unit)
Elements of wave mechanics necessary to explain band theory. Fermi-Dirac statistics, introduction to the theory of electrical conductivity in semiconductors, optical and thermal properties, diffusion of electrons, and holes in solids.
Prerequisite: ELEC_ENG 381-0.

ELEC_ENG 404-0 Quantum Electronics (1 Unit)
Review of quantum mechanics. Harmonic oscillator. Perturbation theory. Phonons and photons. Interaction of radiation and atomic systems. Einstein coefficients. Laser oscillation. Laser photon statistics.

ELEC_ENG 405-0 Advanced Photonics (1 Unit)
Physical description of compound semiconductors; optical properties of heterostructures, quantum wells, superlattices, quantum wires and quantum dots; physics and technology of optoelectronic devices; light emitting diodes (LEDs) and lasers.
Prerequisite: ELEC_ENG 381-0 or ELEC_ENG 401-0.

ELEC_ENG 406-0 Nonlinear Optics (1 Unit)
Nonlinear optical susceptibilities; wave propagation and coupling in nonlinear media; harmonic, sum, and difference frequency generation; parametric amplification and oscillation; phase-conjugation via four-wave mixing; self-phase modulation and solitons.
Prerequisites: ELEC_ENG 382-0 and ELEC_ENG 404-0 or permission of instructor.

ELEC_ENG 407-0 Quantum Optics (1 Unit)
Review of quantum fields; quantization of the electromagnetic field; photodetection theory; direct, homodyne, and heterodyne detection; squeezed and photon-number state generation; application to optical communication and interferometers.
Prerequisites: ELEC_ENG 404-0 and ELEC_ENG 406-0 or permission of instructor.

ELEC_ENG 408-1 Classical Electodynamics (1 Unit)
Introduction to classical analytical techniques for static and dynamic electromagnetic fields. Static electric field and scalar potential; multipole expansions of the scalar potential; magnetostatics and the vector potential; time-varying fields; Maxwell's equations; Coulomb and Lorentz gauge; Green's functions for the wave equation; use of the causal Green's function for electromagnetic radiation; multipole expansions of the radiating field; application to simple antennas.
Prerequisite: ELEC_ENG 308-0.

ELEC_ENG 408-2 Computational Electrodynamics (1 Unit)
Advanced topics in the finite-difference time-domain (FDTD) method for numerical modeling of electromagnetic wave interactions with engineering structures. Reduced-numerical-dispersion algorithms employing fourth-order spatial differencing; uniaxial perfectly matched layer absorbing boundary conditions; generalized grids; incorporation of lumped-circuit elements.

ELEC_ENG 409-0 Semiconductor Lasers (1 Unit)
Basic concepts of lasers; laser applications; gas and liquid lasers; solid-state lasers; semiconductor lasers; materials and devices; rate equations; laser gain and saturation; modulation and light pulse generation; advanced technology for semiconductor laser fabrication and integration; industrial and medical applications of laser diodes.
Prerequisite: ELEC_ENG 403-0 or ELEC_ENG 405-0.

ELEC_ENG 410-0 System Theory (1 Unit)
Unified treatment of continuous and discrete time systems from a state-variable viewpoint; emphasis on linear systems. Concept of state, writing and solving state equations, controllability and observability, transform techniques (Fourier, Laplace, Z), stability, and Lyapunov's method.
Prerequisite: ELEC_ENG 360-0.

ELEC_ENG 411-0 Fundamentals and Applications of Special Relativity (1 Unit)
This course will introduce students to Special Relativity (SR), illustrate the relation between SR and Maxwell's Equations, and explain the origin of magnetic fields and forces. In addition, it will describe quantitatively the role of SR in modern optical devices and systems such as Sagnac interferometers, gyroscopes, free electron lasers, clocks and the global positioning system. The origin of electron spin and the Pauli exclusion principle based on SR will also be discussed.

ELEC_ENG 413-0 Managing People and Workforce Diversity in Energy & Sustainability (0.5 Unit)
This course is built off of a highly successful Kellogg course: Leading & Managing Diverse Organizations. The aim is to develop the cross#cultural competence you need to lead effectively in the modern collaboration# powered global marketplace - one that is more diverse than ever before on multiple dimensions. This course is designed to provide i) evidence# based insights on how to lead ii) individual, interpersonal, enterprise# level strategies to successfully optimize the value of diversity and inclusion in teams and organizations iii) industry specific perspectives for teams in energy & sustainability and guidelines on how to navigate challenges and opportunities specific to these markets.

ELEC_ENG 414-0 Advanced Topics in Quantum Electronics (1 Unit)
Study of advanced topics of current interest in the field of quantum electronics, with an emphasis on atom-laser interaction. Selected topics from the following areas will be covered, with an emphasis on practical applications: Review of Atomic Transitions, Semi-Classical Atom-Laser Interaction, Quantized Radiation Field, Cavity Quantum

Electrodynamics, Fundamental Formalisms in Quantum Noise, Quantum Theory of Spontaneous Emission, and Quantum Theory of Laser.

ELEC_ENG 418-0 Advanced Digital Signal Processing (1 Unit)
Selected topics in digital signal processing such as digital speech processing, multidimensional digital signal processing, spectrum estimation, and error analysis.
Prerequisite: ELEC_ENG 359-0.

ELEC_ENG 420-0 Digital Image Processing (1 Unit)
Fundamentals of image processing. Image compression, enhancement, and restoration. Image reconstruction from projections and partial information.
Prerequisite: ELEC_ENG 359-0 or equivalent.

ELEC_ENG 421-0 Multimedia Signal Processing (1 Unit)
Fundamentals of applying digital signal processing to speech signals. Topics include models of speech production and hearing and analysis/synthesis methods and applications.
Prerequisite: ELEC_ENG 359-0.

ELEC_ENG 422-0 Random Processes in Communications and Control 1 (1 Unit)
Fundamentals of random variables; mean-squared estimation; limit theorems and convergence; definition of random processes; autocorrelation and stationarity; Gaussian and Poisson processes; Markov chains.
Prerequisite: One course in probability.

ELEC_ENG 423-0 Random Processes in Communications and Control 2 (1 Unit)
Advanced topics in random processes: point processes, Wiener processes; Markov processes, spectral representation, series expansion of random processes, linear filtering, Wiener and Kalman filters, optimum receivers, and matched filters.
Prerequisite: ELEC_ENG 422-0.

ELEC_ENG 424-0 Distributed Optimization (1 Unit)
This course studies various models and algorithms in the distributed and parallel settings. Topics include graph theory, algorithms for solving linear equations, iterative methods for convex problems, synchronous and asynchronous setups, consensus algorithms and rate analysis.

ELEC_ENG 425-0 Introduction to Nanoscale Lasers, Quantum Noise, Photons, and Measurement (1 Unit)
Introduction to semiclassical theory of lasers leading to coherent, noise, and modulation properties of lasers, with emphasis on semiconductor lasers. Includes topics on noise in optical amplifiers and effects of optical feedback on lasers. Quantum theory of lasers is introduced, leading to topics on quantum states of laser light.
Prerequisite: ELEC_ENG 404-0 or permission of instructor.

ELEC_ENG 426-0 Signal Detection and Estimation (1 Unit)
Simple-hypothesis detection problems, detection of signals with unknown parameters, Bays' maximum likelihood estimation, estimation of signal parameters, detection of stochastic signals, nonparametric detection and estimation.
Prerequisites: ELEC_ENG 307-0 and ELEC_ENG 422-0.

ELEC_ENG 427-0 Optical Communications (1 Unit)
Optical communication systems, optical wave propagation, photodetection statistics, heterodyne receiver, and noise sources. Evaluation of communication performance for the free-space channel. Introduction to fiber optic communication and fiber optic networks.
Prerequisites: ELEC_ENG 307-0 and probability.

ELEC_ENG 428-0 Information Theory and Learning (1 Unit)
This course gives students analytical tools to quantify information, perform inference, and study the relationship of information and learning. The course covers information measures, the source and the channel coding theorems, statistical inference, and learning with neural networks. In particular, the course explores a common set of models and tools used by both machine learning and state-of-the-art data compression and error-control codes. This course is aimed at students in engineering, science, mathematics, and computing. It expects familiarity with undergraduate-level calculus, probability theory, and linear algebra.
Perquisite: Students must have graduate standing to register for this course.

ELEC_ENG 429-0 Selected Topics in Quantum Information Science and Technology (1 Unit)
Basic general principles of quantum mechanics for applications to quantum information science andtechnology. The fundamentals will be covered, together with topics of current interest among the areas of quantum teleportation, quantum computation,and quantum cryptography.
Prerequisites: Knowledge of quantum mechanics and permission of instructor.

ELEC_ENG 431-0 Human Perception and Electronic Media (1 Unit)
Fundamentals of visual, acoustic, and tactile perception; display devices; perceptual models for image, video, acoustic, and tactile signal analysis, compression, quality evaluation, and understanding; multimodal signal processing and perception; content-based retrieval; sense substitution.
Prerequisites: ELEC_ENG 359-0 or equivalent.

ELEC_ENG 432-0 Advanced Computer Vision (1 Unit)

ELEC_ENG 433-0 Statistical Pattern Recognition (1 Unit)
Fundamental and advanced topics in statistical pattern recognition including Bayesian decision theory, Maximum-likelihood and Bayesian estimation, Nonparametric density estimation, Component Analysis and Discriminants, Kernel machines, Feature selection, dimension reduction and embedding, Boosting, Minimum description length, Mixture models and clustering, Spectral clustering, Bayesian network and Hidden Markov models, with the applications to image and video pattern recognition.

ELEC_ENG 435-0 Deep Learning: Foundations, Applications, and Algorithms (1 Unit)
The course covers the fundamentals of deep learning and numerical optimization, with many application examples.

ELEC_ENG 436-0 Game Theory and Networked Systems (1 Unit)
The strategic interactions among multiple agents is a fundamental feature of many networked systems. Examples include peering agreements among Internet Service Providers, licensing agreements for wireless spectrum, designing the right incentives for crowdsourcing platforms, competition among producers of electricity, engaging robotic groups to cooperate. Game theory is a basic tool for understanding such interactions. This course gives an interdisciplinary introduction to the fundamentals of game theory and it applications to such networked systems.

ELEC_ENG 454-0 Advanced Communication Networks (1 Unit)
Basic techniques for modeling and analyzing data communication networks. Protocol specification and correctness, queuing models, loss networks, multi-class queues and scheduling, graph-based and flow-based routing, congestion control and pricing.
Prerequisites: ELEC_ENG 302-0; ELEC_ENG 333-0 helpful but not required.

ELEC_ENG 463-0 Adaptive Filters (1 Unit)
Applications of adaptive filtering, autoregressive and moving average processes, linear prediction, Wiener filter, Least Mean Square (LMS)

algorithm, lattice filter, least squares filtering, Kalman filter, convergence analysis.

ELEC_ENG 470-0 Introduction to Nonlinear Control Theory (1 Unit)
This course is an introduction to the foundations of nonlinear control theory, with an emphasis on feedback stabilization. As needed, topics from differential geometry and other mathematical disciplines are introduced to support the development of basic concepts. The focus of the course is on mathematical tools for the analysis and design of nonlinear feedback systems, not the hardware and software technology required for their implementation.
Prerequisites: Prior or concurrent registration in ELEC_ENG 410 or equivalent; a previous course in linear feedback systems (such as ELEC_ENG 360) is desirable.

ELEC_ENG 473-0 Deep Reinforcement Learning (1 Unit)
Fundamentals of Deep Reinforcement Learning starting from its roots in dynamic programming and optimal control, and ending with some of the most popular applications in practice today; basic Q-Learning algorithm and its extensions; deep Q-Learning. Through exercises and a final course project students will gain significant hands-on experience coding up and testing reinforcement systems on a variety of interesting problems.
Prerequisites: ELEC_ENG 475-0 and ELEC_ENG 435-0.

ELEC_ENG 475-0 Machine Learning: Foundations, Applications, and Algorithms (1 Unit)
The course covers the fundamentals of machine learning and numerical optimization, with many application examples.

ELEC_ENG 478-0 Advanced Digital Communications (1 Unit)
Digital modulation, complex base band signaling, sequence estimation, the Viterbi algorithm, probability of error analysis, equalization, and code-division multiple access.
Prerequisites: ELEC_ENG 359-0, ELEC_ENG 378-0 and ELEC_ENG 422-0.

ELEC_ENG 495-0 Special Topics in Electrical Engineering (1 Unit)

ELEC_ENG 499-0 Projects (1 Unit)
Special projects carried out under faculty direction. Permission of instructor and department required.

ELEC_ENG 510 Seminar (1 Unit)
Seminar on topics of current interest.

ELEC_ENG 590-0 Research (1-4 Units)
Independent investigation of selected problems pertaining to thesis or dissertation. May be repeated for credit.