ELECTRICAL ENGINEERING

Areas of focus in electrical engineering include photovoltaic, wind and renewable energy systems, power electronics systems, electromagnetic theory, microwave systems, antennas, remote sensing, bioelectronics and biomedical engineering, communications and signal processing, medical imaging, optoelectronics, nanophotonics and nanodevices, biophotonics, human/machine interfaces, controls theory, embedded systems engineering, and complex network systems.

With a highly regarded faculty and $7.1 million awarded in new contract and grant funding in fiscal year 2021, the Department of Electrical, Computer and Energy Engineering (http://www.colorado.edu/ecee/) is the perfect place to take your education to the next level.

We offer several degree options tailored to both working engineers looking to advance their careers and to those looking to pursue a career in academia. Research is concentrated in six broad areas: optics, nanostructures and bioengineering; communications and signal processing; computer engineering; systems and controls; electromagnetics, RF and microwaves; and power electronics.

Course code for this program is ECEN.

Research Centers

Colorado Power Electronics Center (CoPEC)

Since it was founded in 1983, the power electronics group at the University of Colorado has maintained a tradition of innovative design-oriented and application-driven research. Colorado Power Electronics Center (CoPEC) activities now span the range of applications from high-efficiency milliwatt converters for portable battery-operated systems, to hundreds or thousands of watts for computer, data centers, telecommunications, aerospace, and medical applications, to hundreds of kilowatts for electrified transportation, solar photovoltaic and wind power systems.

Our current research activities include projects in high-efficiency, high-power converter technology, power electronics for portable, battery-operated systems, converter modeling and computer-aided analysis, high-efficiency modular and composite power conversion architectures utilizing wide bandgap power semiconductors, low harmonic rectifier technology for single-phase and three-phase applications, solar photovoltaic power systems, and advanced digital and mixed-signal control techniques. We collaborate with other research groups at the University of Colorado, including those in power and renewable energy systems, microelectronics packaging, RF/microwave systems, control and semiconductor devices. We also maintain collaborations with the National Renewable Energy Laboratory and within the NSF Engineering Research Center ASPIRE, which is focused on electrified transportation. For more information, call 303-492-7327 or visit the CoPEC (http://ecee.colorado.edu/copec/) website.

ASPIRE

Launched in 2020, **ASPIRE** (Advancing Sustainability through Powered Infrastructure for Roadway Electrification) is exploring a diverse range of electrified transportation questions, from electrified highways that energize vehicles to the placement of charging stations, data security and workforce development. Participating in ASPIRE are CU Boulder researchers in electrical, computer and energy engineering, including Colorado Power Electronics Center, Power and Renewable Energy Systems, Optimization, and Data Science, as well as researchers in computer science and mechanical engineering. The ASPIRE Engineering Research Center is funded by a $26 million National Science Foundation (NSF) grant and led by Utah State University.

The University of Colorado Center for Environmental Technology (CET)

Understanding and managing the environment—whether for agriculture, health, water resources, disaster mitigation, energy generation, transportation, weather forecasting, climate modeling or biodiversity—requires accurate knowledge of many variables on a wide range of time and space scales. Measurements for environmental purposes are made either using in situ or remote sensors, and rely upon a variety of different means, including acoustic and electromagnetic waves, point measurements and wide-area imaging and active and passive systems. A variety of different types of platforms can be used for environmental observation, including ships and submersibles, aircraft (both manned and unmanned), spacecraft and stationary sites.

Research and educational activities at the CU Center for Environmental Technology are focused on developing sensors, systems of sensors and associated hardware and algorithms for environmental observation with a focus on new remote and in situ techniques to meet contemporary scientific and applications goals. This is accomplished by direct involvement of CU faculty, CET engineering staff and undergraduate and graduate students on the development of sensing systems to meet the observational needs of a number of government and industry sponsors. CET training involves close interaction between students and experienced professional engineers, practicing scientists and CU faculty.

The CET was established in 2006 with a major donation of equipment from the NOAA Earth System Research Laboratory, and has members, associates and students from within the broad earth science and engineering communities of Colorado. For more information, contact the CET director at 303-492-9688 or visit the Center for Environmental Technology website.

The STROBE Center

The STROBE Science & Technology Center brings together imaging science experts from seven universities and partners with national labs, industry and academe to push the boundaries of imaging science capabilities and technologies, while building a diverse workforce that is prepared for 21st century careers in science and technology.

Modern functional materials require a deep knowledge of interactions within them to understand how heterogeneity defines function. STROBE brings together academia, national laboratories and industry to develop and advance multimodal multi-scale imaging modalities and their application to material and bio-systems science.

Research and Instructional Equipment

The department's special equipment and facilities include a class 1000 clean room facility for epitaxial growth and fabrication of microwave and optical devices; an anechoic chamber; high-vacuum and vacuum deposition equipment for thin-films research; an integrated circuits laboratory; ion implantation equipment; crystal growing facilities; a modern systems laboratory; a laboratory for data storage research; a digital system design laboratory; a power electronics research laboratory; undergraduate laboratories in circuits, electronics; power electronics; digital signal processing and communications; embedded systems; microwaves; a holography and optics laboratory; an advanced optical metrology lab; numerous special purpose computers; a computer system development laboratory; a roof-mounted antenna range; a special

microscope for laser manipulation of microorganisms in vivo; a bio-microwave laboratory; a solar power lab; photovoltaic device fabrication and characterization facilities; and bioelectronics fabrication and integration capabilities.

The Colorado Shared Instrumentation in Nanofabrication and Characterization (COSINC) is an open user facility on campus. Our mission is to provide expertise, facilities, infrastructure and teaming environments to enable and facilitate interdisciplinary research in microelectronics, optoelectronics and MEMS. We also make use of the campus's HPC system RMACC Summit (https://www.colorado.edu/rc/articles/rmaccsummit/).

The Department of Electrical, Computer and Energy Engineering has a large variety of computing equipment to support its research and instructional activities. In addition to specialized computing equipment, this includes several hundred PCs, Macs, a department server and a student server. These machines are connected to the campus-wide ethernet network.

Master's Degrees

- Electrical Engineering - Master of Engineering (ME) (https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/electrical-engineering/electrical-engineering-master-engineering-me/)
- Electrical Engineering - Master of Science (MS) (https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/electrical-engineering/electrical-engineering-master-science-ms/)
- Electrical Engineering - Professional Master of Science (MSEE) (https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/electrical-engineering/electrical-engineering-professional-master-science-msee/)

Doctoral Degree

- Electrical Engineering - Doctor of Philosophy (PhD) (https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/electrical-engineering/electrical-engineering-doctor-philosophy-phd/)

Certificates

- Embedded Systems Engineering - Graduate Certificate (https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/engineering-applied-science/embedded-systems-engineering-graduate-certificate/)
- Power Electronics - Graduate Certificate (https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/engineering-applied-science/power-electronics-graduate-certificate/)
- Photonics - Graduate Certificate (https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/electrical-engineering/photonics-graduate-certificate/)

Faculty

While many faculty teach both undergraduate and graduate students, some instruct students at the undergraduate level only. For more information, contact the faculty member's home department.

Akos, Dennis M. (https://experts.colorado.edu/display/fisid_131119/)
Professor; PhD, Ohio University

Anderson, Dana Z. (https://experts.colorado.edu/display/fisid_102371/)
Professor; PhD, University of Arizona

Baker, Kyri A. (https://experts.colorado.edu/display/fisid_159754/)
Assistant Professor; PhD, Carnegie Mellon University

Barnes, Frank S. (https://experts.colorado.edu/display/fisid_104148/)
Distinguished Professor Emeritus; PhD, Stanford University

Barton, Taylor Wallis (https://experts.colorado.edu/display/fisid_157939/)
Faculty Fellow, Associate Professor; DSc, Massachusetts Institute of Technology

Becker, Stephen R. (https://experts.colorado.edu/display/fisid_154263/)
Associate Professor; PhD, California Institute of Technology

Blum, Arielle Melissa (https://experts.colorado.edu/display/fisid_154695/)
Instructor; MS, University of Colorado Boulder

Bogatin, Eric (https://experts.colorado.edu/display/fisid_151431/)
Lecturer; PhD, University of Arizona

Brancucci, Carlo
Lecturer; PhD, Technische Universiteit Delft (Netherlands)

Bright, Victor Mark (https://experts.colorado.edu/display/fisid_112696/)
Professor; PhD, Georgia Institute of Technology

Carter Carston, Ronald McKell (https://experts.colorado.edu/display/fisid_154921/)
Assistant Professor; PhD, California Institute of Technology

Chang, Bor-Yuh Evan (https://experts.colorado.edu/display/fisid_146087/)
Associate Professor; PhD, University of California, Berkeley

Chaudhary, Sumeet (https://experts.colorado.edu/display/fisid_167980/)
Instructor; PhD, University of Cincinnati

Chen, Xudong (https://experts.colorado.edu/display/fisid_158323/)
Assistant Professor; PhD, Harvard University, Cambridge, MA

Clauset, Aaron (https://experts.colorado.edu/display/fisid_147554/)
Associate Professor; PhD, University of New Mexico

Cogswell, Carol (https://experts.colorado.edu/display/fisid_141919/)
Research Professor; MArch, University of Oregon

Combes, Josh (https://experts.colorado.edu/display/fisid_166284/)
Assistant Professor; PhD, Griffith University

Corradini, Luca (https://experts.colorado.edu/display/fisid_146380/)
Associate Professor, Visiting Associate Professor; PhD, University of Padova (Italy)

Correll, Nikolaus J. (https://experts.colorado.edu/display/fisid_147555/)
Associate Professor; PhD, Ecole Polytech Federale de Lausanne (Switzerland)

Dall'Anese, Emiliano (https://experts.colorado.edu/display/fisid_158949/)
Assistant Professor; PhD, University of Padova (Italy)

Diddams, Scott A. (https://experts.colorado.edu/display/fisid_148274/)
Visiting Professor, Professor Adjoint; PhD, University of New Mexico

Erickson, Robert W. (https://experts.colorado.edu/display/fisid_105514/)
Professor; PhD, California Institute of Technology

Femrite, Andrew (https://experts.colorado.edu/display/fisid_154841/)
Senior Instructor, Faculty Director; BS, University of Colorado Boulder

Fiez, Terri S. (https://experts.colorado.edu/display/fisid_156578/)
Professor; PhD, Oregon State University

Filipovic, Dejan S. (https://experts.colorado.edu/display/fisid_126278/)
Professor; PhD, University of Michigan Ann Arbor

Gasiewski, Albin J. (https://experts.colorado.edu/display/fisid_142882/)
Professor; PhD, Massachusetts Institute of Technology

Gopinath, Juliet T. (https://experts.colorado.edu/display/fisid_147075/)
Professor; PhD, Massachusetts Institute of Technology

Grunwald, Dirk C. (https://experts.colorado.edu/display/fisid_102261/)
Professor; PhD, University of Illinois at Urbana–Champaign

Hauser, John (https://experts.colorado.edu/display/fisid_102555/)
Associate Professor; PhD, University of California, Berkeley

Heckman, Christoffer (https://experts.colorado.edu/display/fisid_155294/)
Assistant Professor; PhD, Cornell University

Herzfeld, Ute C. (https://experts.colorado.edu/display/fisid_106575/)
Research Professor; PhD, Johannes Gutenberg-Universität Mainz (Germany)

Hodge, Bri-Mathias (https://experts.colorado.edu/display/fisid_158358/)
Associate Professor; PhD, Purdue University

Huang, Shu-Wei (https://experts.colorado.edu/display/fisid_159847/)
Assistant Professor; PhD, MIT, Cambridge

Izraelevitz, Joe (https://experts.colorado.edu/display/fisid_166042/)
Assistant Professor; PhD, University of Rochester

Kapteyn, Henry C. (https://experts.colorado.edu/display/fisid_115334/)
Professor; PhD, University of California, Berkeley

Keller, Eric Robert (https://experts.colorado.edu/display/fisid_151647/)
Associate Professor; PhD, Princeton University

Kuester, Edward F.
Professor Emeritus

Lasser, Gregor (https://experts.colorado.edu/display/fisid_156178/)
Assistant Research Professor; PhD, Technische Universität Wien (Austria)

Le, Hanh-Phuc (https://experts.colorado.edu/display/fisid_156223/)
Assistant Professor; PhD, University of California, Berkeley

Lehman, Tamara (https://experts.colorado.edu/display/fisid_165649/)
Assistant Professor; PhD, Duke University

Lightner, Michael R. (https://experts.colorado.edu/display/fisid_101723/)
Professor; PhD, Carnegie Mellon University

Liu, Youjian (https://experts.colorado.edu/display/fisid_126283/)
Associate Professor; PhD, Ohio State University

MacCurdy, Robert B. (https://experts.colorado.edu/display/fisid_163307/)
Assistant Professor; PhD, Cornell University

Majerfeld, Arnoldo
Professor Emeritus

Maksimovic, Dragan (https://experts.colorado.edu/display/fisid_105609/)
Professor; PhD, California Institute of Technology

Mathys, Peter (https://experts.colorado.edu/display/fisid_100084/)
Associate Professor; PhD, ETH Zürich (Switzerland)

McAuliffe, Rik
Lecturer

McClure, Linden
Professor Adjunct

McLeod, Robert R. (https://experts.colorado.edu/display/fisid_107547/)
Professor; PhD, University of Colorado Boulder

Mendelson, Jay
Lecturer

Mickelson, Alan R. (https://experts.colorado.edu/display/fisid_100286/)
Associate Professor; PhD, California Institute of Technology

Mihran, Richard
Professor Adjunct

Mishra, Shivakant (https://experts.colorado.edu/display/fisid_118376/)
Professor; PhD, University of Arizona

Moddel, Garret (https://experts.colorado.edu/display/fisid_105440/)
Professor; PhD, Harvard University

Murnane, Margaret (https://experts.colorado.edu/display/fisid_115333/)
Distinguished Professor; PhD, University of California, Berkeley

Myers, Chris (https://experts.colorado.edu/display/fisid_167168/)
Professor, Chair, Endowed Chair; PhD, Stanford University

Nicotra, Marco M. (https://experts.colorado.edu/display/fisid_164182/)
Assistant Professor

Palo, Scott E. (https://experts.colorado.edu/display/fisid_109033/)
Professor; PhD, University of Colorado Boulder

Pao, Lucy Y. (https://experts.colorado.edu/display/fisid_107151/)
Professor; PhD, Stanford University

Park, Won (https://experts.colorado.edu/display/fisid_122676/)
Professor, Associate Chair; PhD, Georgia Institute of Technology

Perkins, Mike
Lecturer; PhD, Stanford University

Piestun, Rafael (https://experts.colorado.edu/display/fisid_118538/)
Professor; PhD, Israel Instit of Tech (Israel)

Piket-May, Melinda J. (https://experts.colorado.edu/display/fisid_102097/)
Associate Professor; PhD, Northwestern University

Pleszkun, Andrew R.
Professor Emeritus

Popovic, Zoya (https://experts.colorado.edu/display/fisid_101494/)
Distinguished Professor; PhD, California Institute of Technology

Poveda, Jorge (https://experts.colorado.edu/display/fisid_164183/)
Assistant Professor

Psychogiou, Dimitra (https://experts.colorado.edu/display/fisid_158311/)
Assistant Professor; PhD, ETH Zürich (Switzerland)

Sankaranarayanan, Sriram (https://experts.colorado.edu/display/fisid_147413/)
Professor; PhD, Stanford University

Scherr, Timothy (https://experts.colorado.edu/display/fisid_156259/)
Senior Instructor; MS, University of Utah

Schibli, Thomas Richard (https://experts.colorado.edu/display/fisid_143464/)
Professor; PhD, Univ of Karlsruhe (Germany)

Shaheen, Sean Eric (https://experts.colorado.edu/display/fisid_153664/)
Professor; PhD, University of Arizona

Sheafor, Steve (https://experts.colorado.edu/display/fisid_163388/)
Lecturer; PhD, University of Illinois

Siewert, Sam
Associate Professor Adjunct

Sluiter, David
Professor Adjunct; BS, Michigan Technological University

Somenzi, Fabio (https://experts.colorado.edu/display/fisid_103969/)
Professor, Associate Chair; PhD, Politecnico Di Torino (Italy)

Spriggs, Benjamin
Lecturer, Scholar in Residence

Thayer, Jeffrey P. (https://experts.colorado.edu/display/fisid_134469/)
Professor; PhD, University of Michigan Ann Arbor

Trivedi, Ashutosh (https://experts.colorado.edu/display/fisid_156589/)
Assistant Professor; PhD, University of Warwick (UK)

Van Zeghbroeck, Bart J. (https://experts.colorado.edu/display/fisid_104113/)
Professor, Associate Chair; PhD, University of Colorado Boulder

Varanasi, Mahesh K. (https://experts.colorado.edu/display/fisid_103090/)
Professor; PhD, Rice University

Wagner, Kelvin (https://experts.colorado.edu/display/fisid_105344/)
Professor; PhD, California Institute of Technology

Walkes, Dan
Lecturer

Williamson, James A.
Lecturer

Wustrow, Eric A. (https://experts.colorado.edu/display/fisid_156419/)
Assistant Professor; BE, University of Michigan Ann Arbor

Zabotin, Nikolay (https://experts.colorado.edu/display/fisid_127038/)
Research Professor

Courses

ECEN 5005 (3) Special Topics
Examines a special topic in Electrical, Computer and Energy Engineering.
Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.
Additional Information: Departmental Category: Nanostructures and Devices

ECEN 5008 (3) Special Topics
Examines a special topic in Electrical, Computer and Energy Engineering.
Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.
Requisites: Restricted to graduate students only.
Additional Information: Departmental Category: Dynamical Systems and Control

ECEN 5009 (3) Special Topics
Examines a special topic in Electrical, Computer and Energy Engineering.
Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.
Requisites: Restricted to graduate students only.
Additional Information: Departmental Category: VLSI CAD Methods

ECEN 5011 (1-4) Special Topics
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4011
Repeatable: Repeatable for up to 9.00 total credit hours.
Requisites: Restricted to graduate students only.
Additional Information: Departmental Category: Bioengineering

ECEN 5012 (3) Special Topics
Requisites: Restricted to graduate students only.
Additional Information: Departmental Category: Digital Signal Processing Communications

ECEN 5013 (3) Special Topics
Examines a special topic in Electrical, Computer and Energy Engineering.
Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.
Requisites: Campus section restricted to ECEE graduate students in Academic subplans ESE or C-EEENP or C-ECENEEEP only.
Grading Basis: Letter Grade

ECEN 5016 (3) Special Topics
Examines a special topic in Electrical, Computer and Energy Engineering.
Additional Information: Departmental Category: Optics

ECEN 5018 (1-4) Special Topics
Examines a special topic in Electrical, Computer and Energy Engineering.
Requisites: Restricted to graduate students only.
Additional Information: Departmental Category: Dynamical Systems and Control

ECEN 5021 (1-4) Special Topics
Examines a special topic in Electrical, Computer and Energy Engineering.
Repeatable: Repeatable for up to 9.00 total credit hours.
Requisites: Restricted to graduate students in Electrical Engineering (EEEN) or in Electrical/Computer Engineering (ECEN) or to Electrical or Electrical/Computer Engineering BS/MS Concurrent degree students or to Graduate Certificate Engineering (CRTGE) students.
Additional Information: Departmental Category: Bioengineering

ECEN 5023 (3) Special Topics
Examines a special topic in Electrical, Computer and Energy Engineering, Embedded Systems.
Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.
Requisites: Campus section restricted to graduate students in EEEN or BS/Professional MS concurrent degree students with BS portion in EEEN or ECEN.
Additional Information: Departmental Category: Embedded Systems Engineering

ECEN 5024 (3) Special Topics
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4024
Repeatable: Repeatable for up to 9.00 total credit hours.
Additional Information: Departmental Category: Electromagnetics and Remote Sensing

ECEN 5028 (3) Special Topics
Examines a special topic in Electrical, Computer and Energy Engineering.
Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.
Additional Information: Departmental Category: Dynamical Systems and Control

ECEN 5032 (3) Special Topics
Additional Information: Departmental Category: Bioengineering

ECEN 5053 (3) Special Topics
Examines a special topic in Electrical, Computer and Energy Engineering - Embedded Engineering.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4053
Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.
Requisites: Campus section restricted to CU Boulder graduate students in Academic sub-plans ESE or C-EEENP or C-ECENEEEP.
Additional Information: Departmental Category: Embedded Systems Engineering

ECEN 5104 (3) Passive Microwave Circuits
Building on fundamentals taught in a class such as ECEN 3410 (Electromagnetic Waves), this course teaches fundamentals of microwave passive circuit analysis using scattering parameters. Design of impedance matching networks, impedance transformers, couplers, filters, dividers/combiners and other typical circuits used at microwave frequencies are covered. Using an industry-standard CAD tool, design of microstrip circuits is emphasized. Assignments include theoretical and CAD approaches to analysis and design of passive microwave transmission-line circuits.
Additional Information: Departmental Category: Electromagnetics and Remote Sensing

ECEN 5110 (1-3) Graduate Teaching Practicum
Provides training and hands-on experience in teaching of ECEE courses. Students will work with an instructor of an ECEE course to carry out teaching activities such as lecturing, leading discussion sessions, writing homework and examination problems, and relevant grading.
Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.

ECEN 5114 (3) Electromagnetic Theory
This course covers theory and applications of Maxwell's equations at the graduate level, including various electromagnetic wave types. Additionally, fundamental electromagnetic theorems such as Poynting, equivalence, duality, reciprocity and compensation, are studied through examples across the electromagnetic spectrum.
Additional Information: Departmental Category: Electromagnetics and Remote Sensing

ECEN 5122 (3) Wireless Local Area Networks
Emphasis on the IEEE P802.11 family of WLAN standards. Students learn the legacy versions of the standard (802.11DS/b), the current generation of WLAN systems (802.11a/g/n/ac), and will to analyze and critique upcoming versions (802.11ax/ba), and gain insight into proposals for new research in WLAN. Exposure to the interoperability and certification process for WLAN by the Wi-Fi Alliance, study the newest Wi-Fi Certified¿ programs, and will learn how to model and analyze WLAN traffic using industry standard tools.
Equivalent - Duplicate Degree Credit Not Granted: CSCI 5220 and CYBR 5220
Requisites: Requires prerequisite course of ECEN 3810 or APPM 3570 or MATH 4510 (minimum grade D-).
Recommended: Prerequisite CYBR 5430.
Additional Information: Departmental Category: Digital Signal Processing Communications

ECEN 5126 (3) Computational Optical Imaging
Covers the fundamentals of computational optical imaging modalities, namely systems in which the hardware (optics, sensors, illumination) is designed in conjunction with algorithms (implemented optically, electronically and via software) to deliver information about a scene. Students learn the analysis and design of modern imaging systems. Covers a variety of applications including biomedical imaging, nanoscopy, photography and space imaging.
Requisites: Restricted to graduate students only.
Grading Basis: Letter Grade

ECEN 5133 (3) Fundamentals of Computer Security
Practice thinking like an attacker by exploring several modern computer security attacks and defenses through hands-on programming projects. Topics include applied cryptography (encryption, authentication), web security (XSS, CSRF, SQL Injection), network security (TLS, MITM attacks), application security (shell injection, buffer overflows), and other current events and trends (government surveillance, botnets, cryptocurrencies).
Grading Basis: Letter Grade

ECEN 5134 (3) Electromagnetic Radiation and Antennas
This course is introduction to antenna theory and antenna applications in applied electromagnetics. Elements of electromagnetic theory are first reviewed through the discussion of fundamental antenna parameters. Topics such as input impedance, radiation pattern, gain, radar cross section, near- and far-field, antenna temperature, and others are discussed first. The theory of operation of electric and magnetic dipoles, small and large dipoles, monopoles, and loops, as well as impact of different grounds on their parameters are discussed next. Other antennas such as bicones, helices, Yagi-Uda, microstrip patches, horns, reflectors, slots, spirals, log-periodics, etc. are also discussed. The fundamentals of array theory inclusive of linear, planar and circular topologies, coupling, beamforming, as well as elements of array synthesis are also discussed. Students will be exposed to the commercial software tools used to design antennas and will work individually or in teams to accomplish different project assignme
Additional Information: Departmental Category: Electromagnetics and Remote Sensing

ECEN 5138 (3) Control Systems Analysis
Analysis and design of continuous time control systems using classical and state space methods. Laplace transforms, transfer functions and block diagrams. Stability, dynamic response, and steady-state analysis. Analysis and design of control systems using root locus and frequency response methods. Computer aided design and analysis. Topics covered in this course will be investigated in more depth, require external readings, additional homework will be assigned, and the exams will be more difficult.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4138 MCEN 4138 or MCEN 5138
Requisites: Restricted to graduate students in Electrical Engineering (EEEN) or in Electrical/Computer Engineering (ECEN) or to Electrical or Electrical/Computer Engineering BS/MS Concurrent degree students or to Graduate Certificate Engineering (CRTGE) students.
Recommended: Prerequisite ECEN 3300.
Additional Information: Departmental Category: Dynamical Systems and Control

ECEN 5139 (3) Computer-Aided Verification
Covers theoretical and practical aspects of verification of finite-state systems (hardware) and infinite-state systems (programs). Model checking: temporal logics, explicit-state and symbolic search, BDDs. Constraint solvers: SAT solvers, decision procedures. Program verification: invariants, partial vs. total correctness, abstraction. Department enforced requisite: general proficiency in discrete mathematics and programming.
Equivalent - Duplicate Degree Credit Not Granted: CSCI 5135
Requisites: Restricted to Electrical/Computer Engineering (EEEN) graduate students or Concurrent Degree students in Electrical Engineering (C-EEEN) or Electrical/Computer Engineering (C-ECENEEEN) or to Graduate Certificate Engineering (CRTGE) students.
Recommended: Prerequisite CSCI 2824.
Additional Information: Departmental Category: VLSI CAD Methods

ECEN 5154 (3) Computational Electromagnetics
This course is introduction to the frequency domain methods used in computational electromagnetics (CEM) for solving complex radio-frequency (RF) problems. The course starts with the review of electromagnetic theory and mathematical concepts used in CEM, followed by the introduction to the partial differential and integral equation based methods. Specifically, the fundamentals behind the finite difference method, finite element method, and method of moments are discussed and implemented to solve problems such as shielded microstrip line, charge distribution on metallic objects, waveguide modes, wire antennas, etc. Students will work independently and in teams to develop their own codes to solve given boundary value problems. The implementation of different methods in commercial software tools is continuously emphasized. An understanding of electrostatics and electromagnetic waves (such as covered in ECEN 3400 and ECEN 3410) is assumed.
Additional Information: Departmental Category: Electromagnetics and Remote Sensing

ECEN 5156 (3) Physical Optics
Covers the application of Maxwell's equations to optical wave propagation in free space and in media.Topics include polarization, dispersion, geometrical optics, interference, partial coherence, and diffraction.
Requisites: Restricted to graduate students only.
Recommended: Prerequisite ECEN 3410.
Additional Information: Departmental Category: Optics

ECEN 5164 (3) Electromagnetic Metamaterials
Enables students to design engineered structures to realize materials with desired electromagnetic properties that are difficult or impossible to achieve using conventional materials. Exact and approximate techniques are explored to develop an intuitive understanding of the electromagnetic response of these structures.
Recommended: Prerequisite ECEN 3410 (EM Waves and Transmissions) or equivalent course in fundamental electromagnetic theory.

ECEN 5224 (3) High Speed Digital Design
Covers fundamentals of high-speed properties of logic gates, measurement techniques, transmission lines, ground planes and layer stacking, terminations, vias, power systems, connectors, ribbon cables, clock distribution and clock oscillators.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4224
Requisites: Restricted to graduate students only.
Additional Information: Departmental Category: Electromagnetics and Remote Sensing

ECEN 5244 (3) Stochastic / Environmental Signal Processing
Provides a baseline understanding for research and development in signal processing and analytics for environmental and other data-intensive applications. Topics include parameter estimation, transforms, linear and nonlinear estimation, data assimilation and detection. Applications include numerical weather prediction, GNSS sensing, ionospheric sounding, radar, radiometry, surveillance, target detection and tracking. Previous coursework in linear systems and electromagnetic waves recommended.
Grading Basis: Letter Grade

ECEN 5253 (3) Datacenter Scale Computing - Methods, Systems and Techniques
Covers the primary problem solving strategies, methods and tools needed for data-intensive programs using large collections of computers typically called "warehouse scale" or "data-center scale" computers. Examines methods and algorithms for processing data-intensive applications, methods for deploying and managing large collections of computers in an on-demand infrastructure and issues of large-scale computer system design.
Equivalent - Duplicate Degree Credit Not Granted: CSCI 4253 and CSCI 5253 and CSPB 4253
Requisites: Restricted to graduate students only.
Recommended: Prerequisite CSCI 5273 or ECEN 5273.

ECEN 5254 (3) Remote Sensing Signals and Systems
Examines passive and active techniques for remote sensing with emphasis on fundamental noise and detection issues from radio to optical frequencies. Emphasis is placed on electromagnetic wave detection, statistical signal and noise analysis, remote sensing system architecture, and hardware for remote sensing systems. Systems studied include radiometers, radars (real and synthetic aperture), interferometers, and lidars. Applications to detection and surveillance, Earth remote sensing, astronomy, and imaging systems are covered.
Additional Information: Departmental Category: Electromagnetics and Remote Sensing

ECEN 5264 (3) Electromagnetic Absorption, Scattering, and Propagation
Electromagnetic waves in communication, navigation, and remote sensing systems from radio to optical frequencies, including propagation in deterministic and random media. Topics include absorption and refraction by gases, discrete scattering by precipitation, clouds, and aerosols, continuous scattering by refractivity fluctuations, earth-space propagation and Faraday rotation in plasmas, and radiative transfer theory.
Recommended: Prerequisites ECEN 3400 and ECEN 3410.
Additional Information: Departmental Category: Electromagnetics and Remote Sensing

ECEN 5273 (3) Network Systems
Focuses on design and implementation of network programs and systems, including topics in network protocols, architectures, client-server computing, software-driven networking, and other contemporary network hardware-software system design and programming techniques. Familiarity with C and Unix is required.
Equivalent - Duplicate Degree Credit Not Granted: CSCI 5273
Additional Information: Departmental Category: Computer and Digital Systems

ECEN 5295 (3) Foundations of Quantum Hardware
Introduces students to the principles and operation of quantum hardware. In this course you will learn how to describe many different physical systems (trapped Ions, superconducting circuits, and optical systems) mathematically. This will allow you to model quantum sensors, communication systems and computing hardware.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4295

ECEN 5313 (3) Concurrent Programming
Introduces the theory and practice of multicore programming. The first part of the course presents foundations of concurrent programming: mutual exclusion, wait-free and lock-free synchronization, spin locks, monitors, memory consistency models. The second part presents a sequence of concurrent data structures and techniques used in their implementations (coarse-grained, fine-grained, optimistic and lock-free synchronization).
Equivalent - Duplicate Degree Credit Not Granted: CSCI 5313 and ECEN 4313 and CSCI 4313
Requisites: Requires prerequisite courses of CSCI 2270 and ECEN 2360 or CSCI 2400 (minimum grade C). Restricted to graduate students only.
Recommended: Prerequisite ECEN 3593.

ECEN 5322 (3) Data and Network Science
The course covers the theory and design of algorithms that are used to model, analyze, and extract information from large scale datasets and networks. The course includes a project.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4322
Requisites: Restricted to graduate students only.
Additional Information: Departmental Category: Digital Signal Processing Communications

ECEN 5341 (3) Bioelectromagnetics
Effects of electric and magnetic fields on biological systems are described with applications to therapy and safety. The complexity of biological systems is described to provide a better understanding of the distribution of fields inside the body. Risk analysis is also introduced.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4341
Requisites: Restricted to graduate students only.
Additional Information: Departmental Category: Bioengineering

ECEN 5345 (3) Introduction to Solid State Physics
Provides an introduction to the electronic, photonic and phononic properties of solid state materials and devices. Covers optical constants, free electron gas, plasmons, energy bands, semiconductors and doping, excitons, quantum wells, phonons and electrooptical effects. Makes use of quantum mechanical methods. Department enforced prerequisite: basic quantum mechanics.
Requisites: Restricted to graduate students only.
Additional Information: Departmental Category: Nanostructures and Devices

ECEN 5355 (3) Principles of Electronic Devices 1
Relates performance and limitations of solid state devices to their structures and technology. Examines semiconductor physics and technology. Includes Pn-junction, Mos, and optoelectronic devices. For both advance circuit and device engineers.
Requisites: Restricted to graduate students only.
Recommended: Prerequisite ECEN 3320.
Additional Information: Departmental Category: Nanostructures and Devices

ECEN 5395 (3) Organic Electronic Materials and Devices
Covers the materials and physics principles of organic electronic devices, including organic light emitting diodes (OLEDs), photovoltaics (OPVs), field effect transistors (OFETs), electrochemical transistors (OECTs), and bioelectronic and neuromorphic devices. The molecular, structural, and electronic properties of organic semiconductors are introduced, and the architectures and operating principles of the devices are then taught. Assignments will require computational solutions and simulations. Previously offered as a special topics course.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4395
Recommended: Prerequisite ECEN 5345.

ECEN 5407 (3) Renewable Energy and the Future Power Grid
This course will begin with an introduction to the power grid including planning and operations for the transmission and distribution level power grid. The course will reflect that while many of the solutions to the integration of variable generation are technical in nature, policy and economics play a large role in the changes that are occurring within the power system. After examining the technological specifications of the most important variable generation sources (wind power, solar photovoltaics, and solar thermal power), as well as traditional power generation sources, other aspects of power system planning and operations in the future power grid will be examined in detail.
Requisites: Restricted to students in College of Engineering and Applied Science (ENGR) only.
Grading Basis: Letter Grade

ECEN 5414 (3) Essential Principles of Signal Integrity
Designing a robust and cost-effective product is about following a process that helps apply your engineering intuition to balance cost and design tradeoffs specific to your product. This class introduces essential principles of signal integrity, including principles of transmission lines, reflections, inductance, ground bounce, differential pairs, losses, terminations, routing, discontinuities, impedance, PDN design and EMC with respect to optimized design.
Recommended: Prerequisite students are expected to have completed an electromagnetics course during their undergraduate curriculum; in the CU curriculum it would be ECEN3400.

ECEN 5417 (3) Power System Analysis
This course covers the basics of power system analysis techniques. Students will be introduced to the concepts behind the fundamental principles of traditional bulk power systems. The difference between single and three phase powers will be discussed. Students will learn how to model bulk power system components and the per unit system. Understanding the flow of power in the system will be examined in detail as students will learn about and apply both AC and DC powerflow formulations.
Recommended: Corequisite ECEN 5407.
Grading Basis: Letter Grade

ECEN 5423 (3) Chaotic Dynamics
Explores chaotic dynamics theoretically and through computer simulations. Covers the standard computational and analytical tools used in nonlinear dynamics and concludes with an overview of leading-edge chaos research. Topics include time and phase-space dynamics, surfaces of section, bifurcation diagrams, fractal dimension and Lyapunov exponents.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4423 and CSCI 4446 and CSCI 5446
Additional Information: Departmental Category: Computer and Digital Systems

ECEN 5427 (3) Power System Planning & Operations
This course will focus on bulk power system planning and operations, with special emphasis on systems with high variable renewable energy penetrations. Electricity markets will also be presented, and the differences with vertically integrated utilities will be discussed. Students will develop an understanding of electricity market dynamics in one of the course projects by participating in an electricity market game. The application of optimization problems in bulk power system operations will be discussed and applied by the students in another course project. They will develop a production cost model to simulate bulk power system operations of a test system under different scenarios.
Requisites: Requires prerequisite course ECEN 5407 (minimum grade B-).
Recommended: Prerequisite ECEN 5417.
Grading Basis: Letter Grade

ECEN 5434 (3) S-Parameters for Signal Integrity in High Speed Digital Engineering
Designing a robust and cost-effective product is about following a process that helps apply your engineering intuition to balance cost and design tradeoffs specific to your product. This class introduces design principles obtained by understanding S-Parameter results for complex PCB structures. Single-ended and Differential Transmission lines are analyzed and four common S-Parameter patterns are identified.
Requisites: Requires prerequisite ECEN 5414 ECEN minimum grade C-.
Recommended: Prerequisite students are expected to have completed an electromagnetics course during their undergraduate curriculum; in the CU curriculum it would be ECEN 3400.

ECEN 5437 (3) Distribution System Analysis
Fundamental aspects of the analysis of power distributions systems, including the traditional distribution grid, loads, components, topologies, operational aspects, and power flow analysis. Includes how the distribution system is changing with the introduction of distributed energy resources.
Requisites: Requires corequisite course of ECEN 5407.
Recommended: Corequisite ECEN 5417.
Grading Basis: Letter Grade

ECEN 5444 (3) Electromagnetic Compatibility (EMC) for High-Speed Digital Engineering
Understanding and applying the theoretical principles of electromagnetics to high speed digital engineering with respect to electromagnetic compatibility (EMC). Faster data rates and shorter rise times make signal integrity in high-speed digital engineering (HSDE) increasingly difficult. Signal distortion has adverse effects on EMC. This course covers understanding the radiation mechanisms and susceptibility of PCB circuits in HSDE.
Recommended: Prerequisite students are expected to have completed an electromagnetics course during their undergraduate curriculum; in the CU curriculum it would be ECEN 3400.

ECEN 5447 (3) Power System Dynamics with Renewable Energy
To introduce the current and future electrical power systems dynamics coupled with inverter based renewable generators. Fundamentals of renewable generators dynamic models, power system dynamics will be introduced. Previously offered as a special topics course.
Recommended: Prerequisites ECEN 5417: Power systems analysis, ECEN 5407: Renewable Energy and the Future Power Grid, and graduate standing in the College of Engineering and Applied Science.

ECEN 5448 (3) Advanced Linear Systems
Offers a state space approach to analysis and synthesis of linear systems, state transition matrix, controllability and observability, system transformation, minimal realization, and analysis and synthesis of multi-input and multi-output systems.
Equivalent - Duplicate Degree Credit Not Granted: MCEN 5448
Requisites: Restricted to graduate students only.
Recommended: Prerequisites ECEN 3300 and ECEN 4138.
Additional Information: Departmental Category: Dynamical Systems and Control

ECEN 5457 (3) Energy Systems Optimization
Covers basic elements of power system modeling; optimization tasks at the transmission level such as economic dispatch and DC optimal power flow (OPF); and essential techniques for formulating linear, second-order cone, and semidefinite programming approximations to AC OPF problems for transmission and distribution systems. Distributed optimization approaches are covered and tied to future architectural frameworks for smart power systems. Previously offered as a special topics course.
Recommended: graduate standing in the College of Engineering and Applied Science.

ECEN 5458 (3) Sampled Data and Digital Control Systems
Provides an analysis and synthesis of discrete-time systems. Studies sampling theorem and sampling process characterization, z-transform theory and z-transferfunction, and stability theory. Involves data converters (A/D and D/A), dead-beat design, and digital controller design.
Requisites: Restricted to graduate students only.
Recommended: Prerequisites ECEN 3300 and ECEN 4138.
Additional Information: Departmental Category: Dynamical Systems and Control

ECEN 5467 (3) Data Analytics and Data-Driven Decision Making for Modern Power and Energy Systems
Focuses on modern power and energy systems with high penetration of distributed energy resources (solar, batteries, electrical vehicles). Analytical methods for inference and decision making in such systems will be covered, including state estimation, forecasting, and optimal control. The emphasis is on data-driven methods, rooted in machine-learning techniques, such as kernel-based regression and reinforcement learning.
Recommended: Prerequisite ECEN 5407 and graduate standing in the College of Engineering and Applied Science.

ECEN 5478 (3) Online Convex Optimization and Learning
Covers basics of convex optimization, online learning, time-varying optimization, online first-order methods, learning problems over networks, zeroth-order methods, bandit optimization, projection-free methods, distributed methods for online convex optimization. Application domains considered in the course include Machine Learning, Signal Processing, and Data-driven Control. Specific application examples include the Internet of Things, recommendation systems, power systems, sensor networks, and transportation systems. Previously offered as a special topics course.
Requisites: Restricted to graduate students only.
Recommended: Prerequisite ECEN 5448.

ECEN 5488 (3) Geometric Control Theory
Introduce geometric approaches to study dynamical control systems over manifolds. Cover fundamental control-theoretical results, such as controllability, observability, feedback stabilizability, symmetries and group actions, that are beyond linear control systems. Establish connections between control theory and mathematics, especially topology, differential geometry, Lie groups and Lie algebras. Final project focuses on engineering applications related to students¿ own research interests.
Equivalent - Duplicate Degree Credit Not Granted: MCEN 5488
Requisites: Restricted to graduate students only.
Recommended: Prerequisites a solid foundation in Linear Algebra and ECEN 4138/5138 and ECEN 5448.

ECEN 5498 (3) Stochastic Control Theory
Introduce a toolbox for dealing with stochastic control systems. Cover topics such as stochastic calculus, linear and nonlinear filtering, and dynamic programming. Discuss system theoretic issues and derive optimal control laws for a variety of stochastic control problems, including, e.g., the separation principle for Linear-quadratic-Gaussian problems. Final project focuses on engineering applications related to students¿ own research interests.
Equivalent - Duplicate Degree Credit Not Granted: MCEN 5498
Requisites: Restricted to graduate students only.
Recommended: Prerequisites a solid foundation in Probability Theory and ECEN 4138/5138, ECEN 5448 and ECEN 5612.

ECEN 5514 (3) Principles of Electromagnetics for High-Speed Digital Engineering
Teaches understanding and application of the theoretical principals of electromagnetics to printed circuit board design. Students learn to apply advanced concepts related to Maxwell¿s equations for SI and PI and High-Speed applications. Some topics covered include: skin effect, surface roughness, non-uniform dielectric constant, coupling, reflection, and losses; boundary conditions and boundary value problems; displacement and conduction currents.
Recommended: Prerequisite students are expected to have completed an electromagnetics course during their undergraduate curriculum; in the CU curriculum it would be ECEN 3400.

ECEN 5517 (3) Power Electronics and Photovoltaic Power Systems Laboratory
Focuses on analysis, modeling, design and testing of electrical energy processing systems in a practical laboratory setting. Studies power electronics converters for efficient utilization of available energy sources, including solar panels and utility. Experimental projects involve design, fabrication and testing of a solar power system.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4517
Requisites: Requires prerequisite course of ECEN 5797 (minimum grade C-).
Additional Information: Departmental Category: Power

ECEN 5523 (3) Compiler Construction
Introduces the principles and techniques for compiling high-level programming languages to assembly code. Topics include parsing, instruction selection, register allocation, and compiling high-level features such as polymorphism, first-class functions, and objects. Students build a complete compiler for a simple language.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4553 and CSCI 4555 and CSCI 5525
Requisites: Restricted to Electrical/Computer Engineering (EEEN) graduate students or Concurrent Degree students in Electrical Engineering (C-EEEN) or Electrical/Computer Engineering (C-ECENEEEN) or to Graduate Certificate Engineering (CRTGE) students.
Additional Information: Departmental Category: Computer and Digital Systems

ECEN 5524 (3) Principles of Computational Electromagnetics for Signal and Power Integrity
Introduces students to practical computational electromagnetics (CEM) and numerical methods concepts necessary for solving SI/PI problems. Fundamentals behind finite difference, finite element, and method of moments are studied to solve problems like a microstrip line and others related to SI-PI applications. Students will study the concepts of accuracy, stability, convergence and boundary conditions as they apply to commercial EM tools.
Recommended: Prerequisite students are expected to have completed an electromagnetics course during their undergraduate curriculum; in the CU curriculum it would be ECEN 3400.

ECEN 5527 (3) Power Electronics Design Laboratory
Create, build, and debug an original design of a power converter to meet given a specification, project schedule, and related requirements. Lectures provide supporting information. Compliance to the specification is shown through a formal test report and demonstration to an instructor.
Requisites: Requires prerequisite courses of ECEN 5517 and ECEN 5797 (all minimum grade B-). Restricted to Electrical and Computer Engineering (ECEN) graduate students with Power Electronics (PPE) subplan only.
Grading Basis: Letter Grade

ECEN 5532 (3) Digital Signal Processing Laboratory
Develops experience in code development, debugging and testing of real-time digital signal processing algorithms using dedicated hardware. Applications include filtering, signal synthesis, audio special effects and frequency domain techniques based on the Fast Fourier Transform.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4532
Additional Information: Departmental Category: Digital Signal Processing Communications

ECEN 5533 (3) Fundamental Concepts of Programming Languages
Considers concepts common to a variety of programming languages--how they are described (both formally and informally) and how they are implemented. Provides a firm basis for comprehending new languages and gives insight into the relationship between languages and machines.
Equivalent - Duplicate Degree Credit Not Granted: CSCI 5535
Requisites: Requires prerequisite course CSCI 3155 (minimum grade D-).
Additional Information: Departmental Category: Computer and Digital Systems

ECEN 5534 (3) Practical Signal Integrity Measurements
Taking accurate measurements are the anchor to reality in all HSDE analysis. This course introduces the three important high speed measurement instruments; the VNA, the TDR and the high-speed oscilloscope. Measurements above 200 MHz bandwidth require special considerations. Topics covered include S-parameter analysis of interconnects, de-embedding, probing methods, measurement-simulation correlation and building circuit topology models from S-parameters.
Requisites: Requires prerequisites ECEN 5224 and ECEN 5730 (all minimum grade C-).
Recommended: Prerequisite students are expected to have completed an electromagnetics course during their undergraduate curriculum; in the CU curriculum it would be ECEN 3400.

ECEN 5543 (3) Software Engineering of Standalone Programs
Applies engineering principles to phases of software product development, project planning, requirements definition, design, design patterns, validation and maintenance. Emphasizes practical methods for communicating and verifying definitions and designs: prototyping, inspections, and modeling (primarily UML). Includes relation to embedded systems and object-oriented design.
Equivalent - Duplicate Degree Credit Not Granted: CSCI 5548
Requisites: Restricted to graduate students only.
Recommended: Prerequisites CSCI 1300 and CSCI 2270 (minimum grade C-).
Additional Information: Departmental Category: Computer and Digital Systems

ECEN 5544 (3) EM Signal Modeling for HSDE using Ansys HFSS and Q3D
Doing high speed digital engineering using HFSS from Ansys. This is a one semester hands-on capstone design course for the high-speed digital engineering professional master¿s program. Students will deepen their understanding of EM signal modeling for HSDE applications while learning how to correctly use HFSS to do a variety of high-speed designs for PCBs.
Requisites: Requires prerequisite course of ECEN 5524 (minimum grade C-).
Recommended: Prerequisite students are expected to have completed an electromagnetics course during their undergraduate curriculum; in the CU curriculum it would be ECEN 3400.

ECEN 5554 (3) Designing PCB Memory Systems using Keysight ADS
Doing high speed digital engineering using ADS from Keysight. This is a one semester hands-on capstone design course for the high-speed digital engineering professional master¿s program. Students will deepen their understanding of EM signal modeling for HSDE PCB memory applications while learning how to correctly use ADS to do a variety of high-speed memory designs for PCBs.
Requisites: Requires prerequisite course of ECEN 5524 (minimum grade C-).
Recommended: Prerequisite students are expected to have completed an electromagnetics course during their undergraduate curriculum; in the CU curriculum it would be ECEN 3400.

ECEN 5555 (3) Principles of Energy Systems and Devices
Develops principles underlying electronic, optical and thermal devices, materials and nanostructures for renewable energy. Provides a foundation in statistical thermodynamics and uses it to analyze the operation and efficiency limits of devices for photovoltaics, energy storage (batteries & ultra-capacitors), chemical conversion (fuel cells and engines), solid state lighting, heat pumps, cooling and potentially harvesting zero-point energy from the vacuum.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4555
Requisites: Restricted to students with 57-180 credits (Juniors or Seniors) or Graduate students only.
Additional Information: Departmental Category: Nanostructures and Devices

ECEN 5565 (3) Advanced Network Systems
Provides an advanced study of network architecture, across the end hosts, the network elements, and the people and systems that manage the network. The course provides the foundation for modern network systems, beyond the basic understanding of the OSI layers, and into the system which make networks work.
Requisites: Requires prerequisite of CSCI 4273 or CSCI 5273 or ECEN 5273 (minimum grade C). Restricted to graduate students in the College of Engineering.
Grading Basis: Letter Grade

ECEN 5573 (3) Advanced Operating Systems
Intended to create a foundation for operating systems research or advanced professional practice. Examines the design and implementation of a number of research and commercial operating systems and their components, system organization and structure, threads, communication and synchronization, virtual memory, distribution, file systems, security and authentication, availability and Internet services.
Equivalent - Duplicate Degree Credit Not Granted: CSCI 5573
Additional Information: Departmental Category: Computer and Digital Systems

ECEN 5592 (3) Modern Signal Processing
Presents a mathematical tour of modern signal processing focusing on sparse signal representations and their applications. Extends classical Fourier transform and traditional digital signal processing techniques to enable various types of computational harmonic analysis. Covers time-frequency and wavelet analysis, filter banks, nonlinear approximation of functions, compression, signal restoration, compressive sensing, and convolutional neural networks.
Recommended: Prerequisites familiarity with Fourier transforms, z-transforms, filters, linear algebra, bases, norms, inner products, eigendecompositions, singular value decomposition (SVD) and MATLAB.

ECEN 5593 (3) Advanced Computer Architecture
Provides a broad-scope treatment of important concepts in the design and implementation of high-performance computer systems. Discusses important issues in the pipelining of a processor, out-of-order instruction issue and superscalar designs, design of cache memory systems and architectural features required for multicore processor designs. Also studies current and historically important computer architectures, including hardware security concepts.
Equivalent - Duplicate Degree Credit Not Granted: CSCI 5593 and ECEN 4693
Requisites: Campus section restricted to graduate students in EEEN or BS/Professional MS concurrent degree students with BS portion in EEEN or ECEN.
Recommended: Prerequisite ECEN 3593, ECEN 5090.
Additional Information: Departmental Category: Computer and Digital Systems

ECEN 5603 (3) Software Project Management
Presents topics and techniques critical to the management of software product development, including estimating, planning, quality, tracking, reporting, team organization, people management and legal issues. Gives special attention to problems unique to software projects.
Requisites: Requires prerequisite courses ECEN 4583 and ECEN 5543 and CSCI 4318 (all minimum grade D-). Restricted to graduate students only.
Additional Information: Departmental Category: Computer and Digital Systems

ECEN 5606 (3) Optics Laboratory
Provides advanced training in experimental optics. Consists of optics experiments that introduce the techniques and devices essential to modern optics, including characterization of sources, photodetectors, modulators, use of interferometers, spectrometers,and holograms and experimentation of fiber optics and Fourier optics. Department enforced prerequisite: undergraduate optics course (e.g. PHYS 4510).
Equivalent - Duplicate Degree Credit Not Granted: PHYS 5606
Additional Information: Departmental Category: Optics

ECEN 5607 (3) Power Electronics for Electrified Transportation
Covers analysis, modeling, control, simulations, and design of electric-drive vehicles and the charging infrastructure. Vehicle system architectures and dynamics are used to determine the requirements and to validate the performance of electric-vehicle drivetrain subsystems. Analysis, modeling, and design of the subsystems are addressed, including battery systems, battery management electronics, dc-dc converters, dc-ac inverters, motor drives, and chargers.
Requisites: Restricted to Electrical/Computer Engineering (EEEN) graduate students or Concurrent Degree students in Electrical Engineering (C-EEEN) or Electrical/Computer Engineering (C-ECENEEEN) or to Graduate Certificate Engineering (CRTGE) students.

ECEN 5612 (3) Random Processes for Engineers
Deals with random time-varying functions and is therefore useful in the broad range of applications where they occur. Topics include review of probability, convergence of random sequences, random vectors, minimum mean-square error estimation, basic concepts of random processes, Markov processes, Poisson processes, Gaussian processes, linear systems with random inputs, and Wiener filtering. Applications range from communications, communication networks, and signal processing to random vibration/stress analysis, mathematical finance, physics, etc.
Additional Information: Departmental Category: Digital Signal Processing Communications

ECEN 5613 (3) Embedded System Design
Introduces system hardware and firmware design for embedded applications. Students independently design and develop a hardware platform encompassing a microcontroller and peripherals. Firmware is developed in C and assembly. A significant final project is designed, developed, documented and presented. Prioritized for EEEN graduate students with ESE (Embedded Systems Engineering) sub-plan.
Requisites: Campus section restricted to CU Boulder graduate students in Academic sub-plans ESE or C-EEENP or C-ECENEEEP.
Additional Information: Departmental Category: Embedded Systems Engineering

ECEN 5616 (3) Optoelectric System Design
Examines optical components and electro-optic devices with the goal of integrating into well design optoelectronic systems. Sample systems include optical storage, zoom lenses and telescopes.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4616
Requisites: Restricted to graduate students only.
Additional Information: Departmental Category: Optics

ECEN 5622 (3) Information Theory and Coding
Covers fundamental limits of data compression, reliable transmission of information and information storage. Topics include information measures, typicality, entropy rates of information sources, limits and algorithms for lossless data compression, mutual information, and limits of information transmission over noisy wired and wireless links. Optional topics include lossy data compression, limits of information transmission in multiple-access and broadcast networks, and limits and algorithms for information storage.
Requisites: Restricted to Electrical/Computer Engineering, Computer Science, Applied Math or Physics graduate students only.
Additional Information: Departmental Category: Digital Signal Processing Communications

ECEN 5623 (3) Real-Time Embedded Systems
Design and build a microprocessor-based embedded system application requiring integration of sensor/actuator devices, a real-time operating system and application firmware and software. Real-time rate monotonic theory and embedded architecture are covered. Prioritized for EEEN graduate students with ESE (Embedded Systems Engineering) sub-plan.
Requisites: Campus section restricted to CU Boulder graduate students in Academic sub-plans ESE or C-EEENP or C-ECENEEEP.
Additional Information: Departmental Category: Embedded Systems Engineering

ECEN 5626 (3) Active Optical Devices
Analysis of active optical devices such as semiconductor laser, detector and flat panel display by clearly defining and interconnecting the fundamental physical mechanism, device design and operating principles and device performance.
Requisites: Restricted to graduate students only.
Recommended: Prerequisite ECEN 5355.
Additional Information: Departmental Category: Optics

ECEN 5632 (3) Theory and Application of Digital Filtering
Digital signal processing and its applications are of interest to a wide variety of scientists and engineers. The course covers such topics as characterization of linear discrete-time circuits by unit pulse response, transfer functions, and difference equations, use of z-transforms and Fourier analysis, discrete Fourier transform and fast algorithms (FFT), design of finite and infinite impulse response filters, frequency transformations, study of optimized filters for deterministic signals.
Requisites: Restricted to Electrical/Computer Engineering (EEEN) graduate students or Concurrent Degree students in Electrical Engineering (C-EEEN) or Electrical/Computer Engineering (C-ECENEEEN) or to Graduate Certificate Engineering (CRTGE) students.
Additional Information: Departmental Category: Digital Signal Processing Communications

ECEN 5634 (3) Microwave and RF Laboratory
This course is a hands-on introduction to RF and microwave topics, from fundamentals including vector network analyzer (VNA) calibration and operation, power measurements, and antenna characterization, to system-level topics such as RADAR systems and superheterodyne links. Students work in small groups on weekly experiments based on both coaxial and waveguide setups. An understanding of electromagnetic waves (such as covered in ECEN 3400 and ECEN 3410) is assumed.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4634
Requisites: Restricted to any graduate students or Electrical/Computer Engineering or Electrical Engineering Concurrent Degree majors only.
Additional Information: Departmental Category: Electromagnetics and Remote Sensing

ECEN 5638 (3) Control Systems Laboratory
Provides experience in control system design and analysis, using both real hardware and computer simulation. Covers the entire control system design cycle: modeling the system, synthesizing a controller, conducting simulations, analyzing the design to suggest modifications and improvements, and implementing the design for actual testing.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4638
Requisites: Requires prerequisite course of ECEN/MCEN 4138/5138 (minimum grade D-). Restricted to graduate students only.

ECEN 5645 (3) Introduction to Optical Electronics
Introduces lasers, Gaussian optics, modulators, nonlinear optics, optical detectors, and other related devices.
Requisites: Restricted to graduate students only.
Additional Information: Departmental Category: Nanostructures and Devices

ECEN 5652 (3) Detection and Extraction of Signals from Noise
Introduces detection, estimation, and related algorithms. Topics in detection include simple/composite hypothesis testing, repeated observations and asymptotic performance and sequential detection. Topics in estimation include Bayesian estimation including minimum mean-square estimation and non-random parameter estimation. Topics in algorithms vary. Examples include algorithms for state estimation and smoothing in Hidden Gauss-Markov models and the expectation-maximization algorithm. Applications include communications, radar/sonar/geophysical signal processing, image analysis, authentication, etc.
Requisites: Restricted to Electrical/Computer Engineering, Computer Science, Applied Math or Physics graduate students only.
Additional Information: Departmental Category: Digital Signal Processing Communications

ECEN 5672 (3) Digital Image Processing
Course objective is to present the fundamental techniques available for image representation and compression (e.g., wavelets), filtering (e.g., Wiener and nonlinear filter), and segmentation (e.g., anisotropic diffusion).
Requisites: Requires prerequisite course ECEN 5632 (minimum grade C-).
Additional Information: Departmental Category: Digital Signal Processing Communications

ECEN 5673 (3) Distributed Systems
Examines systems that span multiple autonomous computers. Topics include system structuring techniques, scalability, heterogeneity, fault tolerance, load sharing, distributed file and information systems, naming, directory services, resource discovery, resource and network management, security, privacy, ethics and social issues.
Equivalent - Duplicate Degree Credit Not Granted: CSCI 5673
Recommended: Prerequisite CSCI 5573 or a course in computer networks.
Additional Information: Departmental Category: Computer and Digital Systems

ECEN 5678 (3) Control of Multi-agent Systems
Covers basics of matrix theory and graph theory; distributed averaging and consensus methods on graphs; parallel computation of fixed points; basics of optimization; parallel and distributed optimization methods over graphs; convergence analysis. The techniques and methodologies presented in the course are introduced through application setups including Internet of Things, power and energy systems, sensor networks, transportation systems, and social networks. Previously offered as a special topics course.
Requisites: Restricted to graduate students only.
Recommended: Prerequisites ECEN 5448 and courses in convex optimization.

ECEN 5682 (3) Theory and Practice of Error Control Codes
Introduces error control coding techniques for reliable transmission of digital data over noisy channels. Topics include algebraic characterizations of cyclic codes, convolutional codes, modern graph codes, decoding algorithms for block codes, Viterbi algorithm and iterative decoding on graphs. Applications include modern digital communication and storage systems including deep space communications, satellite broadcasting, cellular networks, and optical disk storage.
Requisites: Restricted to Electrical/Computer Engineering (EEEN) graduate students or Concurrent Degree students in Electrical Engineering (C-EEEN) or Electrical/Computer Engineering (C-ECENEEEN) or to Graduate Certificate Engineering (CRTGE) students.
Additional Information: Departmental Category: Digital Signal Processing Communications

ECEN 5692 (3) Principles of Digital Communication
Introduces fundamental principles of efficient and reliable transmission of information used in wired and wireless digital communication systems including cable modems, smart phones/tablets, cellular networks, local area (wi-fi) networks, and deep-space communications. Topics include bandwidth and power constraints, digital modulation methods, optimum transmitter and receiver design principles, error rate analysis, channel coding potential in wired/wireless media, trellis coded modulation, and equalization.
Requisites: Restricted to Electrical/Computer Engineering (EEEN) graduate students or Concurrent Degree students in Electrical Engineering (C-EEEN) or Electrical/Computer Engineering (C-ECENEEEN) or to Graduate Certificate Engineering (CRTGE) students.
Additional Information: Departmental Category: Digital Signal Processing Communications

ECEN 5696 (3) Fourier Optics
Introduces a system level approach to the analysis and design of optical systems. Topics include holography, Fourier transform properties of lenses, two-dimensional convolution and correlation functions, spatial filtering and optical computing techniques. Also covers coherent and incoherent imaging techniques, tomography, and synthetic aperture imaging.
Requisites: Restricted to graduate students only.
Recommended: Prerequisites ECEN 3300 and ECEN 3410.
Additional Information: Departmental Category: Optics

ECEN 5712 (3) Machine Learning for Engineers
Prepares students to apply/improve machine learning methods for engineering applications and to perform related research. Covers popular algorithms and theories for learning from data, e.g., supervised learning, unsupervised learning, online learning, neural networks, VC-dimension, PAC learning theory. Explores the connections with detection/estimation theory and information theory. The course project focuses on engineering applications related to students¿ majors.
Recommended: Prerequisites ECEN 5612, 5652 and 5622.

ECEN 5713 (3) Advanced Embedded Software Development
Building on fundamentals taught in ECEN 5813 PES, this course teaches more advanced programming principles for embedded systems that are implemented with the use of an embedded operating system. Topics include Linux kernel space and user programming, driver design, multi-threaded programming, and operating systems fundamentals, software design patterns, sound development methods and practices, and use of debugging and performance tools to create applications and enhance operating systems' services embedded system prototypes and products.
Requisites: Requires prerequisite course of ECEN 5813 (minimum grade D-). Restricted to students with an Embedded Systems Engineering (ESE) subplan or Electrical Engr-Prof Degree (C-EEENP) or Elec CmpElec Eng-Prof Degree (C-ECENEEEP) only.
Recommended: Prerequisites This course assumes students have direct coding and tool experience including C-programming Bare Metal Firmware Design, Compilation with GCC & Build Systems with GNU Make, Git, Linux command line operations, shell environment, compilation, Lab instruments, DVM, Logic Analyzer, Oscilloscope or demonstration of portable, maintainable, and testable software design.

ECEN 5720 (1) Practical Printed Circuit Board Design Accelerator
This course introduces students to the most important skills needed to convert a back-of-the-napkin circuit sketch into a working widget with first time success. Students will learn the seven steps in every board project: planning, selecting components, schematic entry, layout, assembly, bring up and debug, and documentation. This process will be exercised with a custom board design project. A commercial EDA tool widely used in the electronics industry will be used for the project. Previously offered as a special topics course.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4730 or ECEN 5730 ECEN 4720
Recommended: Prerequisites ECEN 2250 and ECEN 2260 and ECEN 2270.

ECEN 5730 (3) Practical Printed Circuit Board Design and Manufacture
This course prepares students with all skills needed to convert a back-of-the-napkin circuit sketch into a working widget with first time success. Students will master the seven steps in every board project: planning, selecting components, schematic entry, layout, assembly, bring up and debug, and documentation. This process will be exercised with three different board design projects with increasing challenge. A commercial EDA tool widely used in the electronics industry will be used for all projects. Previously offered as a special topics course. Degree credit not offered for this course and ECEN 4720 or ECEN 5720 or ECEN 3730.
Recommended: Prerequisites ECEN 2250 and ECEN 2260 and ECEN 2270.

ECEN 5737 (3) Adjustable-Speed AC Drives
Presents unified treatment of complete electrical drive systems: mechanical load, electrical machine, power converter, and control equipment. Emphasizes induction, synchronous, and permanent-magnet drives. Uses simulation programs (e.g., SPICE, Finite Element/Difference Program) to simulate drive system components (e.g., gating, inverter, electric machine).
Requisites: Restricted to Electrical/Computer Engineering (EEEN) graduate students or Concurrent Degree students in Electrical Engineering (C-EEEN) or Electrical/Computer Engineering (C-ECENEEEN) or to Graduate Certificate Engineering (CRTGE) students.
Recommended: Prerequisite ECEN 3170.
Additional Information: Departmental Category: Power

ECEN 5738 (3) Theory of Nonlinear Systems
Nonlinear systems and control. Introduction to nonlinear phenomena: multiple equilibria, limit cycles, bifurcations, complex dynamical behavior. Planar dynamical systems, analysis using phase plane techniques. Input-output analysis and stability. Passivity. Lyapunov stability theory. Feedback linearization. Exploration of examples and applications. Formerly ECEN 7438.
Requisites: Requires prerequisite course of ECEN 5448 (minimum grade C-). Restricted to graduate students only.
Recommended: Prerequisite knowledge in differential equations.
Additional Information: Departmental Category: Dynamical Systems and Control

ECEN 5752 (3) Communication Laboratory
Analysis and design of realistic communication signals in a modern digital signal processing environment. Covers both analog and digital communication signals with and without noise and distortion. Pulse amplitude modulation is used initially at baseband and then combined with amplitude and phase/frequency modulation to produce the kind of bandpass signals that are used in cell phones and wireless data networks.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4752
Requisites: Requires prerequisite course of ECEN 4242 (minimum grade C-). Restricted to College of Engineering majors only.

ECEN 5753 (3) Computer Performance Modeling
Presents a broad range of system modeling techniques, emphasizing applications to computer systems. Covers stochastic processes, queuing network models, stochastic Petri nets and simulation (including parallel processing techniques). Also requires second-semester calculus.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4753 and CSCI 4753 and CSCI 5753
Additional Information: Departmental Category: Computer and Digital Systems

ECEN 5763 (3) Embedded Machine Vision and Intelligent Automation
Introduces students to machine vision and machine learning methods used in automation, autopilots and security and inspection systems. Embedded and automation topics include implementation of algorithms with FPGA or GP-GPU embedded real time co-processing for autopilots (intelligent transportation), general automation and security including methods for detection, classification, recognition of targets for inspection, surveillance, search and rescue, and machine vision navigation applications.
Requisites: Campus section restricted to CU Boulder graduate students in Academic sub-plans ESE or C-EEENP or C-ECENEEEP.
Grading Basis: Letter Grade
Additional Information: Departmental Category: Embedded Systems Engineering

ECEN 5773 (3) Developing the Industrial Internet of Things
This course goes beyond consumer IoT hype to emphasize a much greater space for potential embedded system applications and growth: The Industrial Internet of Things (IIoT), also known as Industry 4.0. Cisco¿s CEO stated: ¿IoT overall is a $19 Trillion market. IIoT is a significant subset including digital oilfield, advanced manufacturing, power grid automation, and smart cities¿. The course examines emerging markets, technology trends, applications and skills required for exploring career opportunities in this space.
Requisites: Restricted to students with an Embedded Systems Engineering (ESE) subplan or Electrical Engr-Prof Degree (C-EEENP) or Elec Cmp Elec Eng-Prof Degree (C-ECENEEENP) only.
Recommended: Prerequisites ECEN 5613, ECEN 5823, ECEN 5053, and ECEN 5133.

ECEN 5783 (3) Embedded Interface Design
This course deeply explores interface design approaches and architectures for creating embedded system prototypes and products. For both machine and user interfaces, we will examine best practices for the interface design process, including considerations of characteristics of the information to be transferred between devices or between a device and a user. Projects leverage the now standard Raspberry Pi 3 single-board computer (SBC), providing a strong foundation for exploring many elements of interface design.
Requisites: Restricted to students with an Embedded Systems Engineering (ESE) subplan or Electrical Engr-Prof Degree (C-EEENP) or Elec Cmp Elec Eng-Prof Degree (C-ECENEEENP) only.
Recommended: Prerequisites knowledge of programming, particularly Python, ECEN 2120, ECEN 2350, ECEN 1030, ECEN 1310, CSCI 1300.

ECEN 5793 (3) Secure Computer Architecture
Explore cutting-edge secure architectures that look to protect the system from the hardware up. This course covers advanced topics in security with an emphasis on computer architecture on both the attack and defense sides. Discussion oriented classes will deepen understanding of weekly technical reading assignments, enhance the ability to analyze technical papers, and help carry out a semester long research project.
Requisites: Requires prerequisite or corequisite course of ECEN 5593 (minimum grade D-).

ECEN 5797 (3) Introduction to Power Electronics
An introduction to switched-mode converters. Includes steady-state converter modeling and analysis, switch realization, discontinuous conduction mode and transformer-isolated converters. Ac modeling of converters using averaged methods, small-signal transfer functions, feedback loop design and transformer design.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4797
Requisites: Restricted to Electrical/Computer Engineering (EEEN) graduate students or Concurrent Degree students in Electrical Engineering (C-EEEN) or Electrical/Computer Engineering (C-ECENEEEN) or to Graduate Certificate Engineering (CRTGE) students.
Additional Information: Departmental Category: Power

ECEN 5803 (3) Mastering Embedded Systems Architecture
Acquire an understanding of embedded systems architectures for the purpose of creating prototypes or products for a variety of applications. The salient issues in the decision making process will be examines, including trade-offs between hardware and software implementations, processor and operating system selection and IP creation or acquisition. Projects will involve the latest software development and tools and hardware platforms.
Requisites: Campus section restricted to CU Boulder graduate students in Academic sub-plans ESE or C-EEENP or C-ECENEEEP.
Grading Basis: Letter Grade
Additional Information: Departmental Category: Embedded Systems Engineering

ECEN 5807 (3) Modeling and Control of Power Electronic Systems
Studies modeling and control topics in power electronics. Averaged switch modeling of converters, computer simulation, ac modeling of the discontinuous conduction mode, the current programmed mode, nulldouble injection techniques in linear circuits, input filter design, and low-harmonic rectifiers.
Requisites: Requires prerequisite course of ECEN 5797 (minimum grade C-).
Additional Information: Departmental Category: Power

ECEN 5813 (3) Principles of Embedded Software
Introduces principles around embedded software elements and software development needed for the Embedded Systems Engineering core curriculum. Student will write C program applications hat employ efficient, high performance and robust software design techniques. Topics include bare-metal firmware, c-programming optimization and introductions to underlying embedded architecture. Sound testing and debug practices will be instilled and utilized in several application projects.
Requisites: Campus section restricted to CU Boulder graduate students in Academic sub-plans ESE or C-EEENP or C-ECENEEEP.
Grading Basis: Letter Grade
Additional Information: Departmental Category: Embedded Systems Engineering

ECEN 5817 (3) Resonant and Soft-Switching Techniques in Power Electronics
Covers resonant converters and inverters, and soft switching; sinusoidal approximations in analysis of series, parallel, LCC, and other resonant dc-dc and dc-ac converters; state-plane analysis of resonant circuits; switching transitions in hand-switched and soft-switched PWM converters; zero-voltage switching techniques, including resonant, quasi resonant, zero voltage transition, and auxiliary switch circuits.
Requisites: Requires prerequisite course of ECEN 5797 (minimum grade C-).
Additional Information: Departmental Category: Power

ECEN 5821 (3) Neural Systems and Physiological Control
A biophysical exploration of human physiology from the standpoints of control systems and neural information processing. Topics include: neural control of movement and cardiovascular performance, tissue growth and repair, carcinogenesis, and physiological responses to microgravity.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4821 and ASEN 4426 and ASEN 5426
Additional Information: Departmental Category: Bioengineering

ECEN 5823 (3) Internet of Things Embedded Firmware
Acquire firmware development skills to meet low energy and internet connectivity demands of embedded systems. Event-driven firmware techniques will be explored through programming assignments, transitioning to programming an Internet of Things RF Network Protocol such as Bluetooth Low Energy or Thread. The coursework will align with the latest industry firmware and embedded wireless protocol trends.
Requisites: Campus section restricted to CU Boulder graduate students in Academic sub-plans ESE or C-EEENP or C-ECENEEEP.
Grading Basis: Letter Grade
Additional Information: Departmental Category: Embedded Systems Engineering

ECEN 5827 (3) Analog IC Design
Covers the fundamentals of transistor-level analog integrated circuit design. Starting with motivations from application circuits, the course develops principles of dc biasing, device models, amplifier stages, frequency response analysis and feedback and compensation techniques for multi-stage operational amplifiers.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4827
Requisites: Restricted to Electrical/Computer Engineering (EEEN) graduate students or Concurrent Degree students in Electrical Engineering (C-EEEN) or Electrical/Computer Engineering (C-ECENEEEN) or to Graduate Certificate Engineering (CRTGE) students.
Additional Information: Departmental Category: Power

ECEN 5828 (3) Hybrid Dynamical Systems: Theory and Applications
Students will study the basic properties of differential and difference equations and inclusions including: existence of solutions, uniqueness, invariance principles; introduction to basic hybrid systems that combine continuous-time and discrete-time dynamics: automata, switched systems, etc.; Lyapunov theory for hybrid systems; and examples and applications in the areas of optimization, feedback control, machine learning, energy systems, social networks, multi-agent systems, and asynchronous systems. Previously offered as a special topics course.
Requisites: Restricted to graduate students only.

ECEN 5830 (3) Special Topics
Examines a special topic in Electrical, Computer and Energy Engineering.
Repeatable: Repeatable for up to 9.00 total credit hours. Allows multiple enrollment in term.
Additional Information: Departmental Category: General

ECEN 5833 (3) Low Power Embedded Design Techniques
The course explores through weekly quizzes, assignments, and a course project, low energy hardware design concepts, selecting components to meet reliability goals, radio implementation, power supply design, product design, and system bring up. The programming of the microcontroller or SoC will most likely be ¿coding to the metal¿ to control individual microcontroller peripherals and utilizing them in the most energy efficient ways.
Requisites: Restricted to students with an Embedded Systems Engineering (ESE) subplan or Electrical Engr-Prof Degree (C-EEENP) or Elec Cmp Elec Eng-Prof Degree (C-ECENEEENP) only.
Recommended: Requisites Students should have knowledge of assembly and C programming, digital logic design, and embedded computer architecture, and have had at least one course in each of these subjects, such as ECEN 5813 or ECEN 5823, students should also have experience using a microcontroller Integrated Development Environment (IDE) and its associated tools including its debugger and register views.

ECEN 5837 (3) Mixed-Signal IC Design Lab
Software laboratory course extends the concepts developed in ECEN 5827 to full design and layout of mixed analog and digital custom integrated circuits. Assignments explore implementation of analog to digital and digital to analog converters, and final project developes a full custom IC for a target application.
Requisites: Requires prerequisite course of ECEN 5827 (minimum grade C-).
Additional Information: Departmental Category: Power

ECEN 5840 (1-6) Independent Study
Offers an opportunity for students to do independent, creative work at the master's level. Numbered ECEN 5840-5849. Department consent required.
Repeatable: Repeatable for up to 6.00 total credit hours.
Additional Information: Departmental Category: General

ECEN 5853 (3) Embedding Sensors and Motors
Introduces students to the design of sensors and motors, and methods that integrate them into embedded systems used in consumer and industrial products. Students will learn about sensor technologies and motors through lectures, recorded and online videos, online reading, and through laboratory experiments. Students will build systems that take sensor inputs, and sort, filter and evaluate the resulting data. They will also learn how to use sensor input to measure properties of motors.
Requisites: Restricted to students with an Embedded Systems Engineering (ESE) subplan or Electrical Engr-Prof Degree (C-EEENP) or Elec Cmp Elec Eng-Prof Degree (C-ECENEEENP) only.
Recommended: Prerequisites ECEN 1400, ECEN 2250, ECEN 2260 and ECEN 2440 or equivalent coursework.

ECEN 5857 (3) Digital Control for Power Electronics
Focuses on analysis, modeling and design of digitally controlled power converters. Covers the dynamical discrete-time analysis of power converters, digital compensator design and main nonlinear phenomena due to quantization effects. Addresses the basics of controller autotuning.
Requisites: Requires prerequisite course of ECEN 5797 (minimum grade C-).

ECEN 5863 (3) Programmable Logic Embedded System Design
Learn to design programmable systems on a chip for the purpose of creating prototypes or products for a variety of applications. Explore complexities, capabilities and trends of Field Programmable Gate Arrays (FPGA) and Complex Programmable Logic Devices (CPLD). Implement synchronization and timing closure in these devices. Projects will involve the latest software and FPGA development tools and hardware platforms.
Requisites: Campus section restricted to CU Boulder graduate students in Academic sub-plans ESE or C-EEENP or C-ECENEEEP.
Grading Basis: Letter Grade
Additional Information: Departmental Category: Embedded Systems Engineering

ECEN 5907 (3) Special Topics
Special topics class.
Repeatable: Repeatable for up to 3.00 total credit hours. Allows multiple enrollment in term.

ECEN 5915 (3) Foundations of Quantum Engineering
Introduces engineers to quantum theory. In this course you will learn how to describe many different physical systems (such as atoms, electrons, light, mechanical oscillators, and tops) mathematically. It also explores different notions of quantumness such as entanglement and non-contextuality. The foundations obtained in this course are important for further study of quantum hardware (sensors), communication, and computing.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 3915

ECEN 5925 (3) Foundations of Quantum Hardware
Introduces students to the principles and operation of quantum hardware. In this course you will learn how to describe many different physical systems (trapped Ions, superconducting circuits, and optical systems) mathematically. This will allow you to model quantum sensors, communication systems and computing hardware.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4295

ECEN 5930 (1-3) Industry Internship
This class provides a structure for ECEE graduate students to receive academic credit for internships with industry partners that have an academic component to them suitable for graduate-level work. Participation in the program will consist of an internship agreement between a student and an industry partner who will employ the student in a role that supports the academic goals of the internship. Instructor participation will include facilitation of mid-term and final assessments of student performance as well as support for any academic-related issues that may arise during the internship period. May be taken during any term following initial enrollment and participation in ECEE graduate programs.
Repeatable: Repeatable for up to 3.00 total credit hours.
Grading Basis: Letter Grade

ECEN 5933 (3) Engineering Genetic Circuits
Presents recent research into methods and software tools for the modeling, analysis, and design of genetic circuits that are enabling the new field of synthetic biology. Teaches both biological and engineering principles in order to enable collaborations between engineers and biologists working in the field of synthetic biology.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 4933
Recommended: Prerequisite some familiarity with genetics, cell biology, molecular biology, or biochemistry or familiarity with engineering methods for modeling, analysis and design, but students are not expected to have knowledge in both.

ECEN 6016 (1-3) Special Topics
Additional Information: Departmental Category: Optics

ECEN 6106 (3) Numerical Methods in Photonics
Teaches students how to create and use their own computational techniques to explore optical physics, devices and systems. Learning is project-based, that is no traditional homework or exams are used. Instead, students write their own series of different numerical tools such as finite difference time domain and Fourier beam propagation. Previously offered as a special topics course.
Requisites: Restricted to graduate students only.
Recommended: Prerequisite ECEN 5696 Fourier Optics or equivalent and some familiarity with a numerical programming language such as Matlab is strongly recommended.

ECEN 6139 (3) Logic Synthesis of VLSI Systems
Studies synthesis and optimization of sequential circuits, including retiming transformations and don't care sequences. Gives attention to hardware description languages and their application to finite state systems. Also includes synthesis for testability and performance, algorithms for test generation, formal verification of sequential systems, and synthesis of asynchronous circuits.
Recommended: Prerequisites ECEN 5139 and CSCI 5454.
Additional Information: Departmental Category: VLSI CAD Methods

ECEN 6144 (3) Electromagnetic Boundary Problems
Provides mathematical and physical fundamentals necessary for the systematic analysis of electromagnetic fields problems. Covers basic properties of Maxwell's equations, potentials and jump conditions; scattering and diffraction by canonical structures; Green's functions, integral equations and approximate methods. Requires some maturity in electromagnetics.
Requisites: Requires prereq course of ECEN 5114 or 5134 (minimum grade C-). Restricted to graduate students in Electrical Engr (EEEN) or Electrical/Computer Engr (ECEN) or Electrical Engr Concurrent or Electrical/Computer Engr Concurrent Degree students only.
Additional Information: Departmental Category: Electromagnetics and Remote Sensing

ECEN 6800 (3) Master of Engineering Report
Additional Information: Departmental Category: General

ECEN 6940 (1) Master's Candidate for Degree
Registration intended for students preparing for a thesis defense, final examination, culminating activity, or completion of degree.
Additional Information: Departmental Category: General

ECEN 6950 (1-6) Master's Thesis
Repeatable: Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.
Additional Information: Departmental Category: General

ECEN 6960 (3) Master of Engineering Project
Additional Information: Departmental Category: General

ECEN 7840 (1-6) Independent Study
Offers an opportunity for students to do independent, creative work at the doctoral level. Department consent required.
Repeatable: Repeatable for up to 6.00 total credit hours.
Additional Information: Departmental Category: General

ECEN 7849 (1-6) Independent Study
Offers an opportunity for students to do independent, creative work at the doctoral level. Department consent required.
Repeatable: Repeatable for up to 6.00 total credit hours.
Additional Information: Departmental Category: VLSI CAD Methods

ECEN 8990 (1-10) Doctoral Dissertation
Repeatable: Repeatable for up to 10.00 total credit hours.
Additional Information: Departmental Category: General