ELECTRICAL AND COMPUTER ENGINEERING

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Master'S and Doctoral Degrees

Why study engineering at the University of Denver?

DU's Department of Electrical and Computer Engineering (ECE) is creating the future of technology by providing a graduate education that emphasizes both multi-disciplinary and cross-disciplinary knowledge. The distinguished faculty is creating multi-disciplinary education programs that cover both depth and breadth, and research programs that incorporate and account for technological trends in research and development, along with industry. Graduate students join the faculty in conducting cutting-edge basic and applied research in emerging disciplines developing novel and unique solutions to old and new problems and opportunities.

All laboratories in the Department contain state-of-the-art equipment and software to support basic and applied research in hardware and software design, hardware/software interfacing, communications and signal processing, image processing, computer vision and pattern recognition, optoelectronics, power and energy systems, robotics, mechatronic systems, intelligent systems, unmanned systems, among other research areas. Small classes support our multi-disciplinary and real-time focus by providing close contact between students and faculty, which allows us to meet students' individual career goals.

Denver is a first-rate location for business, government and laboratory partnerships, and technology employment. The Colorado Front Range is consistently rated as one of the top high-tech areas in the country, and DU is located just minutes from the Denver Technological Center, the site of many top technology companies. The Department of Electrical and Computer Engineering is committed to active collaboration with these industry leaders. As a result, our students graduate with relevant research experience and a network of employment contacts in the technology sector that is second to none!

The ECE Department offers, among other degrees, a master's and a PhD degree in Mechatronic Systems Engineering (MSE). DU/ECE is the only University in the United States that offers BS, MS and PhD degrees in MSE.

Doctor of Philosophy in Electrical and Computer Engineering

The objective of the PhD in Electrical and Computer Engineering degree program is to provide an educational environment that encourages students to develop the ability to contribute to the advancement of science, engineering and technology, through independent research. The PhD students of the 21^{st} century may pursue academic, research, entrepreneurial, and/or industrial careers. We offer opportunities to develop individualized plans of study based on the students' previous experience and desired research areas. The plan of study allows students to work on interdisciplinary research, while also satisfying the PhD in ECE degree requirements.

Research requires an in-depth study of engineering problems with a broad knowledge base in science and engineering. Therefore, advanced courses are offered to strengthen the fundamentals and to broaden the engineering and science perspective. The minimum credit requirements are different for individuals entering a program with a closely related master's degree and for those entering with a bachelor's only. All requirements for the degree must be completed within seven years (eight years without a master's degree) from admission to candidacy. A grade of C or better must be obtained in each course in order for that course to count toward the credit hour requirements. An overall minimum GPA of 3.0 is also required for graduation.

The PhD in ECE is appealing to students because it offers the much needed specialization component and the 'degree identity' required to be competitive in the job market. Graduates from this program will be well equipped to follow academic careers, or be hired in federal laboratories, industry and the private sector.

Doctor of Philosophy in Mechatronics Systems Engineering

The objective of the PhD in Mechatronics Systems Engineering (MSE) degree program is to provide an educational environment that encourages students to develop the ability to contribute to the advancement of science, engineering and technology, through independent research. The PhD students of the 21^{st} century may pursue academic, research, entrepreneurial, and/or industrial careers. We offer opportunities to develop individualized plans of study based on the students' previous experience and desired research areas. The plan of study allows students to work on interdisciplinary research, while also satisfying the PhD in MSE degree requirements.

Research requires an in-depth study of engineering problems with a broad knowledge base in science and engineering. Therefore, advanced courses are offered to strengthen the fundamentals and to broaden the engineering and science perspective. The minimum credit requirements are different for individuals entering a program with a closely related master's degree and for those entering with a bachelor's only. All requirements for the degree must be completed within seven years (eight years without a master's degree) from admission to candidacy. A grade of C or better must be obtained in each course in order for that course to count toward the credit hour requirements. An overall minimum GPA of 3.0 is also required for graduation.

The PhD in MSE is at the forefront and intersection of the coupled disciplines of Electrical, Mechanical, Computer Engineering, and Computer Science. This unique degree is appealing to students because they will acquire the knowledge and ability to deal with and solve highly complex problems where integration is a key component. This degree provides a holistic approach to graduate education focusing on the ability to cover both breadth and depth of knowledge. Graduates of this program will lay the foundation for the modern engineering departments of the future, where 'integration' will be the key ingredient of studies.

Master of Science in Computer Engineering

The Master of Science in Computer Engineering (MSCpE) is designed to advance the student's knowledge in several areas of engineering. This degree provides breadth while permitting the student to achieve depth in a specialization area. This specialization area, with thematic sequences of courses, has been selected to coincide with those of high current interest as well as those emerging technologies that hold promise of increasing importance for the future. The purpose of this program is to serve the profession of engineering and the Colorado community through advanced study in computer engineering, electrical engineering, and other related fields. This program prepares the student for academic and industrial advancement. The program offer a thesis and a non-thesis option.

The Department of ECE offers both part-time and full-time programs. The Department recognizes that a student may be employed full-time while studying for a degree. Therefore, most courses are offered at times and on days that will permit a student to complete the program by taking courses either late in the day or outside normal business hours. The MSCpE program can generally be completed in about four years if one course is taken each quarter, but it is usually possible to take two courses per quarter, bringing completion time closer to the more common duration of two years. Also, students who select the one-year non-thesis will be able to graduate within 12 months, four academic quarters. For part-time students who are working in industry positions and who have chosen the thesis option, a topic related to the job function may be acceptable as the thesis research topic. Furthermore, a qualified staff member at the place of employment may be approved to serve as an adjunct faculty on the thesis committee.

Students not interested in pursuing a degree but interested in taking an occasional course may register as special status students by following an abbreviated admissions process. However, only 15 QH earned as a special status student may be applied toward a MS degree.

Master of Science in Mechatronic Systems Engineering

The Master of Science in Mechatronic Systems Engineering (MSMSE) is designed to advance the student's knowledge in several areas of engineering. This degree provides breadth while permitting the student to achieve depth in a specialization area. This specialization area, with thematic sequences of courses, has been selected to coincide with those of high current interest as well as those emerging technologies that hold promise of increasing importance for the future. The purpose of this programs is to serve the profession of engineering and the Colorado community through advanced study in computer engineering, electrical engineering, and other related fields. This program prepares the student for academic and industrial advancement. The program offer a thesis and a non-thesis option.

The Department of ECE offers both part-time and full-time programs. The Department recognizes that a student may be employed full-time while studying for a degree. Therefore, most courses are offered at times and on days that will permit a student to complete the program by taking courses either late in the day or outside normal business hours. The MS degree program can generally be completed in about four years if one course is taken each quarter, but it is usually possible to take two courses per quarter, bringing completion time closer to the more common duration of two years. Also, students who select the one-year non-thesis will be able to graduate within 12 months, four academic quarters. For part-time students who are working in industry positions and who have chosen the thesis option, a topic related to the job function may be acceptable as the thesis research topic. Furthermore, a qualified staff member at the place of employment may be approved to serve as an adjunct faculty on the thesis committee.

Students not interested in pursuing a degree but interested in taking an occasional course may register as special status students by following an abbreviated admissions process. However, only 15 QH earned as a special status student may be applied toward a MS degree.

Master of Science in Mechatronic Systems Engineering (Corporate Sponsor Program)

The Master of Science in Mechatronic Systems Engineering (MSMSE) (Corporate Sponsor Program) is a program available only to current Lockheed Martin and United Launch Alliance employees and is designed to advance the student's knowledge in several areas of engineering. This degree provides breadth while permitting the student to achieve depth in a specialization area. This specialization area, with thematic sequences of courses, has been selected to coincide with those of high current interest as well as those emerging technologies that hold promise of increasing importance for the future. The purpose of this programs is to serve the profession of engineering and the Colorado community through advanced study in computer engineering, electrical engineering, and other related fields. This program prepares the student for academic and industrial advancement. The program offer a thesis and a non-thesis option.

The Department of ECE offers both part-time and full-time programs. The Department recognizes that a student may be employed full-time while studying for a degree. Therefore, most courses are offered at times and on days that will permit a student to complete the program by taking courses either late in the day or outside normal business hours. The MS degree program can generally be completed in about four years if one course is taken each quarter, but it is usually possible to take two courses per quarter, bringing completion time closer to the more common duration of two years. Also, students who select the one-year non-thesis will be able to graduate within 12 months, four academic quarters. For part-time students who are working in industry positions and who have chosen the thesis option, a topic related to the job function may be acceptable as the thesis research topic. Furthermore, a qualified staff member at the place of employment may be approved to serve as an adjunct faculty on the thesis committee.

Students not interested in pursuing a degree but interested in taking an occasional course may register as special status students by following an abbreviated admissions process. However, only 15 QH earned as a special status student may be applied toward a MS degree.

Doctor of Philosophy in Electrical & Computer Engineering

Degree and GPA Requirements

- Bachelors degree: All graduate applicants must hold an earned baccalaureate from a regionally accredited college or university or the recognized equivalent from an international institution.
- Grade point average: The minimum undergraduate GPA for admission consideration for graduate study at the University of Denver is a cumulative 2.5 on a 4.0 scale or a 2.5 on a 4.0 scale for the last 60 semester credits or 90 quarter credits (approximately two years of work) for the baccalaureate degree. An earned master's degree or higher from a regionally accredited institution supersedes the minimum standards for the baccalaureate. For applicants with graduate coursework but who have not earned a master's degree or higher, the GPA from the graduate work may be used to meet the requirement. The minimum GPA is a cumulative 3.0 on a 4.0 scale for all graduate coursework undertaken.
- **P**rogram GPA requirement: The minimum undergraduate GPA for admission consideration for this program is a cumulative 3.0 on a 4.0 scale.

Prerequisites:

- Students with a MS in CpE, MS in MSE, MS in EE, MS in ME, or closely related areas may apply for admission to the PhD in ECE or PhD in MSE programs. Admission with only a BS in this field is also possible, but students with only a BS degree are strongly encouraged to enroll first in the MS (CpE, EE, MSE) programs. All graduate engineering courses presuppose mastery of the subject matter of a modern ABET-accredited curriculum in engineering. Students with a BS in other engineering or related science fields and students with a BSCpE, BSEE, or BSME who have not taken graduate academic work for some time may be required to complete preparatory courses that are prerequisites for the core courses of the engineering concentrations on which the qualifying exams are based. These courses carry no credit toward the graduate degree.

Standardized Test Scores

- The Graduate Record Examination (GRE) is required. Scores must be received directly from the appropriate testing agency by the deadline. The institution code for the University of Denver is 4842.

English Language Proficiency Test Score Requirements

The minimum TOEFL/IELTS/CAE test score requirements for this degree program are:

- Minimum TOEFL Score (Internet-based test): 80
- Minimum TOEFL Score (Paper-based test): 570
- Minimum IELTS Score: 6.5
- Minimum CAE Score: 169

English Conditional Admission: In cases where minimum TOEFL/IELTS/CAE scores were not achieved or no English proficiency test was taken, the Electrical and Computer Engineering program may offer English Conditional Admission (ECA) to academically qualified non-native English speakers.

Doctor of Philosophy in Mechatronic Systems Enigineering

Degree and GPA Requirements

- Bachelors degree: All graduate applicants must hold an earned baccalaureate from a regionally accredited college or university or the recognized equivalent from an international institution.
- Grade point average: The minimum undergraduate GPA for admission consideration for graduate study at the University of Denver is a cumulative 2.5 on a 4.0 scale or a 2.5 on a 4.0 scale for the last 60 semester credits or 90 quarter credits (approximately two years of work) for the baccalaureate degree. An earned master's degree or higher from a regionally accredited institution supersedes the minimum standards for the baccalaureate. For applicants with graduate coursework but who have not earned a master's degree or higher, the GPA from the graduate work may be used to meet the requirement. The minimum GPA is a cumulative 3.0 on a 4.0 scale for all graduate coursework undertaken.
- Program GPA requirement: The minimum undergraduate GPA for admission consideration for this program is a cumulative 3.0 on a 4.0 scale.

Prerequisites:

- Students with a MS in CpE, MS in MSE, MS in EE, MS in ME, or closely related areas may apply for admission to the PhD in ECE or PhD in MSE programs. Admission with only a BS in this field is also possible, but students with only a BS degree are strongly encouraged to enroll first in the MS (CpE, EE, MSE) programs. All graduate engineering courses presuppose mastery of the subject matter of a modern ABET-accredited curriculum in engineering. Students with a BS in other engineering or related science fields and students with a BSCpE, BSEE, or BSME who have not taken graduate academic work for some time may be required to complete preparatory courses that are prerequisites for the core courses of the engineering concentrations on which the qualifying exams are based. These courses carry no credit toward the graduate degree.

Standardized Test Scores/Other Requirements

- We recommend PhD applicants contact faculty to find a research advisor BEFORE submitting the application. If we receive an application and there is no research advisor commitment, we will consider the applicant for the master's program only.
- The Graduate Record Examination (GRE) is required. Scores must be received directly from the appropriate testing agency by the deadline. The institution code for the University of Denver is 4842.

English Language Proficiency Test Score Requirements

The minimum TOEFL/IELTS/CAE test score requirements for this degree program are:

- Minimum TOEFL Score (Internet-based test): 80
- Minimum TOEFL Score (Paper-based test): 570
- Minimum IELTS Score: 6.5
- Minimum CAE Score: 169

English Conditional Admission: In cases where minimum TOEFL/IELTS/CAE scores were not achieved or no English proficiency test was taken, the Mechatronic Systems Engineering program may offer English Conditional Admission (ECA) to academically qualified non-native English speakers.

Master of Science in Electrical Engineering, Computer Engineering or Mechatronic Systems Engineering

Degree and GPA Requirements

- Bachelors degree: All graduate applicants must hold an earned baccalaureate from a regionally accredited college or university or the recognized equivalent from an international institution.
- Grade point average: The minimum undergraduate GPA for admission consideration for graduate study at the University of Denver is a cumulative 2.5 on a 4.0 scale or a 2.5 on a 4.0 scale for the last 60 semester credits or 90 quarter credits (approximately two years of work) for the baccalaureate degree. An earned master's degree or higher from a regionally accredited institution supersedes the minimum standards for the baccalaureate. For applicants with graduate coursework but who have not earned a master's degree or higher, the GPA from the graduate work may be used to meet the requirement. The minimum GPA is a cumulative 3.0 on a 4.0 scale for all graduate coursework undertaken.
- Program GPA requirement: The minimum undergraduate GPA for admission consideration for this program is a cumulative 3.0 on a 4.0 scale.

Prerequisites:

- A Bachelor of Science (BS) degree in computer engineering (BSCpE), electrical engineering (BSEE), or closely related field from a regionally accredited college or university is required for admission to the programs. Those students whose backgrounds differ significantly from EAC/ABET-accredited BS computer, electrical programs may be required to complete prerequisite undergraduate courses. Such courses are not considered part of the 45 quarter hour requirements for the degree. A competency examination may be required of candidates who do not possess a 3.0 GPA or a BS in electrical, electronic, or computer, from an EAC/ABET accredited program. Students with BS degrees in physics, mathematics, computer science, engineering science, electrical engineering technology, engineering physics, or similar BS degrees from a regionally accredited college or university may also be admitted. However, these students should be able to demonstrate competency in the following basic subjects by passing an appropriate competency examination: MSCpE: Circuits and Electronics, Digital Systems, Computer Organization, a high- or low-level computer language; MSEE: Digital Design Methods, Physical Electronics, Introductory Electromagnetics, Signals and Systems, Principles of Communications, Circuits and Electronics; MSE: Controls, Robotics, Signals and Systems, Circuits and Electronics, Digital Design Methods, Mechanics, Electromagnetics.

Standardized Test Scores

- The Graduate Record Examination (GRE) is required. Scores must be received directly from the appropriate testing agency by the deadline. The institution code for the University of Denver is 4842.

English Language Proficiency Test Score Requirements

The minimum TOEFL/IELTS/CAE test score requirements for this degree program are:

- Minimum TOEFL Score (Internet-based test): 80
- Minimum TOEFL Score (Paper-based test): 570
- Minimum IELTS Score: 6.5
- Minimum CAE Score: 169

English Conditional Admission: In cases where minimum TOEFL/IELTS/CAE scores were not achieved or no English proficiency test was taken, the Electrical Engineering program may offer English Conditional Admission (ECA) to academically qualified non-native English speakers.

Master of Science in Electrical Engineering - Lockheed Employees Only, Computer Engineering - Lockheed Employees Only, Computer Science and Engineering - Lockheed Employees Only, Mechatronic Systems Engineering - Lockheed employees Only or Mechatronic Systems Engineering - United Launch Employees Only

Degree and GPA Requirements

- Bachelors degree: All graduate applicants must hold an earned baccalaureate from a regionally accredited college or university or the recognized equivalent from an international institution.
- Grade point average: The minimum undergraduate GPA for admission consideration for graduate study at the University of Denver is a cumulative 2.5 on a 4.0 scale or a 2.5 on a 4.0 scale for the last 60 semester credits or 90 quarter credits (approximately two years of work) for the baccalaureate degree. An earned master's degree or higher from a regionally accredited institution supersedes the minimum standards for the baccalaureate. For applicants with graduate coursework but who have not earned a master's degree or higher, the GPA from the graduate work may be used to meet the requirement. The minimum GPA is a cumulative 3.0 on a 4.0 scale for all graduate coursework undertaken.
- Program GPA requirement: The minimum undergraduate GPA for admission consideration for this program is a cumulative 2.5 on a 4.0 scale.

English Language Proficiency Test Score Requirements

The minimum TOEFL/IELTS/CAE test score requirements for this degree program are:

- Minimum TOEFL Score (Internet-based test): 80
- Minimum TOEFL Score (Paper-based test): 550
- Minimum IELTS Score: 6.5
- Minimum CAE Score: 169

English Conditional Admission: In cases where minimum TOEFL/IELTS/CAE scores were not achieved or no English proficiency test was taken, the program may offer English Conditional Admission (ECA) to academically qualified non-native English speakers.

Doctor of Philosophy in Electrical and Computer Engineering

Program requirements

All PhD students who have been admitted to the PhD in ECE program must successfully complete three milestones before the PhD degree can be conferred. These milestones refer to:

- Demonstrating that the student is qualified to begin PhD studies
- Demonstrating that the student may identify and formulate a research problem
- Demonstrating that the student can defend her/his dissertation

These three milestones are referred to as the "PhD Qualifying Exam", the "Comprehensive Exam" (also known as the "PhD Proposal"), and the "Dissertation Defense", respectively.

Coursework requirements

The PhD in ECE does not have specific course requirements. The courseswork plan needs to approved by the student's advisor and the department chair.

Minimum credit requirements

Students with a Bachelor of Science in Engineering/Science

For students admitted to the PhD program with a bachelor's degree, 90 QH are required, 75 of which must be completed at the University of Denver. A minimum of 48 QH must be at the 4000-level or higher and may include as many dissertation research hours (Independent Research and Independent Study) as considered appropriate by the advisor and department chair. The student with his/her advisor will develop an appropriate plan of study with core requirements, an area of specialization (depth requirement), breadth requirement and advanced mathematics. The core will consist of 8 QH of coursework. The area of specialization will consist of 16 QH of coursework. An additional 6 QH of coursework (excluding independent research) is required as related breadth requirement. The student must complete a minimum of 16 QH at the 4000-level courses, excluding independent research. Prior to completion of the comprehensive exam, the plan of study must be approved by the student's PhD committee and the chair.

If a student is entering the PhD program without a relevant master's degree, the student should work with his/her advisor in order to meet the degree requirements for a master's degree. All requirements for the given master's degree must be met.

Code	Title	Credits
A minimum of 48 QH must be at the 4000-level or higher, may include Independent Research or Independent Study as considered appropriate by advisor and assuming a minimum of 16 QH are earned excluding independent research		48
Core Requirement		8
Depth Requirement - Specialization Area		16

Breadth Requirement [1]	6
Total Credits	**90**

[1] The breadth requirement must be pre-approved by the student's advisor.

Students with a Master of Science in Engineering/Science

If a student is admitted with a closely related master's degree, up to 45 hours may be transferred and applied to the doctorate degree. The student with his or her advisor will develop an appropriate program consisting of a minimum of 28 quarter hours at the 4000-level, which may include as many dissertation research hours (Independent Research and Independent Study) as considered appropriate by the advisor and the department chair. The student with his or her advisor will develop an appropriate plan of study with an area of specialization, breadth requirements and advanced mathematics. Prior to completion of the comprehensive exam, the student's plan of study must be approved by the student's PhD committee and the department chair.

Code	Title	Credits
A minimum of 36QH must be at the 4000-level or higher, may include Independent Research or Independent Study as considered appropriate by advisor		36
Student with his or her advisor will develop an appropriate plan of study with an area of specialization, breadth requirements and advanced mathematics		
Total Credits		**90**

Non-coursework Requirements

Qualifying Examination

Each student must demonstrate sufficient breadth and depth of basic engineering knowledge relevant to electrical and computer engineering and be able to demonstrate ability to organize and present her/his thoughts in a convincing manner. The PhD Qualifying Exam achieves this through two components: a written Common Exam of basic engineering knowledge (breadth) and two written Specific Area Exams (depth). Failure to pass any component of the PhD Qualifying Exam will prevent the student from continuing in the PhD program.

All PhD students who are admitted into the Department of Electrical and Computer Engineering must pass the PhD Qualifying Exam. There are two components of the PhD Qualifying Exam consisting of three test subject areas. The two components are

PhD Common Exam

This is a common two-hour written exam. Each student, with advice from his/her advisor must choose one of the three subject areas. The Common Exam will be graded as pass/fail. Minimum of 70% is required and serves as passing grade.

- Engineering Mathematics (Calculus, Engineering Analysis, Linear Algebra)
- Circuits and Electronics
- Digital Design, Computer Organization, and HDL

PhD Specific Area Exam

This part of the exam will consist of two written subject area texts lasting two hours each. Students must pick two specific subject areas and cannot be the same subject area as the topic chosen for the PhD Common Exam. The Specific Area Exam will be graded as pass/fail; Minimum of 70% is required and serves as passing grade.

- Digital Design, Computer Organization, and HDL (only if NOT taken for the common component)
- Circuits and Electronics (only if NOT taken for the common component)
- Microprocessors
- Data Structures, Algorithms, & Operating Systems
- Control, Signals & Systems
- Electromagnetics
- Power & Energy Systems
- Optoelectronics and Optical Fiber Communication
- Communication & DSP
- Robotics
- Image Processing & Computer Vision
- Pattern Recognition

If a student is unable to pass the PhD Common Exam and/or any of the PhD Specific Area Exams, the student must take the same exam(s) during the second attempt; the student is not allowed to switch subject areas.

All PhD students **must** attempt the PhD Qualifying Exam (first time) by the end of their first year. If a student is unsuccessful at passing all three test areas, the student **must** take the exam for the second time, the next time it is offered. A student shall be considered to have passed the PhD Qualifying Exam only after all three test areas have been successfully completed within the given time constraints identified.

Comprehensive Examination

The purpose of the Comprehensive Examination is to ascertain the potential of the student for PhD quality research. At least two quarters prior to the final defense, the student shall schedule and take the Comprehensive Examination. This oral and written examination will be attended by a minimum of three faculty members, the same faculty who will attend the student's final dissertation defense. The Comprehensive Exam may be open to other students based on the requirements of the student's advisor. The student is expected to make a 30 to 40 minute concise presentation on her/his dissertation topic. The oral and written presentation will highlight previous work in this area, demonstrate a need for the given research, and explain how the given research will contribute to the advancement of the area. The student will also present completed work and results, anticipated work and results, and a detailed plan for project completion. In addition, the student will be expected to answer general fundamental questions in the area of her/his concentration and detailed questions in the area of the student's graduate course work.

The PhD Qualifying Examination must be taken and passed prior to the student taking the Comprehensive Examination. The Comprehensive Examination can be taken at most 2 times. If the student does not pass the Comprehensive Exam on the second try, the student will be terminated from the program. The comprehensive exam will be graded on a pass/fail system.

Dissertation

The student is required to complete and defend a dissertation of publishable quality based on the student's original research. The dissertation must be completed in written form in accordance with the University's Graduate School guidelines. A summary of the dissertation must be presented in a public seminar and subsequently defended by the student in the final oral defense. The defense committee will consist of the student's entire PhD committee.

Residence Requirement

Enrollment in at least six quarters (four semesters), including at least two consecutive quarters (one semester) of full-time attendance is required for graduation.

PhD Committee

The PhD committee should consist of at least four faculty members. Three faculty members must be from within the student's specialty area; these can include the student's advisor, other faculty in that degree program and, if necessary, off-campus experts. Finally, for the final oral defense of the dissertation, an oral defense chair, who must be a tenured faculty member outside the Department of Electrical and Computer Engineering and Mechanical and Materials Engineering, needs to be identified in consultation with the DU Graduate Studies Office. The PhD committee needs to be identified with the dissertation advisor and approved by the chair of the department and the Office of Graduate Studies.

Doctor of Philosophy in Mechatronics Systems Engineering

Program requirements

All PhD students who have been admitted to the PhD in ECE or PhD in MSE programs must successfully complete three milestones before the PhD degree can be conferred. These milestones refer to:

- Demonstrating that the student is qualified to begin PhD studies
- Demonstrating that the student may identify and formulate a research problem
- Demonstrating that the student can defend her/his dissertation

These three milestones are referred to as the "PhD Qualifying Exam", the "Comprehensive Exam" (also known as the "PhD Proposal"), and the "Dissertation Defense", respectively.

Coursework requirements

The PhD in MSE does not have specific course requirements. The courseswork plan needs to approved by the student's advisor and the department chair.

Minimum credit requirements

Students with a Bachelor of Science in Engineering/Science

For students admitted to the PhD program with a bachelor's degree, 90 QH are required, 75 of which must be completed at the University of Denver. A minimum of 48 QH must be at the 4000-level or higher and may include as many dissertation research hours (Independent Research and Independent Study) as considered appropriate by the advisor and department chair. The student with his/her advisor will develop an appropriate plan of study with core requirements, an area of specialization (depth requirement), breadth requirement and advanced mathematics. The core will consist of 8 QH of coursework. The area of specialization will consist of 16 QH of coursework. An additional 6 QH of coursework (excluding independent research) is required as related breadth requirement. The student must complete a minimum of 16 QH at the 4000-level courses, excluding independent research. Prior to completion of the comprehensive exam, the plan of study must be approved by the student's PhD committee and the department chair.

If a student is entering the PhD program without a relevant master's degree, the student should work with their advisor in order to meet the degree requirements for a master's degree. All requirements for the given master's degree must be met.

Code	Title	Credits
A minimum of 48 QH must be at the 4000-level or higher, may include Independent Research or Independent Study as considered appropriate by advisor and assuming a minimum of 16 QH are earned excluding independent research		48
Core Requirement		8
Depth Requirement - Specialization Area		16
Breadth Requirement [1]		6
Total Credits		90

1 The breadth requirement must be pre-approved by the student's advisor.

Students with a Master of Science in Engineering/Science

If a student is admitted with a closely related master's degree, up to 45 hours may be transferred and applied to the doctorate degree. The student with his or her advisor will develop an appropriate program consisting of a minimum of 28 quarter hours at the 4000-level, which may include as many dissertation research hours (Independent Research and Independent Study) as considered appropriate by the advisor. The student with his or her advisor will develop an appropriate plan of study with an area of specialization, breadth requirements and advanced mathematics. Prior to completion of the comprehensive exam, the student's plan of study must be approved by the student's PhD committee.

Code	Title	Credits
A minimum of 36QH must be at the 4000-level or higher, may include Independent Research or Independent Study as considered appropriate by advisor		36
Student with his or her advisor will develop an appropriate plan of study with an area of specialization, breadth requirements and advanced mathematics		
Total Credits		90

Non-coursework Requirements

Qualifying Examination

Each student must demonstrate sufficient breadth and depth of basic engineering knowledge relevant to electrical and computer engineering and be able to demonstrate ability to organize and present her/his thoughts in a convincing manner. The PhD Qualifying Exam achieves this through two components: a written Common Exam of basic engineering knowledge (breadth) and two written Specific Area Exams (depth). Failure to pass any component of the PhD Qualifying Exam will prevent the student from continuing in the PhD program.

All PhD students who are admitted into the Department of Electrical and Computer Engineering must pass the PhD Qualifying Exam. There are two components of the PhD Qualifying Exam consisting of three test subject areas. The two components are

PhD Common Exam

This is a common two-hour written exam. Each student, with advice from his/her advisor must choose one of the three subject areas. The Common Exam will be graded as pass/fail; with 70% constituting as passing grade.

- Engineering Mathematics (Calculus, Engineering Analysis, Linear Algebra)
- Circuits and Electronics
- Digital Design, Computer Organization, and HDL

PhD Specific Area Exam

This part of the exam will consist of two written subject area texts lasting two hours each. Students must pick two specific subject areas and cannot be the same subject area as the topic chosen for the PhD Common Exam. The Specific Area Exam will be graded as pass/fail; with 70% constituting as passing grade.

- Digital Design, Computer Organization, and HDL (only if NOT taken for the common component)
- Circuits and Electronics (only if NOT taken for the common component)
- Microprocessors
- Data Structures, Algorithms, & Operating Systems
- Control, Signals & Systems
- Electromagnetics
- Power & Energy Systems
- Optoelectronics/Optical Fiber Communication
- Communication & DSP
- Robotics

- Image Processing & Computer Vision
- Pattern Recognition

*Students who will obtain a PhD in Mechatronic Systems Engineering may take both exams from the above list or they may elect to take ONE exam from the list below:

- Solid Mechanics*
- Materials Science*
- Fluids & Heat Transfer*
- Thermodynamics*

If a student is unable to pass the PhD Common Exam and/or any of the PhD Specific Area Exams, the student must take the same exam(s) during the second attempt; the student is not allowed to switch subject areas.

All PhD students must attempt the PhD Qualifying Exam by the end of their first year. If a student is unsuccessful at passing all three test areas, the student will be given an additional year to pass the PhD Qualifying Exam. All students must take and pass the PhD Qualifying Exam by the end of their second year. A student shall be considered to have passed the PhD Qualifying Exam only after all three test areas have been successfully completed within the given time constraints identified.

Comprehensive Examination

The purpose of the Comprehensive Examination is to ascertain the potential of the student for PhD quality research. At least two quarters prior to the final defense, the student shall schedule and take the Comprehensive Examination. This oral and written examination will be attended by a minimum of three faculty members, the same faculty who will attend the student's final dissertation defense. The Comprehensive Exam may be open to other students based on the requirements of the student's advisor. The student is expected to make a 30 to 40 minute concise presentation on her/his dissertation topic. The oral and written presentation will highlight previous work in this area, demonstrate a need for the given research, and explain how the given research will contribute to the advancement of the area. The student will also present completed work and results, anticipated work and results, and a detailed plan for project completion. In addition, the student will be expected to answer general fundamental questions in the area of her/his concentration and detailed questions in the area of the student's graduate course work.

The PhD Qualifying Examination must be taken and passed prior to the student taking the Comprehensive Examination. The Comprehensive Examination can be taken at most 2 times. If the student does not pass the Comprehensive Exam on the second try, the student will be terminated from the program. The comprehensive exam will be graded on a pass/fail system.

Dissertation

The student is required to complete and defend a dissertation of publishable quality based on the student's original research. The dissertation must be completed in written form in accordance with the University's Graduate School guidelines. A summary of the dissertation must be presented in a public seminar and subsequently defended by the student in the final oral defense. The defense committee will consist of the student's entire PhD committee.

Residence Requirement

Enrollment in at least six quarters (four semesters), including at least two consecutive quarters (one semester) of full-time attendance is required for graduation.

PhD Committee

The PhD committee should consist of at least four faculty members. Three faculty members must be from within the student's specialty area; these can include the student's advisor, other faculty in that degree program and, if necessary, off-campus experts. Finally, for the final oral defense of the thesis, an oral defense chair, who must be a tenured faculty member outside the Department of Electrical and Computer Engineering and Mechanical and Materials Engineering, needs to be identified in consultation with the DU Graduate Studies Office. The PhD committee needs to be identified with the dissertation advisor and approved by the chair of the department and the Office of Graduate Studies.

Master of Science in Computer Engineering

Minimum Credit Requirements

Every candidate for the MS degree must complete 45 QH of credit, at least 36 of which must be completed at the University of Denver.

Program Structure

Candidates may elect either the thesis or non-thesis option. This choice may be made at any time, although a delay in declaration may impact the completion date. Students who are GTAs or who receive financial support from a University research grant, such as GRAs, are required to elect the thesis option. The program is designed to be completed in about six quarters if two courses (usually 8 QH) are taken each quarter.

Non-Thesis Option

The non-thesis option is the more flexible of the two options. This program is designed with the working professional in mind. For this option, a grade of C or better must be obtained in each course in order for that course to count toward the requirement of 45 QH. An overall minimum GPA of 3.0 is also required for graduation. Students may only take up to 8 quarter hours of independent study to be counted toward the degree, after approval by their advisor and the Chair. Each student must take a minimum of 24 quarter hours at the 4000-level.

One Year (four quarters) – Non-thesis Option

The Department of Electrical and Computer Engineering (ECE) offers a one-year, non-thesis option. Students who select the one-year program will be able to graduate within 12 months, four academic quarters, as there are enough courses offered in each specialization to meet the 20 QH depth requirement. The breadth requirement (14 QH) is fulfilled by taking courses offered in other specializations. In addition, every year courses that satisfy the mathematics requirement (3 QH) are offered. The MS non-thesis structure is shown below. QH in each category denote minimum requirements that must be satisfied. Any changes in the student's plan of study must be approved a-prior by the student's advisor.

The basic structure of the minimum 45 QH for the non-thesis option is as follows:

Requirements for Non-Thesis Option (minimum QH)

Code	Title	Credits
Core Requirement		8
Depth Requirement - Specialization Area		20
Mathematics Requirement (requires one approved course at the 3000-level or higher) [1]		3
Breadth Requirement		14
Total Credits		45

1 This indicates minimum number of quarter hours. Any credits over the 3 QH from the mathematics courses will count toward the breadth requirement.

Thesis Option

A thesis permits a candidate to obtain depth in an area of study and it is especially useful for individuals who seek to pursue a subsequent degree, for example, a PhD degree. Thesis candidates work closely with a thesis advisor. The thesis option is required for all GRAs and GTAs. For this option, a grade of C or better must be obtained in each course in order for that course to count toward the 45 QH hour requirements. An overall minimum GPA of 3.0 is also required for graduation. Students may only take up to 8 quarter hours of independent study to be counted toward the degree. Each student must take a minimum of 16 quarter hours at the 4000-level.The basic structure of the minimum 45 QH for the thesis option is as follows:

Requirements for Thesis Option (minimum QH)

Code	Title	Credits
Core Requirement		8
Depth Requirement - Specialization Area		16
Breadth Requirement [1]		6
Thesis		15
Total Credits		45

1 The breadth requirement must be pre-approved by the student's advisor.

If a student who has elected to pursue a thesis option, then at any time thereafter elects to change to a non-thesis option, all requirements for the non-thesis must be met. Any independent research taken may be forfeited and students must adhere to the grade requirements of the non-thesis option.

Breadth Requirement (Non-Thesis and Thesis Option)

Breadth Requirement courses (each with not less than 3 QH of credit) may be chosen from courses offered in other specialization areas. A course that appears in more than one specialization area may only be counted toward either the specialization requirement or the breadth requirement. The remaining courses are chosen from appropriate courses numbered 3000 or higher, offered by the Department Mechanical & Materials Engineering, Department of Computer Science or NSM (Natural Sciences and Mathematics). Prior approval by the student's advisor is required. It is strongly recommended that students choose math related courses to satisfy the breadth requirement.

The MSCpE program offers one area of specialization:

- Computer Systems Engineering

The student's degree program will be a combination of the core courses, specialization areas (depth requirement) and the breadth requirement. Each student is required to complete the 2 core courses. Students may choose from any of the courses from their area of specialization but should keep in mind the 4000-level requirement of the degree.

Core courses for all Computer Engineering Students

The following courses are required for all computer engineering students:

Code	Title	Credits
ENCE 4110	Modern Digital Systems Design	4
ENGR 3620	Advanced Engineering Mathematics	4

Specialization in Computer Systems Engineering

This area of specialization prepares students with fundamental and working knowledge of methods for analysis, design, and implementation of intelligent systems (IS). Particular attention is given to signal and information processing in IS, design of IS, and implementation of IS using state-of-the-art technology. This is accomplished through several theoretical courses and applied courses. Students must choose from the following courses:

Code	Title	Credits
ENCE 3321	Network Design	4
ENCE 4231	Embedded Systems Programming	4
ENCE 4250	Advanced Hardware Description Language (HDL) Modeling and Synthesis	4
ENCE 4620	Advanced Computer Vision	4
ENCE 4630	Advanced Pattern Recognition	4
ENEE 3670	Introduction to Digital Signal Processing	4

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

The Master of Science in Electrical Engineering (MSEE) is designed to advance the student's knowledge in several areas of engineering. This degree provides breadth while permitting the student to achieve depth in a specialization area. This specialization area, with thematic sequences of courses, has been selected to coincide with those of high current interest as well as those emerging technologies that hold promise of increasing importance for the future. The purpose of this programs is to serve the profession of engineering and the Colorado community through advanced study in computer engineering, electrical engineering, and other related fields. This program prepares the student for academic and industrial advancement. The program offer a thesis and a non-thesis option.

The Department of ECE offers both part-time and full-time programs. The Department recognizes that a student may be employed full-time while studying for a degree. Therefore, most courses are offered at times and on days that will permit a student to complete the program by taking courses either late in the day or outside normal business hours.. The MS degree program can generally be completed in about four years if one course is taken each quarter, but it is usually possible to take two courses per quarter, bringing completion time closer to the more common duration of two years. Also, students who select the one-year non-thesis will be able to graduate within 12 months, four academic quarters. For part-time students who are working in industry positions and who have chosen the thesis option, a topic related to the job function may be acceptable as the thesis research topic. Furthermore, a qualified staff member at the place of employment may be approved to serve as an adjunct faculty on the thesis committee.

Students not interested in pursuing a degree but interested in taking an occasional course may register as special status students by following an abbreviated admissions process. However, only 15 QH earned as a special status student may be applied toward a MS degree.

Minimum Credit Requirements

Every candidate for the MS degree must complete 45 QH of credit, at least 36 of which must be completed at the University of Denver.

Program Structure

Candidates may elect either the thesis or non-thesis option. This choice may be made at any time, although a delay in declaration may impact the completion date. Students who are GTAs or who receive financial support from a University research grant, such as GRAs, are required to elect the thesis option. The program is designed to be completed in about six quarters if two courses (usually 8 QH) are taken each quarter.

Non-Thesis Option

The non-thesis option is the more flexible of the two options. This program is designed with the working professional in mind. For this option, a grade of C or better must be obtained in each course in order for that course to count toward the requirement of 45 QH. An overall minimum GPA of 3.0 is also required for graduation. Students may only take up to 8 quarter hours of independent study to be counted toward the degree, after approval by their advisor and the Chair. Each student must take a minimum of 24 quarter hours at the 4000-level.

One Year (four quarters) – Non-thesis Option

The Department of Electrical and Computer Engineering (ECE) offers a one-year, non-thesis option. Students who select the one-year program will be able to graduate within 12 months, four academic quarters, as there are enough courses offered in each specialization to meet the 20 QH depth requirement. The breadth requirement (14 QH) is fulfilled by taking courses offered in other specializations. In addition, every year courses that satisfy the mathematics requirement (3 QH) are offered. The MS non-thesis structure is shown below. QH in each category denote minimum requirements that must be satisfied. Any changes in the student's plan of study must be approved a-prior by the student's advisor.

The basic structure of the minimum 45 QH for the non-thesis option is as follows:

Requirements for Non-Thesis Option (minimum QH)

Code	Title	Credits
Core Requirement		8
Depth Requirement - Specialization Area		20
Mathematics Requirement (requires one approved course at the 3000-level or higher) [1]		3
Breadth Requirement		14
Total Credits		45

1 This indicates minimum number of quarter hours. Any credits over the required 3 QH from the mathematics courses will count toward the breadth requirement.

Thesis Option

A thesis permits a candidate to obtain depth in an area of study and it is especially useful for individuals who seek to pursue a subsequent degree, for example, a PhD degree. Thesis candidates work closely with a thesis advisor. The thesis option is required for all GRAs and GTAs. For this option, a grade of C or better must be obtained in each course in order for that course to count toward the 45 QH hour requirements. An overall minimum GPA of 3.0 is also required for graduation. Students may only take up to 8 quarter hours of independent study to be counted toward the degree. Each student must take a minimum of 16 quarter hours at the 4000-level.The basic structure of the minimum 45 QH for the thesis option is as follows:

Requirements for Thesis Option (minimum QH)

Code	Title	Credits
Core Requirement		8
Depth Requirement - Specialization Area		16
Breadth Requirement [1]		6
Thesis		15
Total Credits		45

1 The breadth requirement must be pre-approved by the student's advisor.

If a student who has elected to pursue a thesis option, then at any time thereafter elects to change to a non-thesis option, all requirements for the non-thesis must be met. Any independent research taken may be forfeited and students must adhere to the grade requirements of the non-thesis option.

Breadth Requirement (Non-Thesis and Thesis Option)

Breadth Requirement courses (each with not less than 3 QH of credit) may be chosen from courses offered in other specialization areas. A course that appears in more than one specialization area may only be counted toward either the specialization requirement or the breadth requirement. The remaining courses are chosen from appropriate courses numbered 3000 or higher, offered by the Department Mechanical & Materials Engineering, Department of Computer Science or NSM (Natural Sciences and Mathematics). Prior approval by the student's advisor is required. It is strongly recommended that students choose math related courses to satisfy the breadth requirement.

The MSEE program offers three areas of specialization:

- Control & Communication Systems
- Electric Power & Energy Systems
- Optics/Optoelectronics/Photonics

Each student must choose an area of specialization. The student's degree program will be a combination of the core courses, specialization areas (depth requirement) and the breadth requirement. Each student is required to complete the 2 core courses. Students may choose from any of the courses from their area of specialization but should keep in mind the 4000-level requirement of the degree.

Core courses for all Electrical Engineering Students

The following courses are required for all electrical engineering students, regardless of area of specialization:

Code	Title	Credits
ENEE 4640	Electromagnetic Compatibility	4
ENGR 3621	Advanced Engineering Mathematics	4

Specialization in Control & Communication Systems

This area of specialization prepares students for basic and applied research and development of complex systems, including, electrical, mechanical, bio-inspired, mechatronic systems, robotic systems, and unmanned systems. This is accomplished through several theoretical courses and applied courses. Students must choose from the following courses:

Code	Title	Credits
ENCE 4231	Embedded Systems Programming	4
ENEE 3670	Introduction to Digital Signal Processing	4
ENGR 3721 & ENGR 3722	Controls and Control Systems Laboratory	4
ENEE 4141	Digital Communications	4
ENGR 4350	Reliability [1]	4
ENGR 4620	Optimization [1]	3,4
ENGR 4730	Introduction to Robotics	4
ENGR 4735	Linear Systems	4
ENGR 4740	Adaptive Control Systmes	4
ENGR 4745	Adv Non-Linear Control System	4
ENGR 4750	Networked Control Systems	4
ENGR 4755	Optimal Control	4
ENGR 4760	Multivariable Control	4

1 This course may count toward the specialization with advisors pre-approval. This course may not be offered on a regular basis.

Specialization in Electric Power and Energy Systems

This area of specialization prepares students with the basic foundation and advanced knowledge, required for the research and development in the area of power systems, renewable energy systems, and power electronic devices. This is accomplished through several theoretical courses and applied courses. Students must choose from the following courses:

Code	Title	Credits
ENGR 3510	Renewable and Efficient Power and Energy Systems	4
ENGR 3540	Electric Power Systems	4
ENGR 3721 & ENGR 3722	Controls and Control Systems Laboratory	4
ENGR 4530	Intro to Power and Energy	4
ENGR 4545	Electric Power Economy	4
ENGR 4560	Power Generation Operation and Control	4
ENGR 4590	Power System Protection	4
ENGR 4735	Linear Systems	4
ENGR 4740	Adaptive Control Systmes	4

Specialization in Optics/Optoelectronics/Photonics

This area of specialization prepares students for research, development, and design of devices and systems operating based on wave theory; focusing on laser, optics, light wave devises, and systems.

Code	Title	Credits
ENEE 4030	Optoelectronics	4
ENEE 4141	Digital Communications	4
ENEE 4035	Nanophotonics	4
ENGR 4200	Introduction to Nanotechnology	4
ENCE 4250	Advanced Hardware Description Language (HDL) Modeling and Synthesis	4
ENGR 4735	Linear Systems	4
ENGR 4740	Adaptive Control Systmes	4

MASTER OF SCIENCE IN MECHATRONIC SYSTEMS ENGINEERING

Minimum Credit Requirements

Every candidate for the MS degree must complete 45 QH of credit, at least 36 of which must be completed at the University of Denver.

Program Structure

Candidates may elect either the thesis or non-thesis option. This choice may be made at any time, although a delay in declaration may impact the completion date. Students who are GTAs or who receive financial support from a University research grant, such as GRAs, are required to elect the thesis option. The program is designed to be completed in about six quarters if two courses (usually 8 QH) are taken each quarter.

Non-Thesis Option

The non-thesis option is the more flexible of the two options. This program is designed with the working professional in mind. For this option, a grade of C or better must be obtained in each course in order for that course to count toward the requirement of 45 QH. An overall minimum GPA of 3.0 is also required for graduation. Students may only take up to 8 quarter hours of independent study to be counted toward the degree, after approval by their advisor and the Chair. Each student must take a minimum of 24 quarter hours at the 4000-level.

One Year (four quarters) – Non-thesis Option

The Department of Electrical and Computer Engineering (ECE) offers a one-year, non-thesis option. Students who select the one-year program will be able to graduate within 12 months, four academic quarters, as there are enough courses offered in each specialization to meet the 20 QH depth requirement. The breadth requirement (14 QH) is fulfilled by taking courses offered in other specializations. In addition, every year courses that satisfy the mathematics requirement (3 QH) are offered. The MS non-thesis structure is shown below. QH in each category denote minimum requirements that must be satisfied. Any changes in the student's plan of study must be approved a-prior by the student's advisor.

The basic structure of the minimum 45 QH for the non-thesis option is as follows:

Requirements for Non-Thesis Option (minimum quarter hours)

Code	Title	Credits
Core Requirement		8
Depth Requirement - Specialization Area		20
Mathematics Requirement (requires one approved course at the 3000-level or higher) [1]		3
Breadth Requirement		14
Total Credits		45

1 This indicates minimum number of quarter hours. Any credits over the required 3 QH from the mathematics courses will count toward the breadth requirement.

Thesis Option

A thesis permits a candidate to obtain depth in an area of study and it is especially useful for individuals who seek to pursue a subsequent degree, for example, a PhD degree. Thesis candidates work closely with a thesis advisor. The thesis option is required for all GRAs and GTAs. For this option, a grade of C or better must be obtained in each course in order for that course to count toward the 45 QH hour requirements. An overall minimum GPA of 3.0 is also required for graduation. Students may only take up to 8 quarter hours of independent study to be counted toward the degree. Each student must take a minimum of 16 quarter hours at the 4000-level.The basic structure of the minimum 45 QH for the thesis option is as follows:

Requirements for Thesis Option (minimum quarter hours)

Code	Title	Credits
Core Requirement		8
Depth Requirement - Specialization Area		16
Breadth Requirement [1]		6
Thesis		15
Total Credits		45

1 The breadth requirement must be pre-approved by the student's advisor.

If a student who has elected to pursue a thesis option, then at any time thereafter elects to change to a non-thesis option, all requirements for the non-thesis must be met. Any independent research taken may be forfeited and students must adhere to the grade requirements of the non-thesis option.

Breadth Requirement (Non-Thesis and Thesis Option)

Breadth Requirement courses (each with not less than 3 QH of credit) may be chosen from courses offered in other specialization areas. A course that appears in more than one specialization area may only be counted toward either the specialization requirement or the breadth requirement. The remaining courses are chosen from appropriate courses numbered 3000 or higher, offered by the Department Mechanical & Materials Engineering, Department of Computer Science or NSM (Natural Sciences and Mathematics). Prior approval by the student's advisor is required. It is strongly recommended that students choose math related courses to satisfy the breadth requirement

The MSE program offers one area of specialization:

- Robotic Systems

The student's degree program will be a combination of the core courses, specialization areas (depth requirement) and the breadth requirement. Each student is required to complete the 2 core courses. Students may choose from any of the courses from their area of specialization but should keep in mind the 4000-level requirement of the degree.

Core courses for all Mechatronic Systems Engineering Students

The following courses are required for all mechatronic systems engineering students regardless of area of specialization:

Code	Title	Credits
ENEE 4640	Electromagnetic Compatibility	4
or ENCE 4110	Modern Digital Systems Design	
ENGR 3620	Advanced Engineering Mathematics	4

Specialization in Robotics Systems

This area of specialization is designed to meet the needs of industry and federal research laboratories for engineers with multidisciplinary experience and ability to design and integrate complex systems requiring knowledge from diverse engineering disciplines. Said differently, mechatronic systems involves integration of mechanical, electrical, and computer engineering to design complex systems that perform real-world tasks. This program includes a broad set of common course requirements along with a selection of appropriate technical electives providing both breadth and depth of knowledge in a student's area of interest.

Code	Title	Credits
ENCE 4231	Embedded Systems Programming	4
ENCE 4250	Advanced Hardware Description Language (HDL) Modeling and Synthesis	4
ENCE 4620	Advanced Computer Vision	4
ENGR 3350	Reliability [1]	4
ENGR 3630	Finite Element Methods [1]	4
ENGR 4620	Optimization [1]	3,4
ENGR 4730	Introduction to Robotics	4
ENGR 4735	Linear Systems	4
ENME 4020	Adv Finite Element Analysis [1]	4
ENMT 4220	Mechatronics II	4
ENGR 4740	Adaptive Control Systmes	4
ENGR 4745	Adv Non-Linear Control System	4

1 This course may count toward the specialization with advisors preapproval. This course may not or may not be offered on a regular basis.

Master of Science in Mechatronic Systems Engineering (Corporate Sponsor Program)

Minimum Credit Requirements

Every candidate for the MS degree must complete 45 QH of credit, at least 36 of which must be completed at the University of Denver.

Program Structure

Candidates may elect either the thesis or non-thesis option. This choice may be made at any time, although a delay in declaration may impact the completion date. Students who are GTAs or who receive financial support from a University research grant, such as GRAs, are required to elect the thesis option. The program is designed to be completed in about six quarters if two courses (usually 8 QH) are taken each quarter.

Non-Thesis Option

The non-thesis option is the more flexible of the two options. This program is designed with the working professional in mind. For this option, a grade of B or better must be obtained in each course in order for that course to count toward the requirement of 45 QH. An overall minimum GPA of 3.0 is also required for graduation. Students may only take up to 8 quarter hours of independent study to be counted toward the degree, after approval by their advisor and the Chair. Each student must take a minimum of 24 quarter hours at the 4000-level.

One Year (four quarters) – Non-thesis Option

The Department of Electrical and Computer Engineering (ECE) offers a one-year, non-thesis option. Students who select the one-year program will be able to graduate within 12 months, four academic quarters, as there are enough courses offered in each specialization to meet the 20 QH depth requirement. The breadth requirement (14 QH) is fulfilled by taking courses offered in other specializations. In addition, every year courses that satisfy the mathematics requirement (3 QH) are offered. The MS non-thesis structure is shown below. QH in each category denote minimum requirements that must be satisfied. Any changes in the student's plan of study must be approved a-prior by the student's advisor.

The basic structure of the minimum 45 QH for the non-thesis option is as follows:

Requirements for Non-Thesis Option (minimum quarter hours)

Code	Title	Credits
Core Requirement		
ENMT 4100	Systems Engineering	4
ENMT 3210	Mechatronics I	4

ENGR 4810	Advanced Topics (ENGR) (Engr Project Management)	4
ENGR 3721	Controls	4
ENGR 3620	Advanced Engineering Mathematics (Engineering Analysis)	4
ENGR 4620	Optimization (Optimization in Design)	3-4
or ENGR 4350	Reliability	
ENMT 4000	Space Systems Design I [1]	4
ENMT 4010	Space Systems Design II [1]	4
Open Engineering Electives		12-22
Total Credits		45

1 These courses may be replaced with Open Engineering Electives by Lockheed students / ULA students are prohibited from taking these courses

Thesis Option

A thesis permits a candidate to obtain depth in an area of study and it is especially useful for individuals who seek to pursue a subsequent degree, for example, a PhD degree. Thesis candidates work closely with a thesis advisor. The thesis option is required for all GRAs and GTAs. For this option, a grade of C or better must be obtained in each course in order for that course to count toward the 45 QH hour requirements. An overall minimum GPA of 3.0 is also required for graduation. Students may only take up to 8 quarter hours of independent study to be counted toward the degree. Each student must take a minimum of 16 quarter hours at the 4000-level.The basic structure of the minimum 45 QH for the thesis option is as follows:

Requirements for Thesis Option (minimum quarter hours)

Code	Title	Credits
Core Requirement		
ENMT 4100	Systems Engineering	4
ENMT 3210	Mechatronics I	4
ENGR 4810	Advanced Topics (ENGR) (Engr Project Management)	4
ENGR 3721	Controls	4
ENGR 3620	Advanced Engineering Mathematics (Engineering Analysis)	4
ENGR 4620	Optimization (Optimization in Design)	3-4
or ENGR 4350	Reliability	
ENMT 4000	Space Systems Design I [1]	4
ENMT 4010	Space Systems Design II [1]	4
Open Engineering Electives		12-22
Total Credits		45

1 These courses may be replaced with Open Engineering Electives by Lockheed students / ULA students are prohibited from taking these courses

If a student who has elected to pursue a thesis option, then at any time thereafter elects to change to a non-thesis option, all requirements for the non-thesis must be met. Any independent research taken may be forfeited and students must adhere to the grade requirements of the non-thesis option.

Master of Science in Systems Engineering

The Master of Science in Systems Engineering (MS-SysEng) covers depth and breadth in system design, analysis and synthesis, testing, validation and verification. It deviates from traditional system analysis paradigms, centering on how to design, build, test and evaluate high-confidence systems with performance guarantees even in the presence of external or internal disturbances, failures and faults.

The program is built for graduate students and industry professionals, and it includes a thesis and a non-thesis option. The total of 45 QHs is required to complete the MS-SysEng, regardless of followed option. Courses must be at the 4000 level or higher. Students who wish to enroll in 3000 level that also may count as Graduate Courses must receive prior approval by the Program Director or Graduate Coordinator.

To enroll in the program, a Bachelor of Science (BS) in Electrical, Mechanical, Computer, Industrial or Mechatronic Systems Engineering is required. Graduates with a BS in Mathematics, Physics or Computer Science may be asked to enroll in additional courses to satisfy prerequisite requirements.

MS-SysEng Structure: Non-thesis Option **(45 QHs)**

- *Core required courses*: Minimum 12 QHs
- *Concentration Courses*: Minimum 16 QHs
  - Specialization in Space Systems Engineering
  - Specialization in Systems Engineering
- *Technical Electives*: 16 QHs

    - Choose four courses from ‘thematic sequences’ or, any courses from a provided list of electives
- *Course Project*: 1 QH

For courses to count towards graduation, a grade of B or better is required along with a cumulative GPA of 3.0 or better.

***MS-SysEng Structure: Thesis Option* (45 QHs)**

- *Core required courses*: Minimum 12 QHs
- *Concentration Courses*: Minimum 8-12 QHs
- *Technical Electives*: 8-12 QHs
    - Choose courses from ‘thematic sequences’ or, any courses from a provided list of electives
- : 13-17 QHs

A cumulative GPA of 3.0 or better is required for graduation. For thesis option students, a grade of C in maximum of two courses is allowed, provided that the cumulative GPA is 3.0 or higher.

The program offers the flexibility of course choice and selection if the minimum QHs for core and concentration courses are met. Core Required and/or Concentration Courses may count as Technical Electives, too. This allows for students to complete the two concentrations on Space Systems and Systems Engineering, instead of registering in (free) electives.

Students wishing to continue for a PhD, may do so by completing 45QHs, post-MS, which include at least 24 QHs of dissertation research.

Specialized Graduate Certificate in the Fundamentals of Space Systems

This Specialized Graduate Certificate requires completion of (a minimum of) **four** graduate level courses, or 16 QHs. Three courses, 12 QHs, are required courses, and one course, 4 QHs, is an elective course. Completion of this certificate provides expertise in fundamentals of Space Systems Engineering, Space System Design and Integration, and Space Project Management, where Space Systems include, at a minimum, spacecraft and missiles.

This Introduction to Space Systems certificate is offered (only) to Lockheed Martin employees and professionals.

Code	Title	Credits
Required Courses		
ENMT 4000		4
ENMT 4010		4
ENMT 4100		4
Recommended Elective Courses (Choose at least one course)		
ENMT 4225		4
MGMT 4304		4
ENGR 4865		4

Note that completion of three Specialized Graduate Certificates leads to the Master of Science in Systems Engineering that requires a minimum of 45 QHs for completion. Detailed information is provided in the RSECS Graduate Catalog.

Specialized Graduate Certificate in Systems Applications

This Specialized Graduate Certificate requires completion of (a minimum of) **four** graduate level courses, or 16 QHs. Two courses, 8 QHs, are required courses, and two courses, 8 QHs, are elective courses. Completion of this certificate provides hands-on expertise in system design, integration, implementation and testing.

Code	Title	Credits
Required Courses		
ENMT 4275		4
ENGR 4680		4
Recommended Elective Courses (Choose at least two courses)		
ENMT 4270		4
ENMT 4280		4
ENGR 4620		4
ENCE 4231		4

Note that completion of three Specialized Graduate Certificates leads to the Master of Science in Systems Engineering that requires a minimum of 45 QHs for completion. Detailed information is provided in the RSECS Graduate Catalog.

Specialized Graduate Certificate in System Design and Architecture

This Specialized Graduate Certificate requires completion of (a minimum of) **four** graduate level courses, or 16 QHs. Two courses, 8 QHs, are required courses, and two courses, 8 QHs are elective courses. Completion of this certificate provides expertise with emphasis on support for proposals, after contract award and through critical design reviews, as well as in System Design and Integration.

Code	Title	Credits
Required Courses		
ENMT 4285		4
ENGR 4790		4
Recommended Elective Courses (choose at least two courses)		
ENMT 4225		4
ENMT 4270		4
ENMT 4280		4
ENGR 4750		4

Note that completion of three Specialized Graduate Certificates leads to the Master of Science in Systems Engineering that requires a minimum of 45 QHs for completion. Detailed information is provided in the RSECS Graduate Catalog.

Engineering, Computer Courses

ENCE 3231 Embedded Systems Programming (4 Credits)
Design, construction and testing of microprocessor systems. Hardware limitations of the single-chip system. Includes micro-controllers, programming for small systems, interfacing, communications, validating hardware and software, microprogramming of controller chips, design methods and testing of embedded systems. Prerequisite: ENCE 3210.

ENCE 3250 HDL Modeling & Synthesis (3 Credits)
Introduction to Hardware Design Language (HDL). Language syntax and synthesis. Applications related to digital system implementation are developed. Project. Prerequisite: ENCE 2101 or instructor's permission.

ENCE 3261 Fault Tolerant Computing (3 Credits)
Basic concepts of dependable computing. Reliability of nonredundant and redundant systems. Dealing with circuit-level defects. Logic-level fault testing and tolerance. Error detection and correction. Diagnosis and reconfiguration for system-level malfunctions. Degradation management. Failure modeling and risk assessment.

ENCE 3321 Network Design (4 Credits)
Introduction to network components. Layering of network architecture. Analysis of Local Area Network (LAN) concepts and architecture based on IEEE standards. Design principles including switching and multiplexing techniques, physical link, signal propagation, synchronization, framing and error control. Application of probability and statistics in error detecting and control. Ethernet, Token-ring, FDDI (Fiber Distributed Data Interface), ATM (Asynchronous Transfer Mode), ISDN (Integrated Service Data Networks). Prerequisite: ENEE 3111, ENCE 2101 or permission of instructor.

ENCE 3501 VLSI Design (3 Credits)
Design of Very Large Scale Integration systems. Examination of layout and simulation of digital VLSI circuits using a comprehensive set of CAD tools in a laboratory setting. Studies of layouts of CMOS combinational and sequential circuits using automatic layout generators. Fundamental structures of the layout of registers, adders, decoders, ROM, PLA's, counters, RAM and ALU. Application of statistics and probability to chip performance. CAD tools allow logic verification and timing simulation of the circuits designed. Cross listed with ENCE 4501. Prerequisite: ENCE 3231.

ENCE 3620 Computer Vision (4 Credits)
This course is an introduction to the basic concepts in image processing and computer vision. First, an introduction to low-level image analysis methods, including radiometry and geometric image formation, edge detection, feature detection, and image segmentation are presented. Then, geometric-based image transformations (e.g., image warping and morphing) for image synthesis will be presented in the course. Furthermore, methods for reconstructing three-dimensional scenes including camera calibration, Epipolar geometry, and stereo feature matching are introduced. Other important topics include optical flow, shape from shading, and three-dimensional object recognition. In conclusion, students learn and practice image processing and computer vision techniques that can be used in other areas such as robotics, pattern recognition, and sensor networks. Cross listed with ENCE 4620. Prerequisite: ENEE 3311.

ENCE 3630 Pattern Recognition (4 Credits)
This class provides an introduction to classical pattern recognition. Pattern recognition is the assignment of a physical object or event to one of several prescribed categories. Applications includes automated object recognition in image and videos, face identification, and optical character recognition. Major topics include Bayesian decision theory, Parametric estimation and supervised learning, Linear discriminant functions, Nonparametric methods, Feature extraction for representation and classification, Support Vector Machines. Cross listed with ENCE 4630.

ENCE 3631 Machine Learning (4 Credits)
This class covers topics in machine learning including but not limited to Bayesian decision theory, supervised learning, unsupervised learning and clustering, linear discriminant functions, deep learning, neural networks, linear classification techniques, manifold learning, bag of words, and Support Vector Machines. Cross listed with ENCE-4631.

ENCE 4100 High Speed Digital Design (4 Credits)
Fundamental topics related to the development of high speed digital systems. Topics include signal integrity and reliability related to crosstalk, parasitic, and electromagnetic interference caused by device clocking speed and system complexity. Project. Cross listed with ENCE 3110.

ENCE 4110 Modern Digital Systems Design (4 Credits)
This course focuses on the design of digital systems using combinational, sequential, and programmable logic devices and Hardware Description Languages (HDL). Techniques for logic design including asynchronous logic, physical world interfaces to digital systems, and system performance analysis methods are studied. Students also learn HDL-Verilog to program CPLD devices and FPGA systems. Cross listed with ENCE 3100.

ENCE 4210 Microprocessor Systems I (4 Credits)
Introduction to microprocessors and to the design and operation of computer systems. A study of the microprocessor and its basic support components. Analysis of CPU architectures of modern computers. Assembly language programming. Use of an assembler and other development tools for programming and developing microprocessor-based systems. Cross listed with ENCE 3210.

ENCE 4231 Embedded Systems Programming (4 Credits)
Design, construction and testing of microprocessor systems. Hardware limitations of the single-chip system. Includes micro-controllers, programming for small systems, interfacing, communications, validating hardware and software, microprogramming of controller chips, design methods and testing of embedded systems.

ENCE 4250 Advanced Hardware Description Language (HDL) Modeling and Synthesis (4 Credits)
This course covers advanced concepts in Hardware Description and Language (HDl) modeling and Synthesis. It covers topics including but not limited to digital system design, simulation, and synthesis using Verilog HDL and VHDL. The course also covers RTL design, behavioral description, system Verilog, and timing analysis using CAD tools.

ENCE 4501 Advanced VLSI Design (4 Credits)
Advanced techniques in the fabrication and design of VLSI circuits and systems. Modeling of parasitic components. Floor-planning, clock distribution, routing, and low power design. Cross listed with ENCE 3501. Prerequisite: ENCE 3501 or permission of instructor.

ENCE 4601 Detection and Estimation Theory (4 Credits)
The subject of the detection and estimation theory course is on signal and information processing for the purpose of making desired inferences. The purpose of this course is to provide the fundamentals of theory and principles underlying the techniques for such processing. The following topics are involved in this course: receiver operating characteristics, hypothesis testing, Neyman-Pearson theorem, detection of deterministic signals with known parameters in Guassian noise, matched filters principles, detection of random signals with known characteristics, estimator-correlator, linear models, estimation bias, variance, Cramer-Rao bounds and Fisher matrix, Bayesian estimation, maximum likelihood estimation, minimum mean-squared estimation, detection of deterministic signals with unknown parameters, signal parameter estimation, Bayesian approach and generalized likelihood ratio test, detection of random signals with unknown characteristics, unknown noise parameters; signal processing applications. Prerequisite: basic understanding of probability theory and statistics, or permission of instructor.

ENCE 4620 Advanced Computer Vision (4 Credits)
This course covers advanced concepts in image processing and computer vision including but not limited to image radiometry and geometric formation, edge detection, geometric based transformations (e.g., image warping and morphing), camera calibration, Epipolar geometry, and stereo feature matching. Other advanced topics include optical flow, shape from shading, and three-dimensional object recognition. In conclusion, students learn and practice advanced topics in image processing and computer vision techniques that can be used in other areas such as robotics, pattern recognition, and sensor networks. Cross listed with ENCE 3620. Prerequisite: ENEE 3311.

ENCE 4630 Advanced Pattern Recognition (4 Credits)
This class covers advanced topics in pattern recognition including but not limited to Bayesian decision theory, parametric estimation and supervised learning, linear discriminant functions, nonparametric methods, feature extraction for representation and classification, manifold learning, bag of words, and Support Vector Machines. Cross listed with.

ENCE 4680 Time-Frequency Signal Analysis (4 Credits)
This course focuses on time-frequency signal processing methods. Many TFRs and their usefulness in many applications is covered. Course topics include: signals and signal properties; uncertainty principle. Review of 1-D transforms: Fourier transform (FT), group delay, instantaneous frequency. Desirable properties: linear vs. quadratic TFRs. Linear TFRs: Short-timer Fourier transform (STFT); Wavelet transform; filter banks. Spectrogram: relation to STFT; tradeoff between TF resolution and cross-term attenuation; application examples. Wignor distribution (WD): definition; properties; signal examples; relation to narrowband ambiguity function; cross-term geometry; applications; Smoothed WDs. Scalogram: relation to wavelet transform; properties; TF resolution' applications. Adaptive TRFs: adaptive spectrogram; positive TRFs; short-time techniques; time-frequency distribution series. Reassignment method; matching pursuit algorithms. TFRs in real-world applications: wireless communications, biomedicine, radar, sonar, detection, estimation, classification, speech processing, image processing, structural health monitoring, and many more. Prerequisites: basic knowledge of signal and systems, and digital signal processing, or permission of instructor.

ENCE 4800 Advanced Topics (CPE) (1-5 Credits)
Various topics in computer engineering as announced. May be taken more than once. Cross-listed with ENCE 3321, ENCE 3620.

ENCE 4900 Machine Learning (4 Credits)
This course provides a broad introduction to machine learning. Topics include: supervised learning (linear regression, logistic regression, parametric/non-parametric, neural networks, support vector machines); unsupervised learning (clustering, dimensionality reduction, kernel methods); anomaly detection and recommender systems. The course also discusses recent applications of machine learning. Recommended prerequisite: basic probability theory and statistics.

ENCE 4991 Independent Study (1-10 Credits)

ENCE 4992 Directed Study (1-10 Credits)

ENCE 4995 Independent Research (1-18 Credits)

ENCE 5995 Independent Research (1-18 Credits)

Engineering, Electrical Courses

ENEE 3011 Physical Electronics (4 Credits)
The basic physical concepts of electronics, electrons and holes in semiconductors, transport and optical processes. Concentration on device concepts, including material synthesis and device processing, P-N junction diodes, junctions with other materials, bipolar transistors, field effect transistors (JFET, MESFET, MOSFET) and optoelectronic effect transistors (JFET, MESFET, MOSFET) and optoelectronic devices (lasers, detectors). Prerequisites: CHEM 1010, CHEM 1610, PHYS 1213, PHYS 1214 or permission of instructor.

ENEE 3111 Signals & Systems (4 Credits)
Introduces continuous time and discrete time linear system analysis, Fourier series, Fourier transforms and Laplace transforms. Specific engineering tools for discrete time linear system analysis include discrete time convolution, Z-transform techniques, discrete Fourier transform and fast Fourier transform (DFT/FFT), and the design and analysis of analog and digital filters for real-world signal processing applications. Prerequisites: ENEE 2012, MATH 2070.

ENEE 3141 Digital Communications (3 Credits)
Introductory course on modern digital communication systems. The basic communication system theory, probability and random processes, baseband digital data transmission, coherent and non-coherent digital modulation techniques and analysis of bit error probability. Bandwidth efficiency and transmission of digital data through band-limited channels. Prerequisites: ENEE 3111, ENGR 3611 or permission of instructor.

ENEE 3611 Analysis and Design of Antennas and Antenna Arrays (4 Credits)
Maxwell's equations applied to antenna analysis and design. Topics include fundamental parameters of antennas, radiation integrals and auxiliary potential functions, analysis and design of linear wire antennas, loop antennas, arrays, broadband antennas, frequency independent antennas, aperture antennas and horns. Integrated lab included. Prerequisite: ENEE 2611.

ENEE 3620 Optical Fiber Communications (4 Credits)
A comprehensive treatment of the theory and behavior of basic constituents, such as optical fibers, light sources, photodetectors, connecting and coupling devices, and optical amplifiers. The basic design principles of digital and analog optical fiber transmission links. The operating principles of wavelength-division multiplexing (WDM) and the components needed for its realization. Descriptions of the architectures and performance characteristics of complex optical networks for connecting users with a wide range of transmission needs (SONET/SDH). Discussions of advanced optical communication techniques, such as soliton transmission, optical code-division multiplexing (optical CDMA) and ultra-fast optical time-division multiplexing (OTDM). Laboratory. Cross listed with ENEE 4620. Prerequisite: ENEE 3030 or permission of instructor.

ENEE 3641 Introduction to Electromagnetic Compatibility (4 Credits)
The study of the design of electronic systems so that they operate compatibly with other electronic systems and also comply with various governmental regulations on radiated and conducted emissions. Topics may include Electromagnetic Compatibility (EMC) requirements for electronic systems; non-ideal behavior of components; radiated emissions and susceptibility; conducted emissions and susceptibility; shielding and system design for EMC. Cross listed with ENEE 4640. Prerequisites: ENEE 3111, ENEE 2611 and ENEE 2223.

ENEE 3670 Introduction to Digital Signal Processing (4 Credits)
Introduction to the theory and applications of Digital Signal Processing. Special attention is paid to the fast Fourier transform and convolution and to the design and implementation of both FIR and IIR digital filters. Prerequisite: ENEE 3111.

ENEE 4030 Optoelectronics (4 Credits)
Optical fibers: structures, waveguiding, and fabrication; attenuation and dispersion; optical sources (LED, LASER, Fiber laser); power launching and coupling; photodetectors (APD, PIN, MSM); and practical optical transmitter and receivers. Cross listed with ENEE 3030.

ENEE 4035 Nanophotonics (4 Credits)
Nanophotonics provides high-speed, high-bandwidth, and ultra-small optoelectronic components. This course covers nanoscale processes, devices and their applications for harnessing and manipulating light on the nanoscale.

ENEE 4141 Digital Communications (4 Credits)
Introductory course on modern digital communication systems. The basic communication system theory, probability and random processes, baseband digital data transmission, coherent and non-coherent digital modulation techniques and analysis of bit error probability. Bandwidth efficiency and transmission of digital data through band-limited channels.

ENEE 4310 Information Theory and Coding (3 Credits)
Information and entropy; coding theory; error detection, correction codes; channel capacity; application to communications engineering.

ENEE 4416 Advanced Digitial Signal Processing Topics (4 Credits)
Study of linear discrete-time systems used to perform operation on random processes for the purposes of signal detection, estimation, spectral estimation, enhancement and parametric modeling of signals and systems, linear difference equations, Z-transforms, random sequences, state variables, matched filtering, Wiener filtering. Prerequisite: ENEE 3670.

ENEE 4460 Real-Time Digital Signal Processing (4 Credits)
Digitial signal processing algorithms and processing of discrete data, finite word length effects on filters, fixed point arithmetic and floating-point arithmetic. Overview of different architectures of digital signal processors. Programming of the DSP processor, implementation of DSP algorithms on DSP hardware in labs. Prerequisite: ENEE 3111, ENEE 3670, or ENCE 3210.

ENEE 4620 Adv Optical Fiber Comm (4 Credits)
A comprehensive treatment of the theory and behavior of basic constituents, such as optical fibers, light sources, photodetectors, connecting and coupling devices, and optical amplifiers. The basic design principles of digital and analog optical fiber transmission links. The operating principles of wavelength-division multiplexing (WDM) and the components needed for its realization. Descriptions of the architectures and performance characteristics of complex optical networks for connecting users who have a wide range of transmission needs (SONET/SDH). Discussions of advanced optical communication techniques, such as soliton transmission, optical code-division multiplexing (optical CDMA), and ultra-fast optical time division multiplexing (OTDM). Advanced Project. Cross listed with ENEE 3620. Prerequisite: instructor permission.

ENEE 4625 Radio over Fiber Comms. (4 Credits)
This course provides comprehensive and technical foundation in Microwave photonic Applications: Radio over optical fiber communications (RoF) is a novel technology in the field of short-range communication applications. The main goal is to enable range extension of 1 to 3 orders of magnitude over a typical ultra wide wideband radio signal in the range of 3.1-10.6 GHz. This technology allows separation of low cost Base-Station (BS)s from the Central-Station (CS). In the RoF technology is targeting the Personal Area Network (PAN) market that is characterized by very low cost and low power (10 uW) access point. In RoF, the optical fiber is used to carry extremely wide RF signals (several GHz).

ENEE 4630 Optical Networking (4 Credits)
This course provides a technical overview of optical networking. It gives students a solid understanding of optical networking field principles and practice. Underlying principles are reviewed along with common optical solutions and practices. It explains and provides practical tips on how to design and implement Networks. Examples are used to demonstrate key concepts of ATM, SONET/SDH and DWDM implementation. Prerequisite: ENEE 3011 or instructor approval.

ENEE 4635 Optical Wireless Communications (OWC) (4 Credits)
This course addresses describing important issues in optical wireless theory, including coding and modulation techniques for optical wireless, wireless optical CDMA communication systems, Optical MIMO systems and optical wireless technology such as visible light communications, IR links and sensor networks. Project in OWC. No prerequisite.

ENEE 4640 Electromagnetic Compatibility (4 Credits)
The study of the design of electronic systems so that they operate compatibly with other electronic systems and also comply with various governmental regulations on radiated and conducted emissions. Topics may include: Electromagnetic Compatibility (EMC) requirements for electronic systems; non-ideal behavior of components; radiated emissions and susceptibility; conducted emissions and susceptibility; shielding and system design for EMC. Final Project. Cross listed with ENEE 3641.

ENEE 4650 Radio Frequency Design in the Wireless World (4 Credits)
Topics include the following: basic concepts in Radio Frequency deign and communications, transceiver architectures, low-noise amplifiers, mixers, oscillators, phase-locked loops, power amplifiers, and transceiver design examples. Final Project. Prerequisites: ENEE 2611, ENEE 2222, and ENEE 3111 or equivalents.

ENEE 4800 Advanced Topics (EE) (1-5 Credits)
Various advanced topics in electrical engineering as announced. May be taken more than once. Cross-listed with ENEE 3035.

ENEE 4991 Independent Study (1-10 Credits)

ENEE 4992 Directed Study (1-10 Credits)

ENEE 4995 Independent Research (1-16 Credits)

ENEE 6991 Ph.D Independent Study (1-10 Credits)

ENEE 6995 Ph.D Independent Research (1-16 Credits)