

Electrical Engineering

College of Science, Engineering and Technology
Department of Electrical & Computer Engineering and Technology
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Electrical Engineering (EE) encompasses research, development, design and operation of electrical and electronic systems and their components. This program leads to a Bachelor of Science in Electrical Engineering (BSEE). The primary objective of the Electrical Engineering program is to educate engineering professionals who possess a sound design and analytical background coupled with a strong laboratory experience. This means that the department prepares its Electrical Engineering graduates for:

1. Entry into the engineering work environment with well developed design and laboratory skills.
2. Further study toward advanced degrees in engineering and other related disciplines.
3. Advancement into managerial ranks and/or entrepreneurial endeavors.

The educational objectives for our Bachelor of Science in Electrical Engineering degree are to prepare our graduates to:

1. Function as responsible members of society with an awareness of the social, ethical, and economic ramifications of their work.
2. Become successful practitioners in engineering and other diverse careers.
3. Succeed in full time graduate and professional studies.
4. Pursue continuing and life-long learning opportunities.
5. Pursue professional registration.
6. Provide foundational education that allows for personal growth and flexibility through their career.

Our metrics for determining success in meeting these objectives will include:

1. Assessment of societal, economic awareness, and ethical performance of our graduates by the graduate and employer.
2. Monitoring of the success of our graduates in the work force.
3. Monitoring of the success of our graduates in graduate and professional programs.
4. Assessment of continuing and life-long learning by the graduate (and their employer as applicable).
5. Reviewing the number and success of our students completing professional registration to advance their careers.

The Electrical Engineering degree curriculum includes the following components:

1. A strong background in the physical sciences, mathematics, and the engineering sciences including extensive hands-on laboratory instruction.
2. An integrated design component including instruction in basic practices and procedures, creativity, control, economics, and synthesis. The process begins with basic instruction during the freshman year and concludes with a capstone design project.
3. A choice of several sub-disciplines in their senior level elective offerings (digital, controls, communications, microelectronics design and fabrication).
4. Opportunities for students to develop sensitivity to the social and humanistic implications of technology and motivate them to make worth while contributions to the profession and society, while upholding the highest standards of professional ethics.
5. Courses in business and economics to promote awareness of management and the economic aspects of engineering.
6. Preparation for continuing study and professional development.

The curriculum offers students the opportunity to emphasize a number of specialized areas including digital systems, communications, controls, and microelectronic design and fabrication.

During the senior year, students must take the first step toward registration as a professional engineer by taking the Fundamentals of Engineering, (FE) examination.

The Electrical Engineering program is accredited by the Engineering Accreditation Board for Engineering and Technology (ABET).

Minnesota State Mankato offers a 3/2 program with regional Liberal Arts colleges. Contact the department for more information.

Recommended high school preparation is two years of algebra, one year of geometry, one-half year of trigonometry, one-half year of college algebra, and a year each of physics and chemistry. Without this background it may take longer than four years to earn the degree. The first two years students take science and mathematics courses common to all branches of engineering (pre-engineering), as well as supporting work in English, humanities and social sciences. Second-year electrical engineering students complete physics, mathematics and 200-level engineering science courses. Some specialization for a particular engineering major occurs in the second year.

Accreditation. The Electrical Engineering program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology, 111 Market Place, Suite 1050, Baltimore, MD 21202-4012; telephone: (410) 347-7700.

Admission to Major. Admission to the college is necessary before enrolling in 300- and 400-level courses. Minimum college admission requirements are:

- a minimum of 32 earned semester credit hours.
 - a minimum cumulative GPA of 2.00 ("C").
- Contact the department for application procedures.

During the sophomore year, students should submit an application form for admission to the electrical engineering program. Admission to the program is selective and, following application to the department, subject to approval of the faculty. The department makes a special effort to accommodate transfer students. Only students admitted to the program are permitted to enroll in upper-division EE courses. No transfer credits are allowed for upper-division EE courses except by faculty review followed by special written permission.

Before being accepted into the program and admitted to 300-level electrical engineering courses (typically in the fall semester), a student must complete a minimum of 46 semester credits including the following:

- General Physics (calculus-based) (10 credits)
- Calculus and Differential Equations (16 credits)
- Electrical Engineering Circuit Analysis I and II (including lab.) (7 credits)
- Chemistry (5 credits)
- English Composition (4 credits)
- Statistics (3 credits)

A cumulative grade-point average of 2.5 for all science, math and engineering courses must have been maintained. Grades must be "C" or better for courses to be accepted. Minnesota State Mankato students should complete the pre-engineering courses listed under the major.

GPA Policy. Students graduating with a degree in Electrical Engineering must have 1) completed a minimum of 20 semester credit hours of upper division EE course work; 2) have a cumulative GPA of 2.25 or higher in all upper division Minnesota State Mankato EE coursework; 3) have completed their senior design sequence at Minnesota State Mankato; and 4) have taken the FE exam and achieved the competency level set by the department.

Petition to evaluate transfer credits must occur no later than the first semester the student is enrolled at Minnesota State Mankato. All international students wishing to have transfer credits granted from non-U.S. schools will be required to use the ECE evaluation service.

P/N Grading Policy. A student who majors in EE must elect the grade option for all courses even if offered by another department.

ELECTRICAL ENGINEERING BSEE

Required for Major (Prerequisites, 45 credits):

CHEM	201	General Chemistry I (5)
EE	230	Circuit Analysis I (3)
EE	231	Circuit Analysis II (3)
EE	240	Evaluation of Circuits (1)
ENG	101	Composition (4)
MATH	121	Calculus I (4)
MATH	122	Calculus II (4)
MATH	223	Calculus III (4)
MATH	321	Ordinary Differential Equations (4)
ME	212	Statics (3)
PHYS	221	General Physics I (4)
PHYS	222	General Physics II (3)
PHYS	223	General Physics III (3)

Required for Major (General Studies, 19 credits):

ENG	271	Technical Communication (4) OR
SPEE	233	Public Speaking for Technical Professionals (3)

* SPEE 102 Public Speaking (3) may be substituted.

Choose a minimum of 13 credits from Humanities and Social Sciences courses:

Humanities (6-7 credits)

HUM xxx HUM xxx HUM xxx

In general, graduation credit toward the humanities requirement is not allowed for any course in subject areas such as speech communication, writing, art, music, or theatre that involve performance or practice of basic skills.

Courses acceptable by department or program include:

ART	160	ART	260	ART	261	ART	413
ART	416	ART	419	ART	460	ART	462
ART	463	ART	466	ART	469	ENG	112W
ENG	113W	ENG	114	ENG	320	ENG	321
ENG	325	ENG	327	ENG	328	ENG	331
ENG	332	ENG	400	ENG	401	ENG	402
ENG	403	ENG	405	ENG	406	ENG	416
ENG	478	ENG	479	ENG	481		

FOREIGN LANGUAGE 200 level or above;

HIST all except HIST 490 and higher;

HUM	150	HUM	155	HUM	250W*	HUM	280W
HUM	281W	HUM	282	MASS	110	MASS	411
MASS	412	MUS	120	MUS	125	MUS	126
MUS	220	MUS	321	MUS	322	MUS	422
MUS	423	MUS	424	MUS	425	MUS	426
MUS	429	MUS	432				

PHIL all except PHIL 490 and higher;

SPEE	203	SPEE	300	SPEE	315	SPEE	403
SPEE	412	SPEE	413	THEA	100	THEA	252
THEA	285W	THEA	481				

For other acceptable courses, please consult with your advisor.

*Note: EET 125 may be substituted for HUM 250W

Social Sciences (6-7 credits)

SS xxx SS xxx SS xxx

Courses acceptable by department or program include:

ANTH all courses except ANTH 480 and above;

GEOG	100	GEOG	101	GEOG	103	GEOG	340
GEOG	341	GEOG	425	GEOG	430	GEOG	435
GEOG	437	GEOG	445	GEOG	446	GEOG	450
GEOG	454	GEOG	456				

POL all except:

POL	420	POL	421	POL	422	POL	490
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and above;

PSYC all except:

PSYC	201	PSYC	202	PSYC	291	PSYC	300 3
PSYC	390	PSYC	391	PSYC	473		and above;

SOC all except:

SOC	201	SOC	202	SOC	466	SOC	469	SOC	470
SOC	485		and above;						

URBS all except:

URBS	301	URBS	302	URBS	481		and above;
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WOST all except:

WOST	260	WOST	277	WOST	290	WOST	320
WOST	430	WOST	460		and above.		For other acceptable coursework, please consult your advisor.

At least 3 credits of the courses selected to complete the above requirements must be 300 level or above. At least one 300 level course must follow a lower level course in the same subject area.

Choose one course from the following:

ECON 201 Principles of Macroeconomics (3)

ECON 202 Principles of Microeconomics (3)

Required Core for Major (Engineering, 51 credits):

EE	106	Introduction to Electrical/Computer Eng. I (3)
EE	107	Introduction to Electrical/Computer Eng. II (3)
EE	235	Microprocessor Engineering Laboratory I (1)
EE	303	Introduction to Solid State Devices (3)
EE	304	Lab: Introduction to Solid State Devices (1)
EE	332	Electronics I (3)
EE	333	Electronics II (3)
EE	336	Principles of Engineering Design I (1)
EE	337	Principles of Engineering Design II (1)
EE	341	Signals and Systems (3)
EE	342	Electronics Laboratory (1)
EE	350	Engineering Electromagnetics (3)
EE	353	Communications Systems Engineering (3)
EE	358	Control Systems (3)
EE	363	Communication Systems Laboratory (1)
EE	368	Control Systems Laboratory (1)
EE	381	Digital System Design with Testability (3)
EE	382	Digital System Design with Testability Lab (1)
EE	467	Principles of Engineering Design III (1)
EE	477	Principles of Engineering Design IV (1)
EE	482	Electromechanics (3)
EE	488	Thermal Systems Engineering (2) OR
ME	299	Thermal Analysis (2)
ME	291	Engineering Analysis (3) OR
MATH	354	Concepts of Probability and Statistics (3)
CS	220	Machine Structures and Programming (3)

Required for Major (Business, 6 credits):

EE 450 Engineering Economics (3)

Choose one course from the following list:

BLAW 200, FINA 362, MGMT 330 or MGMT 440, MRKT 310

Required Electives for Major (7 credits):

Choose a minimum of 7 credits from the following courses. Two courses must be in sequence (same subject area):

EE	453	EE	462	EE	471	EE	472	EE	475
EE	476	EE	479	EE	480	EE	481	EE	484
EE	487								

Required Minor: None.

No minor or other major accepted toward degree.

Electrical Engineering

COURSE DESCRIPTIONS

EE 106 (3) Introduction to Electrical/Computer Engineering I

This introductory course covers digital systems topics including binary numbers, logic gates, Boolean algebra, circuit simplification using Karnaugh maps, flip-flops, counters, shift registers and arithmetic circuits. Problem solving methods, study skills and professional development will be addressed throughout the course.

Pre: MATH 112

Fall Spring

EE 107 (3) Introduction to Electrical/Computer Engineering II

The course presents algorithmic approaches to problem solving and computer program design using the C language. Student will explore Boolean expressions, implement programs using control structures, modular code and file input/output, and interface with external hardware using robots and sensors.

Pre: EE 106

Spring

EE 230 (3) Circuit Analysis I

This course is meant to develop Electrical Engineering Circuit Analysis skills in DC and AC circuits. It includes circuit laws and theorems, mesh and node analysis. Natural and step response of RL, RC, and RLC circuits.

Pre: PHYS 222 or concurrent, MATH 321 or concurrent

Fall

EE 231 (3) Circuit Analysis II

Continuation of Circuit Analysis I to include special topics in circuit analysis.

Pre: EE 230 and EE 240, MATH 321, PHYS 222

Spring

EE 235 (1) Microprocessor Engineering Laboratory I

Laboratory support for EE 234. Use of development boards and assembly language programming to handle interrupts, interface with parallel I/O ports, memory, and timers. Experiments will involve signal and frequency measurements, data conversions, and interface design.

Pre: EE 106, EE 107, CS 200 and EE 235 taken concurrently

EE 240 (1) Evaluation of Circuits

Laboratory support for EE 230. Use of laboratory instrumentation to measure currents and voltages associated with DC and AC circuits. Statistical analysis of measurement data. Measurements of series, parallel and series-parallel DC and AC circuits. Measurement of properties for circuits using operational amplifiers. Measurement of transient responses for R-L and R-C circuits. Simulation of DC and AC circuits using PSPICE. Concepts covered in EE 230 will be verified in the laboratory.

Prerequisites: Must be taken concurrently with EE 230.

Fall

EE 244 (2) Introduction to Digital Systems

Simple coding schemes, Boolean algebra fundamentals, elements of digital building blocks such as gates, flip-flops, shift registers, memories, etc.; basic engineering aspects of computer architecture.

EE 253 (1) Logic Circuits Lab

Laboratory support to complement EE 244. Use of laboratory instrumentation to measure characteristics of various logic circuits and digital subsystems. Experimental evaluation of digital logic devices and circuits including logic gates, flip-flops, and sequential machines.

Prerequisite: EE 230 and concurrent with EE 244.

Spring

EE 254 (1) Digital and Circuits Lab

Laboratory support for EE 231 and EE 244. Experimental evaluation of AC and transient circuits, digital logic devices including logic gates, flip flops, and sequential machines.

Pre: EE 230, EE 240 and concurrently with EE 231 and EE 244

Spring

EE 298 (1-4) Topics

Varied topics in Electrical and Computer Engineering. May be repeated as topics change.

Prerequisite: to be determined by course topic

EE 303 (3) Introduction to Solid State Devices

Introduction to crystal structure, energy band theory, conduction and optical phenomenon in semiconductors, metals and insulators. Study of equilibrium and non-equilibrium charge distribution, generation, injection, and recombination. Analysis and design of PN-junctions, (bipolar transistor, junction) and MOS field-effect transistors. Introduction to transferred electron devices and semiconductor diode laser.

Pre: PHYS 222, and MATH 321

Fall

EE 304 (1) Lab: Introduction to Solid State Devices

Laboratory support for EE 303. Experiments include resistivity and sheet resistance measurements of semiconductor material, probing material, probing of IC chips, PN-junction IV and CV measurements, BJT testing to extract its parameters, MOSFET testing and evaluating its parameters, cv-measurements of MOS structure, and familiarization with surface analysis tools.

Fall

EE 332 (3) Electronics I

Introduction to discrete and microelectronics circuits including analog and digital electronics. Device characteristics including diodes, BJT's, JFET's, and MOSFET's will be studied. DC bias circuits, small and large signal SPICE modeling and analysis and amplifier design and analysis will be discussed.

Pre: EE 231

Fall

EE 333 (3) Electronics II

The second course of the electronics sequence presenting concepts of feedback, oscillators, filters, amplifiers, operational amplifiers, hysteresis, bi-stability, and non-linear functional circuits. MOS and bipolar digital electronic circuits, memory, electronic noise, and power switching devices will be studied.

Pre: EE 332

Spring

EE 334 (3) Microprocessor Engineering II

A more advanced study of microprocessors and microcontrollers in embedded system design. Use of C language in programming, interrupt interfaces such as SPI, I2C, and CAN. External memory design and on-chip program memory protection are also studied.

Pre: EE 234 and EE 295

Fall

EE 336 (1) Principles of Engineering Design I

Electrical and computer engineering project and program management and evaluation techniques will be studied. Emphasis will be placed on the use of appropriate tools for planning, evaluation, and reporting on electrical and computer engineering projects.

Pre: Junior Standing

Fall

EE 337 (1) Principles of Engineering Design II

Application of the design techniques in the engineering profession. Electrical engineering project and program management and evaluation including computer assisted tools for planning and reporting, design-to-specification techniques and economic constraints.

Pre: EE 336

Spring

EE 341 (3) Signals & Systems

Analysis of linear systems and signals in the time and frequency domain. Laplace and Fourier transforms. Z-transform and discrete Fourier transforms.

Pre: EE 230, MATH 321 and PHYS 222

Fall

EE 342 (1) Electronics Laboratory

This lab is designed to accompany EE 332. The lab covers the experimental measurement and evaluation of diode, BJT, and MOS characteristics; various feedback topologies; oscillator and op-amp circuits; and rectifiers and filter circuitry.

Pre: EE 231 and EE 332 taken concurrently.

Fall

EE 344 (1) Microprocessor II Laboratory

Laboratory support for EE 334. Use of development boards and C Programming language to handle I/O devices, interrupts, and all peripheral functions. Multiple functions such as timers, A/D converters, I/O devices, interrupts, and serial modules will be used together to perform desired operations.

Pre: Concurrent with EE 334

Fall

EE 350 (3) Engineering Electromagnetics

Vector fields. Electrostatic charges, potential and fields; displacement. Steady Current/current density; magnetostatic fields, flux density. Materials properties. Faraday's Law and Maxwell's equations. Skin effect. Wave propagation, plane waves, guided waves. Radiation and antennas. Transmission line theory.

Pre: EE 231, MATH 223, MATH 321 and PHYS 222

Spring

EE 353 (3) Communications Systems Engineering

Signals and Systems, Fourier transforms, Parseval's theorem. Autocorrelation functions and spectral density functions. Information theory. Noise and noise figure, probability and statistics. Transformation of random variables, probability of error and bit error rate. Modulation and demodulation. Overview of analog, sampled analog and digital communication systems. Spread spectrum systems.

Pre: EE 341 & MATH 223

Spring

EE 358 (3) Control Systems

Theory and principles of linear feedback control systems. Analysis of linear control systems using conventional techniques like block diagrams, Bode plots, Nyquist plots and root-locus plots. Introduction to cascade compensation: proportional, derivative and integral compensation. State space models.

Pre: EE 341

Spring

EE 363 (1) Communication Systems Laboratory

Measurement techniques using the oscilloscope, spectrum analyzer and network analyzer. Signals and spectra. Frequency response. Noise and noise figure measurements. Intermodulation products. Amplitude and frequency modulation/demodulation. Sampling, aliasing, and intersymbol interference. Bit error measurement.

Pre: Concurrent with EE 353

Spring

EE 368 (1) Control Systems Laboratory

Laboratory support for EE 358. Experimental evaluation of basic control system concepts including transient response and steady state performance. Analog and digital computers.

Pre: EE 341 and concurrent with EE 358

Spring

EE 381 (3) Digital System Design with Testability

Practical aspects of digital systems design and hardware testability will be presented in this course. Software tools and theoretical presentations will emphasize necessary concepts of digital design.

Pre: EE 106, CS 220, and EE 295

Fall

EE 382 (1) Digital System Design with Testability Lab

Laboratory support for EE 381. Practical aspects of digital systems design and hardware testability will be presented through laboratory experiences.

Pre: Concurrent with EE 381

Fall

EE 439 (3) Electronics for Non-Electrical Engineering Majors

Topics covered include power supplies, operational amplifiers and feedback circuits, linear and nonlinear circuits and applications, analog switches, digital logic gates and devices, A/D and D/A converters, microprocessors, and basic control systems.

Pre: PHYS 221 and PHYS 222

Variable

EE 450 (3) Engineering Economics

Overview of accounting and finance and their interactions with engineering. Lectures include the development and analysis of financial statements, time value of money, decision making tools, cost of capital, depreciation, project analysis and payback, replacement analysis, and other engineering decision making tools.

Pre: Advanced standing in the program

Fall

EE 453 (3) Advanced Communications Systems Engineering

Behavior of analog systems and digital systems in the presence of noise, principles of digital data transmission, baseband digital modulation, baseband demodulation/detection, bandpass modulation and demodulation of digital signals. Channel coding, modulation and coding trade-offs, spread spectrum techniques, probability and information theory.

Pre: EE 353 and EE 363

Fall

EE 463 (3) Advanced Digital System Design

Design of combinational and sequential systems and peripheral interfaces. Design techniques using MSI and LSI components in an algorithmic state machine; implementation will be stresses. Rigorous timing analysis transmission-line effects and metastability of digital systems will be studied.

Pre: EE 244

EE 467 (1) Principles of Engineering Design III

The design and organization of engineering projects. Project proposals, reporting, feasibility studies, and interpretation. Specification preparation, interpretation, and control. Issues involving creativity, project planning and control, and intellectual property rights. Students enrolled in this course must initiate and complete a design project in a small team format.

Pre: EE 337 and senior standing

Fall

EE 471 (3) Advanced Control Systems

This course is a continuation of EE 358. Techniques for the analysis of continuous and discrete systems are developed. These techniques include pole placement, state estimation, and optimal control.

Pre: EE 358 and EE 368

Fall

EE 472 (3) Digital Signal Processing

Develop design and analysis techniques for discrete signals and systems via Z-transforms, Discrete Fourier Transforms, implementation of FIR and IIR filters. The various concepts will be introduced by the use of general and special purpose hardware and software for digital signal processing.

Pre: EE 341

Spring

EE 475 (3) Integrated Circuit Engineering

Introduction to theory and techniques of integrated circuit fabrication processes, oxidation, photolithography, etching, diffusion of impurities, ion implantation, epitaxy, metallization, material characterization techniques, and VLSI process integration, their design and simulation by SUPREM.

Pre: EE 303 and EE 332

Fall

Electrical Engineering

EE 476 (3) Antennas, Propagation, & Microwave Engineering

Principles of electromagnetic radiation, antenna parameters, dipoles, antenna arrays, long wire antennas, microwave antennas, mechanisms of radiowave propagation, scattering by rain, sea water propagation, guided wave propagation, periodic structures, transmission lines, microwave/millimeter wave amplifiers and oscillators, MIC & MMIC technology.

Pre: EE 350

Variable

EE 477 (1) Principles of Engineering Design IV

Completion of design projects and reports. Lectures on ethics, issues in contracting and liability, concurrent engineering, ergonomics and environmental issues, economics and manufacturability, reliability and product lifetimes. Lectures by faculty and practicing engineers.

Pre: EE 467 and Senior Standing

Spring

EE 479 (3) Superconductive Devices

Magnetic and superconducting properties of materials, microscopic theory of superconductivity and tunneling phenomenon. Josephson and SQUID devices, survey of computer memories, memory cell and shift register, A/D converters and microwave amplifiers. Integrated circuit technology and high temperature superconductors.

Pre: EE 303

Variable

EE 480 (1) Integrated Circuit Fabrication Lab

Introduction to integrated circuit fabrication processes, device layout, mask design, and experiments related to wafer cleaning, etching, thermal oxidation, thermal diffusion, photolithography, and metallization. Fabrication of basic integrated circuit elements pn junction, resistors, MOS capacitors, BJT and MOSFET in integrated form. Use of analytic tools for in process characterization and simulation of the fabrication process by SUPREM.

Pre: Concurrent with EE 475

Fall

EE 481 (1) VLSI Design Laboratory

This laboratory accompanies EE 484. The laboratory covers the basics of layout rules, chip floor planning, the structure of standard cells and hierarchical design, parasitic elements, routing, and loading. Students will learn to design and layout standard cells as well as how to use these cells to produce complex circuits. The laboratory culminates with the individual design and layout of a circuit.

Pre: Concurrent with EE 484

Spring

EE 482 (3) Electromechanics

Electrical power and magnetic circuit concepts, switch-mode converters, mechanical electromechanical energy conversion, DC motor drives, feedback controllers, AC machines and space vectors, permanent magnet AC machines and drives, induction motors and speed control of induction motors, stepper motors.

Pre: EE 230

Fall

EE 484 (3) VLSI Design

The basics of digital VLSI technology. Bipolar and MOS modeling for digital circuits. Physical transistor layout structure and IC process flow and design rules. Custom CMOS/BICMOS static and dynamic logic styles, design and analysis. Clock generation, acquisition, and synchronization procedures. Special purpose digital structures including memory, Schmitt triggers, and oscillators. Individual design projects assigned.

Pre: EE 333

Spring

EE 487 (3) RF Systems Engineering

Overview of wireless communication and control systems. Characterization and measurements of two-port RF/IF networks. Transmission lines. Smith chart. Scattering parameters. Antenna-preselector-preamplifier interface. Radio wave propagation. Fading. RF transistor amplifiers, oscillators, and mixer/modulator circuits. Multiple access techniques. Transmitter/receiver design considerations. SAW matched filters.

Pre: EE 353 and EE 363

Variable

EE 488 (2) Thermal Systems Engineering

Thermodynamic concepts, properties and laws. Thermodynamic cycles and energy conversion; control volume analysis. Heat transfer by conduction, convective flow and radiation. Heat sink design. Design problems in electronics packaging, reliability, thermoelectric effects and cooling devices. Environmental property sensors.

Pre: PHYS 222 and EE 333

Variable

EE 491 (1-4) In-Service

EE 497 (1-6) Internship

EE 498 (1-4) Topics

Varied topics in Electrical and Computer Engineering. May be repeated as topics change. Prerequisite: to be determined by course topic

EE 499 (1-6) Individual Study