ORIENTATION NOTES FOR GRADUATE STUDENTS

2023-2024

Department of Electrical and Computer Engineering
University of Pittsburgh
Pittsburgh, PA

1. INTRODUCTION

The various aspects of the graduate program in Electrical and Computer Engineering are described in these Notes. Information about the department, the undergraduate and graduate programs, course offerings, laboratory facilities, research interests of the faculty and their publications can be obtained from the departmental web page https://www.engineering.pitt.edu/ece.

Graduate students are expected to read these Notes and the above-mentioned reference materials before consulting with their advisors. Academic questions should be addressed to advisors. The Graduate Program Administrator can answer questions about procedures and regulations. *Each graduate student must understand the regulations concerning graduate study and is responsible for completing the degree requirements.*

2. GENERAL REGULATIONS

2.1. Academic Integrity

Academic integrity is essential for maintaining the quality of scholarship at the University. Students are expected to maintain academic integrity by refraining from academic dishonesty and by refraining from conduct that aids others in academic dishonesty. Violations of academic integrity will result in disciplinary actions including dismissal from the University.

2.2. Graduate Status

Full Graduate Status. This status is either given at the time of admission, or is obtained by satisfying admission provisions. Full graduate status is required to be considered for teaching assistantships and fellowships, to register for thesis credits, and to apply for graduation.

Provisional Graduate Status. A student with this status has been admitted with certain provisions that must be satisfied before achieving full graduate status. These provisions are intended to either fill a gap in the student's background (e.g., a student is required to take Electrical and Computer Engineering undergraduate courses) or to demonstrate his/her academic potential (e.g., a student is required to maintain a QPA of 3.0 by the end of the first academic year.)

Active/Inactive Status. A student is on active status, following his/her initial registration, provided that he/she registers for at least three (3) credits in the calendar year. To continue in the graduate program, an inactive student must submit an application for readmission.

Probation Status. A student whose quality point average (QPA) is below 3.00 for two consecutive academic terms will be placed on probation.

Probation and Dismissal Policy. A student whose quality point average is below 3.00 after completing a minimum of 9 credits will be placed on probation. If the QPA is not restored to a minimum of 3.00 within one academic year, he/she will be subject to dismissal. A student may be subject to immediate probation or dismissal for extremely poor academic performance, e.g., failing a course, having a semester QPA below 2.0, or having an overall QPA of below 2.25 after completing a minimum of 9 credits.

2.3. Advising

It is the student's responsibility to check on his/her progress by consulting with the Graduate Program Administrator and/or consulting with his/her advisor. The following are the sources of advice available to the student.

The Academic Advisor. This is a faculty member selected to advise and supervise the academic program of newly admitted graduate students.

The Major Advisor or Thesis Advisor. This is a faculty member who directs and supervises the student's research and the preparation of his/her thesis.

A faculty member may serve as an academic advisor until the graduate student starts his/her research work, at which time the major advisor assumes the functions of supervising and counseling. The same faculty member is normally the student's academic and major advisor.

A student may change his/her academic advisor by completing a change of advisor form that can be obtained from the Graduate Program Administrator. The new advisor must approve this request by signing the form.

Graduate Program Director. This is the faculty member responsible for the overall operation of the graduate program.

2.4. Grading System

Course Grades. Letter grades A, B, C, D, with "+" or "-", and F are used in grading graduate courses.

Research courses (ECE 2997, 2999, 3997, 3999) as well as the Graduate Seminar (ECE 3893) are graded with S/U (Satisfactory/Unsatisfactory) or S/NC (Satisfactory/No Credit) grades.

Students should be careful to comply with the University and School deadlines and regulations for withdrawing ("W") and auditing ("N") of courses. Refer to the Schedule of Classes for details.

"G"-Incomplete-grades are typically given because of illness, death in the family, or other unusual circumstances. Awarding of the "G" grade is at the instructor's discretion, and it is the student's responsibility to arrange with the instructor how work will be completed. A "G" grade must be changed within a year by completing the work for the course; an unchanged "G" grade will remain on the transcript and courses with such a grade will not be counted toward graduation. It is the student's responsibility to make sure that "G" grades are changed within one year.

Thesis/Dissertation Grades. At the end of each term, students taking thesis/dissertation credits (ECE 2997, 2999, 3997, 3999) should receive an S/U (Satisfactory/Unsatisfactory) or S/NC (Satisfactory/No Credit) grade.

Remarks

- An MS student in the research option (see below) must register for a minimum of six credits in ECE 2999. For PhD students, at least 12 research credits must be in ECE 3999. A minimum of six credits must be in ECE 3997.

- Only students who have been formally admitted to doctoral candidacy (see section 3.4) are permitted to register for ECE 3999 (Dissertation Research). Students may register for ECE 3997 for preliminary dissertation work.

Audit Policy. Students may elect to change any course from credit to audit status during the Monitored Withdrawal Period. The instructor of the course must agree to the audit. Students should obtain an audit form from the Graduate Program Administrator (GPA) and return it to the GPA for processing by the Office of Engineering Administration (151 Benedum Hall)

Academic Standards. All graduate students must maintain a QPA of 3.00 or above to be in good academic standing. Those below this minimum are not permitted to register for MS thesis or to graduate. In addition, a doctoral student must have a cumulative QPA on graduate course work of 3.30 or above to be considered for doctoral candidacy. A student may be placed on probation for poor academic performance and, if no improvement is achieved within a year, he/she may be dismissed. A student may be subject to immediate probation or dismissal for extremely poor performance, i.e. failing a course, having a semester QPA below 2.0, or having an overall QPA below 2.25.

2.5. Maximum and Minimum Study Program

The normal load in the Fall or Spring term for a full-time graduate student is 9 to 15 credits. Teaching assistants and Research assistants are expected to register for at least 9 credits. Non-US students are required by immigration regulations to register for 9 or more credits per term.

Part-time students (those students taking no more than 6 credits per term) should take at least 3 credits per calendar year to continue to be considered active. Part-time students should plan their studies carefully in order not to exceed the statute of limitations associated with the degrees (see section 2.6).

2.6. Statute of Limitations

The purpose of the statute of limitations is to ensure that a graduate degree from the University of Pittsburgh represents mastery of current knowledge in the field of study.

MS Students. The requirements for the Master of Science degree must be completed within a period of five (5) consecutive calendar years from the student's initial registration for graduate study in the department.

PhD Students. The requirements for the PhD degree must be fulfilled within a period of ten (10) calendar years from the student's initial registration for graduate study in the department. If the student entered the PhD program with an MS degree, he/she has six (6) calendar years, counted from the initial registration as a PhD student in the department, to fulfill the PhD requirements.

Under extenuating circumstances, a student may request an extension of the statute of limitations by writing a letter to the Graduate Program Director that can be given to the Graduate Program Administrator. The request must include the approval of the student's advisor and clearly state the circumstances necessitating the extension, the period of extension sought, and evidence that the factors causing delay no longer exist.

2.7. Residence Requirements and Leave of Absence

All students admitted into the PhD degree program must spend at least two terms of study as a full-time student at the University, which excludes any other employment except as approved by the Department. No residence requirements exist for the MS program.

Under special conditions, graduate degree candidates may be granted one leave of absence. A maximum leave of two years may be granted to doctoral candidates, and a maximum leave of one year may be granted to master's candidates. The length and rationale for the leave must be stated in advance, recommended to the Dean by the Department, and approved by the Dean. If approved, the time of the leave shall not count against the total time permitted for the degree being sought by the student. Readmission following an approved leave of absence is a formality.

2.8. International Student Internship and Co-op

Students with at 3.0 QPA or above may enroll in an internship or co-op. Before beginning any type of work, you must apply for work authorization through the Office of International Services. The total time spent on both the internship and/or the co-op cannot exceed 11 months for each degree.

A one credit internship (ECE 3000) was created for international students allowing them to keep their student status while working. The credit(s) do not count for graduation. Students who exercise this option may register for ECE 3000 one time while an MS student and once more as a PhD student. An “S” grade will be issued at the completion of the requirement which cannot go beyond one academic term. You must obtain written permission from the Office of International Services and your advisor.

The School offers a co-op program for up to two semesters. Companies that have an agreement with us may hire you. For this, you need approval from the Office of International Services, the co-op office, your advisor and the Graduate Program Director. An “S” grade for one credit would then be issued to the student and does not count toward graduation.

2.9. Transfer of Credits and Advanced Standing

Graduate courses taken in a degree granting graduate program at other accredited institutions may be credited toward a graduate degree at the University of Pittsburgh provided these courses are comparable to ECE or ECE relevant courses offered at the University of Pittsburgh and that the grade obtained in each of these courses is a B or higher. SSoE regulations pertaining to transfer credits can be found here https://catalog.upp.pitt.edu/content.php?catoid=212&navoid=21145#allowable-credits.

The responsibility of proposing which courses should be considered for credit transfer lies primarily with the student. The student's advisor will make a recommendation on which courses to transfer and record them on the ECE Block Transfer Form and the Course Credit Approval Form that can be obtained from the Graduate Program Administrator. The CCAF is submitted to the Graduate Program Administrator, who then forwards it to the Associate Dean for Academic Affairs for final approval. The grades earned in such courses will not be considered in the calculation of the QPA, but the courses will count towards graduation. The list of courses approved for credit transfer will be included in the student's file. Students should request credit transfers within the first year of their graduate program.

Students accepted for the MS program may transfer a maximum of 6 credits, and PhD students may transfer a maximum of 30 credits of a completed MS degree and up to 12 additional credits of PhD coursework. Students cannot receive credit for courses at the University of Pittsburgh that are equivalent to those for which they have already been given transfer credit. Thesis and dissertation credits are not transferable.

Students may cross-register for PCHE graduate courses at Carnegie Mellon University. Students must be registered for and stay enrolled in at least 9 credits at the University of Pittsburgh when registering for PCHE course(s) at CMU. A PCHE Cross-Registration form may be obtained from the https://www.registrar.pitt.edu/students/enrollment. PCHE courses are listed on the student's transcript and may be counted for credit toward the graduate degree. Unlike the transfer credits, the grades earned in these courses will be used in calculating the student's QPA.

Pitt BS students participating in the ECE EAGr program will be given Advanced Standing in their pre-approved EAGr courses.

2.10. Graduation Procedure

Students must register for at least three credits during the 12-month period preceding graduation and must be registered for at least one credit in the term in which they graduate. The graduation forms are available at https://www.registrar.pitt.edu/students/graduationdiplomas. There is a filing deadline after which a late fee is assessed. If the student does not graduate in the term anticipated, a new application must be filed for the term in which he/she does plan to graduate.

A student completing a thesis or dissertation is required to submit it on-line through the ETD process at https://etd.pitt.edu. In addition, copies of the thesis should be submitted to each member of his/her final oral examination committee. The Graduate Office must sign off on the submission. Please note that the ETD process must be completed in order for a student to graduate in any given term. Students must defend their thesis or dissertation prior to the ETD deadline (usually a month before the end of the term) and meet the ETD completion deadline to be eligible to graduate.

3. GRADUATE DEGREES

3.1. Master of Science (MS) Program in Electrical and Computer Engineering

As a general rule, the admission requirements for the Master of Science degree in Electrical and Computer Engineering are a minimum QPA of 3.0, two letters of recommendation, and TOEFL, IELTS, or Duolingo scores for international applicants. The GRE is currently optional.

The degree of Master of Science in Electrical and Computer Engineering can be obtained by following either a research or a professional option. The research option includes a thesis while the professional option is 30 credits of course work. Students who intend to continue for a PhD degree are highly encouraged to take the research option.

Course selection for either the research or the professional degree options is to be done in consultation with the student's advisor according to the following requirements:

1) the course selection must include at least 15 graduate credits in ECE, and
2) courses outside ECE must come from the list of recommended courses (see section 6.2).

Courses that are required of students admitted on a provisional status are to be considered additional to these requirements. If the student chooses the research option, only 6 credits of ECE 2999 will count towards the degree requirement. Notice that credits in ECE 2997, research for the MS, and in ECE 3893, the graduate seminar, will not be considered towards the degree requirements.

Professional Option. A minimum of 30 credits of course work conforming to the requirements in section 3.1 is required. Although not required, a three-credit graduate project course (ECE 2998) is highly recommended for students who might later choose to enter the PhD program. No comprehensive exam is required for students following the professional option.

Research Option. A minimum of 24 credits of course work is required. In addition, a thesis (with a minimum of six credits of ECE 2999, MS Thesis) must be completed and presented at an oral defense.

It should be emphasized that the above credit requirements for both options are the minimum acceptable and may not necessarily satisfy the degree requirements. In some instances, it might be necessary for a student to take undergraduate courses to be accepted into full graduate status. Thus, depending upon the student's background and program, it may be necessary to take more than the minimum number of credits required.

Thesis Requirement. MS students taking the research option must prepare a thesis showing marked attainment in their area of investigation. A graduate student begins thesis work after the fulfillment of the following conditions:

> Completing at least 12 credits,
> Being on full graduate status, and
> Achieving a cumulative QPA of 3.00 or higher.

Students in the research option must defend their theses orally. A committee consisting of three Electrical and Computer Engineering graduate faculty members and chaired by the student's major advisor is formed to evaluate the thesis and defense. Faculty members with a secondary appointment in Electrical and Computer Engineering may also chair such a committee. The student and committee must agree to a date two weeks before the exam. The student must provide this committee with copies of the thesis at least one week prior to the day of the oral exam. The announcement will be published two weeks ahead of time provided the schedule and document have been completed. The names of the faculty on the committee, the time, the title and the abstract of the thesis should be submitted to the Graduate Program Administrator at least two weeks prior to the exam. The oral exam is open to the public. If the student is interested in pursuing a PhD, this exam may be combined with the PhD Preliminary Exam and the Program Conference.

3.2. Joint MBA/Master's Program

The program consists of 64.5 credits for full-time students or 69 credits part-time students and leads to a Master of Business Administration (MBA) and a Master of Science in Electrical and Computer Engineering (MSECE). The joint full-time program requires students to take 39 credits minimum of business and 25.5 credits minimum in electrical and computer engineering. The full-time option can be completed in two academic years whereas the part-time option may require a period of four to five years. The program is only for those students seeking a professional MS Engineering degree. Please complete an application through the Katz School of Business. Detailed information may be located at http://www.engineering.pitt.edu/Departments/Electrical-Computer/_Content/Graduate/Electrical-and-Computer-Engineering-Graduate-Programs-content/#IDMBAMSE2

3.3. Electric Power Engineering Post-baccalaureate/Graduate Certificate

This is for electric energy professionals. This program in electric power that allows students to attend lectures in the classroom or in remote participation via the Internet, anywhere in the world.

The curriculum's core strengths are grounded in electric power engineering principles and focus on the expansion and enhanced reliability of electric power grid infrastructure through applications of power electronics and other advanced control technologies. Renewable energy integration and smart grids also play an important role. Program content – combined with distance-enabled delivery and collaborative components – makes this program an attractive and unique choice in graduate engineering.

Electric Power Engineering Certificate Curriculum
Credit hours required: 15

Students may select from any five of the following courses:
ECE 2250: Power Electronics*
ECE 2646: Linear Systems Theory
ECE 2774: Power System Engineering and Analysis 2*
ECE 2775: Advanced Electric Machines & Drives
ECE 2776: Microgrid Concepts and Distributed Generation Technologies
ECE 2777: Power Systems Transients 1*
ECE 2778: FACTS and HVDC Technologies
ECE 2780: Renewable and Alternative Energy
ECE 2781: Smart Grid Technologies & Applications

*prerequisite required

Admission Requirements
-BS in electrical engineering from an ABET-accredited university (no industry experience required) OR
-BS in any engineering field, PLUS a minimum of three years of power industry experience
-Completed application via Pitt's online application portal
-At least two references preferred
-No GRE required

For more information, please refer to https://www.engineering.pitt.edu/ECE/

3.4. Doctor of Philosophy (PhD) Program in Electrical and Computer Engineering

The objective of the PhD program is to achieve a high degree of competence in one major field in Electrical and Computer Engineering.

Application Procedure and Admission Requirements

Students who obtained the MS degree from Pitt ECE:
Students must have a QPA of 3.30 or better and the recommendation from the MS advisor. Students must apply to continue into the PhD program. Application forms can be obtained from the Graduate Program Administrator.

Students who obtained the MS degree from outside Pitt ECE:
Students must follow the regular application procedure for admission to the ECE Graduate Program and submit the following materials: transcripts (both BS and MS); minimum two letters of recommendation; and TOEFL, IELTS, or Duolingo (if required) score reports; statement of purpose; resume.

Exceptionally well-qualified students may be permitted to enter the PhD program without an MS degree.

Students who are currently enrolled in the MS program at Pitt ECE:
The request to transfer an MS student to the PhD program without an MS degree should be initiated by the students' advisor in a letter submitted to the Graduate Program Director. The decision to approve the request is the responsibility of the Graduate Program Director. To be eligible for transfer, the student should have completed a minimum of 15 credits of graduate course work at Pitt and have maintained a minimum QPA of 3.5.

Students who obtained the BS degree only and would like to apply to the PhD program:
To be eligible for direct admission, students must have a minimum QPA of 3.5 and strong recommendations. Students must take the regular application procedure for admission to the ECE Graduate Program, submitting the following materials: transcripts (BS); minimum two letters of recommendation; TOEFL, IELTS, or Duolingo (if required) score reports; statement of purpose; resume.

Degree Requirements.

Students who obtained the MS degree:
Beyond the 30 credit MS requirement, a minimum of 42 credits and a dissertation are required for the PhD degree. The dissertation should embody an extended original and independent investigation of a problem of significance in Electrical and Computer Engineering. Of those 42 credits, at least 18 must be in dissertation research (6 or more in ECE 3997 and 12 or more in ECE 3999), and at least 24 course credits must be attained beyond the MS degree. The 24 credits must include:

(1) At least 4 ECE book courses (12 credits) at the graduate level. These courses will be used for the Comprehensive Exam *
(*) A student with a Pitt ECE MS can waive the 4 ECE book courses requirement. Instead the book courses can be substituted by 12-credit combination of research courses (ECE 3998 and/or ECE 3995)

(2) A maximum 12 credit combination of ECE 3998 and ECE 3995 research/project courses. (*) A student with a Pitt MS maximum 24 credit combination of ECE 3998 and ECE 3995.

Students who obtained the BS degree only:
Students must complete a minimum of 72 credits beyond the BS degree. Of those credits, at least 18 must be in dissertation research (6 or more in ECE 3997 and 12 or more in ECE 3999), and at least 54 course credits must be attained beyond the BS degree. The 54 credits must include:

(1) At least 8 courses (24 credits) that are in the catalog; of those 24 credits, at least 4 courses (12 credits) must be ECE courses at the 2000 or 3000 level.
(2) A maximum 30 credit combination of ECE 3998 and ECE 3995 research/project courses.

All non-native English-speaking PhD students should be prepared to take an English Fluency Exam via Zoom before arriving on campus.

Exams. There are four separate exams that must be passed in order to obtain the PhD degree. The student must also have a Program Conference with a faculty committee to approve his/her plan of study. Descriptions of each follow.

Program Conference. During the first year or immediately after the Preliminary exam, a PhD student must schedule a meeting with a faculty committee to present a tentative program of study for approval. The committee consists of the student's advisor, who chairs the committee, and a minimum of two other faculty members from the Department.

On the Program Conference form, the student must list all of the courses he/she has taken as a graduate student in the department as well as those for which he/she has obtained advanced standing. Courses that he/she is planning to take in the future in Electrical and Computer Engineering as well as in related areas (see Section 6.2) should also be included. Finally, the form should list the four courses that are required for the PhD Comprehensive Exam and a tentative schedule for the different exams and the residency requirements. The committee can approve, reject or make modifications to the proposed program. The advisor is responsible for supervising the student's progress in the approved program.

Preliminary Exam. The purpose of the preliminary exam is to ascertain the capabilities of a student to do independent research. The exam generally consists of an oral presentation of a written document, prepared by the student, to a committee of ECE faculty members. The student and his/her advisor will determine the subject of the document.

Students completing the MS research option who are interested in pursuing doctoral studies have already demonstrated their ability to do independent research. Therefore, their MS thesis oral and the preliminary exam may be administered simultaneously.

Continuing MS students who elected the professional option or who obtained their degrees from other institutions must schedule a preliminary exam. The student must prepare a written document of the same caliber as an MS thesis. This may be done by either taking a graduate project course (ECE 3998) or by using a thesis presented at another institution. The student's advisor will then assist the student in forming a committee with a composition similar to that of an MS thesis exam committee. Two weeks before the exam, the written report should be given to the committee members and the Graduate Program Administrator should be informed of the composition of the committee, time, title and abstract of the thesis in order to publish an announcement.

PhD Comprehensive Exam. To complete the Comprehensive PhD exam, a student must obtain a minimum QPA of 3.3 in the four courses assigned by the PhD program conference committee no later than the first two years of enrollment in the PhD program.

If the student fails to achieve this requirement, he/she must pass an oral exam that takes place at the same time as the PhD Proposal exam and answer general questions related to his/her research area. If he/she fails this oral exam, the student may take it once more three months later.

Dissertation Proposal Exam. For the dissertation proposal examination, the student prepares a written proposal of his/her dissertation and presents it orally to an exam committee. Students must have a cumulative graduate QPA of 3.30 to be considered for doctoral candidacy. The committee consists of at least five members, four of whom must be from the Electrical and Computer Engineering Department, and at least one who must be from outside the department (external member). Three of the departmental members must be graduate faculty members and at least one of the external members must be a graduate faculty member from another department in the university. Other appropriate member(s) may also serve on the committee. A faculty member from another accredited university may serve as an external graduate faculty member of the committee if that individual's academic background is comparable to the qualifications for graduate faculty status at the University of Pittsburgh.

The dissertation proposal should be given to the committee members at least two weeks before the exam, and the student must inform the Graduate Program Administrator of the composition of the committee and provide a proposal with a completion time line as well as a title and an abstract at least two weeks prior to the exam date.

If the doctoral committee approves the dissertation proposal, the student is then formally admitted to Candidacy for the Doctor of Philosophy Degree. The proposal exam must be completed at least two semesters before the student plans to graduate. Students can register for ECE 3997 for preliminary work for the PhD proposal exam.

Final Oral Exam. The final oral exam is administered by the doctoral committee and determines the acceptability of the student's dissertation and his/her ability to comprehend, organize and make original contributions to his/her area of research.

Only students who have passed the dissertation proposal exam may register for dissertation research (ECE 3999). A minimum of 18 research credits is required for graduation, of which at least 12 must be in ECE 3999. Once a student registers for research, he/she must continue to register for Fall and Spring terms until the final oral examination has been passed.

The student must schedule the exam three weeks prior to the defense date. Two weeks prior to the exam, the student must submit the document to the committee. Also at the two week deadline, the announcement will be published. The student must submit a copy of the dissertation to each member of the exam committee and register with the Graduate Program Administrator. The final oral exam is open to the public.

Students scheduling their final oral exam must submit at least one paper from their thesis work to a refereed journal. The publication form must be signed by the major advisor and submitted to the Graduate Program Administrator at least two weeks before the final oral exam. Submitting a paper to a refereed journal is a requirement for the PhD degree.

4. FINANCIAL AID

4.1. Teaching Assistantships (TA) and Teaching Fellowships (TF)

Teaching Assistantships and Teaching Fellowships are awarded to those students who show exceptional promise in graduate work and who are able to assist in the teaching of undergraduate courses. Teaching assistants hold a Bachelor of Science degree in electrical/computer engineering and teaching fellows have an MS degree in electrical/computer engineering. The award of these assistantships is done on a competitive basis. Students who apply for admission to the graduate program on a full time basis are considered for these assistantships by the Graduate Committee. Continuing students can file an application form available from the Graduate Program Administrator. The application deadline is February 1.

The evaluation is based on letters of recommendation, the grade transcripts, the ranking of the institution from which the applicant has graduated, a statement from the student outlining his/her research interests, and the TOEFL, IELTS, or Duolingo exam, in the case of international applicants. Continuing students must request two letters of recommendation from faculty in the department, which together with the students' records are considered in the evaluation. Fluency in English is required for appointment as a teaching assistant. International students who are appointed as TA/TFs will be tested in their fluency in English, and remedial tutoring will be given to those with deficiencies.

TA/TFs are required to work 10 or 20 hours per week as assigned on teaching-related assignments. In addition to a monthly stipend, a tuition scholarship and health insurance are part of the benefits given to TA/TFs. The tuition scholarship includes tuition, student health, security, safety and transportation, and computer and network services fees. Faculty members serve as supervisors of TA/TFs assigned to courses or laboratories.

A TA/TF will receive a warning after obtaining a "C" grade and will lose financial support from the department after the second "C" grade.

4.2. Research Assistantships

Research assistantships (RAs) are typically awarded to graduate students who have been in the department for at least one term and have distinguished themselves for their academic and research abilities. Faculty with research funds select RAs and arrange the conditions and salary on an individual basis.

4.3. Scholarships and Other Sources of Financial Aid

A limited number of scholarships are available to very qualified students. University funds permit the department to offer a few scholarships on a yearly basis. Also, federal agencies as well as companies offer students the opportunity to apply for graduate fellowships.

4.4. Graduate Seminar

The Graduate Seminar, ECE 3893, is a series of presentations given by industry and university researchers. The Graduate Seminar is a one credit course, and it does not count toward graduation. Although registration in this course is not mandatory, it is highly encouraged. All GSRs, TAs and PDTs are required to attend the Graduate Seminar for two semesters as an MS student and four for PhD students.

5. REGISTRATION

Registration usually begins at least two months before the beginning of each term. Newly admitted and readmitted students are permitted to register until the day before classes begin. Continuing students are encouraged to register early in the registration period to ensure that courses have sufficient enrollment and are not cancelled.

All students should consult their faculty advisors about their course of study. Because it is desirable that the advisor be informed about the student's progress in his/her studies, the advisor must approve the selections.

Doctoral students who have completed all credit requirements for the degree, including any minimum dissertation credit requirements, and are working full time on their dissertations should register for Full-Time Dissertation Study (FTDH), which carries no credits or letter grade but provides students full-time status. Students so enrolled are assessed a special tuition fee.

6. COURSE LISTINGS

It is important that students have a good understanding of the course offerings in general, the way courses relate to departmental areas, and the types of courses offered. Prerequisites must be carefully considered in selecting courses. If in doubt about prerequisites or the content of a course, students should contact the faculty member responsible for that course.

ECE 2997 and ECE 2999 are research courses for MS students, and ECE 3997 and ECE 3999 are PhD research courses.

ECE 2997 and ECE 3997 are intended for students who are engaged in preliminary investigations that are expected to lead to their thesis research. ECE 2997 credits are not counted toward graduation requirements. A PhD candidate must complete at least 6 credits of 3997.

ECE 2999 and 3999 are to be used when students have identified and are actively engaged in their thesis research. Six credits of 2999 are used to satisfy thesis credit requirements for the MS with research options, and 12 credits of 3999 are used to satisfy thesis credit requirements for the PhD.

ECE 2998 and ECE 3998 are MS and PhD project courses, respectively, that are used for independent study. Three credits of 2998 may be used toward graduation with MS degree.

ECE 3000, Practicum, is a one credit course for full-time students interested in industrial internships as a means of gaining practical experience in their areas of research. Students are responsible for arranging a practicum with industry. The practicum requires permission.

ECE 3995, Research Topics in Electrical and Computer Engineering, is a research course for PhD students that focuses on specific skills required by students to conduct original research in a particular area of Electrical and Computer Engineering. Students will complete a project, such as a submitted journal/conference paper, a proposal for research funding, or a complete patent application, as specified by the faculty teaching the course. This course requires approval by the PhD Preliminary Exam committee, based on a 1-2 page proposal citing the topic, rationale for the course, the professor, and the specific project to be completed.

6.1. Graduate Electrical and Computer Engineering Courses

Computer Engineering

ECE 2120, Hardware Design Methodologies 1, 3 cr.
This course teaches hardware design processes through use of industry tools. Students use graphical tools to design, simulate and synthesize designs using hardware description languages (e.g. VHDL/Verilog). High-level design and problem decomposition are also taught. Optimization, simulation and synthesis of combinatorial functions, data paths, and finite state machines are covered in depth. Architecture encapsulation and reuse through "Intellectual Property" (IP) modules is described and covered in detail. Students will work individually and as a part of a team to create, simulate, model, document, and test IP models. Prerequisites: ECE/CoE 0142, CoE 1502 or permission of instructor.

ECE 2130, Topics in VLSI CAD, 3 cr.
The course introduces state-of-the-art computer-aided design algorithms with application to VLSI. The course starts with a review of fundamental algorithms, from graph theory, sorting, searching and hashing, and then proceeds to focus on major CAD application areas in architectural, logical, and physical design.

Major topics discussed are multiple level combinational logic synthesis and optimization, sequential logic optimization (retiming, clock scheduling), convex optimization and its applications, testing—test pattern generation and design for testability, placement and routing, simulated annealing. Hot current research topics will be surveyed briefly. Prerequisites: ECE 2192or permission of instructor.

ECE 2140, Systems-on-a-Chip Design, 3 cr.
This course is a full semester project involving the entire class in one System on a Chip design experience. This includes requirements definition, high-level design, system specification, algorithm modeling, decomposition, IP selection and/or IP creation for re-use, synthesis simulation and testing. The system will be a true SoC with at least one processor core with associated system and application software. Lectures will be the philosophy of SoC as well as the practical issues involved in the SoC design methodology. State of the art CAD software will be used for design and co-simulation of the hardware/software platform. Prerequisite: ECE 2120 or permission of instructor.

ECE 2180, Computing and Biology, 3 cr.
This course explores the connections between computer science and engineering concepts (such as artificial intelligence, machine learning, digital computation, circuit theory, synchronous and asynchronous circuits, distributed computing, simulation vs. emulation, computer architecture) and biological systems. Studying biological systems with engineering methods is poised to alter the biologists' approach to modeling and analyzing these systems. At the same time, when studying biological systems, engineers gain insight into how 'biological computation' works, which in turn can be used to design biologically inspired methods and machines. This is a graduate-level, research-oriented course. It is aimed at a wide audience: students with background in electrical and computer engineering, computer science, biomedical engineering, mathematics, or computational biology. This course is about an exciting and novel research field relevant to forthcoming research “waves" in science and engineering.
The topics include:

- Discrete and Analog Modeling of Biological Networks
- Model Inference vs. Model Design
- Data-based (ML) vs. Knowledge-based (broader AI) Modeling
- Modeling Correlations vs. Causality in Biology with ML and AI Methods
- Synchronous and Asynchronous (Biological) Circuits with Uncertainty and Stochasticity
- Static Graph Features vs. Dynamic System Analysis
- Role of Feedback and Feed-forward Loops, Timing Analysis
- Sensitivity, Robustness Analysis, and Model Reduction in Biological Systems
- Hardware Design for Biology
- Role of Advanced Computer Systems in Medicine
- Design of Synthetic Biological Circuits
- Biologically-Inspired Computing

ECE 2141, Validation and Verification Techniques of Digital Systems, 3 cr.
This course presents state of the art methodologies and tools for simulation based validation and formal verification of complex digital systems implemented as a systems on a chip. Topics include testing strategies, test bench design, coverage, and model checking. Prerequisites: ECE 2140 or ECE 2121 or permission of instructor.

ECE 2156, Advanced Information Security, 3 cr.

This course covers information security at the computer system level, the network level, and the human level. Students will first learn general computer security technology and principles such as cryptographic tools, user authentication, access control, malicious software and attacks. Then, we will delve into the details of network attacks and defending techniques. The latter units of the course cover software and system security, including buffer overflow vulnerability, operating system security, and Cloud and IoT security as well as human factors and legal and ethical issues.

ECE 2160, Embedded Computer System Design, 3 cr.
Design and implementation of embedded microprocessor systems. Topics include "C" language, top down iteration for assembly language programming, data structures, co-routines, I/O software structures and real time operating systems. Prerequisite: ECE/CoE 0142

ECE 2161, Embedded Computer System Design 2, 3 cr.
Organized as a full term project carried out by student design groups. A complex embedded system will be designed, implemented and tested using Altera and other CAD tools. Grade will be based on project reviews and the final project report. Proper design process will be emphasized. Prerequisite: ECE 2160

ECE 2162, Computer Architecture 1, 3 cr.
Review of basic architecture concepts, data representation, microprocessor and minicomputer architectures, memory, I/O subsystems, stack computers, parallel and pipelined computers. Prerequisite: ECE/CoE 0142

ECE 2165, Dependable Computer Architecture, 3 cr.
The field of FTCA for dependable computing has recently emerged as one of the most important areas of study in computer engineering. Modern computer system are susceptible to a broad range of potential faults, errors, and failures, and increasing chip density and design complexity exacerbate the problem. Novel methods in hardware, information, network, software, and time redundancy are now available to mitigate these threats in the form of fault-tolerant computer architectures and systems. The focus of studies here is the design and analysis of dependable machines, from small embedded systems to space-based platforms to high-end supercomputers, in terms of reliability, availability, performability, testability, safety, and more. Co-requisite: ECE 2162

ECE 2166, Parallel Computer Architecture, 3 cr.
Introduction to fundamental and newly developing hardware and software topics in parallel computer architecture (PCA) including concepts, models, methods, metrics, systems, and applications. PCA has become one of the most challenging and important areas of ECE, and it is now a dominant theme throughout computer architecture, systems, and programming, from low-power embedded systems to high-end supercomputers, and featuring various forms of fixed-logic (e.g., CPU, DSP, GPU), reconfigurable-logic (e.g., FPGA), and hybrid (e.g., CPU+DSP, CPU+FPGA, CPU+GPU, CPU+FPGA+GPU) processing devices.

ECE 2167, Reconfigurable Computing in Deep Learning, 3 cr.

In this course, we will study heterogeneous computing platform featured with CPUs + FPGAs for reconfigurable customized computing for deep learning applications. We will first cover architecture and programming models for FPGAs as an accelerator platform using high-level synthesis (HLS). Various customization technique on FPGA including customized control/data flow, accelerator memory management, performance & energy modeling and optimization, communication and computation optimization will be discussed. We will then cover deep learning framework (TensorFlow, PyTorch, etc.), applications in computer vision, natural language processing and FPGA accelerators in deep learning domain. Prerequisites: an undergraduate course covering computer organization and architecture, digital circuit design, such as ECE 1110 or ECE 1195

ECE 2168, Neuromorphic Systems Design, 3 cr.
This course will teach principles, design methodology, applications of neuromorphic VLSI architectures and energy efficient event-based sensors like Dynamic Vision Sensors (DVS) and silicon cochlea. The syllabus will cover a brief background of neuroscientific principles for neuron and synapse modelling as well as the evolution of neuromorphic engineering over the decades. Systems and algorithms presented in literature and industry standards will be analyzed and discussed in detail. Students will be required to apply the acquired skills in designing real circuits with industry-level CAD tools. Students will be given the opportunity to extend successful projects into design, fabrication, and testing of custom silicon integrated circuits after completion of the course. By the end of the course, students should understand the steps needed to develop neuromorphic systems from original concept to a working demo.
Prerequisites: an undergraduate course covering the fundamentals of analog/digital circuit design, such as ECE 1192 or ECE 1286.

ECE 2170, Emerging Memory Technologies and Systems, 3 cr.
Discussions on the modern computer system designs and simulations. Topics cover multi-core architecture, CPU, 3D integration, emerging memory hierarchy, solid state data storage, etc. Students are required to read the latest technical references, give seminars, learn how to use simulators and do the self-proposed research projects. Prerequisite: ECE 2160 or ECE 2162

ECE 2180, Computing and Biology, 3 cr.
This course explores the connections between engineering concepts (such as digital computation, circuit theory, synchronous and asynchronous circuits, distributed computing, simulation vs. emulation, computer architecture) and biological systems. The main theme of the course is applying engineering methods when studying biological systems, but also exploring how these methods can inform design of computing systems. Topics include: discrete and analog modeling of biological networks; model inference vs. model design; data-based vs. knowledge-based modeling in biology; modeling correlations vs. causality in biology; synchronous and asynchronous biological circuits, and stochasticity in biology; static vs. dynamic analysis of biological systems; role of feedback and feed-forward loops, timing analysis; sensitivity, robustness analysis, and model reduction in biological systems; hardware design for biology; role of advanced computer systems in medicine; design of synthetic biological circuits; biologically-inspired computing.

ECE 2192, Introduction to VLSI Design, 4 cr.
Introduction to the concepts and techniques of modern integrated circuit design. Use of Computer Aided Design (CAD) tools for circuit design and simulation. Prerequisite: ECE/CoE 142.

ECE 2193, Advanced VLSI Design, 3 cr.
This course is organized as a full semester project in conjunction with lecture material on advanced CMOS and BiCMOS digital design techniques, as well as the group design process itself. Students form groups that design and implement different VLSI projects which are then fabricated by the NSF MOSIS (MOS Implementation Service) facility and returned for testing. The majority of the course is focused on group projects with written and oral reviews and reports. Prerequisite: ECE 2192

ECE 2195, Special Topics: Computers, 3 cr.
An MS level course in special topics of current interest in computer engineering.

ECE 3162, Advanced Computer Architecture, 3 cr.

This upper level graduate course aims to cover the state-of-the-art advances and hot topics in computer architecture research. Topics include emerging non-volatile memory technologies, massive parallel architectures (e.g. GPU), accelerators, optimizing architecture for data analytics etc. Students are required to read contemporary research papers, and present them throughout a semester. One term project, done either individually or in team, is required. Prerequisite: ECE 2162

ECE 3182, Advanced Machine Learning & Deep Learning, 3 cr.
In this course, we will study the cutting-edge advanced research topics in machine learning and deep learning by reading and discussing a set of recent research papers. The main objective of this course is to cover the underlying mathematical concepts and representative algorithms, paper reading, and implementation. The student learning outcomes include understanding the advanced machine learning and deep learning models, large-scale optimization algorithms, present and discuss newly published ICML, NeurIPS, KDD papers in classes. The class projects will include a set of emerging machine learning and deep learning research topics. The project reports will be competed to target for potential machine learning conference submissions.

ECE 3195, Advanced Topics: Computers, 3 cr.
A PhD level course in advanced topics of current interest in the area of computer engineering.

Control

ECE 2646, Linear System Theory, 3 cr.
Linear spaces and operators, mathematical descriptions of linear systems, controllability and observability, irreducible realization of rational transfer-function matrices, canonical forms, state feedback and state estimators, stability.

ECE 2647, Introduction to Nonlinear Control Design, 3 cr.
This course is an introduction to nonlinear control design methods. The main topics include: Lyapunov stability analysis, feedback linearization, sliding mode control, and integrator backstepping. The content will be mathematical, supplemented with application examples from nonlinear systems such as robotic manipulators and human musculoskeletal system.

ECE 2654, Digital Control Systems, 3 cr.
Transform domain approach to analysis and design of digital computer control systems, linear discrete dynamic systems analysis and the z-transform, discrete equivalents to continuous transfer functions, sampled data systems, design of digital control systems using transform techniques, quantization effects, sample rate selection. Prerequisite: ECE 1673

ECE 2671, Optimization Methods, 3 cr.
Analytical and computational aspects of finite dimensional optimization, unconstrained and equality constrained problems, basic descent methods, conjugate direction methods, nonlinear programming and the Kuhn-Tucker theorem, linear programming, dynamic programming, multicriteria optimization.

ECE 2680, Adaptive Control, 3 cr.
Adaptation and learning play an essential role in biological systems, and these characteristics have been widely incorporated in modern control systems. This course introduces the general principles of adaptive control and learning. Topics to be covered include: real-time parameter estimation, self-tuning regulators, model-reference adaptive systems, adaptive control of nonlinear systems, practical aspects and

implementation of adaptive control systems, introduction to computational learning theory and learning in neural systems, and an example of adaptive control by the cerebellum.

ECE 2695, Special Topics: Control, 3 cr.
An MS level course in special topics of current interest in control.

ECE 3650, Optimal Control, 3 cr.
Variation calculus and optimality conditions, linear quadratic problems, the Riccati equation, Pontryagin maximum principle, time-optimal control, dynamic programming and the Hamilton-Jacobi equation, numerical methods, decentralized control, multicontroller-multiobjective systems, differential games. Prerequisite: ECE 2646

ECE 3695, Advanced Topics: Control, 3 cr.
A PhD level course in advanced topics of current interest in the area of control.

Electronics

ECE 2043, Electron Microscopy in Materials Science, 3 cr.
Electron optics, lens aberrations, depth of field, depth of focus, resolution, contrast, bright and dark field microscopy, selected area diffraction, calibration, specimen preparation, electron scattering, electron diffraction, Bragg's law, Laue conditions, structure factor, Ewald construction, double diffraction, twinning Kikuchi lines, contrast theory, kinematical theory of diffraction by perfect and imperfect crystals, limitations, column approximation, extinction contours, dynamical theory, special techniques, high voltage microscopy, applications.

ECE 2231, Fundamentals of Semiconductor and Quantum Electronic Devices, 3 cr.
Fundamental quantum theory, electron in potential well, harmonic oscillator, band theory of solids, Kronig-Penney model. Prerequisite: ECE 1247

ECE 2233, Focused Ion Beam Scanning and Electron Microscopy, 3 cr.
This course introduces the basic theory of FIB, SEM, X-EDS, and EBSD instrumentation, milling, deposition, and analytical capabilities. It discusses and presents the theory directly related to applications and techniques used in FIB/SEM dual beam platform instruments. Throughout the course, the students will be exposed to these methods and required to apply them to real research projects either provided by the instructor or from their research supervisors.

ECE 2235, Monolithic Integrated Circuits, 3 cr.
Fabrication of integrated silicon monolithic circuits, thermal oxidation, solid state diffusion, epitaxial growth, ion implantation, photo and electron lithography, design considerations, active and passive elements in monolithic blocks, surface effects. Prerequisite: ECE 1247

ECE 2237 CMOS Analog Circuit Design, 4 cr.

The objectives of this course are: to understand the operation of essential CMOS analog circuits and learn how to design them. To design the analog circuits using a 45nm CMOS process and verify their performance by SPICE simulation using a commercial EDA tool (Cadence Spectre).
Topics include: comparators; two-stage amplifiers; folded-cascade amplifiers; voltage and current references; oscillators; linear regulators; switched-capacitor circuits; digital-to-analog converters, analog-to-digital converters; SAR ADCs; delta-sigma ADCs; second order effects & noise assignment; sensor interfaces. Prerequisites: ECE 1286 or equivalent

ECE 2240, Nano-Optics, 3 cr.
A graduate level course designed for students who want to understand the mechanisms of interaction of light and matter at the nanometer scale, and become acquainted with nano-optics-based technologies. Topics include: electromagnetic theory of optical interaction with matter, optical waves in periodic media, photonic bandgap structures, surface plasmons, optical interaction with metal nanostructures (metal nanoapertures and arrays, and metal nanoparticles), surface plasmon resonance spectroscopy, plasmon coupling and concentration/funneling of electromagnetic energy, surface-enhanced Raman scattering, near-field imaging and microscopy, and negative refraction. Prerequisite: Junior or senior level EM theory course.

ECE 2250, Power Electronics, 3 cr.
The objective of this course is to cover the fundamental concepts in the field in sufficient depth to allow students to analyze and design power electronics circuits. The course covers DC-DC converters and DC-AC converters. Prerequisite: ECE 0257

ECE 2260, Scanning Probe Microscopy-based Characterization and Nanofabrication, 3 cr.
The course concentrates on both theoretical and practical issues of advanced scanning problem microscopy (SPM) techniques. It introduces concepts, theoretical backgrounds, and operation principles of varieties of scanning probe microscopies; addresses the fundamental physical phenomena underlying the SPM imaging mechanism; covers the practical aspects of SPM characterization of a wide range of materials as well as operation devices; discusses SPM-based approaches to nanofabrication and nanolithography such as dip-pen nanolithography and nano-robotic manipulation.

ECE 2262, Low Dimensional Nanoelectronic Devices, 3 cr.
This graduate course discusses the electrical transport, electrothermal interactions, and power dissipation in emerging low-dimensional (1D and 2D) nanoelectronics. Topics include band structures, electronic transport in 1D nanowire and nanotubes as well as layered 2D materials (graphene, transition metal dichalcogenides, black phosphorus, and etc.), electrothermal interactions in nanoelectronics, power dissipation in nanoelectronics, thermometry, and system-level power dissipation issues (breakdown, heat sink, etc.). This course is intended to bridge a gap between device operations, solid-state physics, thermal transport, and materials science.

ECE 2263, Emerging Memory Technology from Device Applications, 3 cr.
In today's big data era, trillions of sensors will connect every aspect of our lives to the Internet, constantly producing and processing an overwhelming amount of data. Conventional charge-based memory technology such as DRAM and Flash memory will not sustain the increasing demand for scalable, high-speed, energy-efficient and high density memory devices. In this special topic class, we will discuss the prospect and challenges of various emerging memory technology such as spin transfer torque random access memory (STT RAM), phase change memory (PCM), resistive random access memory (RRAM), conductive bridge random access memory (CBRAM) and possible applications in neuromorphic computing.

ECE 2264, Flexible Electronics, 3 cr.
This course is designed to provide an understanding of scientific and technical aspects of the flexible electronics and to enable students to contribute to the rapidly developing flexible electronics information. The course aims to introduce graduate level students to semiconductor devices, modern electronic devices on flexible substrate, and wearable and stretchable devices.

ECE 2270, Fundamentals of Photovoltaics, 3 cr.

Photovoltaics will play an increasingly important role in a future low-carbon energy economy. The main purposes of this course are to help students acquire the terms and concepts of solar cell device physics and to show them how to formulate and solve relevant physical problems and to make them prepared for future generations of photovoltaics. The course introduces the basic principles of photovoltaics which cover the basic physics of semiconductors in photovoltaic devices, physical models of solar cell operation, characteristics and design of common types of solar cells, and approaches to increasing solar cell efficiency. Besides the first generation of photovoltaics (single crystal), the second generation of photovoltaics (amorphous Si, CdTe, dye-sensitized photochemical, organic) is also covered in the course. The topics of the third generation of photovoltaics (hot electron converter, multiple exciton generation, mid-band photovoltaics, quantum dot solar cells) are also discussed.

ECE 2272, Simulation & Design of Photonic Integrated Circuits, 3 cr.
The goal of this course is to enable students to design basic photonic integrated circuits by providing them with an intuitive understanding of core photonic components (e.g. waveguides, couplers, resonators, etc.) as well as a solid grasp of the tools needed to simulate multi-component designs. By the end of the course, students should understand the steps needed to take a PIC design from original concept to fabrication at a foundry. This includes such topics as:
on-chip filtering/routing using ring resonators and Bragg gratings; methods for optimizing bandwidth and on/off-chip coupling efficiency using edge and grating couplers; integrated high-speed silicon PN modulator design and optimization; integrated high-speed germanium PIN photodetector design and optimization; full photonic circuit simulation using the S-parameter method.
Prerequisites: an undergraduate course covering the fundamentals of electromagnetic waves.

ECE 2295, Special Topics: Electronics, 3 cr.
An MS level course in special topics of current interest in electronics.

ECE 3233, Semiconductor Device Modeling, 3 cr.
Topics of current interest in the field of solid state electron devices. Prerequisite: ECE 2231

ECE 3235, Semiconductor Lasers, 3 cr.
Properties of heterojunctions, stimulated emission in semiconductors, carrier and optical confinement, fabrication and operating characteristics of semiconductor lasers including double-heterostructure lasers, quantum-well lasers, distributed feedback lasers, surface emitting lasers, various modulation techniques of semiconductor lasers. Prerequisite: ECE 2231

ECE 3295, Advanced Topics: Electronics, 3 cr.
A PhD level course in advanced topics of current interest in the area of electronics.

Image Processing/Computer Vision

ECE 2372, Pattern Recognition, 3 cr.
Emphasis on machine pattern recognition and learning: Bayes decision theory, parameter estimation, Bayesian belief networks, discriminant functions, supervised learning, nonparametric techniques, feature extraction, principal component analysis, hidden Markov models, expectation-maximization, support vector machines, artificial neural networks, unsupervised learning, clustering, and syntactic pattern recognition.

ECE 2390, Image Processing and Computer Vision, 3 cr.
This first level graduate course covers essential elements of image processing for computer vision and introductory subjects in computer vision; Image segmentation: region-based, edge detection, scale space,

active contours; shape description, deformable templates; textures; perspective camera model and its parameters; geometry of multiple (2) views, fundamental matrix; scene planes and homographies; consistent labeling; locating objects in 3-D space; motion analysis.

ECE 2395, Special Topics: Image Processing/Computer Vision, 3 cr.
An MS level course in special topics of current interest in image processing/computer vision.

ECE 3374, Applications of Wavelet Transforms, 3 cr.
This course presents applications of wavelet transforms to multiresolution signal/image processing and pattern recognition. Topics include basic notions of scaling functions with compact support, localization property, multiresolution analysis, continuous wavelet transform, discrete dyadic wavelet transform, wavelet packets, image compression, signal/image denoising, edge localization, texture feature extraction, and multiresolution data fusion. Prerequisite: ECE 2390 or ECE 2523 or permission of instructor.

ECE 3395, Advanced Topics: Image Processing/Computer Vision, 3 cr.
A PhD level course in advanced topics of current interest in the area of image processing/computer vision.

Power

ECE 2750 Distribution System Modeling and Analysis, 3 cr.
This course is a graduate, project-based learning course which focuses on modelling and analysis of electric power distribution systems. In this course, students will use a project to learn about distribution system modelling, equipment parameters, simulation data collection, distribution systems loads, non-wire circuit design alternatives, distribution systems economic & environmental considerations, voltage control, voltvar optimization strategies, hosting capactity mapping, and distribution systems proposal writing. Prerequisite: an undergraduate course in electric power systems analysis

ECE 2774, Power System Analysis 2, 3 cr.
Steady state phenomena, matrix transformations, system parameters, system unbalances, digital methods, and numerical analysis techniques applied to load flow, state estimators, and fault studies in large power systems. Prerequisite: ECE 1769

ECE 2775, Advanced Electric Machines and Drives, 3 cr.
This is a course in electric machine and drive analysis and modeling, along with their control systems. The course will cover the dq0 transformation, reference frame theory, saturation, unbalanced operation and dynamics in electric machines. Then cover the converter topologies typically used in machine drives, power electronic device characteristics, pulse-width modulation techniques, current regulation, torque and speed control, and space vector control.

ECE 2776, Microgrid Concepts and Distributed Generation Technologies, 3 cr.
This course describes fundamental concepts related with the development of microgrids and the integration of distributed generation. Technical topics are divided into three modules. The first module introduces microgrid components and discusses the main types of microsources. The second focuses on energy storage technologies. The third includes system integration topics, such as power electronics interfaces; dc and ac architectures,; economics, operation, stabilization, and control; reliability aspects; grid interconnection, and microgrids as part of the "smart" grids. This course also aims at preparing students to conduct research or helping them improve their research skills.

ECE 2777, Power System Transients 1, 3 cr.

Lumped parameter analysis, switching transients in AC/DC systems, arc modeling, damping, current suppression, traveling wave phenomena, line discontinuities, ferroresonance, transient recovery voltage. Prerequisite: ECE 1769

ECE 2778, FACTS and HVDC Technologies, 3 cr.
Advanced Power Electronics (FACTS and HVDC) is a comprehensive course in the area of large-scale power electronics systems, circuits, devices, and the ever-advancing areas of applications. This course will provide graduate students with an understanding of the how the broad spectrum of power electronics is integrated into a wide variety of industries, with an emphasis on utility scale FACTS and HVDC technologies and applications, as well as how applications of power electronics circuits, devices, and systems are utilized for control and operation of various processes and business fields. The course will cover, from a ground-up approach, devices and their characteristics, conversion techniques and circuits, and applications of power electronics with an emphasis on power conversion fundamentals for FACTS and HVDC applications.

ECE 2780, Renewable and Alternative Energy, 3 cr.
This course covers an in-depth analysis and understanding of various renewable and alternative energy technologies – including wind, solar, biomass, thermal, wave, hydro, and other sources and systems. Investigation of applications, integration, markets, policy, and other aspects of renewable development will be studied. Supporting technologies, such as energy storage, power electronics, and controls as applied to renewable and alternative energy applications are also explored.

ECE 2781, Smart Grid Technologies & Applications, 3 cr.
This is a comprehensive course designed to introduce students to new technologies dedicated to reliably, efficiently and safely managing electric power across utility, commercial, industrial, and residential networks. The course will cover the application of smart grid technologies from power generation through power consumption including grid automation, smart meters, demand response, communication, electric vehicle integration, grid connectivity, renewable energy, cyber security, microgrids and the business processes. Students will gain an understanding of the how the broad spectrum of smart grid technologies is integrated into the electrical energy industry, with an emphasis on distribution systems within homes, buildings, factories, transportation systems, and the utilities serving them.

ECE 2782, Protective Relaying and Automation, 3 cr.
This course provides a basic understanding of the role of protective relaying in the power system. Critical elements of protection philosophy are presented. Electromechanical and microprocessor based relay technologies are studied. Traditional and innovative methods in different voltage levels, including over-current protection in the distribution network, distance protection in transmission systems, and pilot protection schemes, are explored. Instrument transformer selection and application are covered, followed by application schemes of unit protective relays such as differential protection to protect transmission lines, AC generators and motors, transformers, and buses.

ECE 2795, Special Topics: Power, 3 cr.
An MS level course in special topics of current interest in power.

ECE 3750, Electric Power Grids and Systems Resilience, 3 cr.
This course discusses selected topics in resilience engineering at an advanced level. The focus is on power systems and on information and communication networks as a critical load for electric power grids. Discussed topics include both theoretical and applied concepts. The course is divided in three main parts. The first part is mostly theoretical and presents the definitions, models and metrics to be used in the rest of the course. The second part is dedicated to study the performance of electric power grids and of information and communication networks in past disasters using engineering forensic tools. The third part

of this course discusses approaches for improved resilience in electric power grids and in information and communication networks.

ECE 3776, Power System Control and Stability, 3 cr.
The power system model for stability studies, response to disturbances, the behavior of machines, the effect of excitation, and mathematical techniques for stability studies. Prerequisite: ECE 2774

ECE 3777, Power Electronics Conversion 2, 3 cr.
This course discusses selected topics in power electronics systems and circuits at a medium graduate level. The course content includes advanced modeling techniques of power electronic components and switched circuits. It also includes advanced concepts in power electronic circuits design, such as thermal and reliable based designs, and controls, including both time domain and geometric based controllers. Some primary applications include microgrids, renewable and alternative energy, sustainable systems, reliable power conversion circuits, smart grids, motor control, and others. Prerequisite: ECE 2250

ECE 3778, Power Systems Transients 2, 3 cr.
Project-based course in simulation and modeling techniques for power system electromagnetic transients. Frequency-dependent and non-linear component models, with applications to transmission, distribution, power electronic and measurement systems. Prerequisite: ECE 2777

ECE 3779, High Frequency Power Electronics Design, 3 cr.
This course addresses the motivations and inherent design issues associated with high frequency switched mode power supply design. Origins and dependencies of frequency dependent losses will be reviewed, with specific emphasis on potential design approaches which reduce energy loss and facilitate high frequency operation. Resonance and its application to power converters will be discussed. Students will learn steady-state and dynamic modeling techniques which allow the analysis and design of converters containing significant resonant intervals, for which traditional small ripple assumptions do not hold. Prerequisite: ECE 2250

ECE 3783, Modern Control and Optimization for Energy and Complex Engineering Systems, 3 cr.
The main goal of this course is to help the student develop a working knowledge of convex and nonconvex optimizations, i.e., to develop the skills and background needed to recognize, formulate, and solve convex and nonconvex optimization problems in engineering problems. This course provides a fundamental understanding of the operation of complex engineering system problems including energy and power networks, and machine learning from a control and optimization perspective. Students will learn how mathematical tools and computational methods are used for the design, modeling, planning, and 2 real-time operation of engineering systems. They will also learn about the mathematical modeling and calculation engines of related problems. Prerequisites: ECE 1769, ECE 2671, Math 0280, or ECE 2646.

ECE 3795, Advanced Topics: Power, 3 cr.
A PhD level course in advanced topics of current interest in power.

Signal Processing/Communications

ECE 2521, Analysis of Stochastic Processes, 3 cr.
Probability theory, random variables, sums and limits of random variable sequences, time and frequency domain, modeling of continuous and discrete random signals, least-squares estimation.

ECE 2523, Digital Signal Processing, 3 cr.

Discrete-time signal processing, discrete Fourier transform and FFT implementation, design and stability considerations of FIR and IIR filters, filter implementation and finite register effects.

ECE 2525, Detection and Estimation Theory, 3 cr.
A study of optimal techniques for extracting information from the observation of random variables or random signals. This includes hypothesis testing, estimation theory, optimal receiver design, Wiener and Kalman-Bucy filtering, and application such as digital communications and medical imaging.
Prerequisite: ECE 2521

ECE 2555, Biomedical Signal Processing, 3 cr.
This course introduces advanced signal processing methods that are commonly used to perform feature extraction, reduction and classification in many biomedical applications. During the course, students will be exposed to methods for extraction of statistical measures (e.g., scaling components), information-theoretic measures (e.g., the approximate entropy) and measures based on the time-frequency and wavelet representations of the signals. Lastly, approaches for feature reduction and classifications such as linear discriminate analysis and principle component analysis will be reviewed. Throughout the course, the student will be required to apply these methods to real data either provided by the instructor or from their own research projects. While the course will focus on biomedical applications, we will also discuss other applications if interest arises. Co-requisites: ECE 2521 or ECE 2523

ECE 2556, Neuro-signal Modeling and Analysis, 3 cr.
This course will focus on statistical theory and practical application related to brain imaging analysis. The topics will include statistical inference, analysis of variance, Bayesian analysis, likelihood and factor analysis (exploratory and confirmatory). The content ranges from the traditional to the contemporary. While specific applications are not treated, this course is strongly motivated by bio applications, especially in computational neuroscience. This would be a graduate level course taught through hands-on examples and tutorial data sets and cover the theory and implementation of these methods. Undergraduates with statistical knowledge background are encouraged to take this course as well. Prerequisites: strong familiarity with at least one programming language; undergraduate courses on statistics, signal and systems.

ECE 2570, Robot Control, 3 cr.
This course focuses on the application of control theory in robotics. Topics to be covered include: review of classical and modern control design methods such as PID control, state feedback, optimal control, adaptive control, and hybrid system control; control of mobile robots; control of robot manipulators; reinforcement learning; cognitive robotics.

ECE 2595, Special Topics: Signal Processing/Communications, 3 cr.
An MS level course in special topics of current interest in signal processing/communications.

ECE 3524, Digital Speech Processing, 3 cr.
The application of digital signal processing techniques in the representation, analysis, and synthesis of speech signals. Topics include digital modeling of speech signals, waveform coders, time and frequency methods in speech processing, linear predictive coding of speech, and discussion of speech processing systems in the area of human-machine communication by voice. Prerequisites: ECE 2521, ECE 2523

ECE 3526, Modern Spectral Estimation, 3 cr.
An overview of concepts of modern spectral analysis covering traditional approaches and modern estimation methods. The properties, advantages and disadvantages of each estimator will be covered in detail and demonstrated using computer experiments. Also covered are applications of spectral estimation to signal detection and beam forming. Prerequisite: ECE 2521

ECE 3557, Statistical Signal Processing, 3 cr.
Random vectors, discrete-time stochastic processes; rational and state-space Gaussian-Markov discrete-time models; estimation; parameter estimation, Wiener and Levinson filtering, Kalman filtering (modeling, filtering and prediction, stability and computational aspects); adaptive filtering. Prerequisites: ECE 2521, ECE 2523, ECE 2646

ECE 3595, Advanced Topics: Signal Processing, 3 cr.
A PhD level course in advanced topics of current interest in the area of signal processing/ communications.

ECE 3650, Optimal Control, 3 cr.
Variation calculus and optimality conditions, linear quadratic problems, the Riccati equation, Pontryagin maximum principle, time-optimal control, dynamic programming and the Hamilton-Jacobi equation, numerical methods, decentralized control, multicontroller-multiobjective systems, differential games. Prerequisite: ECE 2646

ECE 3695, Advanced Topics: Control, 3 cr.
A PhD level course in advanced topics of current interest in the area of controls.

6.2. Non-ECE Courses

BIOENGINEERING
BioE 2045, Computational Case Studies in Bioengineering
BioE 2186, Neural Engineering
BioE 2330, Medical Imaging
BioE 2351, Computer Applications in Bioengineering
BioE 2385, Engineering Medical Devices for Quantitative Image Analysis & Visualization
BioE 2525, Applied Biostatistics
BioE 2580, Biomedical Applications of Signal Processing
BioE 2630, Methods in Image Analysis
BioE 2650, Motor Learning and Control
BioE 2810, Biomaterials and Biocompatibility
CHEMISTRY
Chem 2210, Electroanalytical Chemistry
Chem 2620, Atoms, Molecules and Materials
COMPUTATIONAL BIOLOGY
MSCBIO 2040, Cellular and Systems Modeling
COMPUTER SCIENCE
CS 2012, Algorithm Design
CS 2045, Introduction to High Performance Computing Systems
CS 2055, Database Management Systems
CS 2110, Theory of Computation
CS 2150, Design & Analysis of Algorithms
CS 2210, Compiler Design
CS 2310, Software Engineering
CS 2510, Computer Operating Systems
CS 2520, Wide Area Networks
CS 2530, Computer & Network Security
CS 2550, Principles of Database Systems
CS 2610, Interface Design & Evaluation
CS 2620, Interdisciplinary Modeling and Visualization
CS 2650, Distributed Multimedia Intelligence

CS 2710, Foundations of Artificial Intelligence
CS 2731, Introduction to Natural Language Processing
CS 2750, Machine Learning & Communications
CS 2770, Computer Vision
INDUSTRIAL ENGINEERING
IE 2081, Nonlinear Optimization
IE 2186, Reinforcement Learning
IE 3053, Global Optimization
IE 3055, Robust Optimization
IE 3186, Approximate Dynamic Programming
LAW
Law 5719, Applied Legal Data Analytics & AI
MATH
Math 2030, Iterative Methods
Math 2070, Numerical Methods 1
Math 2071, Numerical Methods 2
Math 2301, Analysis 1
Math 2302, Analysis 2
Math 2303, Analysis 3
Math 2304, Analysis 4
Math 2500, Alegbra 1
Math 2370, Matrices & Linear Operators 1
Math 2371, Matrices & Linear Operators 2
Math 3375, Computational Neuroscience
Math 3380, Mathematical Biology
MECHANICAL ENGINEERING & MATERIALS SCIENCE
ME 2016 Nonlinear Dynamical Systems 1
ME 2045, Linear Control Systems
ME 2046, Digital Control Systems
ME 2047, Finite Element Analysis
ME 2055, Computer Aided Analysis in Transport Phenomena
ME 2060, Numerical Methods
ME 2101, Nuclear Plant & Reactor Dynamics 1
ME 2102, Nuclear Plant Dynamics and Control
ME 2104, Nuclear Operations Safety
ME 2257, Transport Phenomena in Nano- to Micro-Scale
MSE 2037, Nanomechanics, Materials and Device
ME 2039 Basics & Applications of Power Magnetics (Formerly MSE 2033)
ME 2232 Fundamentals of Data Enabled Science and Engineering
PHYSICS
Phys 2513, Dynamical Systems
Phys 2541, Statistical Mechanics & Thermodynamics
Phys 2555, Classical Electricity & Magnetism 1
Phys 2565, Non-Relativistic Quantum Mechanics 1
Phys 2566, Non-Relativistic Quantum Mechanics 2
Phys 3715, Solid-State Physics
Phys 3716, Advanced Solid State Physics
STATISTICS
STAT 2131, Applied Statistical Methods I
STAT 2132, Applied Statistical Methods II
STAT 2211, Categorical Data Analysis
STAT 2221, Advanced Applied Multivariate Analysis
STAT 2320, Applied Time Series
STAT 2321, Advanced Applied Time Series
STAT 2630, Intermediate Probability
STAT 2631, Theory of Statistics I

STAT 2661, Linear Models Theory I
STAT 2691, Nonparametric Theory
TELECOMMUNICATIONS
Telcom 2310, Applications of Networks
Telcom 2700, Wireless Networks
Telcom 2811, Hacking for Defense
Telcom 2821, Network Security