



2008-2009 Undergraduate Bulletin

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Contact

☰ Timothy Prickel
Registrar
(812) 877- 8438

Course Descriptions - Electrical and Computer Engineering

Professors C. Berry, F. Berry, Black, Doering, Eccles, Grigg, Herniter, Hoover, Hudson, Moore, Mu, Padgett, Radu, Rostamkolai, Simoni, Song, Throne, D. Walter, P. Walter, Wheeler, and Yoder.

ECE 130 Introduction to Logic Design 4R-0L-4C F,W,S Pre: None

Combinational logic analysis and design, Boolean algebra, gate-level optimization, switch-level circuits, propagation delay, and standard combinational components. Sequential circuit analysis and design, flip-flops, timing diagrams, registers, counters, and finite state machine controllers. Design projects using circuit simulator and implementation in hardware.

ECE 160 Engineering Practice 0R-4L-2C F, W Pre: none

The principles of system engineering design and teamwork are used by student teams as they design, test, and build an autonomous robot to meet a set of performance specifications. An end-of-term competition for testing the robots performance to meet the design specifications and for honor and glory features exciting matchups between teams. Students and instructors are encouraged to have fun throughout the course!

ECE 200 Circuits & Systems 3R-3L-4C F,W,S Pre: ES 203 with a grade of C or better, MA 221

Mutual inductance. First- and second-order circuits. Laplace transform. Applications in the s-domain. Bode diagrams. Passive and active filters. Two-port networks. Integral laboratory includes circuit design problems.

ECE 203 DC Circuits 3R-3L-4C F, W, S Pre: MA111 and PH112

Definition of voltage, current, energy and power. Ohm's Law. Non-ideal dc voltage and current sources. Measurement of voltage, current and resistance. Kirchhoff's Laws. Circuit simplification by series and parallel reduction. Thevenin, Norton and Maximum Power Theorems. Superposition Theorem. Mesh and Nodal Analysis. Two-Port Circuits. Operational Amplifiers. Integral laboratory.

ECE 204 AC Circuits 3R-3L-4C F, W, S Pre: ECE203 with a grade of C or better and PH113

Capacitance, Self and Mutual Inductance. Root-mean-square values of waveforms. Application of phasors to sinusoidal steady-state. Impedance of circuit elements. Mesh and Nodal Analysis applied to ac circuits. Thevenin and Norton theorems applied to ac circuits. Single-phase ac power. Power factor correction. Voltage regulation and efficiency of feeders. Balanced three-phase systems. Ideal and non-ideal transformer models. Integral laboratory.

ECE 205 Dynamical Systems 3R-3L-4C F, W, S Pre: ECE204 and MA222

Review of matrix and differential equations. Bode plots. System classification, impulse and step response, convolution. Laplace and inverse Laplace transforms, block and signal flow diagrams. Benefits of feedback. Modeling and simulating electrical, mechanical, and thermal systems. Matlab and Simulink. Integral laboratory.

ECE 206 Elements of Electrical Engineering 4R-0L-4C F,W,S Pre: MA 221

A course designed for engineers (other than electrical or computer) covering analysis of passive DC circuits, introduction to op-amps, steady-state sinusoidal circuit analysis and power in AC systems. EE or CPE majors may not take this course as a free elective.

ECE 207 Electrical Engineering 3R-3L-4C F,W Pre: ES 203

A course designed for engineers (other than electrical or computer) covering AC power, three-phase systems, magnetic circuits, transformers, machines, strain gauges, RTDs and thermocouples, noise and shielding, and feedback systems. Integral laboratory. EE or CPE majors may not take this course as a free elective.

ECE 230 Microcontrollers and Computer Architecture 3R-3L-4C F, W, S Pre: ECE130, CSSE120

Microcontroller architecture, instruction sets, assembly language programming, interrupts, and device interfacing. Integral laboratory and design project.

ECE 250 Electronic Device Modeling 3R-3L-4C F,W,S Pre: ECE 200, MA 222

Modeling, analysis, and simulation of electronic circuits that contain two-terminal and three-terminal semiconductor devices. Large-signal, biasing, and small-signal analysis models. Introduction to wave shaping circuits, switching circuits, and amplifiers. Integral laboratory.

ECE 300 Signals & Systems 3R-3L-4C F,W,S Pre: MA 222, ECE 200

System and signal modeling. Convolution. Fourier series and Fourier transforms. Filters. Sampling. Use of numerical analysis software. Integral laboratory.

ECE 310 Communication Systems 3R-3L-4C F,S Pre: ECE 300

Transmission of information over bandlimited, noisy communication channels. Line codes, probability of error, intersymbol interference. Modulation techniques, synchronization and frequency conversion. Discussion of a current ethical issue. Integral laboratory.

ECE 320 Linear Control Systems 3R-3L-4C F,W,S Pre: ECE 200 or ECE207

Analysis of linear control systems using classical and modern control theories. Plant representation, closed loop system representation, time response, frequency response, concept of stability, and root locus method. Computer modeling and simulation of feedback systems. Integral laboratory.

ECE 331 Embedded System Design 3R-3L-4C F,S Pre: CSSE 232, ECE 250

Microcontroller architecture. Software development in both assembly language and the C programming language. Real-time event measurement and generation. Interrupt design and applications. Interfacing with peripheral digital and analog devices. Integrated development and debugging environment. Design and implementation of embedded systems for control, measurement, and display, etc. Integral laboratory. Credit cannot be obtained for both ECE 331 and ECE 430.

ECE 332 Computer Architecture II 4R-0L-4C F,S Pre: CSSE 232

Pipelining, memory hierarchy, busses, instruction level parallelism, cost-performance tradeoffs, and review of new topics in areas of computer architecture or parallel processing. Team research project. Complements CS 332.

ECE 333 Digital Systems 3R-3L-4C F,W,S Pre: ECE 130, ECE 250

Capabilities and limitations of digital CMOS logic devices. Design and evaluation of combinational and sequential logic circuits using Programmable Logic Devices. System integration with multiple components (FPGA, GAL, discrete components). CAD tools for design entry, timing simulation, and mapping to target devices. Troubleshooting using laboratory instrumentation. Laboratory notebooks. Informal reports. Integral laboratory.

ECE 340 Electromagnetic Fields 4R-0L-4C F,W Pre: ES 203, MA 222

Static and dynamic fields. Electric and magnetic properties of materials. Energy, force and power. Resistors, capacitors, and inductors. Application in sensing and actuation. Maxwell's equations. Introduction to electromagnetic waves. Use of vector calculus and numeric approximation. Technical reports and/or term papers.

ECE 341 Electromagnetic Waves 4R-0L-4C W,S Pre: ECE 340

Wave propagation and reflection. Power and lossy materials. Quasistatic analysis. Steady-state and transient analysis of transmission lines. Application in high-speed systems. Introduction to antennas. Technical reports and/or term papers.

ECE 342 Introduction to Electromagnetic Compatibility 3R-3L-4C F,W Pre: ECE 300 and Computer Engineering Major

Electromagnetic compatibility (EMC) regulations and measurement. Frequency behavior of passive components. Electromagnetic fields and waves. Transient behavior of transmission lines. Dipole and monopole antennas. Four coupling mechanisms: electrical and magnetic fields, common impedance, and electromagnetic wave. Conducted emissions. Radiated emissions. Electromagnetic shielding and grounding.

ECE 351 Analog Electronics 3R-3L-4C F,W,S Pre: ECE 250

Amplifier design and analysis including discrete and integrated circuit topologies. Cascaded amplifier, input and output stages, frequency response. Linear and non-linear op-amp circuits. Introduction to the non-ideal properties of op-amps. Integral laboratory.

ECE 361 Engineering Practice 1R-3L-2C F,W Pre: ECE 200

Creativity, project design specifications, team roles, effective conduct of team meetings, written and oral communication skills, ethics and professionalism, completion of team project(s).

**ECE 362 Principles of Design 3R-0L-3C W, S
Pre for EE: ECE160, ECE250, ECE300, ECE340
Pre for CPE: ECE160, ECE250, ECE300**

A formal design course that emphasizes the design process. Project management, project reporting and decision-making are learned by student teams as they carry a project through several stages of a formal design process.

ECE 370 Power & Energy Systems 3R-1L-4C F, W Pre: ECE204

Analysis of generation systems consisting of: modeling of synchronous and induction generators, examination of fossil, nuclear, hydroelectric, solar, wind, and fuel cell technologies. Analysis of transmission and distribution systems consisting of modeling: power transformers, transmission lines, switchgear, and protection systems. Analysis of customer systems consisting of modeling: induction motors, linear and non-linear loads.

ECE 371 Sustainable Energy Systems 3R-3L-4C F, W Pre: ECE204

Conventional and modern sources of energy for power generation in electric power industry with the imposed economic, regulatory, and environmental constraints. Wind, solar-photovoltaic, micro-hydropower, and fuel cell systems. Integral laboratory.

ECE 380 Discrete Time & Continuous Systems 4R-0L-4C W,S Pre: ECE 300

System properties: linearity and time-invariance. Sampling and reconstruction. Convolution in discrete-time systems. Z-transform, FIR and IIR filters. Discrete-time filter design. Discrete Fourier transform.

ECE 398 Undergraduate Projects 1-4C Arranged Pre: Consent of instructor

Special design or research projects.

ECE 410 Communication Networks 4R-0L-4C Pre: Senior standing or consent of instructor

Layered architectures. Circuit and packet switching. ISO Reference Model. Point-to-point protocols, error control, framing. Accessing shared media, local area networks. Virtual circuits, datagrams, routing, congestion control. Reliable message transport, internetworking.

ECE 412 Software Defined Radio 4R-0L-4C S Pre: ECE 380 and ECE 310 or consent of instructor

A software-defined radio (SDR) is characterized by its flexibility: Simply modifying software can completely change the radio's functionality. This course addresses many of the choices an SDR designer must make to build a complete digital radio. Topics could include: modeling corruption, (de)modulation, AGC, filtering, bits to symbols, carrier and timing recovery, pulse shaping, equalization, coding, noise figure for the RF front-end, and clock-jitter of the A/D. As a course project students will design and simulate a complete software-defined radio.

ECE 414 Wireless Systems 4R-0L-4C Pre: ECE 310

Introduction to mobile radio communications with application to cellular telephone systems, wireless networks, and personal communication systems. System design, propagation, modulation, spread spectrum, coding, and multiple-access techniques.

ECE 415 Wireless Electronics 2R-6L-4C Pre: Consent of instructor

Design, fabrication, and testing of a high frequency transmitter-receiver system including but not limited to oscillators, mixers, filters, amplifiers, and matching networks. Integral laboratory.

ECE 416 Introduction to MEMS: Fabrication and Applications 3R-3L-4C S Pre: JR or SR standing

Properties of silicon wafers; wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration, simple actuators. Introduction to microfluidic systems. MEMS applications: capacitive accelerometer, cantilever and pressure sensor.

ECE 418 Fiber Optic Systems 4R-0L-4C W Pre: ECE 310 or consent of instructor

Analysis and design of common photonic systems such as fiber optic communication links, optical sensing systems, and optical signal processors. Topics include component overview, basic system design, and expected degradations along with mitigation techniques. An oral presentation of a research project is required.

ECE 419 Advanced MEMS: Modeling and Packaging 3R-3L-4C F Pre: PH410 or equivalent course

Design process, modeling; analytical and numerical. Actuators; dynamics and thermal issues. Use of software for layout and simulation. Characterization and reliability of MEMS devices. Electrical interfacing and packaging of MEMS. Microsensors, microfluidic systems, applications in engineering, biology, chemistry, and physics.

ECE 420 Nonlinear Control Systems 3R-3L-4C Pre: ECE 320 or ME 406

Modeling nonlinear systems. Use of modeling software to design nonlinear control

systems. Intuitive control strategies. Fuzzy control, computer and hardware implementation of fuzzy controllers, adaptive fuzzy control. Integral laboratory.

ECE 430 Microcontroller-Based Systems 3R-3L-4C F Pre: ECE 250 for ECE students, consent of instructor for other students.

Microcontroller register set, addressing modes and instruction set. Microcontroller peripheral support modules. Assembly language and C programming. Fundamental data structures. Interrupts. Real time programming. Data communications. Microcontroller interface to displays, digital and analog devices, sensors, and actuators. Embedded system design, implementation and applications. Integrated development environment. Formal final report and oral presentation. Integral laboratory. Credit cannot be obtained for both ECE 331 and ECE 430.

ECE 451 Nonlinear Electronics 3R-3L-4C Pre: ECE 351

Analysis and design of Class C and D amplifiers, high-power switching amplifiers, negative-resistance oscillators, low-noise transistor and operational amplifier circuits, and parametric amplifiers. Emphasis on nonlinear and time-varying circuit analysis and design techniques. Integral laboratory.

ECE 452 Power Electronics 3R-3L-4C Pre: ECE 250

Analysis and design of networks that use electronic devices as power switches. Silicon-controlled rectifiers, power transistors, and power MOSFETS are used to form phase-controlled rectifiers, AC voltage controllers, choppers, and inverters. Integral laboratory.

ECE 454 System Level Analog Electronics 3R-3L-4C W Pre: ECE 351

Analysis and design of Op-Amp circuits: wave shaping circuits, Schmitt triggers, power amplifiers, high power buffers, controlled current sources, peak detectors, sample and hold circuits. Precision Op-Amp Circuits. Non-ideal properties of Op-Amps. Integral laboratory.

ECE 460 Engineering Design I 1R-6L-3C F, S Pre: ECE 362

A continuation of a sequence of formal design courses that emphasizes completion of a client-driven project using a formal design process. Student teams carry a project from inception to completion to satisfy the need of a client. Integral laboratory.

ECE 461 Engineering Design II 1R-9L-4C F, W, S

Pre for EE: ECE310, ECE320 ECE333, ECE341, ECE351, ECE370 or ECE371, ECE380, ECE460

Pre for CPE: CSSE332, ECE331, ECE332, ECE333, ECE342, ECE351, ECE380, ECE460

Continuation of the design project from ECE460. Integral laboratory.

ECE 462 Engineering Design III 1R-3L-2C W, S Pre: ECE461

Completion of the design project from ECE 460 and ECE 461. Integral laboratory.

ECE 466 Consulting Engineering Seminar 2R-0L-2C Pre: Junior class standing

Discussion problems in the field of consulting engineering; seminars presented by practicing consulting engineers.

ECE 470 Power Systems I 3R-3L-4C Pre: ECE 370

Per-unit concepts. Modeling and analysis of synchronous machines. Configuration of transmission and distribution lines. Modeling of power system components. Formulation of power flow equations. Computer solutions of the load-flow problem. Fault-level evaluation by symmetrical components. Principles of grounding. Integral laboratory.

ECE 471 Industrial Power Systems 4R-0L-4C Pre: ECE 370

Design and analysis techniques for low and medium voltage power distribution systems. Harmonics, transients, system coordination, reliability and economics. A design project is carried throughout the course.

ECE 472 Power Systems II 3R-3L-4C Pre: ECE 470

Power system protection and stability. Design and application of relaying schemes for protection of transformers, buses, distribution lines, transmission lines, generators, motors, capacitors, and reactors. Power system stability and generator rotor dynamics phenomenon with use of the equal-area criterion. Integral laboratory.

ECE 480/PH 437 Introduction to Image Processing 3R-3L-4C Pre: MA 222 and Junior standing

Basic techniques of image processing. Discrete and continuous two-dimensional transforms such as Fourier and Hotelling. Image enhancement through filtering and histogram modification. Image restoration through inverse filtering. Image segmentation including edge detection and thresholding. Introduction to image encoding. Integral laboratory. Same as PH 437.

ECE 481 Electronic Music Synthesis 4R-0L-4C Pre: ECE 380

Analog synthesis techniques. Instrument control using MIDI. FM, additive and subtractive synthesis. Physical modeling and sound spatialization. Course project.

ECE 483 DSP System Design 3R-1L-4C F Pre: ECE 380

Study of finite word length effects in DSP systems. Cascaded filter structures. Coefficient quantization, roundoff noise, scaling for overflow prevention. Discrete-time noise, filtering noise, power spectral density. Polyphase filtering, interpolation and decimation. Implementation and system design and test issues for a SSB communication system. Integral laboratory based on a fixed point programming project.

ECE 497 Special Topics in Electrical Engineering 1-4C arranged Pre: Consent of instructor and department head

Topics of current interest to undergraduate students.

ECE 498 Engineering Projects and Design 2R-6L-4C Pre: Senior standing

Aspects of design and design presentations. Development of preliminary design and proposal for hardware project. Formal proposal and component selection. Construction, testing, and performance demonstration of previously designed project. Formal final report and oral presentation.

UNDERGRADUATE-GRADUATE COURSES**ECE 510 Error Correcting Codes 4R-0L-4C Pre: Senior standing or consent of instructor**

Coding for reliable digital communication. Topics to be chosen from: Hamming and BCH codes, Reed-Solomon codes, convolutional codes, Viterbi decoding, turbo codes, and recent developments, depending on interests of class and instructor. Mathematical background will be developed as needed.

ECE 511 Data Communications 4R-0L-4C Pre: ECE 310, MA 223 or MA 381

Design of digital communication systems. Topics to be chosen from: Channel characterization, data compression and source coding, baseband data transmission, noise modeling, probability of error, optimal receiver structures, modulation methods, synchronization.

ECE 516 Introduction to MEMS: Fabrication and Applications 3R-3L-4C S Pre: JR or SR standing

Properties of silicon wafers; wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration, simple actuators. Introduction to microfluidic systems. MEMS applications: capacitive accelerometer, cantilever and pressure sensor.

Students enrolled in PH510, ME516, ECE516, CHE505, BE516 must do project work on a topic selected by the instructor.

ECE 519 Advanced MEMS: Modeling and Packaging 3R-3L-4C F Pre: PH410 or equivalent course

Design process, modeling; analytical and numerical. Actuators; dynamics and thermal issues. Use of software for layout and simulation. Characterization and reliability of MEMS devices. Electrical interfacing and packaging of MEMS. Microsensors, microfluidic systems, applications in engineering, biology, chemistry, and physics.

Students enrolled in PH511, ME519, ECE519, CHE519, BE519 must do project work on a topic selected by the instructor.

ECE 520 Discrete-Time Control Systems 3R-3L-4C W Pre: ECE 320 or ME 406

Digital control. Z-transform, sampling systems, sampled data control systems. Digital compensator (filter) design. Compensator sign pre- and post-conditioning. Discrete state-variable model. Integral laboratory.

ECE 521 Modern Control Systems 3R-3L-4C Pre: ECE 320 or ME 406

State variable modeling of physical systems. Lagrangian formulations, applications of linear algebra, controllability, observability, state feedback design, design of observers. Laboratory projects emphasize control system design using state variable methods. Integral laboratory.

ECE 530 Advanced Microcomputers 3R-3L-4C Pre: ECE 430 or ECE 331

Design of a microcomputer using a big honkin microprocessor. Architecture and assembly programming. Integral laboratory.

ECE 531 Microprogrammable Microcomputers 3R-3L-4C Pre: ECE 430

Architecture and application of microprogrammed CPU's. Microprogrammed control, hardwired control. Students will be required to develop their own microprogrammed CPU. Integral laboratory.

ECE 532 Advanced Computer Architecture 4R-0L-4C Pre: ECE 332 or both ECE 530 and ECE 531

Selected topics in computer architecture depending on interests of class and instructor. Projects investigating current issues in computer architecture.

ECE 533 Programmable Logic System Design 3R-3L-4C Pre: ECE 330 or ECE 333 or consent of instructor

Digital system-on-chip design techniques, including an advanced hardware description language, test-benches and verification, area and timing optimization, embedded microprocessors, and design for testing. Integral laboratory using contemporary CAD tools and FPGA devices.

ECE 534 High-Speed Digital Design 4R-0L-4C W Pre: ECE 340 or ECE 342

Signal integrity issues in high-speed digital systems at printed-circuit board (PCB) and chassis levels. Frequency spectrum of digital signals. Frequency behaviors of passive components. Behavior models of drivers and receivers. Transient behaviors of transmission lines. Time-domain reflectometry. Signal reflection and ringing on printed-circuit board. Impedance discontinuity and matching. Load termination techniques. Capacitive and inductive crosstalk. Ground noise. Power plane noise and resonance. High-speed PCB design guidelines. PCB simulation tools.

ECE 540 Antenna Engineering 3R-3L-4C Pre: ECE 341

Electromagnetic radiation, antenna terminology and characteristics, dipole antennas, arrays, aperture antennas, measurements, computer-aided analysis, design projects and reports.

ECE 541 Microwave/Millimeter-Wave Engineering 4R-0L-4C Pre: ECE 341

Wave-guide structures, scattering parameters, passive components, active components, computer-aided design of amplifiers, oscillators and mixers, microwave/millimeter-wave systems, microwave and millimeter-wave integrated circuits.

ECE 542 Advanced Electromagnetics 4R-0L-4C Pre: ECE 341

Maxwell's equations, power and energy, material properties, waves, reflections, radiation, EM field theorems, boundary value problems, skin effect.

ECE 543 Mathematical Methods of Electromagnetics 4R-0L-4C Pre: ECE 341

Perturbational and variational techniques, moment methods, integral equation and Wiener-Hopf techniques, development of computer programs.

ECE 550 Linear Active Networks 3R-3L-4C Pre: ECE 351

Indefinite admittance matrix and expansion of the two-port methods of linear network analysis and design. Brune's tests. Llewellyn's stability criteria for two-port networks. Optimum terminations and mismatch design. Neutralization and unilateralization of amplifiers. Oscillators. Computer-aided design and analysis are emphasized. Integral laboratory.

ECE 551 Digital Integrated Circuit Design 3R-3L-4C Pre: ECE 333

Design, performance analysis, and physical layout of CMOS logic. Custom and standard cell methodologies. Use of commercial CAD tools. Design issues such as interconnect, timing, and testing methods. Integral laboratory and project.

ECE 552 Analog Integrated Circuit Design 3R-3L-4C Pre: ECE 351

Design, performance analysis, and physical layout of analog integrated circuits. Focus on operational amplifier design and op-amp circuits. Introduction to mixed-signal circuit design such as switch-capacitors, A/D, or D/A systems. Integral laboratory and design project.

ECE 553 Radio-Frequency Integrated Circuit Design 3R-3L-4C Pre: ECE 310 and ECE 351

Design, analysis, and physical layout of high-frequency analog integrated-circuits for modern RF transceivers. Circuit design for each primary transceiver component. General issues such as impedance matching and design of inductors on integrated circuits. Integral laboratory and design project.

ECE 554 Instrumentation 4R-0L-4C Pre: ECE 351

Transducers and their applications. Instrumentation amplifiers. A/D and D/A converters. Shock protection. Generation, recording and analysis of biological potentials (ECG, EMG, EEG). Ultrasound techniques and instrumentation. X-ray CAT techniques. Project involving the design of a significant instrument will run throughout the course. No laboratory, but emphasis on computer simulation of the circuits studied.

ECE 556 Power Electronics: DC Power Supplies 3R-3L-4C W Pre: ECE 351

Analysis and design of AC-DC and DC-DC converters. Linear, basic switching, charge-

pump, and fly-back topologies. Introduction to devices used in a power switching supplies. Thermal management. Integral laboratory.

ECE 571 Control of Power Systems 3R-3L-4C Pre: ECE 470

Principles of interconnected operation of power systems. Optimum scheduling of generation using economic dispatch and unit commitment. Primary and secondary load-frequency control. Voltage and reactive-power flow control. Principles of state estimation. Integral laboratory.

ECE 580 Digital Signal Processing 4R-0L-4C W Pre: ECE 380 or consent of instructor. MA 367 recommended

Digital filters. Fundamental concepts of digital signal processing. Analysis of discrete-time systems. Sampling and reconstruction. Theory and application of z-transforms. Design of recursive and nonrecursive digital filters. Window functions. Discrete Fourier transforms and FFT algorithm.

ECE 581 Digital Signal Processing Projects 2R-2L-2 or 4C Pre: ECE 580 or concurrent registration

Computer-aided design of digital filters and other DSP modules. Software and hardware realization using modern DSP chips. DSP chip architectures, C-language programming, and interfacing techniques. Optional advanced project may be done to earn four credit hours; otherwise two credit hours are given. Integral laboratory.

ECE 582/PH 537 Advanced Image Processing 3R-3L-4C Pre: CSSE 220 or ME 323 or ECE 380 or consent of instructor; MA 221

Introduction to color image processing and image recognition. Morphological methods, feature extraction, advanced segmentation, detection, recognition and interpretation. Integral laboratory. Same as PH 537.

ECE 597 Special Topics in Electrical Engineering 4C Pre: Consent of instructor

Special topics of current interest to graduate students and senior undergraduates.

ECE 598 Thesis Research 1-4C arranged

Thesis topic selected in consultation with adviser. Graduate students only.

