

# ELECTRICAL ENGINEERING

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## Overview

### Electrical Engineering Programs

Modern electrical engineering is a very broad and diverse field. Never before has electrical engineering been at the forefront of some many technologies and societal challenges. Today's electrical engineers work in aerospace, communications, quantum computing, space sciences, artificial intelligence, green energy, electromobility, and military and medical systems, to name just a few. Electrical engineering technologies range in size from microprocessors and tiny transistors to megawatt energy conversion systems.

### Mission Statement

We provide graduate programs and an ABET-accredited undergraduate program that are accessible to a diverse group of students—students of different economic and cultural backgrounds, full-time students, as well as those who have considerable work and family commitments outside their academic learning, and students with a wide variety of work experiences.

## Graduate Program

The Department of Electrical Engineering offers graduate programs with the following areas of emphasis: controls, communication, and signal processing; microelectronics and VLSI; electromagnetics and RF engineering; computer engineering and embedded systems design; and energy and power systems. The department offers graduate programs leading to the degrees of master of science in electrical engineering (<http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-engineering-design-computing/electrical-engineering/electrical-engineering-ms/>) and master of engineering (<http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-engineering-design-computing/electrical-engineering/electrical-engineering-meng/>). The department also offers a Modern Energy and Power Systems certificate (<http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-engineering-design-computing/electrical-engineering/modern-energy-power-systems-certificate/>) and an RF and Antenna certificate. (<http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-engineering-design-computing/electrical-engineering/rf-antenna-engineering-certificate/>) In addition, the multidisciplinary engineering and applied science doctor of philosophy (<http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-engineering-design-computing/engineering-applied-science-phd/>) degree is available through the Department of Electrical Engineering.

## Requirements for Admission

Additional admissions information, including links to the online application, is available on the college website.

The minimum requirements for “regular” admission to the master’s program are: BS in electrical engineering, or equivalent degree in math, physics or other engineering disciplines, from a reputable institution, with a GPA of at least 3.0, on a 4.0 scale. Satisfaction of minimum requirements does not guarantee admission: The grades obtained in the student’s area of concentration are important factors in the consideration, and so are possible multiple repetitions of fundamental courses. Students who do not meet the requirements for direct admission to the program may be admitted “conditionally”: that is, they may be required to take or repeat certain undergraduate courses before their admission to the program is official.

For those undergraduate students with degrees in science and non-electrical engineering wishing to pursue graduate study in the electrical engineering department, there is no restriction or constraint in being admitted into the master of science in electrical engineering graduate program.

Applicants must submit evidence of adequate preparation for graduate study by either

1. Documenting an earned bachelor’s degree with a GPA of 3.00 or higher from an institution accredited by a U.S. accreditation body, or an earned master’s degree with a GPA of 3.00 or higher or from an institution accredited by a U.S. accreditation body.
2. Or submitting official GRE scores (not required).

All applications must be submitted online (<https://graduateschool.ucdenver.edu/admissions/apply/>). Send all supporting application materials to the Graduate School at the following address:

### Mailing Address:

#### Office of Admissions

Campus Box 167  
P.O. Box 173364  
Denver, CO 80204

### Courier Address (UPS, FEDEX, etc.):

#### Office of Admissions

1201 Larimer Street, Suite 1005  
Denver, CO 80204

For admissions questions, contact [graduateadmissions@ucdenver.edu](mailto:graduateadmissions@ucdenver.edu) or 303-315-5969.

## International Applicants

More information for international applicants is available through the Office of International Admissions (<http://catalog.ucdenver.edu/cu-denver/graduate/international-admissions/>).

## Programs

- Electrical Engineering, MEng (<http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-engineering-design-computing/electrical-engineering/electrical-engineering-meng/>)
- Electrical Engineering, MS (<http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-engineering-design-computing/electrical-engineering/electrical-engineering-ms/>)
- Engineering and Applied Science, PhD (<http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-engineering-design-computing/electrical-engineering/engineering-applied-science-phd/>)

- Modern Energy and Power Systems Certificate (<http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-engineering-design-computing/electrical-engineering/modern-energy-power-systems-certificate/>)
- Quantum Information Technology Graduate Certificate (<http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-engineering-design-computing/electrical-engineering/quantum-information-technology-graduate-certificate/>)
- RF and Antenna Engineering Certificate (<http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-engineering-design-computing/electrical-engineering/rf-antenna-engineering-certificate/>)

## Faculty

### Professors

**Hamid Fardi**, PhD, University of Colorado Boulder

**Stephen Gedney**, PhD, University of Illinois at Urbana-Champaign

**Mark Golkowski**, PhD, Stanford University

**Fernando Mancilla-David**, PhD, University of Wisconsin at Madison

**Miloje Radenkovic**, PhD, University of Belgrade, Yugoslavia

**Jaedo Park**, PhD, The Pennsylvania State University

### Associate Professors

**Tim Chifong Lei**, PhD, University of Michigan

### Assistant Professors

**Vijay Harid**, PhD, Stanford University

**Nam Bui**, PhD, University of Colorado Boulder

### Senior Instructor:

**Lary Speakman**, BS, MBA, University of Colorado Denver

## Electrical Engineering (ELEC) Courses

**ELEC 5005 - IC Design (3 Credits)**

Explores digital integrated circuit design including MOS processing steps, physical operation, building blocks of digital circuits, advanced nMOS, pMOS and CMOS circuit design, silicon VLSI technology and circuit and chip level. Spice and lay-out Editor are used. The physical relationship between circuit design and actual silicon layout and structure and technology are emphasized. Prereq: Graduate standing or permission of instructor. Cross-listed with ELEC 4005. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Restriction: Restricted to students with graduate standing.

**ELEC 5025 - Device Electronics (3 Credits)**

A course relating performance and limitations of solid state devices to their structures and technology. For both advanced circuit and device engineers. Semiconductor physics and technology, pn-junction and MOS devices used in modern integrated circuits. Prereq: ELEC 3225 and senior standing. Cross-listed with ELEC 4025. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3225 Restriction: Senior standing

**ELEC 5033 - Advanced Electromagnetic Fields (3 Credits)**

A course focused on electromagnetic waves. Topics include: Poynting's power theorem, reflection and transmission of uniform plane waves in layered media, two-conductor transmission lines, rectangular wave guides, Smith Chart elements of radiation and antenna. Prereq: ELEC 3133 and permission of instructor for undergraduates. Cross-listed with ELEC 4133. Max Hours: 3 Credits.

Grading Basis: Letter Grade

**ELEC 5133 - Electromagnetic Radiation and Antenna (3 Credits)**

Solution of inhomogeneous wave equation. Radiation fields of elementary dipole, linear wire antenna, uniform and non-uniform linear arrays. Array synthesis. Farzone field patterns, directivity and beamwidth. Diffraction fields of aperture sources, horn antenna, conic surface reflector sources, lens antenna. Ray tracing methods. Transient-receive link. Selected Topics. Prereq: ELEC 4133, graduate standing and permission of instructor for undergraduates. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 4133 or ELEC 5033

**ELEC 5134 - Introduction to Microwave Circuit Design (3 Credits)**

This course provides the basic principles of microwave circuit design, including transmission line theory, network parameters, signal flow graphs, design of high frequency matching networks, filters, hybrids and couplers using waveguide elements, high frequency amplifier and mixer design. Prereq: ELEC 3133. Cross-listed with ELEC 4134. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3133 or graduate standing

**ELEC 5154 - Electric and Hybrid Vehicle Powertrains (3 Credits)**

Covers the fundamental components and operation of electric and hybrid vehicles' drivetrain. Topics include electric vehicle history, major vehicle components, fundamental vehicle dynamics, electric and hybrid drivetrain configurations, electric motors and drives, energy storage, and power electronics chargers. Cross-listed with ELEC 4154. Max hours: 3 Credits.

Grading Basis: Letter Grade

Typically Offered: Fall.

**ELEC 5164 - Electric Machines and Drives (3 Credits)**

Covers power electronics drives for rotating electric machinery. Topics include power electronics elements for drives, load characteristics, dynamic modeling of AC machines, fundamental control algorithms, simulation and practical commercial drives. Prereq: ELEC 3164. Cross-listed with ELEC 4164. Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

Typically Offered: Fall.

**ELEC 5170 - Electric Machines and Drives Laboratory (1 Credit)**

Offers hands-on experience on rotating electric machine drive simulations and commercial systems. Sessions include pulse-width modulation (PWM) inverter, induction, DC, and synchronous machine drives. Matlab/Simulink and a commercial inverter will be utilized. Prereq: ELEC 4164 or equivalent. Cross-listed with ELEC 4170. Max hours: 1 Credit.

Grading Basis: Letter Grade

**ELEC 5174 - Power Electronic Systems (3 Credits)**

Topics to be covered include: power electronics fundamentals and applications in power systems; uncontrolled, semi-controlled and fully controlled power semiconductors; converters design and control. Prereq: ELEC 3164 and graduate standing or permission of instructor. Cross-listed with ELEC 4174. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3164 or Graduate Standing

**ELEC 5184 - Power Systems Analysis (3 Credits)**

Topics to be covered include: complex power; per-unit quantities; modeling of generators, transformers and transmission lines; power flow problem; economic dispatch; faults and sequence networks; and an introduction to power system protection and dynamics. Prereq: ELEC 3164 and graduate standing or permission of instructor. Cross-listed with ELEC 4184. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3164 or Graduate Standing

**ELEC 5194 - Power Systems Operation and Control (3 Credits)**

This course introduces the student to various operational strategies the power industry uses today to operate the power system. Topics to be covered include: economic dispatch, unit commitment, optimal power flow (linear and nonlinear), transmission congestion, control areas, state estimation, and an introduction to power markets. Prereq: ELEC 4184 or ELEC 5184 or graduate standing. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 4184 or ELEC 5184 or graduate standing.

**ELEC 5210 - Optimization Methods in Engineering (3 Credits)**

Unconstrained optimization, gradient methods, conjugate direction methods, data fitting and function estimation. Applications in control, system identification and radar systems. Optimization over a convex set, LMS algorithms in adaptive systems, convergence properties. Nonlinear programming, Lagrange multipliers, projection algorithms, games and minimax theorem, application to H infinity control, communication and signal processing. Prereq: MATH 3191 and 3200/3195. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: MATH 3191 and (3200 or 3195)

**ELEC 5212 - Fundamentals of Reliability Engineering (3 Credits)**

Reliability Engineering is a critical part of systems engineering and sustainability design. There are four objectives of this course: 1) to introduce systems and controls in the design process, 2) to apply reliability fundamentals to civil, computer science, bio-engineering, mechanical, and electrical engineering projects and systems, 3) to employ and explore sustainability design in engineering projects, and 4) to prepare for the American Society of Quality Control (ASQC) test: the Certified Reliability Engineer Certification (CRE). Restriction: Graduate Standing. Cross-listed with ELEC 4212. Max hours: 3 Credits.

Grading Basis: Letter Grade

Restriction: Graduate level students.

Typically Offered: Summer.

**ELEC 5220 - Methods of Engineering Analysis (3 Credits)**

Real sequences and infinite series, convergence of the parameter estimates in self-tuning control. Uniform convergence and application to adaptive FIR filters. Improper integrals, application in filtering, prediction and communication. Analytic functions, Hardy spaces, maximum modulus theorem. Argument principle and Nyquist stability criteria. Calculus of residues, LQG problem. Conformal mappings, Nevelinna-Pick problem. Prereq: MATH 3191 and 3200/3195, graduate standing. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: (MATH 3191 and 3200) or MATH 3195 or Graduate Standing

**ELEC 5230 - Advanced Linear Systems (3 Credits)**

Mathematical description of both continuous and discrete-time systems; vector, normed and inner-product spaces; state-space, impulse response and transfer function descriptions; state-transition response matrices; eigenvalues and eigenfunctions; controllability; canonical form; state feedback; observers; realization theory. Prereq: MATH 3191, MATH 3200/3195 and permission of instructor. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: (MATH 3191 and 3200) or MATH 3195 or Graduate Standing

**ELEC 5248 - Digital Communication Systems (3 Credits)**

Introduces digital communication systems covering elements of information theory; mathematical representation of signals and systems; modulation and demodulation for the additive Gaussian noise channel; Performance analysis of various transmission formats; synchronization; coded waveforms; decoding algorithms; and other related topics. Prereq: ELEC 3316, 3817; recommended ELEC 4247. Cross-listed with ELEC 4248. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: (ELEC 3316 and 3817) OR Graduate Standing

**ELEC 5249 - Wireless networking (3 Credits)**

Fundamentals of wireless communication from a physical-layer perspective. Multipath signal propagation and fading channel models. Design of constellations to exploit time, frequency, and spatial diversity. Reliable communication and single-user capacity. Interference management, multiple-access protocols, and multi-user capacity. Cellular uplink and downlink. Multiple-antenna systems and architectures. Communications with Intelligent Reflecting Surfaces. mmWave and THz communications. Connections to modern standards. Prereq: Elec 3817 and Elec 3316. Cross-listed with ELEC 4249. Max hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3316 and ELEC 3817

**ELEC 5250 - Information Inference and Learning Algorithms (3 Credits)**

We indulge in a journey from the theory of information to the world of applications. We talk about what information means and provide the means to measure it. We then investigate various methods for extracting what matters from the available data. We bring in topics such as Bayesian data modeling, clustering algorithms, and neural networks to name a few. Prereq: ELEC 3817 or CSCI 4535 or MATH 3800. Cross-listed with ELEC 4250. Max hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3817 OR CSCI 4535 OR MATH 3800 OR Graduate Standing

**ELEC 5252 - Computer Communication Networks (3 Credits)**

Comprehensive study of issues arising in modern computer-communication networks, both wire-line and wireless, carrying traffics with heterogeneous characteristics. A conceptual and analytical approach to the design of network protocols in harmony with the appropriate modeling of the traffic and network environments. Issues covered include routing, transmission, performance monitoring, as well as and network management in ATM multi-media networks. Prereq: Graduate standing or permission of instructor. Max Hours: 3 Credits. Grading Basis: Letter Grade

**ELEC 5276 - Digital Control Systems (3 Credits)**

Analysis and design of discrete-time systems, as occurs when a digital computer is used to control physical systems. Topics include difference equations, Z-transform, sampled-data system modeling, sampling, discrete equivalents, stability, and discrete control design by root locus, direct design, frequency-response, and state space. Prereq: ELEC 3316, ELEC 3817, and graduate standing. Cross-listed with ELEC 4276. Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

Prereq: ELEC 4136 or Graduate Standing

**ELEC 5294 - Advanced Power Electronic Systems (3 Credits)**

The course focuses on the design, modeling, modulation, control and simulation of three-phase two-level voltage sourced inverters with emphasis on applications. Student will also be introduced to advanced topologies including diode clamped multilevel inverters, modular multilevel inverters and matrix converters. Prereq: ELEC 4174 or ELEC 5174. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 4174 or 5174

**ELEC 5333 - Introduction to Computational Electromagnetics (3 Credits)**

An intro to computational electromagnetics based on the Finite Difference Time-Domain (FDTD) covering, finite difference methods, the Yee algorithm, numerical error, stability, boundary conditions, source excitations, hands-on programming experience and application of FDTD to real problems. Prereq: ELEC 3133 or grad standing. Cross-listed with ELEC 4333. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3133 or graduate standing

**ELEC 5334 - Advanced Computational Electromagnetics (3 Credits)**

This course on advanced computational electromagnetics covers Green's theorems and identities, vector potential theory, equivalence principles, numerical linear algebra, numerical integration, method of weighted residuals, integral equation methods, method of moments, and Prereq: ELEC 4133 or ELEC 5133 or grad standing. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 4133 or ELEC 5133 or grad standing

**ELEC 5373 - Optical Engineering (3 Credits)**

This course introduces some of the most important concepts in optical engineering and prepares students a solid foundation to apply them to applications in the industry and academic research. Prereq: ELEC 3133. Cross-listed with ELEC 4373. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3133 Restriction: Restricted to students within the College of Engineering, Design and Computing

**ELEC 5375 - Engineering Neuroscience (3 Credits)**

In this course, mathematical models and data processing strategies will be introduced as well as other cutting-edge research techniques to help students understand how these techniques can be applied to solve modern neuroscience problems. Prereq: ELEC 3316 or graduate standing. Cross-listed with ELEC 4735 and NRSC 7674 (Anschutz Medical Campus course). Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3316 or Graduate Standing

**ELEC 5423 - Radio Frequency Laboratory (1 Credit)**

Projects involve modern RF analyzers, waveguide devices, time-domain techniques, characterization of devices, signal propagation and scattering, harmonic mixing, and radio frequency identification. Students will gain experience using MATLAB for data acquisition and processing. Graduate students will explore projects in greater detail. Cross-listed with ELEC 4423. Max Hours: 1 Credit.

Grading Basis: Letter Grade

Typically Offered: Fall, Spring.

**ELEC 5433 - Fundamentals and Applications of Plasmas (3 Credits)**

This course provides an introduction to plasmas, also known as the fourth state of matter, in nature and industry. Topics covered include single particle motions, plasma kinetic and fluid theory, cold and warm plasma models and interaction of electromagnetic waves with plasmas. Applications ranging from space sciences to medicine are explored. Prereq: ELEC 3133 for undergraduate students or permission of the instructor. No prerequisite for CEDC graduate students. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3133 + Engineering undergraduates or Prereq: Graduate Engineering

Typically Offered: Fall, Spring.

**ELEC 5436 - Nonlinear Control Systems I (3 Credits)**

Analysis and synthesis of nonlinear feedback control systems. Linearization's and stability in the small, equivalent linearization and the describing function. The dual input describing function. Stability in the large and the second method of Lyapunov. Stability of time-varying systems. Popov's method and extensions. Prereq: ELEC 4136 or 4276. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 4136 or ELEC 4276 or Graduate Standing

**ELEC 5444 - Power System Laboratory (1 Credit)**

This lab introduces the student to modern computational tools used in power system analysis. Algorithms to solve the "power flow problem", the "economic dispatch problem", and the "optimal power flow problem" are discussed and implemented in the Matlab-Simulink mathematical analysis software package. Coreq: ELEC 4184. Max hours: 1 Credit.

Grading Basis: Letter Grade

Coreq: ELEC 4184.

**ELEC 5446 - Introduction to Modern Control Theory (3 Credits)**

State space representation of dynamic systems. Canonical forms. Frequency domain analysis. Controllability and observability. Design by statespace methods: pole-placement, linear observers, separation principle, robustness. Linear, quadratic optimum control. Prereq: ELEC 4136 or 4276. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 4136 or ELEC 4276.

ELEC 5455 - Computer Methods for Device Electronics (3 Credits)  
 Numerical analysis of PN junctions, Bipolar transistors, GAAS MESFETS, and MOSFETS. Numerical solution of discrete-form equations. Finite-difference method for semiconductor devices. Two-dimensional models: DC, transient, and small signal numerical analysis. Prereq: Graduate standing or permission of instructor. Max Hours: 3 Credits.  
 Grading Basis: Letter Grade  
 Restriction: Restricted to students with graduate standing.

ELEC 5456 - Sampled Data and Digital Control Systems (3 Credits)  
 Elements of sampling theory. Overview of design approaches via transform methods. Analysis and design in state space. Optimal control systems. Emphasis is placed on computer-aided design projects. Prereq: ELEC 4276. Max Hours: 3 Credits.  
 Grading Basis: Letter Grade  
 Prereq: ELEC 4276 or Graduate Standing

ELEC 5466 - Adaptive Control System Design (3 Credits)  
 Basic concepts in adaptive feedback control. Overview of application areas. Stability of non-linear systems and hyperstability approach to the design of adaptive controllers. Passivity concept and Liapunov stability. Design of model reference adaptive systems, self-tuning regulators, stochastic adaptive, and dual control systems. Computer-based design applications. Emphasis is placed on design projects. Prereq: ELEC 4136 or 4276 or Graduate Standing. Max hours: 3 Credits.  
 Grading Basis: Letter Grade  
 Prereq: ELEC 4136 or ELEC 4276 or Graduate Standing

ELEC 5474 - Power Electronics Laboratory (1 Credit)  
 The power electronics laboratory introduces students to seven fundamental switchmode power conversion topologies, along with voltage and current feedback control, assembled on a reconfigurable power pole circuit board with external power supplies and laboratory. Cross-listed with ELEC 4474. Max Hours: 1 Credit.  
 Grading Basis: Letter Grade

ELEC 5476 - Optimal Control Systems (3 Credits)  
 Liapunov stability and quadratic optimal control problems. The minimum principle and the Pontryagin maximum principle. Variational calculus and Hamilton-Jacoby-Bellman equation. The separation principle of LQG control. Combined optimal state estimation and control. Differential and difference Riccati equations. Tracking and disturbance rejection. Computer-aided design applications. Prereq: ELEC 4136 or 4276. Max Hours: 3 Credits.  
 Grading Basis: Letter Grade  
 Prereq: ELEC 4136 or ELEC 4276 or Graduate Standing

ELEC 5486 - Modeling and System Identification (3 Credits)  
 Linear time-invariant and time-varying models. Nonlinear state space models. Non-parametric methods. Parameter estimation methods. Convergence and consistency. Computational methods in estimation. Recursive estimation methods. Experiment design and choice of identification criterion. Model structure selection and model validation. Prereq: ELEC 3817 or MATH 3800, and ELEC 4136 or 4276. Max Hours: 3 Credits.  
 Grading Basis: Letter Grade  
 Pre-req: (ELEC 3817 or MATH 3800) AND (ELEC 4136 or 4276) OR Graduate Standing

ELEC 5496 - Robust Control (3 Credits)  
 Background mathematics: function spaces and operators, and factorization theory. Stability theory: stability and stabilizability parameterization, closed-loop transfer matrices. Model-Matching Theory: solution existence, SISO Design, the Nehari problem. Performance bounds. Prereq: Graduate standing or permission of instructor. Max Hours: 3 Credits.  
 Grading Basis: Letter Grade

ELEC 5501 - Microprocessor-Based Design (3 Credits)  
 Covers advanced treatment of embedded system design using microprocessors. Analog input circuitry is interfaced to a microprocessor, and a PC board layout is created to develop a complete system design. Software/Operating System is implemented for realtime I/O. Prereq: Graduate standing or permission of instructor. Cross-listed with ELEC 4501. Max Hours: 3 Credits.  
 Grading Basis: Letter Grade

ELEC 5511 - Hardware-Software Interface (3 Credits)  
 Computer engineering methods in hardware and software design applied to problems drawn from the mini- and micro-computer systems field. Hardware and software techniques for the design of combined hardware or software are developed. Interface and real-time programming techniques are considered. Graduate level requires additional projects and homework. Prereq: ELEC 3520. Cross-listed with ELEC 4511. Max hours: 3 Credits.  
 Grading Basis: Letter Grade  
 Prereq: ELEC 3520.

ELEC 5521 - Design and Test of Digital Systems (3 Credits)  
 Application of hardware description languages to the design, synthesis, analysis, and testing of digital and computer systems; modeling and simulation constructs; modern hardware description languages, including VHDL, logic and behavioral synthesis; rapid-prototyping; FPGA and standard-cel ASIC design; design for testability; and electronic design automation. Prereq: ELEC 3651 or graduate standing. Max Hours: 3 Credits.  
 Grading Basis: Letter Grade  
 Prereq: ELEC 3651 or Graduate Standing

ELEC 5522 - VLSI Systems (3 Credits)  
 Examines the design of very large-scale integrated (VLSI) systems from the logic to physical levels, including MOS transistor design, CMOS fabrication and design rules, device and wafer processing, inverter and complex gate design, mask level layout, VLSI system components and architectures, algorithms for VLSI computer-aided design, and testability. Prereq: ELEC 3215 and 3651 or graduate standing. Max Hours: 3 Credits.  
 Grading Basis: Letter Grade  
 Pre-req: (ELEC 3215 and 3651) or Graduate Standing

ELEC 5531 - Introduction to Deep learning and PyTorch (3 Credits)  
 This course provides a foundation on neural networks of deep learning. Students will gain both theoretical and practical understanding of different deep neural networks and will work on a few real-world problems. Prereq: ELEC 3520. Cross-listed with ELEC 4531. Max hours: 3 Credits.  
 Grading Basis: Letter Grade  
 Prereq: ELEC 3520.  
 Typically Offered: Spring, Summer.

**ELEC 5541 - Advanced Deep Learning for Computer Vision (3 Credits)**

This course introduces the state-of-the-art deep learning research work. Students will gain both theoretical and practical understanding of deep learning in computer vision area. Prereq: ELEC 3520. Cross-listed with ELEC 4541. Max hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3520.

Typically Offered: Spring, Summer.

**ELEC 5551 - Pattern Recognition (3 Credits)**

Pattern recognition techniques from image processing and artificial intelligence are explored. Topics include neural networks, morphological processing, wavelets, fractals, and basic image understanding. Prereq: ELEC 3316 and 3651. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: (ELEC 3316 and 3651) or Graduate Standing

**ELEC 5555 - VLSI Circuit Simulation (3 Credits)**

Computer methods for large integrated circuits. Theory and practice of VLSI circuit simulation. Nodal formulations of networks. Computer generation of sensitivities. Modeling active devices. DC solution of nonlinear networks. Prereq: Graduate standing or permission of instructor. Cross-listed with ELEC 4555. Max Hours: 3 Credits.

Grading Basis: Letter Grade

**ELEC 5617 - Random Processes for Engineers (3 Credits)**

Probability, sequences of random variables, specification of stochastic processes, stationarity, correlation functions and spectral densities, linear mean-square estimation, central limit theorems, law of large numbers, non-stationary random processes, stochastic differential equations and Karhunen-Loeve expansion, Kalman filtering. Prereq: ELEC 3316 and ELEC 3817 and permission of instructor. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: (ELEC 3316 and 3817) OR Graduate Standing

**ELEC 5627 - Stochastic Point Processes (3 Credits)**

Presents modeling physical phenomena characterized by highly localized events distributed randomly in a continuum. Applications include optical communications, queuing theory, decision theory, nuclear medicine and electron microscopy. Topics include Poisson counting processes and its generalizations; stochastic differential equations used in filtering; martingales and Brownian motion. Prereq: ELEC 3817 or ELEC 5617. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3817 or 5617

**ELEC 5637 - Digital Signal Processing (3 Credits)**

Discrete-time signals and systems in the time and frequency domain. Digital filter structures, design of FIR filters by windowing, optimum approximations of FIR filters. Design of digital IIR filters from continuous time domain. Computer-aided design of digital filters. The discrete Fourier transform and DSP algorithm implementation. Analysis of finite word length effects. Application of digital signal processing. Prereq: ELEC 3316 and 3817. Cross-listed with ELEC 4637. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: (ELEC 3316 and 3817) OR Graduate Standing

**ELEC 5638 - Digital Image Processing (3 Credits)**

Basics of two-dimensional (2-D) systems theory, including 2-D Fourier transform, Z-transform, and difference equations. Design of 2-D filters for image processing applications. Image transforms, including the 2-D FFT, cosine, Hadamard and KL. Image enhancement and restoration techniques. Method of image coding and compression. Prereq: ELEC 3133, 3215, 3225, 3316, 3817 or graduate standing. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3133, 3215, 3225, 3316, 3817 or graduate standing

**ELEC 5644 - Introduction to Medical Imaging (3 Credits)**

This course will introduce students to the basic physics, technologies, and clinical methodologies underlying Ultrasound, MRI, CT, PET and SPECT imaging systems. The course will include lectures, and visits to campus hospital and research imaging systems as well as hands on ultrasound labs. Prereq: Graduate standing. Cross-listed with ELEC 4644. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Restriction: Graduate level students.

**ELEC 5647 - Adaptive Signal Processing (3 Credits)**

Optimal filtering and identification of signal processing models. Martingales and analysis of recursive estimation algorithms. LMS and RLS adaptive filters. Stability, convergence and robustness of adaptive algorithms. Adaptive noise cancellation, time delay estimation and blind equalization. Adaptive differential pulse code modulation, adaptive prediction, adaptive Kalman Filters. Applications and implementation of adaptive algorithms. Prereq: ELEC 5637. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 5637

**ELEC 5648 - Blind Signal Processing (3 Credits)**

Introduction to gradient optimization methods. Introduction to adaptive filtering. Principal component analysis and whitening. Robust and adaptive PCA. Blind SOS parameter estimation and deconvolution. Fundamentals of independent component analysis. Blind equalization of SIMO and MIMO systems. ICA by maximization of nongaussianity. ICA by MLE and minimization of mutual information. Applications and practical considerations. Prereq: Graduate standing. Cross-listed with ELEC 6648. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Restriction: Restricted to graduate students

**ELEC 5657 - Detection and Estimation Theory (3 Credits)**

Introduces detection and extraction methods used in signal processing, including decision theory; detection of known and random signals; optimum receiver design; estimation theory; Wiener filtering; Kalman-Bucy filtering; and applications to communication systems. Prereq: ELEC 5617. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 5617

**ELEC 5678 - Quantum Computing (3 Credits)**

The course teaches students the principles, the algorithms and the programming methods of quantum computing, and also discusses the associated physics and mathematics background required. Other related topics such as quantum communication and quantum entanglement will also be discussed. Prereq: Graduate standing. Cross-listed with ELEC 4678, PHYS 4678, and PHYS 5678. Max hours: 3 Credits.

Grading Basis: Letter Grade

Restriction: Graduate level students.

**ELEC 5679 - Quantum Computing Algorithms (3 Credits)**

The course discusses several seminal quantum algorithms, including the quantum Fourier transforms, Grover's and Shor's algorithms, followed by explaining several advanced quantum computing algorithms, including quantum error correction, sparse linear systems, and variational eigensolver. Google Cirq quantum programming library will be used for actual quantum programming implementations of the algorithms discussed. Prereq: ELEC 4678 or ELEC 3817 or CSCI 3560 or CSCI 4650 or CSCI 4110 with a C- or higher or Permission of Instructor. Restriction: Restricted to students with graduate standing. Cross-listed with ELEC 4679, PHYS 4679, and PHYS 5679. Max hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 4678 or ELEC 3817 or CSCI 3560 or CSCI 4650 or CSCI 4110 with a C- or higher. Restriction: Restricted to students with graduate standing.

Typically Offered: Fall.

**ELEC 5680 - Quantum Computing Technology (3 Credits)**

Students will explore some of the concepts and experimental practices for realizing quantum computers. They will engage in laboratory practice of relevant skills including high-performance analog electronics; optics based quantum encryption and eraser implementations; RF electronics; and vacuum and cryogenic techniques. Prereq: ELEC 3900 with a C- or higher or Permission of Instructor. Restriction: Restricted to students with graduate standing. Cross-listed with ELEC 4680, PHYS 4680, and PHYS 5680. Max hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3900 with a C- or better or Graduate Standing.

Typically Offered: Fall.

**ELEC 5681 - Quantum Technology Systems (3 Credits)**

Students will explore a systems approach toward experimental practices for realizing quantum information science and engineering (QISE), with a focus on vacuum and cryogenic techniques and integration of electronics subsystems into a "dry" cryostat. They will engage in laboratory practice of relevant skills including creation and measurement of high vacuum, methods for reaching ultra-low temperatures, concerns in the design and construction of cryogenic apparatuses, and operation of a "dry" cryogenic system at 4 K, including measurements on superconducting quantum interference devices. Prereq: PHYS 4680 OR PHYS 5680 OR ELEC 4680 OR ELEC 5680 with a C- or higher or Permission of Instructor. Cross-listed with ELEC 4681, PHYS 4681 and PHYS 5681. Max hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: PHYS 4680 OR PHYS 5680 OR ELEC 4680 OR ELEC 5680 with a C- or higher.

**ELEC 5697 - Optical and Spatial Information Processing (3 Credits)**

Processing of two- and three-dimensional spatial information. The scalar diffraction theory necessary to describe the information-bearing wave-front. Wave-front recording, modulations, and reconstruction. Holography, Fourier transform properties of lenses, two-dimensional convolution and correlation, pattern recognition, and optical information processing.

Prereq: ELEC 3316. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3316 or Graduate Standing

**ELEC 5710 - Advanced Electric Drive Systems (3 Credits)**

Covers advanced theory and implementation techniques for rotating electric machinery drives. Topics include field oriented control theory, detailed dynamic modeling of induction machine/drive system, advanced control algorithms and controller design. Prereq: ELEC 4164/5164 or equivalent. Max Hours: 3 Credits.

Grading Basis: Letter Grade

**ELEC 5714 - Energy Systems Analysis (3 Credits)**

Transmission line constants, including details of GMD methods, skin effect. Analysis of balanced and unbalanced line using distributed parameters, energy flow from circle diagram approach, traveling-wave phenomena, corona, power cables and fundamentals of DC transmission. Prereq: ELEC 4184. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 4184

**ELEC 5720 - Practical Electric Drive Systems (3 Credits)**

Covers practical control theory and implementation techniques for electric machine drives for rotating electric machinery using high-performance hardware and software. Topics include machine theory review, power converter, control theory, controller design and actual implementation of an induction machine drive using up-to-date microcontroller hardware and software. Prereq: ELEC 2520, ELEC 4164/5164 or equivalent. Max Hours: 3 Credits.

Grading Basis: Letter Grade

**ELEC 5723 - High Performance Computer Architecture (3 Credits)**

High Performance Computer Architecture covers the design of advanced computing systems. In particular, the course includes the design of modern microprocessors, characteristics of the memory hierarchy, and issues involved in multithreading and multicore architectures. Prereq: ELEC 3651 Digital Hardware Design. Cross-listed with ELEC 4723. Max Hours: 3 Credits.

Grading Basis: Letter Grade

**ELEC 5725 - Advanced Electric Machinery (3 Credits)**

Covers theoretical principles and techniques of electric machine analysis focusing on rotating machinery. Topics include various machine definitions, properties and analysis, software tools, and examples. Prereq: ELEC 3164 or equivalent. Max Hours: 3 Credits.

Grading Basis: Letter Grade

**ELEC 5727 - Machine Vision Systems (3 Credits)**

This course provides an introduction to machine vision systems regarding concepts, algorithms, and applications, especially revealing how the latest vision systems can mimic and even outperform humans in specific tasks. Through practical assignments and projects, students will learn to develop vision systems that can see, interpret, and act on visual data. Key topics include image/video formation and transformation, feature extraction, object recognition, and evaluating vision system performance. By the end of the course, students will have a solid background in machine vision algorithms and be able to advance their knowledge in solving real-world problems. Prereq: Requires prerequisite course of ELEC 3520 (minimum grade D-). Restriction: Restricted to graduate students only. Cross-listed with ELEC 4727. Term offered: Fall. Max hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 3520.

Typically Offered: Fall.

**ELEC 5755 - Grid Integration of Renewable Energy (3 Credits)**

This course focuses on the modeling, analysis and control of grid-connected wind and photovoltaic energy systems. Prereq: permission of instructor. Cross-listed with ELEC 4755. Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

**ELEC 5764 - Power Distribution Systems (3 Credits)**

Use of per-unit methods to find transient voltage behavior of industrial power systems resulting from motor starting, spotwelders and similar stimuli. System and device responses due to series and shunt capacitors and problems of subharmonics and over-excitation on induction motors. Design of power distribution systems. Prereq: ELEC 4184. Max hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 4184

**ELEC 5774 - Power Systems Dynamics and Protection (3 Credits)**

Topics to be covered include: power system dynamic fundamentals, various stability problems, such as angle, frequency and voltage stability; protection of power systems apparatus and protective relays coordination. Prereq: ELEC 4184/5184 or graduate standing. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 4184 or Graduate Standing

**ELEC 5800 - Special Topics (1-3 Credits)**

Intermediate courses of variable title and variable credit, usually offered once by guest lecturers. See current departmental notices for details.

Repeatable. Max hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

**ELEC 5802 - Special Topics (3 Credits)**

Prereq: ELEC 3701 with a C- or higher for ELEC undergraduates, MATH 2830 or equivalent for non-majors or Graduate standing. Cross-listed with ELEC 4802. Repeatable. Max hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

Prereq: ELEC 3701 with a C- or higher for ELEC undergraduates, MATH 2830 or equivalent for non-majors or Graduate standing. Typically Offered: Fall.

**ELEC 5810 - Special Topics (3 Credits)**

Cross-listed with ELEC 4810. Max hours: 3 Credits.

Grading Basis: Letter Grade

**ELEC 5840 - Independent Study: ELEC (1-6 Credits)**

Offers the opportunity for independent, creative work. Prereq: Permission of instructor. Repeatable. Max Hours: 6 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 6.

**ELEC 5939 - Internship Master Student (1-3 Credits)**

Student will outline internship tasks every 2-3 weeks in a progress report. Reports will include the details of exposure to electrical/computer engineering concepts. Each concept will be described with respect to CU Denver Electrical Engineering degree program. Courses that were taken pre-internship that prepared student for successful understanding for the task requirements. In addition, preparations that would be help, will also be mentioned. Engineering training in design and software tools related to internship tasks will be clearly described. Final semester report will describe all experiences and include recommendations on how students might prepare to be successful for other common tasks. Requisite:

Graduate students must have completed 6 credit hours with a cumulative GPA of 3.0. Repeatable. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 3.

Graduate students must have completed 6 credit hours with a cumulative GPA of 3.0.

**ELEC 5980 - Statistical Quality Control (3 Credits)**

Introduces statistical methods of quality control. Statistical process control, process capability, statistical design of experiments and total quality management. Prereq: Graduate standing or permission of instructor. Max Hours: 3 Credits.

Grading Basis: Letter Grade

**ELEC 6000 - Statistical Signal Processing (3 Credits)**

The objective of this course is to present a systematic coverage of statistical signal processing methods which are fundamental for processing, identifying and classifying stochastically (randomly) generated data sequences. Emphasis will be given to methods which resist data outliers. Important applications include communications and biological systems. Prereq: ELEC 5617 or consent of instructor. Max Hours: 3 Credits.

Grading Basis: Letter Grade

Prereq: ELEC 5617

**ELEC 6800 - Special Topics (1-3 Credits)**

Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

**ELEC 6950 - Master's Thesis (1-8 Credits)**

Repeatable. Max hours: 8 Credits.

Grading Basis: Letter Grade with IP

Repeatable. Max Credits: 8.

Additional Information: Report as Full Time.

**ELEC 6960 - Master's Report (1-8 Credits)**

Repeatable. Max hours: 8 Credits.

Grading Basis: Letter Grade with IP

Repeatable. Max Credits: 8.

Additional Information: Report as Full Time.

**ELEC 7800 - Special Topics (1-3 Credits)**

Courses of variable title and variable credit, usually offered once by guest lecturers. See current departmental notices for details. Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

**ELEC 7801 - Special Topics (1-3 Credits)**

Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

**ELEC 7802 - Special Topics (1-3 Credits)**

Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

**ELEC 7803 - Special Topics (1-3 Credits)**

Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

**ELEC 7804 - Special Topics (1-3 Credits)**

Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

**ELEC 7805 - Special Topics (1-3 Credits)**

Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.



ELEC 7806 - Special Topics (1-3 Credits)

Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

ELEC 7807 - Special Topics (1-3 Credits)

Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

ELEC 7808 - Special Topics (1-3 Credits)

Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

ELEC 7809 - Special Topics (1-3 Credits)

Repeatable. Max Hours: 9 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 9.

ELEC 7840 - Independent Study: ELEC (1-6 Credits)

Offers the opportunity for independent, creative work. Prereq: Permission of instructor. Repeatable. Max Hours: 6 Credits.

Grading Basis: Letter Grade

Repeatable. Max Credits: 6.

ELEC 8990 - Doctoral Dissertation (1-10 Credits)

Repeatable. Max hours: 10 Credits.

Grading Basis: Letter Grade with IP

Repeatable. Max Credits: 10.

Additional Information: Report as Full Time.