ELECTRICAL AND COMPUTER ENGINEERING

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Mail Code: 2155 E Wesley Ave, Room 283, Denver, CO 80208
Phone: 303.871.6618
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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.

Master of science in electrical engineering, computer engineering, mechatronics system engineering

Following are the simple steps to apply for graduate studies in Electrical and Computer Engineering at the University of Denver. If you have any questions about the process, please contact the Office of Graduate Studies (http://www.du.edu/learn/graduates).

Apply Online / Application Deadlines

• Applications for graduate studies at the University of Denver must be submitted online. Apply online (https://gradadmissions.du.edu/apply).
• All online materials must be received, and all supplemental materials including transcripts must be on file in the Office of Graduate Studies (http://www.du.edu/learn/graduates), by the program's stated deadline: February 1, for admission in the fall quarter.
• Students interested in competing for graduate teaching assistantships (GTAs) are encouraged to submit their applications by this deadline to ensure full consideration for an appointment in September of a given year. GTAs are offered to students who have been admitted to the PhD program and rarely to master’s students who have chosen the thesis option.
• Applications received after the priority deadline will be accepted, processed and reviewed on a rolling basis for the fall, winter or spring quarters. International applicants are encouraged to have the admission application and all supporting documents in the Office of Graduate Studies by the deadline or no later than February 1, for fall admission.
• A $65 non-refundable application fee is required for an application to be processed. Application fee waivers are available for McNair Scholars.

Course Degree Prerequisites and Requirements

• Applicants must earn and submit proof of earning the equivalent of a baccalaureate degree from a regionally accredited institution prior to beginning graduate coursework at DU.
• 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

**Transcripts**

- Applicants are required to submit an official transcript from each post-secondary institution they have attended, or are presently attending, where two quarter hours (or one semester hour) or more were completed including study abroad and college coursework completed in high school.
- The applicant is responsible for obtaining all transcripts. Applicants who have earned a degree outside the U.S. must submit transcripts accompanied by certified English translations, if not normally issued in English. DU students and alumni do not need to provide DU transcripts.
- Official study abroad transcripts are required unless the course titles, grades, and credit earned abroad appear on another transcript. Transcripts from outside of the U.S. are evaluated by the Office of International Student Admission. This process can take three to four weeks and must be completed by the program’s stated deadline. Therefore, applicants with a degree from outside of the U.S. are encouraged to apply early. Applicants educated outside the U.S. are encouraged to contact the Office of Graduate Studies for assistance regarding transcript-related materials.
- The University of Denver will consider electronic transcripts official from a domestic institution provided by the following approved agencies: Army/American Council on Education Registry Transcript System (AARTS); Docufide/Parchment; National Student Clearinghouse; Naviance; Royall and Company; and, Scrip-Safe. Electronic transcripts should be sent to gradinfo@du.edu.
- Mail official transcripts to University of Denver Office of Graduate Studies Mary Reed Building, Room 5 2199 S. University Blvd. Denver, CO 80208-4802

**Language Proficiency**

- Official scores from the Test of English as a Foreign Language (TOEFL) or International English Language Testing System (IELTS) are required of all graduate applicants, regardless of citizenship status, whose native language is not English or who have been educated in countries where English is not the native language. Applications will not be processed until the required TOEFL or IELTS score is received. The TOEFL and IELTS scores are valid for two years from the test date. The minimum TOEFL score accepted by the University is 80 (iBT) or 550 (paper-based). The institution code for the University of Denver is 4842. The minimum IELTS score accepted by the University is 6.0. Graduate Teaching Assistants (GTAs) must demonstrate fluency in spoken English by scoring a 26 on the TOEFL speaking section or 8.0 on the IELTS speaking section. Please see the Graduate Policy Manual for complete English language proficiency requirements.
- Applicants may be exempt from English proficiency test requirements if by the time of matriculation they have earned a post-secondary degree from a formally-recognized/accredited university where the language of instruction and examination is English. Such applicants may be exempt from the TOEFL/IELTS requirement but not from other standardized graduate entrance examinations. There are no exemptions for graduate teaching assistants.
- Students whose native language is not English and who are required to submit TOEFL/IELTS (http://bulletin.du.edu/graduate/admissions/additionalstandardsfornonnativeenglishspeakers) scores will be assessed by the University of Denver English Language Center (ELC) prior to matriculation.
- In cases where minimum TOEFL/IELTS 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. Such applicants must take training through DU’s English Language Center to meet the English language requirement. English language training at centers outside of DU will not be counted toward meeting English language proficiency requirements. International applicants with a three-year baccalaureate degree or any other academic deficiencies cannot be granted English Conditional Admission.

**Test Scores**

- The Graduate Record Examination (GRE) is required. Scores must be received directly from the appropriate testing agency by the program’s stated deadline. The institution code for the University of Denver is 4842.
- Competitive GRE scores for MS students admitted to the Department of Electrical and Computer Engineering are as follows:
  - MS: Verbal 146; Quantitative 155; Analytical Writing Section 3.25
Personal Statement
• A personal statement of at least 300 words is required. The statement should be submitted via upload through the online application process. The statement should include information concerning your life, education, practical experience, special interests and specific purposes for furthering your studies in the Department of Electrical and Computer Engineering at the University of Denver.

Resume / C.V.
• A detailed resume or C.V. is required. This should include all educational achievements, relevant work experience, research and/or volunteer work. The resume or C.V. should be submitted via upload through the online application process.

Recommendation Letters
• Three letters of recommendation are required. Letters should be solicited and uploaded by recommenders through the online application system. Request for letters should be sent to recommenders well in advance so the letters are on file by the application deadline.

Financial Support
• To be considered for financial support, domestic applicants should apply early and submit the Free Application for Federal Student Aid (FAFSA) by the priority deadline, February 15. Information about financial aid can be found on the Office of Financial Aid (http://www.du.edu/financialaid/graduate) website. International students are not eligible for federal financial aid.
• The Department of Electrical and Computer Engineering also offers a number of competitive graduate teaching assistantships (GTA) that provide full tuition remission along with a stipend for the nine-month academic year (three academic quarters).
• Other sources of financial support available include graduate research assistantships (GRA) either with or without partial tuition remission, scholarships and fellowships, and work opportunities from the department and from the School of Engineering and Computer Science. Contact the Electrical and Computer Engineering department for more information about financial support.

Application Status
• We encourage you to be actively engaged in the admission process. You can check your application status online at PioneerWeb. Applicants will receive login information post application submission.

Contact Information
• Mail official transcripts and any supplemental admission materials not submitted with the online application to:
  University of Denver
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• Electronic transcripts should be sent to gradinfo@du.edu.
• For more information call (303) 871-2706.

International Applicants
• For complete international applicant information, please visit the Office of Graduate Studies International Student Application Information (http://www.du.edu/learn/graduates/internationalapplicants.html). International applicants are strongly encouraged to have their applications complete, with all materials on file in the admission office, at least eight weeks prior to the program’s application deadline.

Doctor of Philosophy in electrical or computer engineering, mechatronic systems engineering
Following are the simple steps to apply for the Doctor of Philosophy programs in Electrical and Computer Engineering at the University of Denver. If you have any questions about the process, please contact the Office of Graduate Studies (http://www.du.edu/learn/graduates).

Apply Online / Application Deadlines
• Applications for graduate study at the University of Denver must be submitted online. Apply online (https://gradadmissions.du.edu/apply).
• All online materials must be received, and all supplemental materials including transcripts must be on file in the Office of Graduate Studies (http://www.du.edu/learn/graduates), by the program’s stated deadline: February 1, for the fall quarter.
• Students interested in competing for graduate teaching assistantships (GTAs) are encouraged to submit their applications by this deadline to ensure full consideration for an appointment in September of a given year. GTAs are offered to students who have been admitted to the PhD program and rarely to master’s students who have chosen the thesis option.
Applications received after the priority deadline will be accepted, processed and reviewed on a rolling basis for the fall, winter or spring quarters. International applicants are encouraged to have the admission application and all supporting documents in the Office of Graduate Studies by the deadline or no later than May 1, for fall admission.

A $65 non-refundable application fee is required for an application to be processed. Application fee waivers are available for McNair Scholars.

**Course and Degree Prerequisites and Requirements**

- Applicants must earn and submit proof of earning the equivalent of a baccalaureate degree and, if applicable, a master’s degree from a regionally accredited institution prior to beginning graduate coursework at DU.

- 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, MSEE) programs.

- Admission to the PhD programs is based on review of the application and associated references. Normally, a GPA of at least 3.0 is required.

- 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.

**Transcripts** (http://bulletin.du.edu/graduate/admissions/admissionprocessandstandardsforallapplicants/#text)

- Applicants are required to submit an official transcript from each post-secondary institution they have attended, or are presently attending, where two quarter hours or more (or one semester hour or more) were completed including study abroad and college coursework completed in high school.

- The applicant is responsible for obtaining all transcripts. Applicants who have earned a degree outside the U.S. must submit transcripts accompanied by certified English translations, if not normally issued in English. DU students and alumni do not need to provide DU transcripts.

- Official study abroad transcripts are required unless the course titles, grades, and credit earned abroad appear on another transcript. Transcripts from outside of the U.S. are evaluated by the Office of International Student Admission. This process can take three to four weeks and must be complete by the program’s stated deadline. Therefore, applicants with a degree from outside of the U.S. are encouraged to apply early. Applicants educated outside the U.S. are encouraged to contact the Office of Graduate Studies for assistance regarding transcript-related materials.

- The University of Denver will consider electronic transcripts official from a domestic institution provided by the following approved agencies: Army/American Council on Education Registry Transcript System (AARTS); Docufide/Parchment; National Student Clearinghouse; Naviance; Royall and Company; and, Scrip-Safe. Electronic transcripts should be sent to gradinfo@du.edu.

- Mail official transcripts to

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  Mary Reed Building, Room 5
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**Language Proficiency** (http://bulletin.du.edu/graduate/admissions/additionalstandardsfornonnativeenglishspeakers)

- Official scores from the Test of English as a Foreign Language (TOEFL) or International English Language Testing System (IELTS) are required of all graduate applicants, regardless of citizenship status, whose native language is not English or who have been educated in countries where English is not the native language. Applications will not be processed until the required TOEFL or IELTS score is received. The TOEFL and IELTS scores are valid for two years from the test date. The minimum TOEFL score accepted by the University is 80 (iBT) or 550 (paper-based). The institution code for the University of Denver is 4842. The minimum IELTS score accepted by the University is 6.0. Graduate Teaching Assistants (GTAs) must demonstrate fluency in spoken English by scoring a 26 on the TOEFL speaking section or 8.0 on the IELTS speaking section. Please see the Graduate Policy Manual for complete English language proficiency requirements.

- Applicants may be exempted from English proficiency test requirements if by the time of matriculation they have earned a post-secondary degree from a formally-recognized/accredited university where the language of instruction and examination is English. Such applicants may be exempt from the TOEFL/IELTS requirement but not from other standardized graduate entrance examinations. There are no exemptions for graduate teaching assistants.

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- In cases where minimum TOEFL/IELTS 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. Such applicants must take training through DU’s English Language Center to meet the English language requirement. English language training at centers outside of DU will not be counted toward meeting English language proficiency requirements. International applicants with a three-year baccalaureate degree or any other academic deficiencies cannot be granted English Conditional Admission.
Test Scores (http://bulletin.du.edu/graduate/admissions/additionalstandardsfornonnativeenglishspeakers)

- The Graduate Record Examination (GRE) is required. Scores must be received directly from the appropriate testing agency by the program’s stated deadline. The institution code for the University of Denver is 4842.
- Competitive GRE scores for students admitted to the Department of Electrical and Computer Engineering are as follows:
  - PhD: Verbal 146; Quantitative 155; Analytical Writing Section 3.25

Personal Statement

- A personal statement of at least 300 words is required. The statement should be submitted via upload through the online application process. The statement should include information concerning your life, education, practical experience, special interests and specific purposes for furthering your studies in the Department of Electrical and Computer Engineering at the University of Denver.

Resume / C.V.

- A detailed resume or C.V. is required. This should include all educational achievements, relevant work experience, research and/or volunteer work. The resume or C.V. should be submitted via upload through the online application process.

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  Denver, CO 80208-4802

- Electronic transcripts should be sent to gradinfo@du.edu.

- For more information call (303) 871-2706.

International Applicants

- For complete international applicant information, please visit the Office of Graduate Studies International Student Application Information (http://www.du.edu/learn/graduates/internationalapplicants.html). International applicants are strongly encouraged to have their applications complete, with all materials on file in the admission office, at least eight weeks prior to the program’s application deadline.

The Graduate Policies and Procedures provides complete details regarding admission requirements.

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 21st 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.

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 coursework 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.

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

<table>
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<tr>
<th>Core Requirement</th>
<th>8</th>
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<tbody>
<tr>
<td>Depth Requirement - Specialization Area</td>
<td>16</td>
</tr>
<tr>
<td>Breadth Requirement</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total Credits</strong></td>
<td>90</td>
</tr>
</tbody>
</table>

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.

A minimum of 36QH must be at the 4000-level or higher, may include Independent Research or Independent Study as considered appropriate by advisor

| Student with his or her advisor will develop an appropriate plan of study with an area of specialization, breadth requirements and advanced mathematics | 36 |
| 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
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 21st 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.

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 coursework 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.

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

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</tr>
<tr>
<td>Depth Requirement - Specialization Area</td>
<td>16</td>
</tr>
</tbody>
</table>
Breadth Requirement

Total Credits

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.

A minimum of 36QH must be at the 4000-level or higher, may include Independent Research or Independent Study as considered appropriate by advisor

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

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*
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.

Minimum Credit Requirements

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, 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

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.

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 QH)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Minimum QH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Requirement</td>
<td>8</td>
</tr>
<tr>
<td>Depth Requirement - Specialization Area</td>
<td>20</td>
</tr>
<tr>
<td>Mathematics Requirement (requires one approved course at the 3000-level or higher)</td>
<td>3</td>
</tr>
<tr>
<td>Breadth Requirement</td>
<td>14</td>
</tr>
<tr>
<td><strong>Total Credits</strong></td>
<td><strong>45</strong></td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Minimum QH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Requirement</td>
<td>8</td>
</tr>
<tr>
<td>Depth Requirement - Specialization Area</td>
<td>16</td>
</tr>
<tr>
<td>Breadth Requirement</td>
<td>6</td>
</tr>
<tr>
<td>Thesis</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total Credits</strong></td>
<td><strong>45</strong></td>
</tr>
</tbody>
</table>

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:

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:

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 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 offers 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 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-priori 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)
Core Requirement
Depth Requirement - Specialization Area  &  20  
Mathematics Requirement (requires one approved course at the 3000-level or higher)  &  1  
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:

<table>
<thead>
<tr>
<th>Requirements for Thesis Option (minimum QH)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Requirement</td>
<td>8</td>
</tr>
<tr>
<td>Depth Requirement - Specialization Area</td>
<td>16</td>
</tr>
<tr>
<td>Breadth Requirement ¹</td>
<td>6</td>
</tr>
<tr>
<td>Thesis</td>
<td>15</td>
</tr>
<tr>
<td>Total Credits</td>
<td>45</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENEE 4640</td>
<td>Electromagnetic Compatibility</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 3620</td>
<td>Advanced Engineering Mathematics</td>
<td>4</td>
</tr>
</tbody>
</table>

**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:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENCE 4231</td>
<td>Embedded Systems Programming</td>
<td>4</td>
</tr>
<tr>
<td>ENEE 3670</td>
<td>Introduction to Digital Signal Processing</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 3721</td>
<td>Controls</td>
<td>4</td>
</tr>
<tr>
<td>&amp; ENGR 3722</td>
<td>and Control Systems Laboratory</td>
<td></td>
</tr>
<tr>
<td>ENEE 4141</td>
<td>Digital Communications</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 4350</td>
<td>Reliability ¹</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 4620</td>
<td>Optimization ¹</td>
<td>3,4</td>
</tr>
</tbody>
</table>
ENGR 4730  Introduction to Robotics  4
ENGR 4735  Linear Systems  4
ENGR 4740  Adaptive Control Systems  4
ENGR 4745  Adv Non-Linear Control System  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:

ENGR 3510  Renewable and Efficient Power and Energy Systems  4
ENGR 3540  Electric Power Systems  4
ENGR 3721  Controls  4
& ENGR 3722  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 Systems  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 devices, and systems.

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 Systems  4

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 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 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 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-priori 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)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Quarter Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Requirement</td>
<td>8</td>
</tr>
<tr>
<td>Depth Requirement - Specialization Area</td>
<td>20</td>
</tr>
<tr>
<td>Mathematics Requirement (requires one approved course at the 3000-level or higher)¹</td>
<td>3</td>
</tr>
<tr>
<td>Breadth Requirement</td>
<td>14</td>
</tr>
<tr>
<td>Total Credits</td>
<td>45</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Quarter Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Requirement</td>
<td>8</td>
</tr>
<tr>
<td>Depth Requirement - Specialization Area</td>
<td>16</td>
</tr>
<tr>
<td>Breadth Requirement ¹</td>
<td>6</td>
</tr>
<tr>
<td>Thesis</td>
<td>6</td>
</tr>
<tr>
<td>Total Credits</td>
<td>45</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENEE 4640</td>
<td>Electromagnetic Compatibility</td>
<td>4</td>
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<tr>
<td>or ENCE 4110</td>
<td>Modern Digital Systems Design</td>
<td></td>
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<tr>
<td>ENGR 3620</td>
<td>Advanced Engineering Mathematics</td>
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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.

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<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tr>
<td>ENCE 4231</td>
<td>Embedded Systems Programming</td>
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<tr>
<td>ENCE 4250</td>
<td>Advanced Hardware Description Language (HDL) Modeling and Synthesis</td>
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<td>ENCE 4620</td>
<td>Advanced Computer Vision</td>
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<td>ENGR 3350</td>
<td>Reliability</td>
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<td>ENGR 3630</td>
<td>Finite Element Methods</td>
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<td>ENGR 4620</td>
<td>Optimization</td>
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<tr>
<td>ENGR 4730</td>
<td>Introduction to Robotics</td>
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<tr>
<td>ENGR 4735</td>
<td>Linear Systems</td>
<td>4</td>
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<tr>
<td>ENME 4020</td>
<td>Adv Finite Element Analysis</td>
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<td>ENMT 4220</td>
<td>Mechatronics II</td>
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<td>ENGR 4740</td>
<td>Adaptive Control Systems</td>
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<tr>
<td>ENGR 4745</td>
<td>Adv Non-Linear Control System</td>
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This course may count toward the specialization with advisors preapproval. This course may not or may not be offered on a regular basis.

Engineering, Computer Courses

ENCE 3220 Microprocessor Systems II (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 CPU architectures of modern computers. Assembly language programming. Use of an assembler and other development tools for programming and developing microprocessor-based systems. Laboratory. Prerequisite: ENCE 3210.

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 3220.

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)

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 3220.
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, and Support Vector Machines. 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 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.
ENEE 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-time Fourier transform (STFT); Wavelet transform; filter banks. Spectrogram: relation to STFT; tradeoff between TF resolution and cross-term attenuation; application examples. Wigner 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.

ENEE 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.

ENEE 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.

ENEE 4991 Independent Study (1-10 Credits)
ENEE 4992 Directed Study (1-10 Credits)
ENEE 4995 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. 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 2021, 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 3610 or permission of instructor.

ENEE 3161 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 Digital Signal Processing Topics (4 Credits)
Study of lineare 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)
Digital 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 design 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)