GRADUATE STUDENT HANDBOOK

JANUARY 2015

Department of Electrical and Computer Engineering
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Graduate Program in Electrical and Computer Engineering • (848) 445-2578

Website http://www.ece.rutgers.edu/

It is the policy of the Graduate Program in Electrical and Computer Engineering of Rutgers, The State University of New Jersey, to make the benefits and services of its educational programs available to students without discrimination on the basis of race, religion, color, national origin, ancestry, age, sex, sexual orientation, handicap, marital status, or veteran status.

Table of Contents

1. Introduction

The faculty and students of the graduate program in Electrical and Computer Engineering are divided into six specialization areas:

Communications Engineering
Computer Engineering
Digital Signal Processing
Software Engineering
Solid State Electronics
Systems and Controls

This information guide describes the degree requirements in these areas and clarifies the procedures used for admission into the M.S. and Ph.D. programs.

The Graduate School catalog should be consulted for additional information regarding the general policies and procedures of the Graduate School.

2. Admission Requirements

Deadline for all M.S. applicants is *December 1* for fall term admission. Deadlines for Ph.D. applicants are *December 1* for fall term admission and *October 1* for spring term admission. Admission materials are available from the Office of Graduate and Professional Admissions, 18 Bishop Place, Rutgers University, New Brunswick, NJ 08903. An online application is available at http://gradstudy.rutgers.edu.

Admission is competitive. Some applicants who meet or surpass the minimum requirements may be denied admission. Admission is recommended by the Electrical and Computer Engineering Graduate Admissions Committee and must be approved by the dean of the Graduate School. All applicants must identify on their application material (personal statement, resume) one out of five areas for graduate study in this department: (1) Communications, (2) Computer Engineering, (3) Digital Signal Processing, (4) Software Engineering, (5) Solid State Electronics, and (6) Systems and Controls

Foreign nationals can only have full-time student status. US Citizens or Permanent Residents may have either full-time or part-time student status. Part-time students are subject to the same admission requirements as that for full-time students.

2.1. M.S. Program

The requirements for admission into the master's degree program are:

1. A bachelor's degree in Electrical and/or Computer Engineering with a minimum grade point average (GPA) of 3.2 on a 4.0-point scale.

2. Three letters of recommendation

3. The general Graduate Record Examination (GRE). The minimum expected scores are: ***Verbal*** **500 (= 153** new test score**)** , ***Quantitative*** **730** (= **157** new test score), and **Analytical Writing 4.5**. The subject GRE in engineering is not required.

In addition, the Test of English as a Foreign Language (TOEFL) is required of all foreign applicants whose native language is not English unless an undergraduate degree was received in the USA. A minimum score of 250 is expected. Students who obtain a TOEFL score below 250 may be accepted in exceptional cases, but will be required to attend classes in the Program in American Language Studies (PALS). This score corresponds to the new TOEFL Scores: Writing 22, Speaking 23, Reading 21, and Listening 17.

Students with bachelor's degrees in closely related areas such as Physics, Computer Science, Applied Mathematics or Engineering Technology may be considered for admission if they have outstanding GPA's and GRE's and after the following undergraduate electrical engineering courses are completed with a grade of B or better:

332:221,222	Principles of Electrical Engineering I,II
332:231	Digital Logic Design
332:252	Programming Methodology I
332:321	Probability and Random Processes
332:322	Principles of Communication Systems
332:331	Computer Architecture and Assembly Language
332:345	Linear Systems and Signals
332:346	Digital Signal Processing
332:361	Electronic Devices
332:362	Analog Electronics
332:366	Digital Electronics
332:382	Electromagnetic Fields
332:415	Introduction to Automatic Control

2.2 Combined BS/MS Degree(s) in Electrical and Computer Engineering

The requirements for admission in the combined BS/MS degree are:

1. Electrical and Computer Engineering undergraduate students in a good academic standing with a GPA of 3.2 and above will be eligible for admission to the Electrical and Computer Engineering graduate program.

2. The interested student will submit a regular New Brunswick Graduate School application at the beginning of the Fall semester *directly* to the Electrical and Computer Engineering Graduate Director together with a personal statement, three letters of recommendation and an official undergraduate transcript. The GRE requirement will be waived. The deadline for BS/MS applicants is December 1.

3. Students must complete the number of credits required for the Electrical and Computer Engineering B.S. degree before starting the M.S. graduate program. The requirements for the M.S. degree are identical to the requirements in effect for regular Electrical and Computer Engineering M.S. students:

   (a) 24* credits of course work plus the master thesis.
   (b) 30* credits of course work plus the master technical paper and its public presentation.

* See the Graduate School Policy on Double Counting of Credits (graduate and undergraduate credits)

2.3. Ph.D. Program

The requirements for admission into the Ph.D. degree program are:

1. A master's degree in Electrical and/or Computer Engineering with a minimum GPA of 3.5 on a 4.0-point scale and an undergraduate GPA of 3.2 or better.

2. Three letters of recommendation.

3. GRE examination with the same minimum scores as for the M.S. program.

Foreign applicants whose native language is not English and who have not received a bachelor's degree in the USA (or any other English speaking county) must also submit their TOEFL scores.

Students with masters degrees in closely related areas such as Physics, Computer Science, or Applied Mathematics may be accepted on the condition that some or all of the undergraduate EE courses listed in Section 2.1 be completed with a grade of B or better.

Students who have completed the M.S. degree requirements at Rutgers and wish to continue for the Ph.D. must meet the 3.5 GPA requirement and submit a *change of status* form to the graduate director for approval. Foreign students are also required to obtain the approval of the Financial Aid Office regarding their financial status. Final approval is made by the Graduate School.

2.4. Non-Degree Students

Qualified students may apply to the Electrical and Computer Engineering graduate program for nonmatriculated (nondegree) status. Students must have academic credentials that are comparable to those required for regular admission. Transcripts are *required*. Initial application is made through the Electrical and Computer Engineering program. The completed application materials are then submitted to the Nondegree Graduate Study program. Nondegree students must either be US Citizens or Permanent Residents.

The course schedules of nonmatriculated students *must be approved* by the graduate director. After completing 12 credits of relevant graduate courses with a grade of B or better, a nonmatriculated student may apply for matriculated (degree) status. Only 12 credits of non-degree study are allowed.

The criteria for admission into the regular degree programs for nonmatriculated students are the same as for regular degree students. The graduate administrative assistant can provide more information to interested students.

3. M.S. Degree Requirements

Master of Science degree candidates may follow either a thesis or a nonthesis program of study.

The thesis program requires 24 credits of course work, 6 credits of research leading to a master's thesis, and the final defense of the thesis.

In the nonthesis program, the candidate must complete 30 credits of course work with a minimum grade point average of 3.0, and write a Technical Paper which must be approved by at least three members of the ECE Graduate Faculty.

3.1. Course Requirements

At least 15 credits for the thesis option and 21 credits for the nonthesis option, must be fulfilled by the required and elective courses that are *relevant* to the student's area of specialization. The computer engineering option has some additional requirements explained below. All M.S. Students are required to take 2 semesters of 16:332:699 Colloquium in Electrical and Computer Engineering. In order to be graded “Satisfactory” you must attend 80% of the lectures (attendance is taken). *Online and short courses (winter break, spring break, two week courses) can not be used to satisfy the course requirements for any degree (M.S. or Ph. D.).*

The elective courses must be *approved* by the student's advisor or the Graduate Director before registration. A list of recommended electives is provided under each area of specialization.

3.1.1 Communications Engineering

Required courses:

332:541	Stochastic Signals and Systems
332:542	Information Theory and Coding
332:543	Communication Networks I
332:544	Communication Networks II
332:545	Digital Communication Systems
332:546	Wireless Communications Technologies
332:548	Error Control Coding
332:549	Detection and Estimation Theory
332:559	Advanced Topics in Communications Engineering

Recommended elective courses:

332:501	System Analysis
332:505	Control Theory I
332:506	Control Theory II
332:521	Digital Signals and Filters
332:525	Optimum Signal Processing
640:501	Theory of Functions of a Real Variable
640:503	Theory of Functions of a Complex Variable
640:515	Ordinary Differential Equations
642:550	Linear Algebra and Applications
642:573	Topics in Number Theory I
642:574	Topics in Number Theory II
642:591	Topics in Probability and Ergodic Theory
642:621	Financial Mathematics I
642:622	Financial Mathematics II
960:580	Basic Probability and Statistics
960:582	Introduction to Methods and Theory of Probability

3.1.2 Computer Engineering

I.) Students taking the THESIS option will take:
- 3 core courses
- 3 courses from the Computer Engineering group courses
- 2 additional courses of their choice

II.) Students taking the NON-THESIS option will take:
- 3 core courses
- 4 courses from the Computer Engineering group courses
- 3 additional courses of their choice

Required core courses:

332:563	Computer Architecture I
332:573	Data Structures and Algorithms (or 198:513 Design and Analysis of Data Structures and Algorithms)
One math elective	

Note: If any of the following undergraduate courses are missing in the student's undergraduate transcripts, they must be made up:

332:231	Digital Logic Design
332:331	Computer Architecture and Assembly Language
332:351	Programming Methodology II or 198:112 Data Structures
198:416	Operating Systems (required for software track)

Computer Engineer courses:

332:560	Computer Graphics
322:561	Machine Vision
332:562	Visualization and Advanced Computer Graphics
332:564	Computer Architecture II
332:566	Introduction to Parallel and Distributed Computing
332:567	Software Engineering I
332:568	Software Engineering Web Applications
332:569	Database System Engineering
332:570	Robust Computer Vision
332:571	Virtual Reality Technology
332:574	Computer Aided Digital VLSI Design
332:576	Testing of ULSI Circuits
332:577	Analog and Low-Power Digital VLSI Design
332:579	Advanced Topics In Computer Engineering
332:542	Information Theory and Coding
332:544	Communication Networks II
198:515	Programming Languages and Compilers
198:519	Operating Systems

Mathematical electives (one course required):

332:501	System Analysis
198:510	Numerical Analysis
198:521	Linear Programming
198:522	Network and Combinatorial Optimization Algorithms
198:524	Nonlinear Programming Algorithms
198:528	Parallel Numerical Computing
642:550	Linear Algebra and Applications
642:573	Topics in Number Theory I
642:587	Selected Topics in Discrete Mathematics
642:621	Financial Mathematics I
642:622	Financial Mathematics II

3.1.3 Digital Signal Processing

Required courses:

332:521 Digital Signals and Filters
332:525 Optimum Signal Processing
332:527 Digital Speech Processing
332:529 Image Coding and Processing
332:533 Computation Methods for Signal Recovery
332:535 Multi-Dimensional Signal Processing Algorithms
332:541 Stochastic Signals and Systems
332:561 Machine Vision
332:570 Robust Computer Vision

Recommended elective courses:

332:501	System Analysis
332:505	Control Theory I
332:506	Control Theory II
332:565	Neurocomputer Systems Design
640:501	Theory of Functions of a Real Variable
640:503	Theory of Functions of a Complex Variable
642:550	Linear Algebra and Applications
642:573	Topics in Number Theory I
642:574	Topics in Number Theory II
642:621	Financial Mathematics I
642:622	Financial Mathematics II

3.1.4 Software Engineering

I.) Students taking the THESIS option (6 credits of research) will take:
- * 3 core courses
- * 3 courses from the Software Engineering group of elective courses
- * 2 additional courses of their choice

II.) Students taking the NON-THESIS option will take:
- * 3 core courses
- * 5 courses from the Software Engineering group of elective courses
- * 2 additional courses of their choice

Required Core Courses for Software Engineering:

332:563 Computer Architecture
332:567 Software Engineering I
332:568 Software Engineering of Web Applications
332:573 Data Structures and Algorithms

If any of the following undergraduate courses are missing in the student's undergraduate transcripts, they must be made up:

332:252 Programming Methodology I
332:351 Programming Methodology II

ECE Software Engineering Elective Courses:

332: 507 Security Engineering
332:543 Communication Networks I
332:544 Communication Networks II
332:560 Computer Graphics
322:561 Machine Vision
332:562 Visualization and Advanced Computer Graphics
332:566 Introduction to Parallel and Distributed Computing
332:569 Database System Engineering
332:571 Virtual Reality
332:572 Parallel and Distributed Computing
332:579 Advanced Topics in Computer Engineering (Cyber Physical Systems Mobile Apps Engineering and User Experience, Cloud Computing, Big Data)
332: 601 Special Problems

Elective Courses from Other Graduate Programs: (up to 9 credits):

137:560 Introduction to Systems Engineering for Engineering Management (Fall semester)
137:602 Enterprise Software Architecture (Spring semester)
198:536 Machine Learning
198:541 Database Systems
198:544 Computer Security
198:546 Computer System Security
198:547 Security and Dependability of Distributed Systems

3.1.5 Solid State Electronics

Required courses:

332:580	Electric Waves and Radiation
332:581	Introduction to Solid State Electronics
332:583	Semiconductor Devices I
332:584	Semiconductor Devices II
332:587	Transistor Circuit Design

Recommended elective courses:

332:588	Integrated Transistor Circuit Design
332:589	RF Integrated Circuit Design
332:591	Opto-Electronics I
332:592	Opto-Electronics II
332:594	Solar Cells
150:522	Electron Microscopy
642:516	Applied Partial Differential Equations
642:527	Methods of Applied Mathematics I
642:528	Methods of Applied Mathematics II
642:575	Numerical Solutions of Partial Differential Equations
635:501	Theory of Solid State Materials
750:501	Quantum Mechanics I
750:601	Solid State Physics I
750:602	Solid State Physics II

3.1.6 Systems and Controls

Required courses:

332:501	System Analysis
332:505	Control Theory I
332:506	Control Theory II

Recommended elective courses:

332:508	Digital Control Systems
332:510	Optimal Control Systems
332:512	Nonlinear and Adaptive Control
332:514	Stochastic Control Systems
332:519	Advanced Topics in Systems Engineering
332:521	Digital Signals and Filters
332:526	Robotic Systems Engineering
332:541	Stochastic Signals and Systems
332:545	Digital Communication Systems

332:563	Computer Architecture I
640:501	Theory of Functions of a Real Variable
640:503	Theory of Functions of a Complex Variable
640:515	Ordinary Differential Equations
642:516	Applied Partial Differential Equations
642:527	Methods of Applied Mathematics I
642:528	Methods of Applied Mathematics II
642:550	Linear Algebra and Applications
642:573	Topics in Number Theory I
642:575	Numerical Solutions of Partial Differential Equations
642:621	Financial Mathematics I
642:622	Financial Mathematics II

3.2. Master's Thesis

Students writing a master's thesis must choose a thesis advisor who will supervise their research project. In consultation with the graduate director, a thesis committee will be appointed consisting of at least *three* members, including the thesis advisor who will chair the committee.

All members of the thesis committee must be members or associate members of the graduate faculty of the Electrical and Computer Engineering graduate program. One additional non-program member is permitted if appropriate, but must be approved by the graduate director. Substitutions in the committee membership may be made only by the graduate director and will occur only if a member is unable to serve or if a student's thesis topic changes requiring modification of the committee.

A final draft of the thesis (with all figures and references included) must be given to all committee members and the graduate director at least *three* weeks before the thesis defense date. The thesis must be approved by the thesis advisor and accepted by the other members of the student's committee. A final version of the thesis in unbound format must be submitted to the graduate director along with the degree candidacy form after successfully defending the thesis.

If a student fails his/her final thesis defense examination, the student will be allowed one more attempt to rewrite and defend the thesis. Alternatively, at the recommendation of his/her committee, the student may switch to the nonthesis option and take the master's comprehensive examination plus additional courses to raise his/her course credits to 30. In such cases, the comprehensive examination may be taken only once. Failure to pass the repeated thesis or comprehensive examinations will result in a recommendation for dismissal from the Electrical and Computer Engineering Graduate Program.

Teleconferencing is permitted with the thesis presentation being held at Rutgers University.

3.3. M.S. Technical Paper

The MS Technical Paper constitutes a substitution for the Master Comprehensive Exam. The topic of the Master Technical Paper must be chosen in consultation with an ECE graduate faculty member who serves as the student's advisor for the technical paper. The paper must ultimately be approved by three ECE graduate faculty members, of which the student advisor serves as lead reader for the paper. The student and advisor select the additional two members of the graduate faculty who will serve as readers of the technical paper.

It is the responsibility of the student to inform the Graduate Director Office of the committee at least one month before the deadline for the MS candidacy form, as published by the Graduate School. At this time, an electronic version of the student's paper should be provided to the Graduate Director's office as well as to the all three readers. The student must incorporate feedback from the readers, revise the technical paper and ultimately achieve the approval of all three readers before the MS candidacy form submission deadline. A student is given two chances to successfully pass the evaluation of his/her technical paper.

3.4. Candidacy Forms/Deadlines

The Master of Science *candidacy form* should be completed *several weeks* before the student's anticipated graduation. The completed form must be first submitted to the Graduate Director for approval, and then brought to the Graduate School for verification of credits and grades. Upon completion of either Master Thesis or M. S. Technical Paper and collection of all required signatures the form must be submitted to the Graduate School (Barbara Sirman's Office, 848-932-8122) by the following dates:

For	October graduation		October 1, 2014
	January graduation	Submit by:	January 6, 2015
	May graduation		April 15, 2015

The Diploma Application is available online at Registrar: http://registrar.rutgers.edu and it must be filed according to the following schedule:

For	October graduation		October 1, 2014
	January graduation	Submit by:	January 4, 2015
	May graduation		March 15, 2015

3.5. Checklist for M.S. Degree - Thesis Option

THESIS FORMAT GUIDE: You may obtain a style guide for thesis available online at Graduate School-New Brunswick: http://gsnb.rutgers.edu, or pick up print copies from the Graduate School Office (25 Bishop Place) or from the graduate administrative assistant. It contains information regarding style, format, paper, margins, footnotes, etc. It should be followed explicitly. Any questions regarding tables, graphs, photos, etc., can be directed to Barbara Sirman at (848) 932-8122 or email at sirman@rci.rutgers.edu.

CANDIDACY FORM AND THESIS:

1. The candidacy form should be picked up (downloaded) either at the Graduate School Office (website) or from the Electrical and Computer Engineering Graduate Program Administrative Assistant in the Electrical Engineering Building.

2. Complete the form and have the Graduate Director sign the front of the form. Hand carry it to the Graduate School Office as soon as possible. They will verify credits and keep the form on file until you are ready to defend your thesis and take your final examination.

3. Pick up the form at the Graduate School and take it to your final examination. Have the members of your thesis committee sign the form on the back (section A and section C), as well as the title page. **Make sure the title page** is on 100% rag or cotton content paper before obtaining signatures. The

Graduate Director must also sign the back of the candidacy form at this time (**Section E**).

4. Submit one copy of the final version of the thesis with signed (photocopy) title page, unbound, single-sided on photocopy paper to the graduate director along with the candidacy form signed by the thesis committee. Please note that the committee must sign also the Comprehensive Exam section (Section C).

5. Submit thesis electronically (https://edt.libraries.rutgers.edu/login.php) to the Graduate School. **One** original title page (printed on 100% rag/cotton paper) must have the original signatures (**in black ink**); also submit your candidacy form. Three (3) additional signed, (photocopies are acceptable) title pages, and three (3) additional abstracts are also required.

6. THE DEADLINE FOR FINAL SUBMISSION OF ALL MATERIALS TO THE GRADUATE SCHOOL IS: October 1, 2014 for an October-dated degree; January 6, 2015 for a January-dated degree; Apri1 15, 2014 for a May-dated degree.

DIPLOMA APPLICATION FORM:

1. Diploma Application form is available online at: Registrar: http://registrar.rutgers.edu.

2. Contact the Graduate Registrar's Office, Administrative Services Building - Room 200F, Busch Campus (848-445-3557) regarding diploma application questions.

3. The deadline for submission of this form is given in Section 3.4.

PLEASE BE SURE THAT YOU ARE CONSISTENT IN THE USE OF YOUR NAME ON THE DIPLOMA APPLICATION, AND TITLE PAGE OF YOUR DISSERTATION. YOUR NAME SHOULD BE THE SAME ON THE TITLE PAGE AND THE DIPLOMA APPLICATION.

3.6. Checklist for M.S. Degree - Non-Thesis Option

CANDIDACY FORM:

1. The candidacy form should be picked up (or downloaded) from your program or at the Graduate School Office (website), 25 Bishop Place, College Avenue Campus.

2. Complete the form and have the Graduate Director sign the front of the form and hand carry it to the Graduate School Office as soon as possible. They will verify credits and keep the form on file until you are ready to take your final examination.

3. Pick up the form, and take it along with you for the final examination. A total of **three** committee signatures are required for **Sections B and C**. The Graduate Director must also sign **Section E** on the back of the candidacy form after the results of the final examination are known.

4. THE DEADLINE FOR FINAL SUBMISSION OF ALL MATERIALS TO THE GRADUATE SCHOOL IS: October 1, 2014 for an October-dated degree; January 6, 2015 for a January-dated degree; April 15, 2015 for a May-dated degree.

DIPLOMA APPLICATION FORM:

1. Diploma Application form is available online at Registrar: http://registrar.rutgers.edu.

2. Contact the Graduate Registrar's Office, Administrative Services Building - Room 200F, Busch Campus (848-445-3557) regarding diploma application questions.

3. The deadline date for submission of this form is given in Section 3.4.

4. Any questions may be directed to either the graduate secretary or Barbara Sirman, at 848-932-8122.

4. Ph.D. Degree Requirements

The Ph.D. degree requires a total of at least 72 credits. The credit requirements for the Ph.D. degree must consist of at least 36 credits in graduate course work, 24 credits of research leading to the Ph.D. dissertation, and an additional 12 credits that may come from either course work or research. In addition, all Ph.D. Students are required to take 4 semesters of 16:332:699 Colloquium in Electrical and Computer Engineering. In order to be graded "Satisfactory", you must attend 80% of the lectures (attendance is taken).

The student who has been admitted to the Ph.D. program must pass the Ph.D. qualifying examination taken within the first two years of entering the Ph.D. program. Finally, the student must successfully defend his/her Ph.D. dissertation in a final public examination.

There are no foreign language requirements for the Ph.D.; however, a student must demonstrate proficiency in English.

Students who decide to continue beyond the M.S. degree and pursue a Ph.D. must submit a Change of Status form, and must adhere to the GPA requirements of the Ph.D. degree.

4.1. Ph.D Qualifying Examination

The purpose of the Ph.D. qualifying examination is to assess the student's creative ability, depth of knowledge, and potential for independent research. Students admitted into the Ph.D. program must *pass* this examination within their first two years of entering the program. Students not yet admitted into the Ph.D. program may take the preliminary exam only if they have a GPA of 3.5 or better and 12 graduate credits at Rutgers.

The qualifying examination is given once each semester. It consists of *three* one-hour oral exams and a two-hour written exam in Engineering Mathematics.

The oral exams cover the following topics:

1. One exam from the following group:

   Electronics and Circuits
   Linear Systems
   Logic/Digital Systems Design

2. Two exams from the following group:

Communications
Computer Algorithms and Software Engineering
Computer Architecture
Computer/Communication Networks
Control Systems
Digital Signal Processing
Electromagnetic Field Theory
Solid State Electronics

The written exam in Engineering Mathematics is offered independently for Computer Engineering students (emphasis on discrete mathematics, probability and stochastic processes, linear algebra) and Electrical Engineering students (emphasis on linear algebra, stochastic processes, real and complex analysis, ordinary and partial differential equations).

The exams cover undergraduate and first-year graduate level material. To prepare for this exam, students must plan their course schedules carefully in the first year. To help students assess the expected content and level of the exams, a list of topical guidelines is provided in Appendix A. To register for this exam, students must submit a registration form (available from the graduate program administrative assistant) to either the thesis advisor or the graduate director for approval.

Each of the four exams is administered jointly by a committee of two faculty members. Each examiner grades the student on a scale from 0 to 4, with the following interpretation: 4 = excellent, 3 = good, 2 = marginal, 1 = poor, 0 = very poor.

A student will pass the exam if his/her overall average score is 2.75 or higher and the scores of all four exams are greater than 2. If a student receives a score of less than 2 in only one of the four exams but his/her average is 2.75 or higher, he/she may retake the exam section within three months. If the re-examination score is less than 2, the student will not pass the preliminary exam.

The grades for the four sections of the qualifying exam are communicated to the graduate faculty for their review and the students are informed of the results within one month of completing the exam.

Students may take the qualifying exam only twice. Failure to pass the exam for the second time will result in a recommendation for dismissal from the Ph.D. program.

Students who passed the Ph.D. Qualifying Exam should complete the Ph.D. Candidacy form, get the signatures of four faculty examiners and the Graduate Director. The form must be submitted to the Graduate School for the change of status from a prequalifying to a post-qualifying doctoral student.

4.1.1 New Ph. D. Qualifying Examination (Effective January 2015)

The new format of the Ph. D. Qualifying Exam will be in effect in Spring 2015. ECE graduate students who are already in the program will be given an option to choose between the old and new formats. Incoming Fall 2015 ECE Graduate students must take the new format.

Goal: Make the qualifier exam a constructive component in the development of a student's research skills and use the course work requirements to distinguish between potential doctoral students and master students.

Exam Structure: The Ph. D. Qualifying Exam has two parts: I) GPA requirement on selected courses, and II) Research potential assessment.

Part I. GPA Course Requirements

A. *ECE Course Requirement*: Prequalified doctoral students are required to pass **four courses** selected from a list of *relevant doctoral courses ("core courses")* with a **GPA of at least 3.75**.

B. *Mathematics/Physics/Statistics Course Requirement*: Prequalified doctoral students are required to pass **one** course in mathematics/physics/statistics with the grade of a **B+** and above.

Each research group (Communications, Computational Sensing, Computer Engineering, Control Systems, Cybersecurity, Digital Signal Processing, Networks, Software Engineering, and Solid State Electronics) has its own list of "core courses" and mathematics/statistics courses.

Part II. Research Potential Assessment Oral Qualifier

Following completion of the course requirements for specified research group, a student will be eligible to take the research potential assessment examination. In this exam, the student will prepare a written report and make a 45-minute oral presentation of his/her own independent research to a Ph.D. Qualifying Committee of four members of the ECE graduate faculty (but excluding a student's advisor). The oral presentation will be followed by an open-ended question and answer session that may include questions specific to the research project as well as questions generally relevant to the research area.
It is strongly recommended (although not required) that the student have a faculty advisor before taking the oral qualifier. Students who have no academic advisors must register for Special Problems in the second year of their doctoral studies and conduct preliminary research with a faculty member in their research area of interest. The subject of the oral exam is to be chosen by the student. It is recommended that this choice be made in consultation with a faculty advisor and the ECE graduate director. A suitable basis for the examination may include, but is not restricted to:

- A conference paper submission based on research under the supervision of a faculty advisor.
- An M.S. thesis in preparation or previously completed thesis (either at Rutgers or any other university.)
- A final project report derived from an ECE graduate Special Problems independent study course. (The student who does not have a faculty research advisor must take the Special Problems class in the second year with an ECE graduate faculty in student's research area of interest).

Unlike the PhD thesis proposal defense, this examination will occur in the early stages of research and the presented paper need not lead to a Ph.D. thesis proposal. For the examination committee, evaluation of the originality and novelty of the research contribution will be secondary to an evaluation of the student's critical thinking skills. Specifically, the committee will focus on the student's ability to analyze, interpret and articulate both strengths and weaknesses of the work.

Nine Areas of the Ph. D. Qualifying Exam

- Communications
- Computational Sensing[1]
- Computer Engineering
- Control Systems
- Cybersecurity

[1] for students interested in computer vision, robotics (cloud-assisted, swarm), devices/circuits for imaging, sensor networks, tele-rehabilitation, integration of sensing with communications and computing, mobile agents, computational photography.

- Digital Signal Processing
- Networking
- Software Engineering
- Solid State Electronics

General Rules:

- The exam must be taken within two years from the time the student starts the Ph.D. Program.
- The student will be allowed two chances to take the Ph.D. Qualifying Exam. The second attempt must be taken within one year.
- The student must apply to the graduate director to take the Ph.D. Qualifying Exam. In this application, the student selects the research group for the exam and identifies how the core course requirements for that group have been met.
- The written report to accompany the oral presentation must be submitted to the graduate director with the application.
- The Ph.D. Qualifying Committee will be composed of four ECE Graduate Program faculty. The student advisor cannot serve on the student's Qualifying Committee.
- Based on the subject of the submitted written report and the student's selected research group, the examination committee will be chosen by the graduate director in consultation with the student and his/her advisor.
- Each member of the Ph. D. Qualifying committee votes. The vote of 3:1 or 4:0 is needed for the student to pass the Ph. D. Qualifying Exam.
- The new format of the Ph. D. Qualifying Exam is offered year around. For scheduling the Ph D Oral Qualifying exam please contact the ECE Graduate Director one month before the exam.

CORE COURSE REQUIREMENTS

Students wishing to take an alternative to these options outside the department may petition the Graduate Director, who will consult the appropriate committees.

COMMUNICATIONS
Faculty Members: Bajwa, Daut, Foschini, Frenkiel, Gajic, Greenstein, Mandayan, Martin, Petropulu, Pompili, Rose, Sarwate, Spasojevic, Trappe, Yates
Core Courses:
332:509 Convex Optimization
332:521 Digital Signals and Filters
332:541 Stochastic Signals and Systems
332:542 Information Theory
332:543 Communications Networks I
332:544 Communications Networks II
332:545 Digital Communications
332:546 Wireless Communication Technologies
332:548 Error Control Coding
332:549 Detection and Estimation Theory

Mathematics/Statistics Courses:

642:527 Methods of Applied Mathematics I
642:528 Methods of Applied Mathematics II
642:550 Linear Algebra and Applications
642:551 Applied Algebra
960:592 Theory of Probability
960:593 Theory of Statistics
640:411 Mathematical Analysis I

COMPUTATIONAL SENSING

Faculty Members: Bajwa, Dana, Petropulu, Pompili, Meer, Sarwate, Trappe, Yates

Core Courses:

332:504 Sensor-based systems
332:509 Convex Optimization
332:521 Digital Signals and Filters
332:525 Optimal Signal Processing
332:526 Robotic System Engineering
332:541 Stochastic Signals and Systems
332:561 Machine Vision
332:591 Optoelectronics
332:539 Advanced Topics in DSP (Statistical learning)
332:579 Advanced Topics in Computer Engineering (Advanced computer vision)
198:534 Computer Vision
198:536 Machine Learning
198:535 Pattern Recognition: Theory and Applications

Mathematics/Statistics courses: Any graduate level course in mathematics or statistics.

COMPUTER ENGINEERING

Faculty Members: Burdea, Dana, Gruteser, Jha, Lindqvist, Marsic, Rodero, Parashar, Pompili, Silver, Zhang

Core Courses:

Must choose three core courses out of the following five courses (if the student had some of these courses at any other graduate school, the student may take additional courses from the next list)

332:563 Computer Architecture
332:567 Software Engineering I
332:573 Data Structure and Algorithms
332:566 Into Parallel & Distributed Computing
332:543 Communication Networks I

Take one course from the list:

332:544 Communication Networks II
332:560 Computer Graphics
332:562 Visualization and Advanced Computer Graphics
332:568 Software Engineering of Web Applications
332:572 Parallel& Distributed Computing
332:579 Advanced Topics in Computer Engineering (Cyber-physical systems, High-performance distributed computing, cloud computing)

Mathematics/Statistics courses: Any graduate level course in mathematics or statistics.

CONTROL SYSTEMS

Faculty Members: Baruh, Gajic, Li, Orfanidis, Sannuti, Shoane, Sontag, Yi, Zou

Core courses:

332: 501 System Analysis
332: 505 Control Theory I
332: 506 Control Theory II (taught now as Applied Controls)
332:509 Convex Optimization for Engineering Applications
332:510 Optimum Control Systems
332:512 Nonlinear and Adaptive Control
332:519 Advanced Topics in Systems Engineering (Kalman filtering, Game theory, Energy systems)
332:521 Digital Signals and Filters

Mathematics courses:

642: 527 Methods of Applied Mathematics I
642:528 Methods of Applied Mathematics II
642 550 Linear Algebra and Applications
642:573 Numerical Analysis

CYBERSECURITY

Faculty Members: Trappe, Lindqvist, Zonouz, Gruteser, Petropulu, Sarwate, Zhang

Core courses:

332:509 Security Engineering
332:542 Information Theory and Coding
332:544 Communication Networks II
332:567 Software Engineering I
332:573 Data Structures & Algorithms
332:519 Advanced Topics in Systems Engineering (Network security)
332:579 Advanced Topics in Computer Engineering (Information and network security, Malware analysis and reverse engineering, Network centric programming, Mobile apps engineering and user experience, Methods in human-computer interaction, cyber-physical systems)
198:544 Computer Security
198:596 Introduction to Cryptography

Mathematics/Statistics courses: Any graduate level course in mathematics or statistics.

DIGITAL SIGNAL PROCESSING

Faculty Members: Bajwa, Dana, Hanson, Mammone, Meer, Najafizadeh, Orfanidis, Rabiner, Petropulu, Sarwate

Core courses:

332:509 Convex Optimization
332:521 Digital Signals and Filters
332:527 Digital Speech Processing
332:539 Advanced Topics in DSP
332:541 Stochastic Signals and Systems
332:542 Information Theory and Coding
332:545 Digital Communication Systems
332:549 Detection and Estimation Theory
332:561 Machine Vision

Mathematics/Statistics courses:

640:411 Mathematical Analysis I
960:554 Applied Stochastic Processes

960:565 Applied Time Series Analysis
960:567 Applied Multivariate Analysis
960:592 Theory of Probability
960:593 Theory of Statistics
Any course in Mathematics at the 500 level or above

NETWORKING
Faculty Members: Gruteser, Mandayam, Marsic, Petropulu Pompili, Raychaurdhuri, Rose, Sarwate, Spasojevic, Trappe, Yates, Zhang

Core Courses:
332:509 Convex Optimization
332:541 Stochastic Signals and Systems
332:543 Communications Networks I
332:544 Communications Networks II
332:546 Wireless Communication Technologies
332:568 Software Engineering Web Applications
332:573 Data Structures and Algorithms
198:512 Introduction to Data Structures and Algorithms
198:513 Design and Analysis of Data Structures and Algorithms
332:519 Advanced Topics in Systems Engineering (Information and Network Security)

Mathematics/Statistics Courses:
642:527 Methods of Applied Mathematics I
642:528 Methods of Applied Mathematics II
642:550 Linear Algebra and Applications
642:551 Applied Algebra
960:592 Theory of Probability
960:593 Theory of Statistics
640:411 Mathematical Analysis I

SOFTWARE ENGINEERING
Faculty Members: Gruteser, Jha, Lindqvist, Marsic, Silver, Zhang, Zonous

Core courses:
332:563 Computer Architecture
332:567 Software Engineering I
332:568 Software Engineering of Web Applications
332:573 Data Structures and Algorithms
332:560 Computer Graphics
322:561 Machine Vision
332:562 Visualization and Advanced Computer Graphics
332:566 Introduction to Parallel and Distributed Computing
332:569 Database System Engineering
332:571 Virtual Reality
332:572 Parallel and Distributed Computing
332:543 Communications Networks I
332:544 Communications Networks II
332:579 Advanced Topics in Computer Engineering (Cyber physical systems, Cloud computing, Mobile apps engineering and user experience, Network centric programming, Big data analytics, Games and virtual reality)

Mathematics/Statistics courses: Any graduate level course in mathematics or statistics.

SOLID STATE ELECTRONICS

Faculty Members: Caggiano, Cheong, Chhowala, Feldman, Godrich, Javanmard, Jeon, Jiang, Lai, Lu, McAfee, Najafizadeh, Oh, Zhao.

Core courses:

The student needs to take four core courses, in a combination of 3+1, within the broad SSE areas (if the student had some of the fundamental courses at any other graduate school, the student may take additional courses from the list of "advanced" courses).

Three courses from the following list of "*fundamental*" courses:

332:580 Electric Wave and Radiation
332:581 Introduction to Solid State Electronics
332:583 Semiconductor Devices I
332:587 Transistor Circuit Design

One course from the following list of "*advanced*" courses, based on the research topic:

332:574 CAD Digital and VLSI Design
332:584 Semiconductor Devices II
332:589 RF Integrated Circuit Design
332:591 Optoelectronics I
332:597 Material Aspects of Semiconductor
332:599- Advanced Topics in SSE (Biosensing and bioelectronics)

Mathematics courses:

642:516 Applied Partial Differential Equations
642:527 Methods of Applied Mathematics I
642:528 Methods of Applied Mathematics II
642:550 Linear Algebra and Applications
642:573 Numerical Analysis
960:565 Applied Time Series Analysis

4.2. Ph.D. Proposal Presentation

The proposal presentation examination is conducted by a committee consisting of the student's thesis advisor and at least *three* other members or associate members of the electrical engineering graduate faculty. Normally, the thesis advisor, at least two other members of this committee, and an outside member, will later serve as the student's thesis committee.

The examination consists of a one-hour presentation and defense of a *thesis research proposal* by the student, followed by an *oral examination* by the committee. The thesis proposal presentation is *not* public; however, any faculty member of the Graduate School may attend.

The student should provide each member of his/her committee and the graduate director with a copy of the thesis proposal *at least three weeks* before the examination. The proposal should include a review of previous work on the subject, a description of the proposed research project, and preliminary research results, such as experimental, theoretical, or simulation results indicating that the project can be successfully undertaken.

4.2.1 ECE Ph.D. Proposal Presentation Policy

The Doctoral Dissertation Proposal presentation will be announced at least *three weeks* before the presentation.

It is the *advisor responsibility* to inform the Graduate Director Office, either via email or a hard copy memo (preferred), that the student is ready to present his/her proposal, and provide the list of at least four (at least three ECE Graduate Program members including the advisor) committee members, time and place of the presentation. The committee may include one or two “outside ECE Graduate Program” members. The outside committee members are appointed by the Graduate ECE Program Director in consultation with the student’s advisor.

It is the *student responsibility* to provide the Graduate Director office with a copy of the dissertation proposal and an electronic version of the proposal abstract at least *three weeks* before the presentation.

Teleconferencing is permitted with the proposal presentation being held at Rutgers University. The proposal presentation is closed to public (Rutgers University regulation). The ECE faculty members are allowed to attend the proposal presentation and/or examine the written copy of the proposal.

For a successful proposal presentation only one non-approval is permitted. A student is given *two* chances to successfully present his/her doctoral dissertation proposal.

4.3. Dissertation Requirements

The dissertation topic is agreed upon by the student and the thesis advisor. The dissertation committee, which consists of the dissertation advisor, at least *two* other members or associate members of the electrical engineering faculty, and an *outside* member, is selected by the student and the thesis advisor, in consultation with the graduate director.

Substitutions in the committee membership may be made only by the graduate director and will occur only if a member is unable to serve or if a student's dissertation topic changes requiring modification of the committee. In cases other than these, approval rests with the Dean of the Graduate School.

The dissertation committee must be kept informed of the student's progress and must agree to follow the student's work and assist in its development. The committee shall also agree to give ample and early warning of any reservations regarding the student's progress and must specify in writing the changes required for dissertation acceptance.

The Ph.D. dissertation should be submitted to the thesis committee and the graduate director at least *four* weeks before the final dissertation defense examination. The dissertation should be in final form with all figures and references.

The final dissertation defense must be announced and is open to the public. *Teleconferencing* is permitted with the dissertation presentation being held at Rutgers University. The dissertation advisor and all but one of the other committee members must approve in order for the student to pass the examination. In the case of two or more dissenting members, an attempt should be made to reconcile the differences. If resolution of the differences is not possible, the dissertation must be judged unsatisfactory. Appeals may be referred to the dean of the Graduate School-NB. The committee members must sign the student's Ph.D. candidacy form, the title page of the thesis if the dissertation is approved,. If approval is not unanimous, a letter from the dissenting members indicating the reasons for disapproval must be sent to the dean of the Graduate School-NB and copies sent to the graduate director, the other committee members, and to the student.

A final version of the dissertation in unbound format must be submitted to the graduate director along with the degree candidacy form after successfully defending the dissertation. After the final signature from the graduate director has been obtained on the candidacy form, the form and the two copies of the dissertation required by the Graduate School must be hand-delivered by the student.

4.4 Checklist for Ph.D. Degree

STYLE GUIDE FOR THESIS AND DISSERTATION PREPARATION: A thesis style guide is available online at Graduate School-New Brunswick: http://gsnb.rutgers.edu, or pick up print copies from the graduate secretary or from the Graduate School Office (25 Bishop Place-CAC). This booklet presents the requirements governing the physical form of the thesis doctoral dissertation. Any questions should be directed to Barbara Sirman at (848) 932-8122, fax (848) 932-7407, or email at sirman@rci.rutgers.edu.

CANDIDACY FORM AND DISSERTATION:

1. The candidacy form should be picked up at the Graduate School Office prior to your defense. Note: The last page of the form, listing both your course and research credits, should be completed right after your taking the Ph.D. Qualifying Examination.

2. At that time, you will be given other forms for completion: (i.e.) payment fee, microfilming, survey, questionnaires, etc.

3. Take the candidacy form to your defense and have your committee members and the Graduate Program Director sign page 3. They should also sign the title page of your dissertation. Be sure that the title page is printed on 100% rag or cotton content paper before obtaining signatures. An outside member is required for the thesis committee. If the person is from outside the University, a resume is required by the Graduate Director such that formal permission can be obtained from the Graduate School.

4. Submit one copy of the final version with photocopy of signed title page, unbound, single-sided on photocopy paper to the graduate director along with the candidacy form signed by the thesis committee.

5. Take the payment forms to either Records Hall or the ASB Cashier. Item #1 is mandatory and Item #2 is optional. If applicable, any restoration payment should be made.

6. Submit to Graduate School electronically copy of the dissertation https://etd.libraries.rutgers.edu/login.php . Submit **ONE (1)** original title page (printed on 100% rag/cotton paper with signatures **in black ink**). Also submit your candidacy and other forms.

   Note: Three (3)) additional signed (photocopies are acceptable) title pages and three (3) additional abstracts are also required.

7. THE DEADLINE FOR FINAL SUBMISSION OF ALL MATERIALS TO THE GRADUATE SCHOOL IS: October 1, 2014 for an October-dated degree; January 6, 2015 for a January-dated degree; and April 15, 2015 for a May-dated degree.

DIPLOMA APPLICATION FORM:

1. Diploma Application form is available online at Registrar: http://registrar.rutgers.edu.

2. Contact the Graduate Registrar's Office, Administrative Services Building - Room 200F, Busch Campus (848-445-3557) regarding diploma application questions.

3. The deadline for submission of this form is: October 1, 2014 for an October-dated degree; January 4, 2015 for a January-dated degree; and March 15, 2015 a May-dated degree.

PLEASE BE SURE THAT YOU ARE CONSISTENT IN THE USE OF YOUR NAME ON THE DIPLOMA APPLICATION, AND TITLE PAGE OF YOUR DISSERTATION. YOUR NAME SHOULD BE THE SAME ON THE TITLE PAGE AND THE DIPLOMA APPLICATION.

5. Scholastic Standing

The academic progress of masters students, Ph.D. students who have not yet selected a thesis advisor, and of all students on academic probation is monitored by the Electrical and Computer Engineering Graduate *Scholastic Standing Committee*, which reviews student performance twice a year.

Master's degree students must maintain a GPA of 3.0 or higher and Ph.D. students a GPA of 3.5 or higher. A student who's GPA falls below the corresponding threshold will be placed on *academic probation* for two semesters. Failure to raise the GPA above the threshold within the next two semesters will result in a recommendation for dismissal from the graduate program.

In addition, **students may not use more than *one* grade of C/C+ towards any degree**. Students receiving two grades of C/C+ or below will be sent an academic probation letter and if, subsequently, they receive a third such grade they will be recommended for dismissal from the program.

The academic progress of post-qualifying Ph.D. students who have selected a thesis advisor is monitored, on a regular basis, by their thesis advisor and thesis committee.

All graduate students are encouraged to become familiar with the Rutgers University POLICY ON ACADEMIC INTEGRITY. A copy of the policy statement can be obtained from the graduate administrative assistant.

5.1. Academic Probation

The following events will automatically trigger Academic Probation for a student:

1 F in a course
2 C's in graduate courses
The following events may trigger Academic Probation for a student:
An Incomplete that is not made up in the immediately following semester.

The following events will trigger a hearing to determine whether to dismiss a student from the Electrical and Computer Engineering Department:
2 F's in graduate courses
3 C's in graduate courses
Repeated problems in maintaining a full-time student course load of 9 credits.

5.2. Degree Time Limits

MS Degree

There is a time limit of 2 years to complete a full-time MS degree in the Electrical and Computer Engineering Department. Students who take longer than that time interval will normally not be admitted to the PhD program.

PhD Degree

There is a time limit of 5 years after the MS degree to complete the PhD degree. Students who take longer that that time interval may be discontinued in the PhD program.

Normally, PhD students who have not initiated research activity will be dismissed after 2 years in the PhD program. Research activity means that the student has a doctoral advisor, has pursued an original thesis topic, and has completed some research.

5.3. Incomplete Grades

Incomplete (IN) grades must be completed within *one* semester. A student who has more than one IN grade will be allowed one semester to reduce the number to one (or none), after which he/she will not be allowed to register for additional courses until the IN's are completed. The graduate school will not allow students with IN's to graduate. The graduate director will not give TA/Fellowship support or Practical Training letters to students with Incompletes.

5.4. Full-Time Student Status Visa Requirements

Our Department considers 9 academic credits (consisting of undergraduate remedial courses, graduate courses, or graduate research 332:701 and 332:702) to be full-time study. The special TA and GA courses do not count towards the academic credits. We do not accept undergraduate course credits toward the MS and PhD graduate degrees. We also will not allow students to take fewer than 9 academic credits and retain full-time enrollment status, except in these situations:

I. The student is in the last term of his/her degree, and has completed all degree course requirements, in which case fewer than 9 credits is permitted.

II. The student is studying for the PhD Qualifying Examination, in which case 6 credits is permitted, either during the semester of the examination, during the semester preceding the examination, or both. The preparation time for this examination is significant, and judged to be equivalent to two 3 credit graduate courses.

In all other situations, we expect students to carry 9 academic credits. If remedial English courses are required, then a student must still carry 9 academic credits. Student's who do not satisfy this policy will be reviewed by the Scholastic Standing Committee of the Electrical and Computer Engineering Department, and also jeopardize their full-time enrollment status.

5.5. Lead-time for Processing of Student Forms

The ECE graduate program is a very large program with research and faculty in many different areas. In order to adequately process the applications and documents of all students in a fair and proper manner, the ECE Graduate Office requests that students provide forms, such as Visa and OPT/CPT forms, at least three weeks in advance of any deadline. The ECE Graduate Office will do its best to accommodate any emergencies that might arise and which necessitate very fast processing of documents. However, students must understand that many deadlines are known significantly in advance of the deadline, e.g. Visa renewal deadlines, and thus it is the responsibility of the student to properly plan their schedules accordingly. Additionally, students should also submit requests for documents related to employment opportunities (e.g. support letters) at least three weeks to properly process. Finally, students should also refer to the Rutgers Center for International Faculty and Student Services for any other deadlines and guidelines.

6. New Graduate Student Information

As a new graduate student it is highly recommended that you spend your first semester in the program familiarizing yourself with the faculty with the aim of identifying a faculty research advisor. Establishing a research path is the most critical step in your graduate career. A timely goal would be to establish a broad idea of the research area that interests you and meet with potential thesis advisors.

7. Ethics

If you are a TA, a GA, or a Fellow, then you are an employee at Rutgers University. The salary, tuition, and fringe benefits that you receive are in return for work, and it is expected that the work will be done very well. If you are a TA, it is expected that you will do an outstanding job of teaching and grading, and of communicating with the undergraduate students. If you are either a TA, a GA, or a Fellow, it is expected that you will achieve excellent grades, and will complete the graduate program requirements in a timely fashion. It is also expected that you will promptly initiate your own research program with a faculty advisor, and will soon become productive in conducting research and writing papers.

TAs are reviewed after one semester in the program. They are expected to make satisfactory academic progress, and to have a research advisor by the end of their first semester. TAs and Fellows are reviewed again after the end of the spring term. In order to continue as a TA, you must be rated by the Professor and the students in the course as an excellent teacher, you must be making satisfactory academic progress in the graduate program, and you must have a research advisor who indicates that your research is proceeding well. In order to continue as a Fellow, you must have outstanding academic progress in the graduate program, you must have a research advisor who says that your research is proceeding well, and you must have a record of service to either the Electrical and Computer Engineering Department or to the Graduate School. It is considered a distinct honor to be a Fellow of the Electrical and Computer Engineering Department.

8. Appeals Procedures

Appeals of a decision to recommend dismissal from the graduate program must be made in writing to the Graduate Scholastic Standing Committee. The committee will consider the appeal and vote to sustain or

rescind the original recommendation.
Student grievances concerning grades on the M.S. comprehensive exam or the Ph.D. qualifying exam should be addressed to the Graduate Director. If the matter is not resolved satisfactorily, the student may appeal in writing to the Graduate Scholastic Standing Committee for a formal review.
Student grievances concerning course grades should be addressed to the instructor of the course. If the matter is not resolved satisfactorily, the student may appeal to the graduate director, who will attempt to resolve the dispute informally. If this attempt is unsuccessful, the student may appeal in writing to the Graduate Scholastic Standing Committee.

Students may appeal decisions of the Graduate Director, Graduate Scholastic Standing Committee, or graduate faculty, in writing, to the Dean of the Graduate School-NB if they feel that the process by which the electrical and computer engineering graduate program reached its decision was unfair.

9. Financial Aid

T*eaching* assistantships (TA's) are available to full time graduate students. TA awards are competitive. Candidates are expected to have excellent undergraduate grades, high GRE scores, and a thorough command of the English language. TA application forms, available from the graduate administrative assistant, must be submitted at least four months prior to the desired starting semester.
G*raduate* assistantships (GA's) are also available. These positions are supported by research grants of individual faculty members. The faculty members should be contacted directly. A list of the faculty and their research interests is given in Appendix B.
Students holding TA/GA positions may not accept employment outside the department without permission of the graduate director and the Dean of the Graduate School.
There are also a number of fellowships, loans, and employment opportunities. The Graduate School catalog may be consulted for more information.
Information and forms regarding benefits for TA/GA's, such as health insurance, can be obtained from, Department Administrator.

10. Transfer of Credits

Credits my not be transferred from other institutions until 12 credits of graduate courses with grades of B or better have been completed at Rutgers. Only courses in which grades of B or better were received can be considered for transfer. (B- in not transferable.) Research credits are not transferable. *Online courses are not transferable*. It is the departmental policy that short courses (winter break, spring break, two week courses) can not be used to satisfy the course requirements for any degree.

A maximum of 12 credits may be transferred towards the M.S. degree. A maximum of 24 course credits may be transferred towards the Ph.D. degree. These credits are normally transferred from the student's M.S. degree.

Application forms for transfer of credit are available from the administrative assistant. The forms are to be submitted to the graduate director for approval and then to the Graduate School for final approval. They must be accompanied by official transcripts unless the transcripts are already available in the student's file. Catalog descriptions and/or syllabi indicating texts used must also be submitted.

11. Registration Questions

11.1. Matriculation Continued

A student who wishes to take a leave of absence under extraordinary circumstances may apply for Matriculation Continued status. The student must complete a *Matriculation Continued Application* available from the graduate administrative assistant and submit it to the graduate director for approval.

Pre-qualifying Ph.D. students who have finished all course requirements may register for matriculation continued until they take their qualifying examination. Post-qualifying Ph.D. students are not permitted to register for Matriculation Continued. They must register for **one** credit of research each semester until they complete their degree.

Master's degree students who have completed all course requirements must register for Matriculation Continued until they take their final examination, unless they are engaged in thesis research on campus, in which case they must register for at least one credit of research.

11.2. Application for Readmission

A student who has missed one or two semesters of registration must complete an *Application for* R*eadmission* and submit it to the graduate director for approval. Students who have missed *more* than two semesters without registration must file a *new Application for Admission* through the Graduate Admissions Office.

11.3. Assistantship Registration

Students with TA/GA's must register their assistantship appointments using the "E" credit prefix. Registration is 6 credits per term for full-time TA/GA's and 3 credits for half-time appointments.

11.4. Special Problems Courses

A student taking a *Special Problems* course must make arrangements with a faculty member to supervise the project and must submit a completed *application* form to the graduate administrative assistant before registering for the course. The student must fill out the "By Arrangement" column on the registration form. The student receives a regular letter grade for the course.

No more than 6 credits of Special Problems will be credited towards the Master's degree and no more than 9 credits towards the Ph.D. degree.

11.5. Undergraduate Courses

No graduate credit is given for undergraduate courses. To register for undergraduate courses, the student must enter the prefix "E" in the credit prefix column of the registration form, and must submit an *application form*, available from the graduate administrative assistant, to the graduate director for approval.

11.6. Non-Credit Courses

Courses taken on a "not for credit" basis require an "N" prefix on the registration form. The student will complete all course work except the final exam and will receive a grade of "S" or "U". Graduate students in the program are not permitted "Pass/Fail" grades for course work.

12. Communication with Students

All graduate students are provided with mailboxes in the Electrical Engineering Building. It is the student's responsibility to inform the graduate program and the graduate school of any changes in address and/or telephone number.

This handbook is subject to amendment at any time. Therefore, students should make sure they have the most recent version.

Any questions not covered in this handbook may be addressed to the graduate program administrative assistant Mrs. Noriada Martinez, Electrical Engineering Building, Room 134, Busch Campus, (848) 445-2578, or to the graduate director: Professor Zoran Gajic, Electrical Engineering Building, Room 134A, Busch Campus, (848) 445-2578. Consultations with Professor Gajic are normally by appointment only.

13. Practical Training

Two types of practical training are offered by the Electrical and Computer Engineering Department:

1. Optional Practical Training (OPT). This is available to any student who is in good academic standing, and has no more than 1 Incomplete, provided that the Incomplete only occurred during the immediately preceding semester. This training counts against your 1-year time limit of Practical Training after obtaining your degree from Rutgers. In order to apply for OPT, please supply these items to the Graduate Program Administrative Assistant:

   a.) A memo to the Graduate Director requesting OPT.
   b.) A complete OPT form (which you obtain from the International Center).

2. Curricular Practical Training (CPT). This is available to PhD students and to Master's Thesis students who have completed 2 semesters of study in the Department. The CPT is semester based. The students must be full-time registered during CPT. The conditions for CPT are:
   a.) You, your advisor, and the company that is employing you must be participating in a joint research project, *which will become part of your MS thesis/PhD dissertation*. Your advisor's letter must indicate the research topic and state that this research work will be an essential part of your MS thesis/PhD dissertation. The company letter must have the job description consistent with your advisor's letter.
   b.) You must register for at least 1 credit of 16:332:701 or 16:332:702 (Graduate Research) during the period of your CPT.
   c.) You must write a technical report about your CPT research and submit it to the Graduate Director.

The report will be reviewed by your advisor and the Graduate Director.

If you meet these criteria, you may apply for CPT in the following way:

a.) Attend a workshop on CPT at the International Center at Rutgers.

b.) Bring the job offer letter, the advisor's letter and the form requesting CPT (which you obtain from the International Center) to the Graduate Director.

Appendix A --- Guidelines for Ph.D. Qualifying Exam

The Ph.D. preliminary exam is not, in principle, tied to any particular Rutgers course, textbook, or instructor. Therefore, the following lists of topics, texts, and courses are to be considered only as *guidelines* to help the student assess the expected content and level of the exam.

Examiners are not necessarily bound by these lists and may ask any questions they deem appropriate for assessing the student's creative ability, depth of knowledge, and potential for independent research.

1. Electronics and Circuits

All students are examined on *analog* electronics only, except for computer engineering students, who are examined only on *digital* electronics.

1.1. Analog Electronics

Transistor circuit analysis at low and high frequencies
Feedback amplifier analysis
Power amplifier analysis
Op-Amp characteristics, parameters, frequency response, and compensation
Pulse circuit design techniques

Recommended texts:

1. P. Gray, P. Hurst, S. Lewis, and R. Meyer, *Analysis and Design of Analog Integrated Circuits*, 5th edition, Wiley, 2009.
2. J. Millman and A. Grabel, *Microelectronics*, 2nd ed., McGraw-Hill, 1987.

The level of knowledge is comparable to that in the following Rutgers course:

332:361 Analog Electronics

1.2. Digital Electronics

Saturating and nonsaturating logic circuits
MOS logic circuits
Sequential logic circuits and systems
Semiconductor Memories including ROM, static read-write and dynamic read-write

Recommended text:
1. D. Hodges and H. Jackson, *Analysis and Design of Digital Integrated Circuits*, 3rd ed., McGraw-Hill, 2003.

The level of knowledge is comparable to that in the following Rutgers course:
332:366 Digital Electronics

2. Linear Systems

Fourier series and Fourier transform
Discrete Fourier transform and fast Fourier transform
One-sided and double-sided Laplace transform
The Z-transform
Hilbert transform
Delta impulse function and its properties
Complex variables and contour integration
Transfer function and representation of continuous and discrete systems
Convolution of continuous and discrete signals
Eigenvalues, eigenvectors, modal and Jordan forms of linear systems
State space representation of continuous and discrete systems
System response to unit step, sinusoidal, and impulse inputs
Time-varying continuous and discrete systems
Fundamental and transition matrices and their properties for time invariant and time varying systems Stability of linear systems

Recommended text:

1. Z. Gajic, Linear Dynamic Systems and Signals, Prentice Hall, 2003
2. Oppenheim and Willsky, Signals and Systems, Prentice Hall, 2nd edition, 1996.
3. F. Szidarouszy and T. Bahill, Linear Systems Theory, 2nd ed., CRC Press, 1997

3. Logic/Digital Systems Design

Coding systems, number representation, and computer arithmetic
Switching algebra
Combinational logic design and minimization
Clocking strategies
Asynchronous state machine design and minimization
Timing hazards and metastability
Logic and state machine implementation (e.g. SSI, MSI, VLSI)
Programmable logic (PLDs and FPGAs)
Logic circuit testing
Pipielining
Microprogramming--horizontal and vertical
Hardware description languages--Verilog and/or VHDL

Recommended texts:

1. John F. Wakerly, Digital Design: *Principles and Practices*, 3rd ed., Prentice-Hall, 2002
2. Victor P. Nelson, H. Troy Nagle, J. David Irwin, and Bill D. Carroll, *Digital Logic Circuit Analysis and Design*, Prentice-Hall, 1995
3. Randy H. Katz, *Contemporary Logic Design*, Benjamin-Cummings, 1994
4. Frederick J. Hill and Gerald R. Peterson, *Computer Aided Logical Design*, 4th ed., Wiley, 1993
5. Israel Koren, *Computer Arithmetic Algorithms*, 2nd ed., Prentice-Hall, 2001
6. Zainalabedin Navabi, *VHDL: Analysis and Modeling of Digital Systems*, McGraw- Hill, 2nd ed., 1997
7. J. Bhasker, *A VHDL Primer*, 3rd ed., Prentice-Hall, 1998

4. Communications

Fourier transforms, Correlation and power spectral density functions
Random signals and systems analysis
Poisson and Markov processes
Amplitude and frequency modulation
Pulse modulation techniques (PAM, PCM, PWM, PPM)
Characterization of digital signals and transmission facilities
Access, multiplexing and error handling on network links
Source models and source encoding
Channel models and channel capacity of the AWGN channel
Representation of bandpass signals and systems
Optimum receiver structures for gaussian noise
Digital carrier modulation and demodulation schemes
Binary and nonbinary systems (BASK, BPSK, BFSK, MASK, MPSK, MFSK)
Coherent and noncoherent signal detection
Carrier recovery techniques
Modulator and demodulator error probability analysis
Symbol synchronization methods
Equalization of symbol interference effects

Recommended texts:

1. Schwartz, *Information Transmission, Modulation and Noise*, 4th ed., McGraw-Hill, 1990

2. Papoulis, *Probability, Random Variables and Stochastic Processes*, 4th ed., McGraw Hill, 2002

3. R. Yates and D. Goodman, *Probability and Stochastic Processes: A Friendly Introduction for Electrical and Computer Engineers*, 2nd ed., Wiley, 2004

4. J.M. Wozencraft and J. Jacobs, *Principles of Communication Engineering*, Reprint Edition, Waveland Press, 1990

5. J.G. Proakis, *Digital Communications*, McGraw-Hill, 4th ed., 2000

6. R.G. Gallager, *Information Theory and Reliable Communication*, Wiley, 1968

7. S. Lin and D. Costello, *Error Control Coding*, Prentice Hall, 2nd ed., 2004

The level of knowledge is comparable to that in the following Rutgers courses:

332:322 Principles of Communication Systems
332:421 Communications Engineering
332:545 Digital Communication Systems

5. Computer Algorithms and Software Engineering

Records
Arrays
Lists
Trees
Graphs
Searching
Sorting
Complexity issues (excluding NP-completeness)
Software production process

Requirements
Analysis
Design & Architecture
Final Software specifications
Verification/Testing management
Planning and Estimation

The level of knowledge is comparable to that in the following Rutgers courses:

332:567 Software Engineering I
332:573 Data Structures and Algorithms

6. Computer Architecture

Computer implementation technologies
Performance metrics and measurements
Instruction sets, addressing modes, instruction encodings
Assembly language programming
RISC architectures (e.g., MIPS, SPARC, PowerPC)
CISC architectures (e.g., VAX, S/370, x86)
Instruction level parallelism
Computer arithmetic
Processor datapath and control design
Pipelining and pipeline hazards
Memory systems--main memory, virtual memory, cache memory
I/O systems--disk systems and networks
Parallel processing-- MIMD, SIMD, SPMD

Recommended texts:

1. David A. Patterson and John L. Hennessy, *Computer Organization and Design: The Hardware/Software Interface*, 5th edition, Morgan Kaufmann, 2013

2. John L. Hennessy and David A. Patterson, *Computer Architecture: A Quantitative Approach*, 5th edition, Morgan Kaufmann, 2011.

3. Israel Koren, *Computer Arithmetic Algorithms*, 2nd ed., Prentice-Hall, 2001

4. Daniel P. Siewiorek, *C. Gordon Bell and Allen Newell, Computer Structures: Principles and Examples*, McGraw-Hill, 1981

The level of knowledge is comparable to that in the following Rutgers courses:

332:563 Computer Architecture I
332:564 Computer Architecture II

7. Computer/Communication Networks

ARQ Protocols
- *Correctness and efficiency*
- *Initialization*

Multiaccess Communication
- *ALOHA*
- *IEEE 802.3 (Ethernet)*
- *IEEE 802.11 (Wi-Fi)*
- *[With Ethernet and Wi-Fi, the emphasis is on the foundations (CSMA protocol), rather than on any commercial technologies.]*

Routing Protocols
- *Shortest path algorithms*
- *Internet addressing*
- *Multicast routing*
- *Ad-hoc network routing protocols*

Delay Models and Queuing Systems
- *M/M/1 Queue*
- *M/G/1 Queue*
- *Networks of Queues*

Quality-of-Service and High-Performance Networks
- *TCP congestion control*
- *Protocols for real-time iteractive applications*
- *Scheduling and policing mechanisms*
- *Integrated and differentiated services*

Recommended Texts:

1. Dimitri Bertsekas and Robert Gallager, Data Networks, 2nd ed., Prentice Hall, 1992

2. Larry L. Peterson and Bruce S. Davie, Computer Networks: A Systems Approach, 3rd ed., Morgan Kauffman Publishers, 2003

3. James F. Kurose and Keith W. Ross, Computer Networking: A Top-Down Approach Featuring the Internet, 3rd ed., Addison Wesley Professional, 2005

The level of knowledge is comparable to that in the following Rutgers courses:

332:423 Telecommunication Networks
332:543 Communication Networks I

8. Control Systems

Open and closed loop control
Transfer functions and block diagrams
State space analysis of linear control systems
Controllability and observability
Observer design
Pole placement technique
Stability of control systems and stability criteria
Transient response of linear systems
Steady state response and steady state errors
Root locus technique
Nyquist and Bode diagrams
Frequency domain design of compensators
Linearization of nonlinear systems
Nonlinear phenomena in control systems
Lyapunov stability criterion for nonlinear systems
Method of describing function for nonlinear systems

Recommended texts:

1. C.T. Chen, *Linear System Theory and Design*, 4th edition, Oxford Press, 2013.
2. Z. Gajic and M. Lelic, *Modern Control Systems Engineering*, Prentice Hall International, 1996
3. K. Ogata, *Modern Control Engineering*, 4th ed., Prentice-Hall, 2001

The level of knowledge is comparable to that in the following Rutgers courses:

332:415 Introduction to Automatic Control Theory
332:505 Control Theory I

9. Digital Signal Processing

A/D, D/A, successive approximation, flash converters and sample/holds
Quantizers: dynamic range, resolution, rms error
Sampling theorem and the Poisson sum formula
Analog reconstructors and staircase reconstructors
Anti-aliasing prefilters and postfilters and their specifications
Overall components of a DSP system
Discrete convolution, Convolution table, Block convolution
Transfer function, frequency response, pole-zero plot of a filter
Z-transforms and Inverse Z-transforms by contour integration
Region of convergence, stability and causality
Digital filter realizations (direct, canonical, cascade)

State space descriptions of digital filters
Hardware/software implementations of digital filters, DSP chips
Pipelining in cascade realizations
Algorithm descriptions in standard programming languages or MATLAB
Quantization effects
Interpolation and decimation
Properties of analog Butterworth filters
IIR designs by bilinear transformation (lowpass, highpass, bandpass)
FIR designs using windows (rectangular, Hamming, Kaiser)
Properties and relative performance of windows
DFT/FFT algorithms. Circular convolution and wrap-around errors
Frequency leakage versus frequency resolution and the use of windows
Overlap-add and overlap-save methods of fast convolution
Matrix descriptions of linear and circular convolution, deconvolution
Deterministic and non-deterministic autocorrelation

Recommended texts:

1. S.Orfanidis, *Introduction to Signal Processing*, Prentice-Hall, 1995

2. Oppenheim and Schafer, *Discrete-Time Signal Processing*, 2nd ed., Prentice-Hall, 1999

3. Proakis and Manolakis, *Introduction to Digital Signal Processing*, Macmillan, 1988

The level of knowledge is comparable to that in the following Rutgers courses:

332:346 Digital Signal Processing
332:445 Multimedia Signal Processing
332:446 Multimedia Signal Processing-Design
332:521 Digital Signals and Filters

10. Electromagnetic Field Theory

Theory of static and quasi-static electric and magnetic fields
Laplace/Poisson equations and boundary conditions
Time-varying electric and magnetic fields
Maxwell's equations
Wave propagation in dielectrics and conductors
Transmission lines
Waveguides (excluding dielectric)
Simple antennas and antenna arrays
Gain and directivity of antennas
Radar equation

Recommended texts:

1. W. Hayt and J. Buck, Engineering Electromagnetics, 6th ed., McGraw-Hill, 2001
2. P. Lorrain, D. Corson, and F. Lorrain, Electromagnetic Fields and Waves, 3rd ed., Freeman & Company, 1988

3. S. Ramo, J. Whinnery and T. Van Duzer, Fields and Waves in Communication Electronics, 3rd ed., Wiley, 1994

The level of knowledge is comparable to that in the following Rutgers courses:

332:382 Electromagnetic Fields
332:580 Electric Waves and Radiation

11. Solid State Electronics

Crystal structures
Quantum theory of electrons
Bond model of solids
Free electron theory
Kronig-Penney model and energy bands
Intrinsic and extrinsic semiconductors
Statistics of semiconductors
Recombination and generation behavior
Charge transport
Principles of JFET, BJET, MOSFET and MESFET
p-n junction, Schottky barrier and heterostructure theory
Device characteristics, I-V, C-V, C-f, frequency response, power and frequency relation of BJET, JFET, MOSFET and MESFET

Recommended texts:

1. R. Eisberg and R. Resnick, Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles, 2nd ed., Wiley, 1985

2. C. Kittel, Introduction to Solid State Physics, 8th ed., Wiley, 2004

3. S. Sze, Physics of Semiconductor Devices, 2nd ed., Wiley, 1981

The level of knowledge is comparable to that in the following Rutgers courses:

332:465 Physical Electronics
332:581 Introduction to Solid State Electronics
332:583 Semiconductor Devices I

12. Engineering Mathematics

Students are examined in the following basic engineering mathematics topics: Complex Analysis (Variables), Differential Equations, Linear Algebra, Numerical Analysis, Probability, Stochastic Processes, and Discrete Mathematics. In general Electrical Engineering students are given 12 problems, 3 problems in each of the following areas: Probability and Stochastic Processes, Linear Algebra, Ordinary and Partial Differential Equations, and Complex Analysis. The students are asked to choose 6 out of 12 problems and solve them within a two-hour period. Similarly, Computer Engineering students are given 12 problems in the following areas: Probability and Stochastic Processes, Linear Algebra, Numerical

Analysis and Differential Equations, and Discrete Mathematics, and asked to choose 6 problems. The following prioritization of these topics is suggested for each specialization area:

1. Communications

Probability
Stochastic Processes
Linear Algebra

2. Computer Engineering

Discrete Mathematics
Linear Algebra
Numerical Analysis
Ordinary and Partial Differential Equations
Probability and Stochastic Processes

3. Digital Signal Processing

Linear Algebra
Numerical Analysis
Probability
Stochastic Processes
Complex Variables

4. Solid State Electronics

Vector Differential Calculus
Ordinary and Partial Differential Equations
Fourier Series and Integrals
Laplace and Fourier Transforms
Complex Variables
Calculus of Variation

5. Systems and Control

Differential Equations
Linear Algebra
Complex Variables
Stochastic Processes

The guidelines for the mathematics topics are given below:

12.1. Complex Variables

Analytic Functions
Cauchy-Riemann equations
Complex integration
Cauchy's integral formula
Residue theorem
Mapping. Conformal mapping
Fourier, Laplace, Z-transforms and their inverses

12.2. Differential Equations

First-order linear and nonlinear differential equations.
Integrability conditions for exact equations.
Second-order linear equations.
Homogeneous and inhomogeneous equations.
Linear independence of solutions, Wronskians.
Variation of parameters method.
Method of undetermined coefficients.
Series solutions near regular and singular points.
Linear systems of differential equations.
Linearly independent solutions.
Eigenvalues and eigenvectors.
Partial differential equations.
Separation of variables method.
Wave, Laplace, Poisson, Helmholtz, Diffusion, Maxwell, Schrodinger equations.
Vector fields, Gradient, Divergence, Curl, Line integrals.
Gauss and Stokes theorems.
Calculus of variations.

12.3. Linear Algebra

Vector spaces, Inner products, Bases, Linear independence, Orthogonality.
Linear transformations, Matrices, Rank, Null subspace.
Unitary, orthogonal, hermitian matrices.
Gram-Schmidt orthogonalization.
Orthogonal projection with respect to a subspace.
Eigenvalues and eigenvectors.
Characteristic polynomial.
Jordan canonical form.
LDU decomposition.
Homogeneous transformation matrices.

12.4. Numerical Analysis

Polynomial interpolation, Lagrange interpolation.

Numerical integration, Newton-Cotes integration rules.
Solving linear systems of equations.
Condition number of a linear system.
Norms for matrices and vectors.
Gaussian elimination, LU factorization.
Linear least-square data fitting.
Iterative methods for nonlinear equations, Newton-Raphson methods.
Iterative methods for eigenvalue problems.
Power method, Inverse power method, Subspace iteration method.
Runge-Kutta methods for ordinary differential equations.
Predictor-corrector methods for ordinary differential equations.

12.5. Probability

Set-theoretic axioms of probability.
Discrete random variables, Bernoulli, Binomial, Poisson.
Continuous random variables.
Probability density and cumulative distribution.
Mean, variance, moments, characteristic function.
Chebyshev inequality.
Normal, uniform, exponential distributions,
Estimates of mean and variance, percentiles, confidence intervals.
Mean square estimation.
Functions of random variables.
Sums of independent random variables.
Joint distributions, conditional distributions, Bayes' rule.
Law of large numbers, Central Limit Theorem.
Random number generators.

12.6. Stochastic Processes

Continuous and discrete-time random processes.
Stationarity, White noise processes, Markov processes.
Autocorrelation and power spectrum, cross-correlation.
Linear filtering of stationary random signals.
Estimating the autocorrelation and the power spectrum.
Wiener-Hopf estimation.

12.7. Discrete Mathematics

Combinatorics
Recursive Relations
Graph theory
Logic and set theory
Boolean and related algebras
Modular arithmetic and applications
State machines, linear sequential machines

Inductions
Complexity (Growth and Big O Analysis)

Recommended texts for Engineering Mathematics:

1. E. Kreyszig, Advanced Engineering Mathematics, 8th ed., Wiley, 1998

2. G. Strang, Introduction to Linear Algebra, 3rd ed., Wellesley Cambridge Press, 2003

3. G. Golub and C. Van Loan, Matrix Computations, 3rd ed., John Hopkins University Press, 1996

4. A. Papoulis, Probability, Random Variables, and Stochastic Processes, 4th ed., McGraw-Hill, 2002

5. W. Press, B. Flannery, S. Teukolsky, and W. Vetterling, Numerical Recipes on C+: The Art of Scientific Computing, 2nd ed., Cambridge University Press, 2002

6. D. Kahaner, S. Moler, and S. Nash, Numerical Methods and Software, Prentice-Hall, 1988
Introduction to Numerical Analysis, 3rd ed., Springer-Verlag, 2002

8. R. Yates and D. Goodman, Probability and Stochastic Processes: A Friendly Introduction for Electrical and Computer Engineers, 2nd ed., Wiley, 2004

9. T. Feil and J. Krone, Essential Discrete Mathematics for Computer Science, Prentice Hall, 2003

10. K. Rosen, Discrete Mathematics and Its Applications, McGraw Hill, 1999

11. F. Preparata and Yeh, Introduction to Discrete Structures, Addison Wesley, 1973

Appendix B -- Faculty Research Areas

I. Androulakis *Biomedical Engineering*, (848) 445-6561, yannis@rci.rutgers.edu; BME-212.
Systems biology. Functional links between cellular events, such as signaling transcription and translation. Interactions that include bidirectional links between cells, tissues, organs, environmental signals, and physiological responses.

W. Bajwa *Digital Signal Processing*, (848) 445-8541, waheed.bajwa@rutgers.edu; CoRE 723.
Digital signal processing, high-dimensional inference and inverse problems, compressed sensing, wireless communications.

H. Baruh *Mechanical and Aerospace Engineering* (848) 445-3680 – baruh@jove.rutgers.edu;
Structural dynamics, control of structures using piezoelectric component, impact dynamics, control of systems describing constrained coordinates, autonomous vehicle control, structural damage detection.

G. Burdea *Computer Engineering* (848) 445-5309 - burdea@ece.rutgers.edu; CoRE-721
Virtual reality systems, force feedback interfaces, medical applications of virtual reality. Telemedicine.

M. Bushnell *Computer Engineering*, Professor Emeritus of Electrical and Computer Engineering.
Computer-Aided Design (CAD) of VLSI circuits. Automatic Test-Pattern Generation (ATPG) for mixed analog/digital combinational and sequential VLSI Circuits. Spectral testing of combined analog and digital circuits. Built-in Self-Testing circuits for systems on a chip. A/D converter testing, and diagnosis. False timing path analysis for sequential circuits. Mathematical programming for low-power circuit design. Formal Hardware Verification.

M. Caggiano, Professor Emeritus of Electrical and Computer Engineering, (848) 445-0678, EE-111
High performance and microwave IC device packaging. Electronic circuits.

T.J. Chakraborty
Design, verification, and test of systems-on-a-chip for communications systems.

M. Chhowalla *Material Science and Engineering* (848)-445-5619, manish1@rci.rutgers.edu
Graphene oxide, copper, organic electronics, optoelectronics, solar cells.

S-W. Cheong *Physics and Astronomy* (848)445-5500 x4607 – sangc@physics.rutgers.edu;
Experimental condensed-matter physics and material science.

D. L. Comaniciu, *Siemens Corporate Technology*, Princeton, NJ, Ph. D. Rutgers University
Medical imaging, scanner automation. Cardiac modeling, image-guided surgery, biomedical informatics, computer vision, and machine learning.

K. Dana *Computer Engineering* (848) 445-5253 - kdana@ece.rutgers.edu; CoRE-528
Computational models for image texture with applications in pattern recognition and scene rendering. Physics-based methods for vision and graphics. Stochastic processes for surface modeling and texture analysis. Medical image processing using image registration, fusion and change detection. Optical imaging models for microscopy.

D. Daut *Communications and Information Processing* (848) 445-5393 - daut@ece.rutgers.edu; EE-232
Image data/bandwidth compression techniques in the context of image coding and transmission. Digital communication system design using various modulation and coding strategies in conjunction with both Gaussian and fading channel characterizations. Application of rate-distortion theoretic principles to digital transmission system design. Fiber optic communication systems. Stochastic image modeling and segmentation for real-world imagery analysis and/or transmission**.**

T.N. Farris *Engineering* (848) 445-2214 – tfarris@rci.rutgers.edu; SOE-B203
Aerospace structures and materials. Tribology, manufacturing, fatigue and fracture.

L. C. Feldman, *Institute of Advanced Materials, Devices and Nanotechnology* (848) 445-4526, l.c.feldman@rutgers.edu; CCR-206
The chemical formation and structure of thin film materials and their applications to problems of semiconductor science and engineering and applications associated with energy. Included in the latter are the fundamentals of photon inter\actions with solids, and radiation effects in semiconductor materials.

G.J. Foschini
Wireless and optical communications.

R.H. Frenkiel *Communications* (848) 932-6857 x635 - frenkiel@winlab.rutgers.edu; WLTC-C111
Wireless systems architecture.

Z. Gajic *Systems and Control* (848) 445-3415; 445-2578 - gajic@ece.rutgers.edu; EE-222 & EE-134A
Singular perturbation methods in control system analysis. Linear stochastic estimation and control. Deterministic and stochastic differential games. Bilinear control systems. Jump parameter linear stochastic systems and Markov chains. Matrix Lyapunov and Riccati equations. Control of power in optical and wireless networks, fuel and solar cells, and energy systems.

H. Godrich (848) 445-0606 – godrich@rci.rutgers.edu; CoRE 516
Statistical and aray signal processing, distributed detection and estimation with application in radar systems, wireless sensor networks, and smart power grids..

L.J. Greenstein (848) 932-6857 x637 – ljg@winlab.rutgers.edu; WLTC-C102
Wireless communications.

M. Gruteser *Communications* (848) 932-6875 x649, (848) 445-1011; CoRE-505
gruteser@rci.rutgers.edu; WLTC-C114
Pervasive computing architectures and prototyping; location tracking, location-aware systems and applications; information privacy and security for wireless networks and sensor-based systems.

S. J. Hanson, *Physiology Newark (Brain Imaging Center)* (973) 353-5440 x 3952, jose@phychology.rutgers.edu
Learning theory and experiment, connectionist models of human characterization and object recognition, brain imaging – predictive decoding/MVPA and graphical models, event perception, language supporting functions.

M. Javanmard, *Electronic*s, (848) 445-3382, EE 211, mehdi.javanmard@rutgers.edu
Nanobiotechnology, BioMEMS, Microfluidics, Micro and Nanofabrication, Biosensing, Bioelectronics, Early Cancer Diagnostic Systems, Pathogen Detection, Diagnostics for the

Developing World

J. Jeon *Solid State Electronics* (848) 445-0436 - jaeseok.jeon@rutgers.edu; EE-217
Nano-electro-mechanical relay devices, energy-efficient electronics, neural relay devices, neuromorphic systems, advanced materials and process technologies for energy-harvesting

S. Jha *Computer Engineering,* (848) 445-8537, shantenu.jha@rutgers.edu , CoRE-705
High-performance and distributed computing, scientific computation, large-scale cyberinfrastructure for supporting scientific and engineering computation.

W. Jiang *Solid State Electronics* (848) 445-2164 – wjiangnj@ece.rutgers.edu; EE-215
Photonic crystals, silicon photonics, nanophotonics, nanoimprint.

W. Y-C. Lai, *Solid State Electronics*, (848) 445-0680, warren.lai@rutgers.edu; EE-115
Using micro/nanofabrication techniques for micro/nanostructures, devices, and systems in semiconductor, MEMS, and nanotechnology; process integration and material engineering

J. K-J. Li *Biomedical Engineering* (848) 445-6582 - johnkjli@rci.rutgers.edu; Biomedical Eng'g Bldg;
Circulatory dynamics; instrumentation; physiological control.

J. Lindqvist *Communications/Computer Engineering* 848-932-6857 x 633 janne.lindvist@rutgers.edu
Human behavior using computer systems, systems security and privacy, security for mobile systems and pervasive computing, automotive computing.

Y. Lu *Solid State Electronics* (848) 445-3466 - ylu@ece.rutgers.edu; EE-217
Wide band gap semiconductor (ZnO and GaN) materials and devices, tunable RF components, dielectric thin films, MOCVD growth.

Anant Madabhushi, *Biomedical Engineering*, (848) 445-6563, - anant.madabhushi@rutgers.edu, Biomedical Engineering Bldg.
Medical image analysis; machine learning; computer-aided diagnosis.

R. Mammone *Digital Signal Processing* (848) 932-4455 - rmammone@vpr.rutgers.edu; CoRE-713
Investigation and applications of new signal extraction algorithms, ultrasound and optical image restoration, speech parameter extraction, equalization of communication channels, machine vision, pattern recognition, expert systems and applications of neuro-networks.

N. Mandayam *Communications* (848) 932-6875 x642 - mandayam@ece.rutgers.edu; WLTC-C108;
(848) 445-0876 - CoRE-509
Communication theory, spread spectrum, wireless system performance, multi-access protocols, multimedia communications over wireless systems, multiuser detection.

I. Marsic *Computer Engineering* (848) 445-6399 - marsic@caip.rutgers.edu; CoRE-711
Distributed Systems for Collaborative/Information Processing and Learning-(DISCIPLE), methods of object recognition in wavelet scale, image reconstruction, and machine vision.

R. Martin *Computer Science* (848) 445-6450 x 2005 – martin@cs.rutgers.edu
Sensor networks, wireless networks, internet, localization, ad-hoc communication networks.

S. McAfee *Solid State Electronics* (848) 445-5247 - mcafee@ece.rutgers.edu; EE-213

Fundamental properties of deep levels in semiconductors. Influence of deep levels on the growth parameters of molecular beam epitaxy silicon, metal-organic chemical vapor deposited Al(GaAs) and InGaAsP materials and devices. Semiconductor processing in silicon and III-V materials for basic research and device applications. Fiber optics with emphasis on fiber optic coupling of lasers and waveguides. Electromagnetic field applications in materials and antennas.

P. Meer *Computer Engineering* (848) 445-5243 - meer@ece.rutgers.edu CoRE-519

Application of modern statistical methods to computer vision and pattern recognition; robust techniques for image understanding; probabilistic algorithms for machine vision problems; representation of semantical visual information.

L. Najafizadeh, *Nano and Microelectronics* (848) 445-0593 – laleh.najafizadeh@rutgers.edu; CoRE-520

Brain imaging, microelectronics and circuits design, signal processing and biophotonics

S. Oh *Physics and Astronomy* (848) 445-5500 (x4017) - ohsean@physics.rutgers.edu; Serin W121

Molecular beam epitaxy of functional oxides and quantum materials, and low dimensional electronic properties.

S. Orfanidis *Digital Signal Processing* (848) 445-5017 - orfanidi@ece.rutgers.edu; EE-230

Adaptive signal processing. Block processing and adaptive eigenvector methods for spectrum estimation, direction finding, and pole retrieval. Neural networks.

M. Parashar *Computer Engineering and Science* (848) 445-5388 - parashar@ece.rutgers.edu; CoRE-628

Parallel and Distributed Computing, Software Engineering, Scientific Computing, Computational Interaction and Steering, Network/Application Quality-of-Service, Active Networks, and Performance Evaluation and Prediction.

A. Petropulu *Digital Signal Processing and Communications* (848) 445-0414 athinap@rutgers.edu; EE-128

Statistical signal processing – system identification; MIMO system estimation; blind source separation; higher-order statistics. Networking – cooperative protocols for wireless networks; high-speed wireline and wireless traffic modeling; cross-layer approaches. Wireless communications – blind channel estimation and equalization; CDMA systems; OFDM systems. Biomedical engineering – tissue characterization for breast cancer detection based on the ultrasound rf echo; resolution improvement of ultrasound images; Raman spectroscopy for tissue characterization.

D. Pompili *Computer Engineering* (848) 445-8533 – pompili@caip.rutgers.edu; CoRE-615

Sensor Networks, Underwater Acoustic Sensor Networks, Sensor and Actor Networks, Ad Hoc Networks, Wireless Internet, Wireless Mobile Networks, Overlay Networks, Traffic Engineering, Optimization, Multimedia Communications, Satellite Networks.

L. Rabiner *Digital Signal Processing* (848) 445-6246 - lrr@caip.rutgers.edu; CoRE-728

Digital Signal Processing, Digital Speech Processing, Communications of Information Signals (Speech, Image, Text, Video) and Networking Issues related to real-time information flows in IP Networks. Human-Machine Communications and Interactions using multiple human modalities of communications on Multimodal Platforms of all types.

D. Raychaudhuri *Communications* (848) 932-6857 x638 - ray@winlab.rutgers.edu; WTLC-C03;
(848) 445-0877; CoRE-501

Network architecture, design and prototyping; Communication protocols/software; Quality-of-service, mobility management, and content delivery in mobile networks; Wireless system design, including spectrum management, radio MAC/link protocols &; network management; Broadband network technologies.

Ivan Rodero, *Computer Engineering*, (848) 445-8536, irodero@rutgers.edu; CoRE 624.

Parallel and distributed computing; extreme-scale computing: energy/power efficiency, cloud and automatic computing, scalable data management and analytics, big data.

C. Rose *Communications* (848) 932-6857 x643 - crose@ece.rutgers.edu; WTLC-C109
(848) 445-5250; CoRE 508

Mobile communication networks, mobility management. Distributed communication systems (packet radio networks). Stochastic search methods including simulated annealing, genetic algorithms and genetic programming.

P. Sannuti *Communications and Control Systems* (848) 445-3127 - sannuti@ece.rutgers.edu; CoRE-525

Singular perturbation theory, H2 optimal control theory, loop transfer recovery, control of linear systems with saturating inputs and states, input decoupled observers, and fault signal estimation.

Anand Sarwate, *Signal Processing*, (848) 445-8516, anand.sarwate@rutgers.edu; CoRE 517

Information processing in distributed systems, using tools from machine learning, signal processing, information theory, statistics, and optimization. I am interested in designing methods to learn from data which is private or sensitive.

G.K. Shoane *Biomedical Engineering* (848) 445-6583 – shoane@rci.rutgers.edu;

Binocular vision; vergence; accommodation model; amblyopia.

D. Silver *Computer Engineering* (848) 445-5546 - silver@ece.rutgers.edu; CoRE-709

Computer graphics, scientific visualization, numerical analysis, computational geometry.

E.D. Sontag *Mathematics* (848) 445-2390 – sontag@math.rutgers.edu; Hill-724

Linear and nonlinear control; neural networks; feedback design.

P. Spasojevic *Communications* (848) 932-6857 x648- spasojev@winlab.rutgers.edu; WLTC-C113
(848) 445-1372; CoRE-504

Wireless and wired digital communications, adaptive and statistical signal processing, sequence and channel estimation, multi-user detection; equalization and synchronization, iterative detection, and receiver implementation.

W. Trappe *Communications* (848) 932-6857 x644 - trappe@winlab.rutgers.edu; WLTC-C110
(848) 445-0611; CoRE-523

Multimedia and multicast information security, signal, image and video processing, wireless networking, cryptography and network security.

M.M. Tremaine *Computer Engineering* – tremaine@caip.rutgers.edu

Human Computer Interaction, User Interfaces, Visualization.

J. Walling *Nano and Microelectronics* -
Design of RF and mixed-signal integrated circuits for low-power wireless networks and high-speed communications.

J. Wilder *Computer Engineering* (848) 445-4280 - wilder@jove.rutgers.edu; CoRE-526
Image processing, pattern recognition and machine vision with particular emphasis on robust, high speed systems for industrial inspection, measurement and guidance.

R. Wright, *Computer Science* (848) 445-5931 - rebecca.wright@rutgers.edu; CoRE-410
Security; privacy; cryptography; fault-tolerant distributed computing

R. Yates *Communications* (848) 932-6857 x641 - ryates@ece.rutgers.edu; WLTC-A102
(848) 445-5249; CoRE-515
Power control, interference suppression and handoff for wireless networks, multiaccess protocols, discrete time queueing networks.

J. Yi, *Mechanical and Aerospace Engineering*, (848) 445-3282 – jgyi@rutgers.edu; Engineering D-157
Autonomous robotic systems; dynamic systems and control; mechatronics; automation science and engineering

Y. Zhang, *Computer Engineering* (848) 932-6857 X646 - yyzhang@ece.rutgers.edu; WLTC-A104
(848) 445-0608; CoRE-518
Operating Systems, Parallel and Distributed Systems and Networking.

J. Zhao, *Solid State Electronics* (848) 445-5240 – jzhao@ece.rutgers.edu ; CoRE-512
Semiconductor electronic and optoelectronic devices, SiC and GaN technologies, and computer modelling of semiconductor devices.

S. Zonouz, *Computer Engineering*, (848) 445-8508 saman.zonouz@rutgers.edu; CoRE 524
Design and implementation for systems and networks security and privacy. Cyber-physical critical infrastructures, embedded systems, operating system security, intrusion detection and forensics analysis, and software reverse engineering.

Q. Zou *Mechanical and Aerospace Engineering* (848)445-3268, qzzou@rci.rutgers.edu; Eng. Bld. D-102
System inversion theory, iterative control theory, experimental design with applications to nanotechnology and biomedical applications.

Appendix C --- Graduate Courses

16:332:501 (F) SYSTEM ANALYSIS (3)
Fundamental system concepts, solution of linear differential and difference equations. Transform methods involving Fourier and Laplace transforms, double-sided Laplace transforms, Z-transforms, Hilbert Transforms, convolution in time and frequency domain. Complex variables and application of Residue Theorem for transform inversion. Review of Matrix algebra involving similarity transformations. Cayley-Hamilton theorem, state space concepts, controllability, observability, minimal realization.

16:332:502 (F) TECHNOLOGY ENTREPRENEURSHIP (3)
Structure and framework of entrepreneurial endeavors. Phases of a startup, business organization. intellectual property, financing, financial modeling, and business plan writing.

16:332:503 (F) PROGRAMMING METHODOLOGY FOR NUMERICAL COMPUTING AND COMPUTATIONAL FINANCE (3)
Fundamentals of object-oriented programming ad C++ with an emphasis in numerical computing and computational finance. Design Oriented. Topics include: C++ basics, objected oriented concepts, data structures, algorithm analysis and applications.

16:332:504 (F) SENSOR-BASED SYSTEMS AND APPPLICATIONS (3)
Corequisite: 16:332:543
The course will develop skills in designing, programming, and testing self-configurable communication protocols and distributed algorithms for wireless sensor networks enabling environmental, health, and seismic monitoring, surveillance, reconnaissance, and targeting.

16:332:505 (S) CONTROL SYSTEM THEORY I (3)
Prerequisite: 16:332:501.
Review of basic feedback concepts and basic controllers. State space and transfer function approaches for linear control systems. Concepts of stability, controllability, and observability for time-invariant and time-varying linear control systems. Pole placement technique. Full and reduced-order observer designs. Introduction to linear discrete-time systems.

16:332:506 (F) CONTROL SYSTEM THEORY II (3)
Prerequisite: 16:332:505.
Review of state space techniques; transfer function matrices; concepts of controllability, observability and identifiability. Identification algorithms for multivariable systems; minimal realization of a system and its construction from experimental data. State space theory of digital systems. Design of a three mode controller via spectral factorization.

16:332:507 (S) SECURITY ENGINEERING (3)
Essential principles, techniques, tools, and methods for systems security engineering. Students work in small collaborative design teams to propose, build, and document a project focused on securing systems. Students document their work through a series of written and oral proposals, progress reports, and final reports. Basics of security engineering, usability and psychology, human factors in securing systems, mobile systems security, intersection of security and privacy, security protocols, access control, password security, biometrics, and topical approaches such as gesture---based authentication.

16:332:508 (S) DIGITAL CONTROL SYSTEMS (3)
Prerequisite: 16:332:505.
Review of linear discrete-time systems and the Z-transform. Sampling of continuous-time liner systems and sampled-data linear systems. Quantization effects and implementation issues. Computer controlled continuous-time linear systems. Analysis and design of digital controllers via the transfer function and state space techniques. Linear-quadratic optimal control and Kalman filtering for deterministic and stochastic discrete-time systems.

16:332:509 (S) CONVEX OPTIMIZATION FOR ENGINEERING APPLICATIONS (3)
The course develops the necessary theory, algorithms and tools to formulate and solve convex optimization problems that seek to minimize cost function subject to constraints. The emphasis of the course is on applications in engineering applications such as control systems, computer vision, machine learning, pattern recognition, financial engineering, communication and networks.

16:332:510 (S) OPTIMUM CONTROL SYSTEMS (3)
Prerequisites: 16:332:505 and 16:332:506.
Formulation of both deterministic and stochastic optimal control problems. Various performance indices; calculus of variations; derivation of Euler-Lagrange and Hamilton-Jacobi equations and their connection to two-point boundary value problems, linear regulator and the Riccati equations. Pontryagin's maximum principle, its application to minimum time, minimum fuel and "bang-bang" control. Numerical techniques for Hamiltonian minimization. Bellman dynamic programming; maximum principle.

16:332:512 (S) NONLINEAR AND ADAPTIVE CONTROL THEORY (3)
Prerequisite: 16:332:505.
Nonlinear servo systems; general nonlinearities; describing function and other linearization methods; phase plane analysis and Poincare's theorem. Liapunov's method of stability; Popov criterion; circle criterion for stability. Adaptive and learning systems; identification algorithms and observer theory; input adaptive, model reference adaptive and self-optimizing systems. Estimation and adaptive algorithms via stochastic approximation. Multivariable systems under uncertain environment.

16:332:514 (S) STOCHASTIC CONTROL SYSTEMS (3)
Prerequisite: 16:332:505.
Response of linear and nonlinear systems to random inputs. Determination of statistical character of linear and nonlinear filter outputs. Correlation functions; performance indices for stochastic systems; design of optimal physically realizable transfer functions. Wiener-Hopf equations; formulation of the filtering and estimation problems; Wiener-Kalman filter. Instabilities of Kalman filter and appropriate modifications for stable mechanization. System identification and modeling in presence of measurement noise.

16:332:519 ADVANCED TOPICS IN SYSTEMS ENGINEERING (3)
Prerequisite: Permission of instructor.
Advanced study of various aspects of automatic control system. Possible topics include identification, filtering, optimal and adaptive control, learning systems, digital and sampled data implementations, singular perturbation theory, large scale systems, game theory, geometric control theory, control of large flexible structures, etc. Topics will vary from year to year.

16:332:521 (F) DIGITAL SIGNALS AND FILTERS (3)
Corequisite: 16:332:501.
Sampling and quantization of analog signals; Z-transforms; digital filter structures and hardware realizations; digital filter design methods; DFT and FFT and methods and their application to fast

convolution and spectrum estimation; introduction to discrete time random signals.

16:332:525 (F) OPTIMUM SIGNAL PROCESSING (3)
Prerequisites: 16:332:521 or Permission of instructor.
Block processing and adaptive signal processing techniques for optimum filtering, linear prediction, signal modeling, and high resolution spectral analysis. Lattice filters for linear prediction and Wiener filtering. Levinson and Schur algorithms and their split versions. Fast Cholesky factorizations. Periodogram and parametric spectrum estimation and superresolution array processing. LMS, RLS, and lattice adaptive filters and their applications. Adaptation algorithms for multilayer neural nets.

16:332:526 (S) ROBOTIC SYSTEMS ENGINEERING (3)
Introduction to robotics; robot kinematics and dynamics. Trajectory planning and control. Systems with force, touch and vision sensors. Telemanipulation. Programming languages for industrial robots. Robotic simulation examples.

16:332:527 (S) DIGITAL SPEECH PROCESSING (3)
Prerequisite: 16:332:521.
Acoustics of speech generation; perceptual criteria for digital representation of audio signals; signal processing methods for speech analysis; waveform coders; vocoders; linear prediction; differential coders (DPCM, delta modulation); speech synthesis; automatic speech recognition; voice-interactive information systems.

16:332:529 (S) IMAGE CODING AND PROCESSING (3)
Prerequisites: 16:332:521, 16:642:550, (16:332:535 recommended).
Visual information, image restoration, coding for compression and error control, motion compensation, advanced television.

16:332:533 (S) COMPUTATIONAL METHODS FOR SIGNAL RECOVERY (3)
Prerequisites: 16:332:521 and 16:332:541.
Computational methods for estimating signals in noise, for forecasting trends in noisy data, for clustering data for the recognition and detection of patterns in data. Kalman filtering, neural networks, support vector machines, and hidden Markov models. Applications in financial engineering and bioinformatics as well as in more traditional signal processing areas such as speech, image, and array processing, face recognition.

16:332:535 (F) MULTIRESOLUTION SIGNAL PROCESSING ALGORITHMS (3)
Prerequisites: 16:332:521 or Permission of instructor. Corequisite: 16:642:550.
Wavelets and subband coding with applications to audio, image, and video processing. Compression and communications issues including low-bit-rate video systems. Design of digital filters for systems with 2 or more channels. Matlab and matrix algorithms for analysis, design, and implementation.

16:332:539 ADVANCED TOPICS IN DIGITAL SIGNAL PROCESSING (3)
Prerequisite: Permission of instructor.
The course deals with selected topics in digital signal processing. Emphasis is given to current research areas. Advanced treatment will be given to such topics as digital filter design, digital filtering of random signals, discrete spectral analysis methods, and digital signal processor architectures. Subject matter may change year to year.

16:332:541 (F) STOCHASTIC SIGNALS AND SYSTEMS (3)

Corequisite: 16:332:501 and 16:642:550.
Axioms of probability; conditional probability and independence; random variables and functions thereof; mathematical expectation; characteristic functions; conditional expectation; Gaussian random vectors; mean square estimation; convergence of a sequence of random variables; laws of large numbers and Central Limit Theorem; stochastic processes, stationarity, autocorrelation and power spectral density; linear systems with stochastic inputs; linear estimation; independent increment, Markov, Wiener, and Poisson processes.

16:332:542 (S) INFORMATION THEORY AND CODING (3)
Prerequisite: 16:332:541.
Noiseless channels and channel capacity; entropy, mutual information, Kullback-Leibler distance and other measures of information; typical sequences, asymptotic equipartition theorem; prefix codes, block codes, data compression, optimal codes, Huffman, Shannon-Fano-Elias, Arithmetic coding; memoryless channel capacity, coding theorem and converse; Hamming, BCH, cyclic codes; Gaussian channels and capacity; coding for channels with input constraint; introduction to source coding with a fidelity criterion.

16:332:543 (F) COMMUNICATION NETWORKS I (3)
Prerequisite: 14:332:226 or equivalent or 16:332:541 or equivalent.
Introduction to telephony and integrated networks. Multiplexing schematics. Circuit and packet switching networks. Telephone switches and fast packet switches. Teletraffic characterization.. Delay and blocking analysis. Queueing network analysis.

16:332:544 (S) COMMUNICATION NETWORKS II (3)
Prerequisite: 16:332:543.
Network and protocol architectures. Layered connection management, including network design, path dimensioning, dynamic routing, flow control, and random access algorithms. Protocols for error control, signaling, addressing, fault management, and security control.

16:332:545 (S) DIGITAL COMMUNICATION SYSTEMS (3)
Prerequisite: 16:332:541.
Signal space and Orthonormal expansions, effect of additive noise in electrical communications vector channels, waveform channels, matched filters, bandwidth and dimensionality. Digital modulation techniques. Optimum receiver structures, probability of error, bit and block signaling, Intersymbol interference and its effects, equalization and optimization of baseband binary and M-ary signaling schemes; introduction to coding techniques.

16:332:546 (S) WIRELESS COMMUNICATIONS TECHNOLOGIES (3)
Prerequisite: 16:332:545
Propagation models and modulation techniques for wireless systems, receivers for optimum detection on wireless channels, effects of multiple access and intersymbol interference, channel estimation, TDMA and CDMA cellular systems, radio resource management, mobility models.

16:332:548 (S) ERROR CONTROL CODING (3)
Prerequisite: 16:332:545.
Continuation of 16:332:545. Application of information-theoretic principles to communication system analysis and design. Source and channel coding considerations, rudiments of rate-distortion theory. Probabilistic error control coding impact on system performance. Introduction to various channel models of practical interest, spread spectrum communication fundamentals. Current practices in modern digital communication system design and operation.

16:332:549 (S) DETECTION AND ESTIMATION THEORY (3)

Prerequisite: 16:332:541.
Statistical decision theory, hypothesis testing, detection of known signals and signals with unknown parameters in noise, receiver performance and error probability, applications to radar and communications. Statistical estimation theory, performance measures and bounds, efficient estimators. Estimation of unknown signal parameters, optimum demodulation, applications, linear estimation, Wiener filtering, Kalman filtering.

16:332:553 (S) WIRELESS ACCESS TO INFORMATION NETWORKS (3)
Prerequisites: 14:332:349 and 14:332:450 or equivalent.
Cellular mobile radio; cordless telephones; systems architecture; network control; switching; channel assignment techniques; short range microwave radio propagation; wireless information transmission including multiple access techniques, modulation, source coding, and channel coding.

16:332:556 (S) MICROWAVE COMMUNICATION SYSTEMS (3)
Prerequisite: 16:332:580 or equivalent.
Overview of modern microwave engineering including transmission lines, network analysis, integrated circuits, diodes, amplifier and oscillator design. Microwave subsystems including front-end and transmitter components, antennas, radar terrestrial communications, and satellites.

16:332:559 ADVANCED TOPICS IN COMMUNICATIONS ENGINEERING (3)
Prerequisite: Permission of instructor.
Topics such as source and channel coding, modern modulation techniques, wireless communication networks, networks security, and information processing. Subject matter changes from year to year.

16:332:560 (F) COMPUTER GRAPHICS (3)
Computer display systems, algorithms and languages for interactive graphics. Vector, curve, and surface generation algorithms. Hidden-line and hidden-surface elimination. Free-form curve and surface modeling. High-realism image rendering.

16:332:561 (F) MACHINE VISION (3)
Prerequisite: 16:332:501.
Image processing and pattern recognition. Principles of image understanding. Image formation, boundary detection, region growing, texture and characterization of shape. Shape from monocular clues, stereo and motion. Representation and recognition of 3-D structures.

16:332:562 (S) VISUALIZATION AND ADVANCED COMPUTER GRAPHICS (3)
Prerequisite: 16:332:560 or permission of instructor.
Advanced visualization techniques, including volume representation, volume rendering, ray tracing, composition, surface representation, advanced data structures. User interface design, parallel and object-oriented graphic techniques, advanced modeling techniques.

16:332:563 (F) COMPUTER ARCHITECTURE I (3)
Fundamentals of computer architecture using quantitative and qualitative principles. Instruction set design with examples and measurements of use, basic processor implementation: hardwired logic and microcode, pipelining; hazards and dynamic scheduling, vector processors, memory hierarchy; caching, main memory and virtual memory, input/output, and introduction to parallel processors; SIMD and MIMD organizations.

16:332:564 (S) COMPUTER ARCHITECTURE II (3)
Prerequisite: 16:332:563.
Advanced hardware and software issues in main-stream computer architecture design and evaluation.

Topics include register architecture and design, instruction sequencing and fetching, cross-branch fetching, advanced software pipelining, acyclic scheduling, execution efficiency, predication analysis, speculative execution, memory access ordering, prefetch and preloading, cache efficiency, low power architecture, and issues in multiprocessors.

16:332:565 (F) NEUROCOMPUTER SYSTEM DESIGN (3)

Prerequisites: 16:332:563.

Principles of neural-based computers, data acquisition, hardware architectures for multilayer, tree and competitive learning neural networks, applications in speech recognition, machine vision, target identification and robotics.

16:332:566 (S) INTRODUCTION TO PARALLEL AND DISTRIBUTED COMPUTING (3)

Prerequisite: 16:332:563.

Introduction to the fundamental of parallel and distributed computing including systems, architectures, algorithms, programming models, languages and software tools. Topics covered include parallelization and distribution models; parallel architectures; cluster and networked meta-computing systems; parallel/distributed programming; parallel/distributed algorithms, data-structures and programming methodologies, applications; and performance analysis. A "hands-on" course with programming assignments and a final project.

16:332:567 (F) SOFTWARE ENGINEERING I (3)

Overview of software development process. Formal techniques for requirement analysis, system specification and system testing. Distributed systems. System security and system reliability. Software models and metrics. Case studies.

16:332:568 (S) SOFTWARE ENGINEERING WEB APPLICATIONS (3)

Prerequisite: 16:332:567.

The course focus is on Web software design with particular emphasis on mobile wireless terminals. The first part of the course introduces tools; Software component (Java Beans), Application frameworks, Design patterns, XML, Communication protocols, Server technologies, and Intelligent agents. The second part of the course presents case studies of several Web applications. In addition, student teams will through course projects develop components for an XML-Based Web, such as browsers, applets, servers, and intelligent agents.

16:332:569 (F) DATABASE SYSTEM ENGINEERING (3)

Relational data model, relational database management system, relational query languages, parallel database systems, database computers, and distributed database systems.

16:332:570 (S) ROBUST COMPUTER VISION (3)

Prerequisite: 16:332:561.

A toolbox of advanced methods for computer vision, using robust estimation, clustering, probabilistic techniques, invariance. Applications include feature extraction, image segmentation, object recognition, and 3-D recovery.

16:332:571 (S) VIRTUAL REALITY TECHNOLOGY (3)

Prerequisite: 16:332:560.

Introduction to Virtual Reality. Input/Output tools. Computing architectures. Modeling. Virtual Reality programming. Human factors. Applications and future systems.

16:332:572 (S) PARALLEL AND DISTRIBUTED COMPUTING (3)

Prerequisite: 16:332:563, 16:332:564 and 16:332:566.

Study of the theory and practice of applied parallel/distributed computing. The course focuses on advanced topics in parallel computing including current and emerging architectures, programming models application development frameworks, runtime management, load-balancing and scheduling, as well as emerging areas such as autonomic computing, Grid computing, pervasive computing and sensor-based systems. A research-oriented course consisting of reading, reviewing and discussing papers, conducting literature surveys, and a final project**.**

16:332:573 (S) DATA STRUCTURES AND ALGORITHM (3)
The objective is to take graduate students in all graduate School of Engineering fields with a good undergraduate data structures and programming background and make them expert in programming the common algorithms and data structures, using the C and C++ programming languages. The students will perform laboratory exercises in programming the commonplace algorithms I C and C++. The students will also be exposed to computation models and computational complexity.

16:332:574 (F) COMPUTER-AIDED DIGITAL VLSI DESIGN (3)
Advanced computer-aided VLSI chip design, CMOS and technology, domino logic, pre-charged busses, case studies of chips, floor planning, layout synthesis, routing, compaction circuit extraction, multi-level circuit simulation, circuit modeling, fabrication processes and other computer-aided design tools.

16:332:575 (S) VLSI ARRAY PROCESSORS (3)
Prerequisite: 16:332:574
VLSI technology and algorithms; systolic and wavefront-array architecture; bit-serial pipelined architecture; DSP architecture; transputer; interconnection networks; wafer-cscale integration; neural networks.

16:332:576 (S) TESTING OF ULTRA LARGE SCALE CIRCUITS (3)
Prerequisite: 16:332:563.
Testing of Ultra Large Scale Integrated Circuits (of up to 50 million transistors) determines whether a manufactured circuit is defective. Algorithms for test-pattern generation for combinational, sequential, memory, and analog circuits. Design of circuits for easy testability. Design of built-in self-testing circuits.

16:332:577 (S) ANALOG AND LOW-POWER DIGITAL VLSI DESIGN (3)
Transistor design and chip layout of commonly-used analog circuits such as OPAMPS, A/D and D/A converters, sample-and-hold circuits, filters, modulators, phase-locked loops, and voltage-controlled oscillators. Low-power design techniques for VLSI digital circuits, and system-on-a-chip layout integration issues between analog and digital cores.

16:332:578 (S) DEEP SUBMICRON VLSI DESIGN (3)
Prerequisite: 14:332:574 CAD Digital VLSI Design
Advanced topics in deep submicron and nanotechnology VLSI design and fabrication. Logic and state machine design for high performance and low power. Tree adders and Booth multipliers. Memory design. Timing testing for crosswalk faults. Design economics. Emergining nanotechnology devices.

16:332:579 ADVANCED TOPICS IN COMPUTER ENGINEERING (3)
Prerequisite: Permission of instructor.
In-depth study of topics pertaining to computer engineering such as microprocessor system design; fault-tolerant computing; real-time system design. Subject areas may vary from year to year.

16:332:580 (F) ELECTRIC WAVES AND RADIATION (3)
Prerequisite: A course in elementary electromagnetics.
Static boundary value problems, dielectrics, wave equations, propagation in lossless and lossy media, boundary problems, waveguides and resonators, radiation fields, antenna patterns and parameters, arrays,

transmit-receive systems, antenna types.

16:332:581 (F) INTRODUCTION TO SOLID STATE ELECTRONICS (3)
Introduction to quantum mechanics; WKB method; perturbation theory; hydrogen atom; identical particles; chemical bonding; crystal structures; statistical mechanics; free-electron model; quantum theory of electrons in periodic lattices.

16:332:583 (F) SEMICONDUCTOR DEVICES I (3)
Charge transport, diffusion and drift current, injection, lifetime, recombination and generation processes, p-n junction devices, transient behavior, FET's, I-V, and frequency characteristics, MOS devices C-V, C-f and I-V characteristics, operation of bipolar transistors.

16:332:584 (S) SEMICONDUCTOR DEVICES II (3)
Prerequisite: 16:332:583.
Review of microwave devices, O and M-type devices, microwave diodes, Gunn, IMPATT, TRAPATT, etc., scattering parameters and microwave amplifiers, heterostructures and III-V compound based BJT's and FET's.

16:332:585 (S SUSTAINABLE ENERGY (3)
The course develops the necessary analysis tools to assess different technologies in terms of cost, Efficiency ad impact and uses them to assess all major non-renewable and renewable energy sources.

16:332:587 (F) TRANSISTOR CIRCUIT DESIGN (3)
Design of discrete transistor circuits; amplifiers for L.F., H.F., tuned and power applications biasing; computer-aided design; noise; switching applications; operational amplifiers; linear circuits.

16:332:588 (S) INTEGRATED TRANSISTOR CIRCUIT DESIGN (3)
Prerequisite: 16:332:587.
Design of digital integrated circuits based on NMOS, CMOS, bipolar BiCMOS and GaAs FETs; fabrication and modeling; analysis of saturating and non-saturating digital circuits, sequential logic circuits, semiconductor memories, gate arrays, PLA and GaAs LSI circuits.

16:332:589 (S) RF INTEGRATED CIRCUIT DESIGN (3)
Basic concepts in RF design, analysis of noise, transceiver architectures, analysis and design of RF integrated circuits for modern wireless communications systems: low noise amplifiers, mixers, oscillators, phase-locked loops.

16:332:591 (F) OPTOELECTRONICS I (3)
Prerequisites: 16:332:580, and 581 or 583.
Waveguides and optical filters, optical resonators, principles of laser action, light emitting diodes, semiconductor lasers, optical amplifiers, optical modulators and switches, photodetectors, wavelength-division-multiplexing and related optical devices.

16:332:592 (S) OPTOELECTRONICS II (3)
Prerequisite: 16:332:591.
Photonic crystals: photonic bandgap, photonic crystal surfaces, fabrication, cavities, lasers, modulators and switches, superprism devices for communications, sensing and nonlinear optics, channel drop filters; advanced quantum theory of lasers: Ferim's golden for laser transition, noise, quantum well lasers,

quantum cascade lasers. Nonlinear optics: parametric amplification, stimulated Raman/Brillouin scattering, Q-switching, mode-locked lasers.

16:332:594 (F) SOLAR CELLS (3)
Prerequisite: 16:332:583 or equivalent.
Photovoltaic material and devices, efficiency criteria, Schottky barrier, p-n diode, heterojunction and MOS devices, processing technology, concentrator systems, power system designs and storage.

16:332:597 (S) MATERIAL ASPECTS OF SEMICONDUCTORS (3)
Prerequisite: 16:332:581.
Preparation of elemental and compound semiconductors. Bulk crystal growth techniques. Epitaxial growth techniques. Impurities and defects and their incorporation. Characterization techniques to study the structural, electrical and optical properties.

16:332:599 ADVANCED TOPICS IN SOLID-STATE ELECTRONICS (3)
Prerequisite: Permission of instructor.
Semiconductor materials, surfaces and devices; opto-electronic devices; sensors; photovoltaics; fiber optics; and analog/digital circuit design. Subject areas may vary from year to year.

16:332:601, 602 SPECIAL PROBLEMS (BA, BA)
Prerequisite: Permission of instructor.
Investigation in selected areas of electrical engineering.

16:332:618 SEMINAR IN SYSTEMS ENGINEERING (1)
Presentation involving current research given by advanced students and invited speakers. Term papers required.

16:332:638 SEMINAR IN DIGITAL SIGNAL PROCESSING (1)
Presentation involving current research given by advanced students and invited speakers. Term papers required.

16:332:658 SEMINAR IN COMMUNICATIONS ENGINEERING (1)
Presentation involving current research given by advanced students and invited speakers. Term papers required.

16:332:678 SEMINAR IN COMPUTER ENGINEERING (1)
Presentation involving current research given by advanced students and invited speakers. Term papers required.

16:332:698 SEMINAR IN SOLID-STATE ELECTRONICS (1)
Presentation involving current research given by advanced students and invited speakers. Term papers required.

16:332:699 COLLOQUIUM IN ELECTRICAL & COMPUTER ENGINEERING (0)
Research presentations by distinguished lecturers.

16:332:701,702 RESEARCH IN ELECTRICAL ENGINEERING (BA, BA)
Research supervised by faculty in the Department of Electrical and Computer Engineering.
Typically 1 to 3 credits per semester.