RUTGERS
School of Engineering

ECE GRADUATE STUDENT HANDBOOK

September 29, 2022

Department of Electrical and Computer Engineering
94 Brett Road • Piscataway • New Jersey 08854-8058
Graduate Program in Electrical and Computer Engineering • (848) 445-2577

Website: www.ece.rutgers.edu

This handbook is subject to amendments by the ECE Graduate Program Office at any time. While students will be informed when an updated version of the handbook is available, it is the student's responsibility to make sure they are referring to the most recent version of the handbook for policies and procedures.

Any questions not covered in this handbook may be addressed to the ECE Graduate Program Coordinator, Electrical Engineering Building, Room 134B, Busch Campus, (848) 445-2577 (ECEGradInfo@gmail.com), or to the ECE Graduate Director, Electrical Engineering Building, Room 134A, Busch Campus, (848) 445-2577 (ECEGradDirector@soe.rutgers.edu). Formal consultations with the ECE Graduate Director are done during the weekly office hours and via email, while the Rutgers ECE Discord Server and Rutgers ECE Slack Workspace can be used for any informal discussion.

It is the policy of the Graduate Program in Electrical and Computer Engineering of Rutgers University–New Brunswick 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 the Department of Electrical and Computer Engineering (ECE) are broadly divided into six specialization areas:

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

This handbook clarifies the procedures used for admission into the **MS** and **PhD** programs within the department, describes the corresponding degree requirements in the six specialization areas as well as any additional subareas for the PhD students, and discusses the various **Graduate Certificates** within the department that are available to both matriculated (enrolled at Rutgers) and non-matriculated students.

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

2. Admission Requirements

Application Deadlines

- Deadlines for the MS applicants are *March 1* for fall term admission with funding considerations, *March 31* for fall term admission without funding considerations, and *October 1* for spring term admission.
- Deadlines for PhD applicants are *December 31* for fall term admission with full funding considerations, *March 1* for fall term admission with limited funding considerations, and *October 1* for spring term admission.

Admission decisions are made on rolling basis provided an application is submitted by the deadline. An online admissions application is available at http://gradstudy.rutgers.edu. Admission materials are also available from the Office of Graduate and Professional Admissions, 56 College Avenue, Rutgers University, New Brunswick, NJ 08901-8541, U.S.A.

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 School of Graduate Studies. All applicants must identify on their application material (personal statement and resume) at least one out of the six areas for graduate study in this department: (1) Communications, (2) Signal and Information Processing, (3) Systems and Controls, (4) Computer Engineering, (5) Software Engineering, and (6) Solid State Electronics.

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.

In addition, the Test of English as a Foreign Language (TOEFL) or IELTS (International English Language Testing System) test score is required of all foreign applicants whose native language is not English, unless the applicant had a minimum of three years of undergraduate studies or a master's degree with the mode of instruction being English. The TOEFL / IELTS scores must be current within 2 years of the semester the student is applying to. The minimum paper-based TOEFL score is 550. The minimum

computer-based TOEFL score is 213. The minimum IBT-internet based TOEFL is Writing 22, Speaking 23, Reading 21, and Listening 17. An acceptable IELTS score is bandwidth 7. Students who obtain a TOEFL / IELTS score below the minimum may be accepted in exceptional cases, but will be required to attend classes in the Program in American Language Studies (PALS).

2.1. MS Program

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

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

Students who do not meet the minimum GPA criterion listed above may be accepted into the MS program in cases of extenuating circumstances, such as severe personal or financial hardship, forced displacement, etc. Students within this category should detail the extenuating circumstances in their personal statement and provide evidence, ideally through their letters of recommendation, that they can handle the rigor of the Rutgers ECE MS program.

Students with bachelor's degrees in closely related areas such as Physics, Computer Science, Applied Mathematics, non ECE Engineering and Technology are also eligible for admission into the MS program provided they have outstanding GPAs.

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

Compared to applying to graduate school from outside of Rutgers, the application process and transition to the graduate program within Rutgers ECE is greatly simplified for bachelor's students currently enrolled in the department: *applicants do not need to pay admission application fees, are not required to write application essays, and may not need to obtain recommendation letters*. There are four parts to the BS/MS graduate application process.

1. **Credits and Coursework:** The student must complete the 123 credits required for the BS degree. The MS degree requires 30 credits. If one plans things carefully, one can finish the MS degree within one additional year.
    - The School of Graduate Studies (SGS) allows use of up to a maximum of 12 undergraduate credits (some at the 300 level, most at the 400 level) towards completion of the BS/MS program.
    - ***Credits counted towards the undergraduate degree (including for the residency requirement) cannot be counted towards the graduate degree***.
    - The School of Graduate Studies, as of Fall 2020, considers 120 credits as the number of credits required to earn the bachelor's degree, which means that credits over 120 are eligible to be transferred to the master's degree after a formal approval from the ECE Graduate Director.

2. **Basic Application:** All applicants should complete the first 3 pages/sections of the Graduate School application, which may be found at: https://rutgers.force.com/ApplicantPortal/AppPortalCustom, and save it as a PDF.

3. **Send Application, Transcripts, and Specialization Area:** Send a copy of your electronic transcripts along with your PDF application and intended specialization area (see Section 3.1. Course Requirements) to the ECE Graduate Program Coordinator (ecegradinfo@gmail.com). (*Note:* The area of specialization can be changed with the approval of the ECE Graduate Program Director.)

4. **Letters of Recommendation:**
   - If a student's GPA is > 3.7, they can become eligible for TA/GA/Fellowship support by getting two (2) letters of recommendation.
   - If a student's GPA is between 3.2 and 3.7, they do not need recommendation letters but will not be considered for TA/GA support.
   - If a student's GPA is between 3.0 and 3.2, they will need one (1) *strong* recommendation from a Rutgers faculty to be admitted to the MS program.
   - If a student's GPA is between 2.8 and 3.0, they will need two (2) *strong* recommendations from Rutgers faculty to be admitted to the MS program.
   - If a student's GPA is lower than 2.8, it is unlikely that they will be admitted to the MS program.

Important Dates:
- **Middle of November of the senior year:** start of the application process.
- **End of December:** initial admission decisions are made.
- **January - August:** continuous review based on grades earned.

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

(a) Thesis option: 24 credits of course work, 6 credits of Research in ECE, plus the master's thesis (p. 14).
(b) Non-thesis option: 30 credits of course work plus the master's technical paper (p. 14).

2.3. PhD Program

The requirements for admission into the PhD degree program are:

1. A bachelor's degree in Electrical and/or Computer Engineering or a comparable program with a minimum grade point average (GPA) of 3.5 on a 4.0-point scale for *direct* PhD admission **OR** a master's degree in Electrical and/or Computer Engineering or a comparable program with a minimum GPA of 3.5 on a 4.0-point scale and an undergraduate GPA of 3.0 or better.
2. Three letters of recommendation.

Students who do not meet the minimum GPA criterion listed above may be accepted into the PhD program in cases of extenuating circumstances, such as severe personal or financial hardship, forced displacement, etc. Students within this category should detail the extenuating circumstances in their personal statement and provide evidence, ideally through their letters of recommendation, that they can handle the rigor of the Rutgers ECE PhD program.

Students with bachelor's and/or master's degrees in closely related areas such as Physics, Computer Science, Applied Mathematics, non ECE Engineering and Technology are also eligible for admission into the PhD program provided they have outstanding GPAs.

Students who have completed the MS degree requirements at Rutgers and wish to continue for the PhD must meet the 3.5 GPA requirement and submit a *change of status* form to the ECE Graduate Director for approval.

2.4. Non-Degree Students

Qualified **US Citizens or Permanent Residents** may apply to the Electrical and Computer Engineering graduate program for nonmatriculated (nondegree) status. Applicants must have academic credentials that are comparable to those required for regular admission. Transcripts are *required*. The **application materials must be submitted** via the School of Graduate Studies admissions website at http://gradstudy.rutgers.edu for the Non-degree Graduate Study program in ECE.

The course schedules of nonmatriculated students *must be approved* by the ECE 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 the regular degree students. The ECE Graduate Program Coordinator can provide more information to the interested students.

3. MS Degree Requirements

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

- **Thesis Option:** This option requires the candidate to complete 24 credits of course work with a minimum grade point average (GPA) of 3.0, 6 credits of research leading to a **master's thesis** (p. 14), and the final defense of the thesis.
- **Non-thesis Option:** In the non-thesis program, the candidate must complete 30 credits of course work with a minimum grade point average (GPA) of 3.0, and write a **Technical Paper** (p. 14) that must be approved by at least three members of the ECE Graduate Faculty.

3.1. Course Requirements

Specialization Area: All MS students should declare their intent to specialize in one of the following areas: (1) Communications, (2) Signal and Information Processing, (3) Systems and Controls, (4) Computer Engineering, (5) Software Engineering, and (6) Solid State Electronics.

The department also encourages **cross-disciplinary specializations**; students whose interests cut across these specialization areas should consult with their thesis advisor (if applicable) and the Graduate Director to chart out a coherent study plan and seek a formal approval for the proposed cross-disciplinary specialization from the Graduate Director *before* registering for the proposed coursework.

Colloquium (0 credits): All MS Students are required to take 2 semesters of 16:332:699—Colloquium in Electrical and Computer Engineering (attendance is taken). In order to be graded "Satisfactory," a student must attend 80% of the colloquia.

Coursework: The coursework for the MS program in each specialization area has been divided into *three* categories: (1) **core courses**, (2) **elective courses**, and (3) **breadth courses**.

- **General Policy:** Unless a student is pursuing an approved cross-disciplinary specialization

coursework, the core and elective courses *must be* from the respective lists of core and elective courses provided below for each specialization area.
    - Students can petition the Graduate Director to replace one or more of the core and/or elective courses in a specialization area with an unlisted course; such petitions should be accompanied with a rationale for the replacement and, if applicable, a note from one's thesis advisor.

- **Core Courses:** Unless specified otherwise below for a specialization area, students must take *at least* 3 courses from the list of core courses for their respective specialization.
- **Breadth Courses:** Unless specified otherwise below for a specialization area, the breadth courses can be any Rutgers graduate course, including from other departments.

ECE Residency Requirement: *At least 15 credits for the thesis option and 21 credits for the non-thesis option must be fulfilled by:*

- ECE graduate courses listed within the respective lists of core and elective courses for students focusing on one of the six specialization areas.
- Relevant ECE graduate courses for students focusing on a cross-disciplinary specialization.

General policy for online courses: Online courses taken outside of the ECE and short courses (winter break, spring break, two-week courses) cannot be used to satisfy the course requirements for the MS degree. Up to four Rutgers University ECE online courses (up to 12 credits) may be used to satisfy the MS degree course requirements.

Exception to the online course policy: An exception to the general online course policy has been made for online ECE (or other approved program) graduate courses taken during the semesters of Spring 2020, Fall 2020, Spring 2021, Fall 2021, and Spring 2022 due to the COVID-19 pandemic. Any approved online courses taken during any of these listed semesters may be attributed towards the MS degree course requirements.

The following sections provide a listing of the core and elective courses in each specialization area, along with any additional course requirements for each area.

3.1.1. Communications

Core 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

Elective courses:

332:501	System Analysis
332:505	Control System Theory
332:506	Applied Controls
332:521	Digital Signals and Filters

332:525 Optimum Signal Processing
332:559 Advanced Topics in Communications Engineering
332:601 Special Problems *(provided it is not taken as part of the CPT; 6 credits limit)*
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. Signal and Information Processing

Core 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

Elective courses:

332:501 System Analysis
332:505 Control System Theory
332:506 Applied Controls
332:539 Advanced Topics in Digital Signal Processing
332:565 Neurocomputer Systems Design
332:579 Advanced Topics in Computer Engineering *(only topics relevant to the area will count; consult the Graduate Director before registering)*
332:601 Special Problems *(provided it is not taken as part of the CPT; ; 6 credits limit)*
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

3.1.3. Systems and Controls

Core courses: ***At least 2 courses****

332:501 System Analysis
332:505 Control System Theory
332:506 Applied Controls

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
332:539 Advanced Topics in Digital Signal Processing
332:541 Stochastic Signals and Systems
332:545 Digital Communication Systems
332:563 Computer Architecture I
332:601 Special Problems *(provided it is not taken as part of the CPT; 6 credits limit)*
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

3.1.4. Computer Engineering

I. Students taking the THESIS option must take:
   a. At least 3 core courses, one of which *must* be a **core Math course**
   b. At least 3 elective courses

II. Students taking the NON-THESIS option must take:
   a. At least 3 core courses, one of which *must* be a **core Math course**
   b. At least 4 elective courses

Core courses:

332:563 Computer Architecture I
332:573 Data Structures and Algorithms
198:513 Design and Analysis of Data Structures and Algorithms

— One **required** core Math course

Core Math courses (choose one):

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

Elective 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
332:601	Special Problems *(provided it is not taken as part of the CPT; 6 credits limit)*
198:515	Programming Languages and Compilers
198:519	Operating Systems

3.1.5. Software Engineering

I. Students taking the THESIS option must take:
   a. At least 3 elective courses, which can include up to 2 elective courses from the "external" elective list

II. Students taking the NON-THESIS option must take:
   a. At least 5 elective courses, which can include up to 3 elective courses from the "external" elective list

Additionally, if any of the following undergraduate courses are missing in the student's undergraduate

transcripts, **they must also be made up**:

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

Core courses:

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

Elective courses:

332:503 Programming Finance
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 *(only topics relevant to the area will count; consult the Graduate Director before registering)*
332:601 Special Problems *(provided it is not taken as part of the CPT)*

External elective courses:

137:560 Introduction to Systems Engineering for Engineering Management
137:602 Enterprise Software Architecture
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

3.1.6. Solid State Electronics

Core 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

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
332:599	Advanced Topics in Solid-State Electronics
332:601	Special Problems *(provided it is not taken as part of the CPT; 6 credits limit)*
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

3.2. Master's Thesis

Students writing a master's thesis must choose a thesis advisor who will supervise their research project. In consultation with the ECE Graduate Director, a thesis committee will be appointed consisting of at least *three* members, including the thesis advisor who will chair the committee. The thesis defense must be announced and is open to the public. *Teleconferencing* is permitted with the presentation being held at Rutgers University. No more than two committee members may participate via teleconferencing.

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 ECE Graduate Director. Substitutions in the committee membership may be made only by the ECE 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 ECE 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 ECE Graduate Director along with the degree candidacy form after successfully defending the thesis.

If a student fails their final thesis defense examination, the student will be allowed one more attempt to rewrite and defend the thesis. Alternatively, at the recommendation of their committee, the student may switch to the non-thesis option, take additional courses to increase their course credits to 30, and write the MS Technical Paper. Failure to pass the repeated thesis examinations will result in a recommendation for dismissal from the Electrical and Computer Engineering Graduate Program.

3.3. MS Technical Paper

The MS Technical Paper constitutes a substitution for the Master Comprehensive Examination required by the Rutgers School of Graduate Studies (SGS) and needs to be completed by all students pursuing the non-thesis MS degree within the department.

Non-thesis option students should start working on their Master Technical Paper sooner, rather than later, in their studies to avoid any unnecessary delays in graduation. 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's advisor serves as the *Lead Reader / Faculty Evaluator / Committee Chairperson* for the paper. The student and advisor select the additional two members of the ECE graduate faculty who will serve as readers of the technical paper. 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 their technical paper.

A general approach to writing a successful technical paper is to expand on one's work as part of course term papers, course projects, or research from Special Problems courses. The course instructor in such instances often serves as the advisor for the technical paper, and the student finds two additional graduate faculty members as readers to go over the technical paper once completed and approved by the course instructor / advisor.

It is highly recommended that the students finalize the members of their technical paper reading committee within the first few weeks of the semester in which they intend to graduate, as faculty members are often unable to take on more reading committee memberships in the latter part of a semester.

Additional Guidelines and Frequently Asked Questions for the MS Technical Paper

It is recommended that the non-thesis option students use some variant of the following template when requesting two additional faculty members to be a part of the reading committee for the technical paper that is based on prior coursework.

> Dear Professor [LAST NAME],
>
> I am writing to request you to be a reader on my MS Technical Paper reading committee for my technical paper titled [TITLE OF PAPER].
>
> The paper is about [SHORT DESCRIPTION OF THE TOPIC]. It is based off a term project that I completed as part of [COURSE NUMBER AND NAME] taught by Professor [LAST NAME], who [HAS/HAS NOT] reviewed the paper and has agreed to approve it as part of my requirements for the MS non-thesis option degree.
>
> I am wondering if you would be able to serve as another reviewer for the paper?
>
> The deadline for approval of the technical paper in order for me to graduate is [DATE]. This should give you [NUMBER] days to read and suggest revisions in case I need to make them.
>
> I hope you will be able to help me with this key requirement for my MS degree.
>
> Thank you,
> [YOUR NAME]

FAQs for the MS Technical Paper

Q: Who should I ask first to approve of my technical paper?

A: If you have written a technical report for a course and gotten a B or above in the course, you should ask the instructor for that class if they think you can use it for your technical paper. If they agree, you should ask them if any revisions are necessary before they will approve it.

Q: To whom should I send this email?

A: If the course instructor has agreed to approve your technical report, then you can ask them to recommend other faculty who might have the expertise to read the paper. You may also know of other faculty who work in the same general area and would have the expertise to review the paper. Please **DO NOT** email every faculty member in the department with the request to be a reader of your paper.

Q: What if my course project was a group project?

A: You may be able to expand on some parts of your group project (for example, the parts that you did) into a standalone technical paper for yourself. You can contact the professor for the class to see what would be appropriate.

3.4. Candidacy Forms and 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 ECE Graduate Director for verification of credits and grades, and then submitted to the School of Graduate Studies. Upon completion of either Master Thesis or MS Technical Paper and collection of all required signatures, the form must be submitted to the School of Graduate Studies per the instructions on the back of the degree candidacy form. Please refer to the dates included on the SGS website for exact deadlines in each semester: https://grad.rutgers.edu/academics/graduation

The Diploma Application is available online from the Registrar's office (http://registrar.rutgers.edu) and it must be filed according to the schedule provided by their office.

3.5. Checklist for the MS Degree – Thesis Option

Thesis Format Guide: You may obtain a style guide for your thesis online from the School of Graduate Studies (https://grad.rutgers.edu), or pick up print copies from either SGS (25 Bishop Place) or the ECE Graduate Program Coordinator. The guide 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@grad.rutgers.edu.

Candidacy Form and Thesis

1. You must make sure to adhere to the deadlines for graduation in each semester, as listed on the SGS website: https://grad.rutgers.edu/academics/graduation.
2. The candidacy form should be picked up (downloaded) either from the School of Graduate Studies (https://grad.rutgers.edu) or from the Electrical and Computer Engineering Graduate Program Coordinator in the Electrical Engineering Building prior to the thesis defense.
3. Complete the form and **have the ECE Graduate Director sign** the front of the form. The ECE Graduate Program Coordinator will verify credits and grades.
4. Have members of the thesis committee sign the form on the back **(Section A and Section C)**, as well as the title page. Please note that the committee must sign the Comprehensive Exam section (Section C). The ECE Graduate Director must also sign the back of the candidacy form at this time **(Section E)**.
5. Submit **a PDF** copy of the final version of the thesis with signed copy (PDF) of the title page to the ECE Graduate Director along with the candidacy form signed by the thesis committee.

6. Submit the thesis electronically (https://edt.libraries.rutgers.edu/login.php) to the School of Graduate Studies. Additionally, submit **one** original title page with the original signatures (**in black ink**) as well as the candidacy form. **Three** additional signed (photocopies are acceptable) title pages, and **three** additional abstracts are also required.

Diploma Application Form

1. The diploma application form as well as the associated submission schedule is available online from the Registrar's office: 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.

Please be sure that you are consistent in the use of your name on the diploma application, and title page of your thesis. Your name should be the same on the title page and the diploma application.

3.6. Checklist for the MS Degree – Non-Thesis Option

Candidacy Form

1. You must make sure to adhere to the deadlines for graduation in each semester, as listed on the SGS website: https://grad.rutgers.edu/academics/graduation.
2. The candidacy form should be picked up (downloaded) either from the School of Graduate Studies (https://grad.rutgers.edu) or from the Electrical and Computer Engineering Graduate Program Coordinator in the Electrical Engineering Building.
3. Complete the form and **request** the ECE Graduate Program Coordinator to verify credits and grades.
4. Have the **three** members of the technical paper reading committee sign the form on the back **(Section B and Section C)**. The ECE Graduate Director must sign the back of the candidacy form at this time **(Section E)**.

Diploma Application Form

1. The diploma application form as well as the associated submission schedule is available online from the Registrar's office: 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.

4. PhD Degree Requirements

Credit Requirements: The PhD degree requires completing a total of at least 72 credits with a minimum grade point average (GPA) of 3.5. The credit requirements for the PhD degree must consist of at least 36 credits of graduate coursework, 24 credits of research leading to the PhD dissertation, and an additional 12 credits that may come from either coursework or research.

Specialization Area: All PhD students should declare their intent to specialize in one of the following areas: (1) Communications, (2) Networking, (3) Signal and Information Processing, (4) Computational Sensing, (5) Systems and Controls, (6) Computer Engineering, (7) Software Engineering, (8) Cybersecurity, and (9) Solid State Electronics.

The department also encourages **cross-disciplinary specializations**; students whose interests cut across these specialization areas should consult with their thesis advisor to chart out a coherent coursework and PhD qualification exam plan, and then seek a formal approval for the proposed cross-disciplinary specialization from the Graduate Director.
Colloquium (0 credits): All PhD Students are required to take 4 semesters of 16:332:699—Colloquium in Electrical and Computer Engineering (attendance is taken). In order to be graded "Satisfactory," a student must attend 80% of the colloquia.

PhD Qualifying Examination: The purpose of the PhD qualifying examination is to assess the student's creative ability, depth of knowledge, and potential for independent research. Students may take the qualifying exam **only twice**. A student who has been admitted to the PhD program must pass the PhD qualifying exam, with the first attempt *no later* than the **first three years** of entering the PhD program and the second attempt within one year of the first one. Failure to pass the exam in two attempts will result in a recommendation for dismissal from the PhD program. Students not yet admitted into the PhD program may take the qualifying exam provided they meet the minimum GPA and course requirements for the qualifying exam, listed on p. 18.

Students who pass the PhD qualifying examination should complete the **PhD Candidacy form**, and get the signatures of the four faculty examiners and the ECE Graduate Director. The form must be submitted to the School of Graduate Studies for the change of status from a pre-qualifying to a post-qualifying doctoral student.

Change of Status from MS to PhD: Students initially admitted into the MS program who decide to continue beyond the MS degree and pursue a PhD degree must submit a Change of Status form, and must adhere to the GPA requirements of the PhD degree.

English Proficiency: There are no foreign language requirements for the PhD degree in the ECE department; however, a student must demonstrate proficiency in English.

4.1. PhD Qualifying Examination

Goal: The PhD qualifying exam is a constructive component in the development of a student's research skills, while it uses the coursework requirements to distinguish between potential doctoral students and master students.

Exam Structure: The PhD qualifying exam has two parts: I) Minimum GPA requirement on selected courses for each specialization area, and II) Research potential assessment.

Part I. Minimum GPA and 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 of the nine specialization areas in the department (Communications, Networking, Signal and Information Processing, Computational Sensing, Systems and Controls, Computer Engineering, Software Engineering, Cybersecurity, and Solid State Electronics) has its own list of "core courses" and mathematics/physics/statistics courses; these lists are available in the handbook starting from p. 20.

Part II. Research Potential Assessment Oral Qualifier

Following completion of the GPA and course requirements for one's specialization area, a PhD student becomes eligible to take the research potential assessment examination. In this exam, the student prepares a written report and makes a 45-minute oral presentation of their own independent research to a PhD Qualifying Committee. The oral presentation is 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 specialization area.

The PhD Qualifying Oral Exam is offered once per semester during a two-week period (the latter-half of October and the latter-half of March) and any time during the summer. The oral exam is administrated by two faculty members (at least one of them must be an ECE graduate faculty), with the student's advisor and the ECE Graduate Director serving as two additional committee members, for a total of four members on the committee. The student needs to receive unconditional approval of the two committee members administrating the exam to pass the exam, with the advisor and the ECE Graduate Director endorsing the decision of the two members.

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 MS thesis in preparation or a 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 course in the second year with an ECE graduate faculty in student's research area of interest).

Note that unlike the PhD thesis proposal defense, the qualifying oral examination occurs in the early stages of research and the presented paper need not lead to a PhD 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.

Summarization of the Policies for the PhD Qualifying Examination

- The exam must be taken within three years from the time the student starts the PhD Program.
- The student is allowed two attempts to pass the PhD Qualifying Exam. The second attempt must be taken within one year of the first attempt.
- The PhD Qualifying Oral Exam is offered once per semester during a two-week period (the latter-half of October and the latter-half of March) and any time during the summer.
- The student must apply to the ECE Graduate Director to take the PhD Qualifying Exam. In this application, the student selects the research specialization area for the exam and identifies how the core course requirements for that area have been met. The application form can be obtained online from the department at https://www.ece.rutgers.edu.

- The written paper/thesis/report to accompany the oral presentation must be submitted to the ECE Graduate Director with the application.
- Based on the subject matter of the submitted written paper/thesis/report and the student's selected research specialization area, the examination committee is chosen by the ECE Graduate Director in consultation with the student and their advisor. The committee must be composed of *at least* three ECE Graduate Program faculty, with two of the committee members being the student's advisor and the ECE Graduate Director.
- Upon finalization of the examination committee, the ECE Graduate Office emails the exam paper and the PhD Qualifying Exam Evaluation Form to the committee members.
- The PhD Qualifying Exam Committee returns the Evaluation Form to the ECE Graduate Office upon the completion of the oral exam with their pass/conditional pass/fail recommendation and detailed comments.
- The student who passes the qualifying exam is required to complete the School of Graduate Studies Qualifying Examination form, provided to them by the ECE Graduate Program Coordinator. The student should obtain four signatures (from each of the PhD Qualifying Exam Committee members) on page 2 and then an additional signature from the ECE Graduate Director on page 2 of the form.
- When all signatures have been obtained on the Qualifying Examination Form, the student must submit the Form to the School of Graduate Studies per the instructions included on the bottom of page 2 of the form and their status will be changed from pre-qualified to post-qualified doctoral student.

4.1.1. Core Course Requirements

This section lists the core courses for each of the pre-approved research specialization areas in the department (Communications, Networking, Signal and Information Processing, Computational Sensing, Systems and Controls, Computer Engineering, Software Engineering, Cybersecurity, and Solid State Electronics). Students wishing to replace one or more of these courses with alternative courses ***OR*** *wishing to pursue a cross-disciplinary specialization area should first consult with their advisor and then petition the ECE Graduate Director with a detailed rationale.*

COMMUNICATIONS

Faculty Members: Waheed U. Bajwa, Yingying Chen, Salim El Rouayheb, Gerard J. Foschini, Richard Frenkiel, Zoran Gajic, Narayan Mandayam, Rich Martin, Athina Petropulu, Dario Pompili, Anand D. Sarwate, Emina Soljanin, Predrag Spasojevic, Wade Trappe, Chung-Tse Michael Wu, Roy 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

NETWORKING

Faculty Members: Yingying Chen, Marco Gruteser, Narayan Mandayam, Ivan Marsic, Athina Petropulu, Dario Pompili, Dipankar Raychaudhuri, Anand D. Sarwate, Predrag Spasojevic, Wade Trappe, Roy Yates, Yanyong Zhang, Yuqian 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

SIGNAL AND INFORMATION PROCESSING

Faculty Members: Waheed U. Bajwa, Kristin Dana, David J. Foran, Ilker Hacihaliloglu, Stephen J. Hanson, Richard Mammone, Peter Mee, Laleh Najafizadeh, Sophocles Orfanidis, Athina Petropulu, Vishal M. Patel, Anand D. Sarwate

Core courses:

332:509 Convex Optimization
332:521 Digital Signals and Filters
332:527 Digital Speech Processing
332:539 Advanced Topics in DSP (Deep Learning, Biometrics)
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

SYSTEMS AND CONTROLS

Faculty Members: Haim Baruh, Zoran Gajic, John K-J. Li, Sophocles Orfanidis, John McGarvey, George K. Shoane, Eduardo D. Sontag, Sumati Sehajpa, Jingang Yi, Qingze Zou

Core courses:

332:501 System Analysis
332:505 Control System Theory
332:506 Applied Controls
332:509 Convex Optimization for Engineering Applications
332:510 Optimal Control Systems
332:512 Nonlinear and Adaptive Control
332:519 Advanced Topics in Systems Engineering
(Kalman Filtering, Game theory, Energy Systems, Information Security)
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

COMPUTATIONAL SENSING

Faculty Members: Waheed U. Bajwa, Kristin Dana, Athina Petropulu, Dario Pompili, Peter Mee, Anand D. Sarwate, Wade Trappe, Roy 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; Deep Learning; Biometrics; Deep Learning for Biometrics)
332:579 Advanced Topics in Computer Engineering
(Cyber-Physical Systems; High-Performance Distributed Computing; Cloud Computing; Computing Principles for Mobile Embedded Systems; Malware Analysis and Reverse

Engineering; Embedded Systems II: Application Development; Intro to Computer Systems; Applied Parallel Computing; Foundations of Cyber-Physical Systems; Into to Quantum Information Science; Hardware and System Security; Embedded Systems III; Biomedical Tech Design and Development; Introduction to Deep Learning)

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: Grigore Burdea, Yingying Chen, Kristin Dana, Maryam Mehri Dehnavi, Marco Gruteser, Shantenu Jha, Janne Lindqvist, Ivan Marsic, Jorge Ortiz, Ivan Rodero, Manish Parashar, Dario Pompili, Deborah Silver, Shen Wei, Bo Yuan, Yanyong Zhang, Yuqian 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
332:573 Data Structure and Algorithms
332:566 Introduction to Parallel & Distributed Computing
332:543 Communication Networks I

Must take one course from the following 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; Computing Principles for Mobile Embedded Systems; Malware Analysis and Reverse Engineering; Embedded Systems II: Application Development; Intro to Computer Systems; Applied Parallel Computing; Foundations of Cyber-Physical Systems; Into to Quantum Information Science; Hardware and System Security; Embedded Systems III; Biomedical Tech Design and Development; Introduction to Deep Learning)

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

SOFTWARE ENGINEERING

Faculty Members: Marco Gruteser, Shantenu Jha, Janne Lindqvist, Ivan Marsic, Deborah Silver, Yanyong Zhang, Saman Zonouz

Core courses:

332:563 Computer Architecture
332:567 Software Engineering
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
(Advanced Topics in Computer Engineering (Cyber-Physical Systems; High-Performance Distributed Computing; Cloud Computing; Computing Principles for Mobile Embedded Systems; Malware Analysis and Reverse Engineering; Embedded Systems II: Application Development; Intro to Computer Systems; Applied Parallel Computing; Foundations of Cyber-Physical Systems; Into to Quantum Information Science; Hardware and System Security; Embedded Systems III; Biomedical Tech Design and Development; Introduction to Deep Learning)

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

CYBERSECURITY

Faculty Members: Yingying Chen, Salim El Rouayheb, Marco Gruteser, Janne Lindqvist, Jorge Ortiz, Athina Petropulu, Anand D. Sarwate, Wade Trappe, Shen Wei, Yanyong Zhang, Yuqian Zhang, Saman Zonouz

Core courses:
332:507 Security Engineering
332:542 Information Theory and Coding
332:544 Communication Networks II
332:567 Software Engineering
332:573 Data Structures & Algorithms
332:519 Advanced Topics in Systems Engineering (Network security)
332:579 Advanced Topics in Computer Engineering
(Cyber-Physical Systems; High- Performance Distributed Computing; Cloud Computing; Computing Principles for Mobile Embedded Systems; Malware Analysis and Reverse Engineering; Embedded Systems II: Application Development; Intro to Computer Systems; Applied Parallel Computing; Foundations of Cyber-Physical Systems; Into to Quantum Information Science; Hardware and System Security; Embedded Systems III; Biomedical Tech Design and Development; Introduction to Deep Learning)
198:544 Computer Security
198:596 Introduction to Cryptography

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

SOLID STATE ELECTRONICS

Faculty Members: Michael Caggiano, Sang-Wook Cheong, Manish Chhowalla, Leonard Feldman, Hana Godrich, Umer Hassan, Mehdi Javanmard, Jaeseok Jeon, Yicheng Lu, Sigrid McAfee, John McGarvey, Laleh Najafizadeh, Seongshik Oh, Sumati Sehajpal, Chung-Tse Michael Wu, Jian 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; Wearable and Implantable Electronic Systems; Microelectronic Processing; Microgrid Concepts and Distributed Generation Technology; Smart Grid: Fundamental Elements of Design)

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. PhD 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 ECE 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. A **recommended timeframe**, *though not required,* for the PhD proposal is between the seventh and tenth semester of a student entering the PhD program.

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 School of Graduate Studies may attend.

The student should provide each member of their committee and the ECE 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 research work can be successfully undertaken. The format of the proposal should follow that of the dissertation guidelines provided by the School of Graduate Studies on their website.

4.2.1. PhD Proposal Presentation Procedure

1. The PhD Proposal Presentation process starts with the student's **advisor** informing the ECE

Graduate Program Office that the student is ready to present their proposal, and providing the list of **at least four** (at least three ECE Graduate Program members including the advisor) committee members. The committee may include one or two "outside ECE Graduate Program" members. The outside committee members are appointed by the ECE Graduate Director in consultation with the student's advisor.

2. Next, the student must select a time and place of the proposal presentation in consultation with their proposal committee, and then provide to the ECE Graduate Program Office a copy of the proposal abstract at least **three weeks** before the presentation. The Graduate Program Office then announces the proposal presentation to the ECE Graduate Faculty.
3. The student must also provide to the members of the committee as well as the ECE Graduate Program Office a draft of the PhD proposal at least **two weeks** before the proposal presentation.
4. For a successful proposal presentation only one non-approval is permitted. A student is given **two** chances to successfully present their PhD proposal.
5. *Teleconferencing* is permitted with the proposal presentation being held at Rutgers University. **No more than two committee members** may participate via teleconferencing.
6. The proposal presentation is closed to the public (Rutgers University regulation). Members of the ECE Graduate Faculty, however, are allowed to attend the proposal presentation and/or examine the proposal.

4.3. PhD 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 ECE graduate faculty, and an **outside member**, is selected by the student and the thesis advisor, in consultation with the ECE Graduate Director. **At least two** faculty members of the dissertation committee must be Rutgers University ECE regular (core) faculty. If the outside member of the committee is from **outside the University**, a CV is required by the ECE Graduate Program Office so that formal permission can be obtained from the School of Graduate Studies for their membership in the committee.

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.

Substitutions in the committee membership may be made only by the ECE 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 School Graduate Studies.

The PhD dissertation should be submitted to the dissertation committee and the ECE Graduate Program Office at least **three 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. No more than two committee members may participate via teleconferencing.

The dissertation advisor and all but one of the other committee members must approve the dissertation 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 a resolution of the differences is not possible, the dissertation must be judged unsatisfactory. Appeals may be referred to the Dean of the School of

Graduate Studies. The committee members must sign the student's PhD candidacy form and the title page of the dissertation 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 School of Graduate Studies and copies sent to the ECE Graduate Director, the other committee members, and to the student.

A **final version of the dissertation** in unbound format must be submitted to the ECE Graduate Program Office along with the degree candidacy form after successfully defending the dissertation. After the final signature from the ECE Graduate Director has been obtained on the candidacy form, the candidacy form and the dissertation must be submitted by the student to the School of Graduate Studies (See Section 4.4 on p. 27).

4.4. Checklist for the PhD Degree

Dissertation Format Guide: You may obtain a style guide for the dissertation online from the School of Graduate Studies (https://grad.rutgers.edu), or pick up print copies from either SGS (25 Bishop Place) or the ECE Graduate Program Coordinator. The guide 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@grad.rutgers.edu.

Candidacy Form and Dissertation

1. You must make sure to adhere to the deadlines for graduation in each semester, as listed on the SGS website: https://grad.rutgers.edu/academics/graduation.
2. The candidacy form should be picked up (downloaded) either from the School of Graduate Studies (https://grad.rutgers.edu) or from the Electrical and Computer Engineering Graduate Program Coordinator in the Electrical Engineering Building prior to the dissertation defense.
3. The student should also pick from the SGS and the Graduate Program Office other relevant forms at this time for completion (e.g., payment fee, microfilming, survey, questionnaires, etc.).
4. Take the candidacy form to your dissertation defense and have your committee members and the ECE Graduate Program Director **sign page 2**. The committee members should also sign the **title page** of your dissertation.
5. Submit **a PDF** copy of the final version of the dissertation with signed PDF copy of the title page to the ECE Graduate Director along with the candidacy form signed by the dissertation committee.
6. Submit the dissertation electronically (https://edt.libraries.rutgers.edu/login.php) to the School of Graduate Studies. Additionally, submit **one** original title page with the original signatures (**in black ink**) as well as the candidacy form and any other forms required by the SGS. **Three** additional signed (photocopies are acceptable) title pages and **three** additional abstracts are also required to be submitted.

Diploma Application Form

1. The diploma application form as well as the associated submission schedule is available online from the Registrar's office: 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.

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. Transfer of Credits

MS Degree: A maximum of 12 course credits *may be* transferred towards the MS degree.

PhD Degree: A maximum of 24 course credits *may be* transferred towards the PhD degree. These credits are normally transferred from the student's MS degree**.**

Requirements: Credits my not be transferred from other institutions until **9 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) cannot be used to satisfy the course requirements for any degree and therefore such courses can be transferred.

Procedure for Transfer of Credits: Application forms for the transfer of credits are available from the ECE Graduate Program Coordinator. The forms are to be submitted to the ECE Graduate Director for approval and then to the School of Graduate Studies for final approval. They must be accompanied by:

- Student's official transcripts, both from the transferring program and Rutgers
- Catalog descriptions and/or syllabi, **including** the texts used in the courses

6. Graduate Certificate Program

6.1. Cybersecurity in Electrical and Computer Engineering CERTIFICATE

6.1.1. Learning Outcome

Students enrolled in this certificate program will learn about techniques, software development, and devices used to secure the cyber system, including how to secure information processed and communicated by the cyber system, and in general how to secure communication links in the cyber-physical system. These techniques will be enhanced from the point of views of communication networks and wireless communications, courses regularly taught in the ECE Graduate Program.

6.1.2. Admission Requirements

Matriculated students: Graduate students (MS or PhD) from ECE Department or related departments, such as Computer Science, Mechanical Engineering, Biomedical Engineering, do not need to apply separately. Interested students should contact the ECE Graduate Program Office and submit a copy of their transcript and a letter of recommendation. The certificate will be administered by the ECE. Documents indicating the completion of the certificate are handled by the Senior Administrator for Degree Certification at SGS.

Non-matriculated students: Applicants should complete the usual application process in the School of Graduate Studies application. Applicants need to upload the necessary documents, including transcripts and one letter of recommendation. Applicants should have completed a bachelor's degree in ECE, CS, or a closely related field.

6.1.3. Credit Requirements

The certificate will be awarded to all non-degree and degree ECE MS or PhD graduate students who complete four courses (12 credits) in the certificate program with a GPA of at least 3.0.

6.1.4. Curriculum

The following courses relevant to the Cybersecurity in Electrical and Computer Engineering Certificate are the regular (SGS approved) courses in the Electrical and Computer Engineering Graduate Program:

332:501 System Analysis
332:507 Security Engineering
332:543 Communication Networks I
332:544 Communication Networks II
332:548 Error Control Coding
332:561 Machine Vision

Several additional Electrical and Computer Engineering courses are also relevant to the cybersecurity certificate. The complete list of such courses can be found in the SGS catalogue and in this handbook.

Among Advanced Topics Classes: (332:519 Advanced Topics in Systems Engineering, 332:559 Advanced Topics in Communications, and 332:579 Advanced Topics in Computer Engineering), the ECE Department has taught in the past few years the following courses relevant to this certificate:

332:519 Information and Network Security
332:579 Hardware and System Security
332:579 Malware Analysis and Reverse Engineering
332:579 Computing Principles of Mobile Embedded Systems
332:579 Foundations of Cyber-Physical Systems

6.1.5. Mode of Delivery (Classroom Instruction/Hybrid/Distance Education)

The primary mode of instruction will be long-distance learning. The online courses will be offered through Canvas. Students may also take regularly offered in-person ECE graduate courses to satisfy the certificate requirement. Students will be given an option to take any four courses from the aforementioned list of courses, relevant to cybersecurity in electrical and computer engineering, with at least six courses being offered online. Non-degree students enrolled in this certificate program have an option to complete this certificate fully on-line. In-person courses will also be available to non-degree students. Regular MS and PhD students may satisfy the certificate requirement by taking all in-person courses. On-line courses will also be permitted for regular MS and Ph. D. students.

6.2. Machine Learning for Electrical & Computer Engineers CERTIFICATE

6.2.1. Learning Outcome

Upon completion of this certificate program, students will be able to use and understand the machine learning techniques to solve practical engineering problems at their workplaces, and to fully understand machine learning software packages used these days in numerous electrical and computer engineering applications. These techniques will be enhanced from the point of views of optimal control systems and

optimum digital signal processing, courses regularly taught in the ECE Graduate Program.

6.2.2. Admission Requirements

Matriculated students: Graduate students (MS or PhD) from ECE Department or related departments, such as Computer Science, Mechanical Engineering, Biomedical Engineering, do not need to apply separately. Interested students should contact the ECE Graduate Director and Graduate Admin and submit a copy of their transcript and a letter of recommendation. The certificate will be administered by ECE. Documents indicating the completion of the certificate are handled by the Senior Administrator for Degree Certification at SGS.

Non-matriculated students: Applicants should complete the usual application process in the School of Graduate Studies application. Applicants need to upload the necessary documents, including transcripts and one letter of recommendation. Applicants should have completed a bachelor's degree in ECE, CS, or a closely related field.

6.2.3. Credit Requirements

The certificate will be awarded to all non-degree and degree ECE MS or PhD graduate students who complete four courses (12 credits) in the area certificate program with a GPA of at least 3.0.

6.2.4. Curriculum

The following courses related to machine learning are the regular (SGS approved) courses in the Electrical and Computer Engineering Graduate Program:

332:509 Convex Optimization
332:510 Optimal Control Systems (covers dynamic programming and calculus of variations)
332:525 Optimum Signal Processing
332:549 Detection and Estimation
332:561 Machine Vision

Several additional Electrical and Computer Engineering courses are also relevant for the machine learning techniques. The complete list of such courses can be found in the SGS catalogue and the ECE Graduate Student Handbook.

Among Advanced Topics Classes: (332:539 in Digital Signal Processing and 332:579 in Computer Engineering), ECE Department taught in the past three years the following courses relevant to the certificate program:

332:579 Machine Learning for IoT
332:579 Introduction to Deep Learning
332:579 Cloud Computing
332:579 Computing Principles for Mobile Embedded Systems

6.2.5. Mode of Delivery (Classroom Instruction/Hybrid/Distance Education)

The primary mode of instruction will be long-distance learning. The online courses will be offered in Canvas. Students may also take regularly offered in-class ECE graduate courses to satisfy the certificate requirement. Students will be given an option to take any four courses from aforementioned list of 10 courses, relevant to machine learning techniques in electrical and computer engineering, with

at least six courses being offered online. Non-degree students enrolled in this certificate program have an option to complete this certificate fully on-line. In-class courses will also be available to non-degree students. Regular MS and PhD students may satisfy the certificate requirement by taking all in-class courses. On-line courses will be also permitted for regular MS and PhD students.

7. Academic Standing

The academic progress of MS students, PhD students who have not yet found a dissertation advisor, and of all students on academic probation is monitored by the Electrical and Computer Engineering **Graduate Academic Standing Committee**, which reviews student performance twice a year.

Master's degree students must **maintain a GPA of 3.0** or higher and PhD students a **GPA of 3.5** or higher. A student whose GPA falls below the corresponding threshold will be placed on **academic probation**. 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+ 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.

Pre-qualifying PhD students who do not find a dissertation advisor within the **first two years** of their studies will be placed on academic probation. The Graduate Academic Standing Committee will oversee the research progress of such students in their **third year** and will recommend dismissal of such students by the end of the third year if they fail to *either* show satisfactory (as deemed by the committee) progress in their research *or* manage to find a dissertation advisor.

The academic progress of **post-qualifying PhD students** who have found a dissertation advisor is monitored on a regular basis by their advisor and the dissertation committee.

All graduate students are **required** to become familiar with the Academic Integrity Policy of Rutgers University–New Brunswick (http://nbacademicintegrity.rutgers.edu/home/academic-integrity-policy). Violation of the academic integrity policy, either within the coursework or the research work, will have serious consequences and may also lead to dismissal from the graduate program.

7.1. Degree Time Limits

MS Degree: There is a time limit of **3 years** to complete a full-time MS degree in the Electrical and Computer Engineering Department. Full-time students who take longer than this will normally not be admitted to the PhD program and are also likely to be dismissed from the graduate program.

PhD Degree: There is a time limit of **6 years** after the MS degree and **7 years** for students with the direct (after bachelor's) PhD admission to complete the full-time PhD degree. Full-time students who take longer than that time interval may be dismissed from the PhD program.

7.2. 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 School of Graduate Studies will not allow students with IN's to graduate. The ECE Graduate Director will not recommend TA/Fellowship support or provide Practical Training letters to students with Incompletes.

7.3. Full-Time Student Status

The ECE Department considers 9 credits (consisting of undergraduate remedial courses, graduate courses, or graduate research 332:701 and 332:702) to be full-time study. The undergraduate course credits are accepted toward the MS and PhD graduate degrees only under some circumstances. The ECE graduate program will not allow students to take fewer than 9 credits and retain full-time enrollment status, except in the following situations:

I. The student is in the last term of their 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, students are expected to carry 9 academic credits for full-time enrollment status. If remedial English courses are required, then a student must still carry 9 credits. Full-time students who do not satisfy this policy will be reviewed by the ECE Graduate Academic Standing Committee, and will also jeopardize their full-time status.

7.4. Academic Probation and Dismissal

The following events will **automatically** trigger the academic probation for a graduate student:

- 1 F in a course
- 2 C+'s or below in courses
- GPA falling below 3.0 (MS students) and 3.5 (PhD students)
- Two years without a dissertation advisor for a pre-qualifying PhD student

The following events **may** trigger the academic probation for a graduate student:

- An Incomplete that is not made up in the immediately following semester

The following events will automatically trigger a meeting of the Academic Standing Committee to determine whether to **dismiss** a student from the ECE graduate program:

- 2 F's in courses
- 3 C+'s or below in courses
- Two continuous semesters of academic probation
- Full-time MS students beyond the third year of their studies
- Full-time PhD students beyond the sixth (after MS) and seventh (direct admission after bachelor's) year of their studies
- PhD students who have not made substantial research progress after three years in the PhD program. This requires that the student has a dissertation advisor, has pursued an original dissertation topic, and has completed some research.

8. 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 Program Office requests that students provide forms **at least three weeks** in advance of any deadline. The ECE Graduate Program 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 in advance for proper processing. Finally, international graduate students should also refer to the Rutgers Global – International Student and Scholar Services (ISSS) website (https://global.rutgers.edu/international-scholars-students) for other deadlines and visa-related guidelines.

9. Information for New Graduate Students

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 potential faculty research advisor for your eventual MS thesis, MS technical paper, or PhD dissertation. Establishing lifelong connections with the faculty is the most critical step in your graduate career and beyond. A worthwhile goal for the first semester would be to settle on a specialization area that interests you and then start meeting with potential advisors who could supervise your MS thesis, MS technical paper, or the PhD dissertation.

10. Ethics Guidelines for University-funded Students

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 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, if applicable, you will promptly initiate your own research program with a faculty advisor, and will soon become productive in conducting research and writing papers.

New TAs and Fellows are reviewed after one semester in the program. They are expected to make satisfactory academic progress and—if pursuing MS with thesis option or PhD—to have a research advisor by the end of their first semester. TAs and Fellows are also reviewed yearly after the end of the spring term. In order to continue as a TA, you must be rated by the course instructor and the students in the course as an excellent teacher, you must be making satisfactory academic progress in the graduate program, and—if pursuing MS with thesis option or PhD—you must have a research advisor who indicates that your research is proceeding well.

It is considered a distinct honor to be a Fellow of the Electrical and Computer Engineering Department. In order to continue as a Fellow, you must have outstanding academic progress in the graduate program and—if pursuing MS with thesis option or PhD—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 or Computer Engineering Department or to the School of Graduate Studies.

11. Appeals Procedures

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

Student grievances concerning grades on the PhD qualifying exam should be addressed to the ECE Graduate Director. If the matter is not resolved satisfactorily, the student may appeal in writing to the Graduate Academic 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 ECE Graduate Director, who will attempt to resolve the dispute informally. If this attempt is unsuccessful, the student may appeal in writing to the Graduate Academic Standing Committee.

Students may appeal decisions of the ECE Graduate Director, Graduate Academic Standing Committee, or graduate faculty, in writing, to the Dean of the School of Graduate Studies if they feel that the process by which the ECE Graduate Program reached its decision was unfair.

12. 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 and a thorough command of the English language.
- Graduate assistantships (GA's) are also available to full-time graduate students. These positions are supported by research grants of individual faculty members. The faculty members should be contacted directly for such support. A list of the faculty and their research interests is given in Appendix A.
- Students holding TA/GA positions may not accept employment outside the department without permission of the ECE Graduate Director and the Dean of the School of Graduate Studies. Information and forms regarding benefits for the TA's/GA's, such as health insurance, can be obtained from the Department Administrator.
- There are also several fellowships and employment opportunities available to graduate students within the department, which are announced through the ECE graduate student mailing list.

13. Registration Policies and Procedures

13.1. 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 ECE Graduate Program Coordinator and submit it to the ECE Graduate Director for approval.

MS degree students who have completed all course requirements must register for Matriculation Continued until they complete the MS Technical Paper, unless they are engaged in thesis research on campus, in which case they must register for at least **one** credit of research.

Pre-qualifying PhD students who have finished all course requirements may register for

matriculation continued until they take their qualifying examination. **Post-qualifying PhD students** are not permitted to register for Matriculation Continued. They must register for at least **one** credit of research each semester until they complete their degree.

13.2. 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 ECE 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.

13.3. 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.

13.4. 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 ECE Graduate Program Coordinator 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.

Important: No more than **6 credits** of Special Problems will be credited towards the Master's degree and no more than **9 credits** towards the PhD degree.

13.5. Undergraduate Courses

In general, 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 ECE Graduate Program Coordinator, to the ECE Graduate Director for approval.

13.6. 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.

14. Communication with Students

All graduate students are provided with Rutgers email accounts as well as mailboxes in the Electrical Engineering Building. It is the student's responsibility to check these (electronic)-mailboxes regularly and promptly inform the ECE Graduate Program, School of Graduate Studies, and Rutgers University–New Brunswick of any changes in addresses and/or telephone number(s).

15. Practical Training for International Students

Two types of practical training are offered by the Electrical and Computer Engineering Department for the international students enrolled in the graduate program:

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 the student's one-year time limit of Practical Training after obtaining the degree from Rutgers. In order to apply for OPT, please supply these items to the ECE Graduate Program Coordinator:
    a. A memo to the ECE Graduate Director requesting OPT.
    b. A completed OPT form (which you obtain from Rutgers Global).
2. **Curricular Practical Training (CPT).** The CPT is semester-based and is available to PhD and Master's students (both Thesis and Non-thesis). The student must be full-time registered during CPT and have completed 2 semesters of study in the Department. 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, MS Technical report or 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, technical paper, or PhD dissertation. The company letter must have the job description consistent with your advisor's letter.
    b. You must register research courses based on the following requirement:
        i. For Master's Thesis students, you must register for 1 to 3 credits of 16:332:701 or 16:332:702 (Graduate Research) during the period of their CPT. The work involved during their CPT will become part of their MS thesis.
        ii. For Master's Non-thesis students, you must register for 1 to 3 credits of 16:332:601 or 16:332:602 (Special Problems) with the permission of a faculty member during the period of their CPT. The work involved during their CPT will become part of their technical paper.
        iii. For PhD students, you must register for 1 to 3 credits of 16:332:701 or 16:332:702 (Graduate Research) during the period of their CPT. The work involved during their CPT will become part of their PhD dissertation.
    c. You must write a technical report about your CPT research and submit it to the ECE Graduate Director. The report will be reviewed by your advisor and the ECE Graduate Director.

    If you meet these criteria, you may apply for CPT in the following way:
    a) Attend a workshop on CPT at Rutgers Global.
    b) Submit a completed CPT form to Rutgers Global.
    c) Send a memo to the ECE Graduate Director requesting CPT, which should include your transcripts, the job offer letter, the advisor's letter, and other pertinent details.

Appendix A — Faculty Research Areas

I. Androulakis *Biomedical Engineering*, (848) 445-6561, ioannis.androulakis@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@rutgers.edu; ENG B242.
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@rutgers.edu; CoRE 721.
Virtual reality systems, force feedback interfaces, medical applications of virtual reality. Telemedicine.

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

Y. Chen, *Cybersecurity, Networking, Computer Engineering*, (848) 445-9151, yingying.chen@rutgers.edu; CoRE 506.
Mobile healthcare, Internet of Things (IoT), Cyber Security and Privacy, Connected vehicles, Mobile Computing and Sensing.

S-W. Cheong *Physics and Astronomy*, (848)445-9023, sangc@physics.rutgers.edu; W123.
Experimental condensed-matter physics and material science.

D. L. Comaniciu, *Siemens Corporate Technology*, DORIN.COMANICIU@SIEMENS-HEALTHINEERS.COM
Medical imaging, scanner automation. Cardiac modeling, image-guided surgery, biomedical, computer vision, and machine learning.

K. Dana *Computer Engineering*, (848) 445-5253, kristin.dana@rutgers.edu; CoRE 514.
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.

M. M. Dehnavi *Computer Engineering*, McGill University, MMEHRIDE@GMAIL.COM
Numerical analysis, machine learning, high-performance computing, compiler and library design, cloud computing.

F. Javier Diez-Garcias *Mechanical & Aerospace Engineering*, (848)445-3665, f.javier.diez@rutgers.edu; ENG B236.
Experimental thermal and fluid sciences, fire safety, sprays, microfluidics, flow diagnostics, turbulence, combustion and energy.

S. El Rouayheb *Communications, Cybersecurity*, (848) 445-9154, salim.elrouayheb@rutgers.edu; CoRE 717.
Information theory, Coding theory, and their applications to data security and privacy.

T.N. Farris *Engineering*, (848) 445-2212, tfarris@rutgers.edu; RWH 405.
Aerospace structures and materials. Tribology, manufacturing, fatigue and fracture.

L. C. Feldman *Institute of Advanced Materials, Devices and Nanotechnology*, (848) 445-4524, l.c.feldman@rutgers.edu.
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.

D. Foran *Bioinformatics, Rutgers Cancer Institute of New Jersey,* (732) 235-6925, foran@cinj.rutgers.edu; Room 3559, Rutgers Cancer Institute of New Jersey.
Design/development/implementation of new approaches in statistical apttern recognition, automated image interpretation and computer assisted decision support for resolving problems in computational biology and diagnostic pathology, radiology and oncology. Development of high-throughput, data-mining technologies and computational methods for characterizing cancer. Work in partnership with basic, clinical and translational researchers to address fundamental problems with cancer detection, precision medicine, disease management, and outcomes studies.

R.H. Frenkiel *Communications*, (732) 446-7992, frenkiel@winlab.rutgers.edu; WLTC C111.
Wireless systems architecture.

Z. Gajic *Systems and Control,* (848) 445-3415, zgajic@rutgers.edu; EE 134A.
Singular perturbation methods in control system analysis. Linear stochastic estimation and control. Control of power in optical and wireless networks, fuel and solar cells, and energy systems.

H. Godrich (848) 445-0606, godrich@rutgers.edu; EE 122.
Statistical and array signal processing, distributed detection and estimation with application in radar systems, wireless sensor networks, and smart power grids.

M. Gruteser *Communications*, (848)932-0993; gruteser@winlab.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.

M. Gurbuzbalaban, Affiliate Member, *Management Science and Information Systems*, (617)324-0645; mgurbuzbalaban@business.rutgers.edu.
Optimization and computational science driven by applications in large-scale information, decision and infrastructure systems, convex optimization, probability and robust control.

I. Hacihaliloglu *Biomedical Engineering*, (848) 445-6564; Ilker.hac@soe.rutgers.edu; BME-214.

Biomedical engineering with emphasis on ultrasound-based, computer-assisted surgery, orthopedics, therapy and medical image analysis.

S. J. Hanson *Physiology Newark (Brain Imaging Center)* (973) 353-5440 x 3952, jose@rubic.rutgers.edu; jose@phychology.rutgers.edu; Smith Hall 324.
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.

U. Hassan *Bioelectrical Engineering, Bioelectronics*, (848)445-2164, umer.hassan@rutgers.edu; EE 215.
Micro/nano sensing for biomedical applications, disease diagnostics and Therapeutics for personalized medicine, BioMEMS & microfluidics and immuno-engineering, predictive prognostics, healthcare systems, point-of-care devices for global health applications.

R. Howard Associate Member, *Communications*, (848)932-0905, reh@winlab.rutgers.edu; WLTC A101.
Low energy sensors/networks, wireless PHY enhancements, HCI technology.

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

J. Jeon *Solid State Electronics*.
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.

J. K-J. Li *Biomedical Engineering*, (848) 445-6582, johnkjli@soe.rutgers.edu; BME 305.
Circulatory dynamics; instrumentation; physiological control.

J. Lindqvist *Communications/Computer Engineering*, (848) 445-0610, janne@winlab.rutgers.edu; CoRE 521.
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@rutgers.edu; EE 236.
Wide band gap semiconductor (ZnO and GaN) materials and devices, tunable RF components, dielectric thin films, MOCVD growth.

R. Mammone *Digital Signal Processing*, (848) 445-5554, rmammone@rutgers.edu; CoRE 518.
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) 445-1494, narayan@winlab.rutgers.edu; EE 128.
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@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) 445-8304, rmartin@rutgers.edu; CoRE 304.
Sensor networks, wireless networks, internet, localization, ad-hoc communication networks.

S. McAfee *Solid State Electronics*, (848) 445-5247, sigridmcafee@aol.com; 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.

J. J. McGarvey Associate Member, *Electronic Circuits and Systems,* (848) 445-9126, johnmcg@soe.rutgers.edu; EE 218.
Design and simulation of power electronic systems, control system modeling via both the classic and modern state-space techniques, and motor control systems.

P. Meer *Computer Engineering*, meer@rutgers.edu.
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) 445-8754, ohsean@physics.rutgers.edu; W121.
Molecular beam epitaxy of functional oxides and quantum materials, and low dimensional electronic properties.

S. Orfanidis *Digital Signal Processing*, (848) 445-5017, sophocles.orfanidis@rutgers.edu; EE 230.
Adaptive signal processing. Block processing and adaptive eigenvector methods for spectrum estimation, direction finding, and pole retrieval. Neural networks.

J. Ortiz *Computer Engineering*, (848) 445-5243, jorge.ortiz@rutgers.edu; CoRE 519.
IoT and cyber physical systems, machine learning, intelligent infrastructure and smart buildings, mobile health, sensor networks, machine learning at the edge, application of machine learning to cyber-physical systems in the context of sustainable systems and smart health applications, development of novel machine learning techniques motivated by real-world use cases in these application domains.

M. Parashar *Computer Engineering and Science*, (848) 445-5388, parashar@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.

V. M. Patel *Electrical and Computer Engineering*, Johns Hopkins University, pvishalm@gmail.com
Computer vision, signal, image and video processing, biometrics, pattern recognition, mobile

security and privacy, radar imaging, computational imaging, compressive sampling, image reconstruction.

A. Petropulu *Digital Signal Processing and Communications*, (848) 445-0414, athinap@rutgers.edu; CoRE 510.
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@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.

D. Raychaudhuri *Communications*, (848) 932-0941, ray@winlab.rutgers.edu; WINLAB WTC 103.
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.

I. Rodero Associate Member. *Computer Engineering*, (732)993-8837, 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.

A. 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.

S. Sehajpal Associate Member, *Electronic Circuits and Systems*, (848) 445-5907, sumati@soe.rutgers.edu; EE 216.
Modeling and analyzing electronic systems using modern state-space based control system approach, the class E and class G RF power amplifiers.

G. K. Shoane *Biomedical Engineering*, (848) 445-6583, shoane@soe.rutgers.edu; BME 306.
Binocular vision; vergence; accommodation model; amblyopia.

D. Silver *Computer Engineering*, (732)445-5117, dsilver@rutgers.edu; CoRE 709.
Computer graphics, scientific visualization, numerical analysis, computational geometry.

V. K. Singh *Library and Information Science*, (848) 932-7588, vivek.k.singh@rutgers.edu ; CI 334.
Data analytics-driven sensing and shaping of human behavior.

E. Soljanin *Communications and Computer Engineering*, (848) 445-5256; emina.soljanin@rutgers.edu; CoRE 511.
Mathematics of distributed systems, in particular concerning mechanisms for efficient, reliable, and secure distributed data storage that provide fast access, download, and streaming of big data files.

Coding, information and queuing theory. Applications of probability, algebra, graph and number theory, and combinatorics to distributed systems.

P. Spasojevic *Communications*, (848) 445-1372, spasojevic@winlab.rutgers.edu ; 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.

M. Striki Associate Member, *Software Engineering*, (848) 445-9145, maria.striki@rutgers.edu; EE 115.
Analysis/design/optimization of data algorithms, statistical analysis, mathematical modeling, big data, data analytics, social networks, information systems, cybernetics, wireless-mobile-ad-hoc-cellular networks, (secure) routing, mobile computing, network-computer security.

W. Trappe *Communications*, (848) 445-0611, trappe@winlab.rutgers.edu; CoRE 523.
Multimedia and multicast information security, signal, image and video processing, wireless networking, cryptography and network security.

M. Turilli Associate Member, *Software Engineering*, (848) 445-8540, matteo.turilli@gmail.com ; CoRE 707.
Parallel and Distributed Computing, Software Design for Distributed Infrastructures, Computer Science, Computer Ethics.

S. Wei *Computer Engineering, Cybersecurity*, (848) 445-5250, sheng.wei@rutgers.edu; CoRE 508.
Hardware security and trust, hardware-enabled system security, heterogeneous system architecture and security, mobile and multimedia systems.

R. Wright *Computer Science*, (848) 445-5931, rebecca.wright@rutgers.edu; CoRE 404.
Computer and communications security, particularly in the areas of privacy, cryptographic protocols, and fault-tolerant distributed computing. Designing protocols, systems, and services that perform their specified computational or communication functions even if some of the participants or underlying components behave maliciously.

M. Wu *Communications, Computational Sensing, Solid State Electronics*, (848) 445-5393, ctm.wu@rutgers.edu; EE 232.
Applied electromagnetics, antennas, passive/active microwave and millimeter-wave components, RF systems and metamaterials.

R. Yates *Communications*, (848) 445-8515, ryates@winlab.rutgers.edu; 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; ENG D157.
Autonomous robotic systems, dynamic systems and control; mechatronics, automation science and engineering.

B. Yuan *Computer Engineering, Signal Processing, Communications*, (848) 445-9152, bo.yuan@soe.rutgers.edu; CoRE 715.
Algorithm and hardware co-design and implementation for machine learning and signal processing systems, error-resilient low-cost computing techniques for embedded and IoT systems and machine learning for domain-specific applications.

Y. Zhang *Computer Engineering*, (848) 445-0608, yyzhang@winlab.rutgers.edu; CoRE 518.
Computer Architecture, Operating Systems, Parallel Computing, Cluster Computer, Performance Evaluation, Sensor Networks.

Yuqian Zhang *Computer Engineering*, (848) 445-9139, yqz.zhang@rutgers.edu; CoRE 719.
Machine Learning, Data Science Computer Vision, Signal Processing, Optimization.

J. Zhao *Solid State Electronics* (848) 445-5240, jzhaoece@gmail.com; jzhao2011@163.com; CoRE 512.
Silicon Carbide (SiC) Semiconductor Devices, SiC JFETs, BJTs, MOSFETS, GTOs, High Efficiency Smart Power Integrated Circuits, SiC Sensors, UV and EUV Detectors, SiC Single Photon Detectors, High Temperature Packaging, SiC Power Limiters/Protector/Circuit Breakers, SiC Inverters/Converters

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@rutgers.edu; ENG D101.
Precision positioning, inversion-based control theory, scanning probe microscopy; nanofabrication.

Appendix B — Graduate Courses

16:332:501 (F) SYSTEM ANALYSIS (3)
Fundamentals of linear system concepts via solution of linear differential and difference equations. State space approach for multi-input multi-output (MIMO) linear systems. Introduction to concepts of linear system stability, controllability, observability, and 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 and 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 (3)
Prerequisite: 16:332:501.
Review of basic feedback concepts and basic controllers in both continuous- and discrete-time domains. State space approach for linear multi-input multi-output control systems. Concepts of stability, controllability, and observability for time-invariant and time-varying linear control systems. Eigenvalue assignment controllers. Full and reduced-order observer designs. Introduction to linear-quadratic optimal controllers and Kalman filtering.

16:332:506 (F) APPLIED CONTROLS (3)
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. 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 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) OPTIMAL 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.

16:332:516 CLOUD COMPUTING AND BIG DATA (3)
The course will introduce fundamental concepts, technologies, and innovative applications of Cloud systems like: Map-Reduce models, Resilient Distributed Datasets (RDDs) operations and Transformations in Spark, Parallel Computing, Graph Problems, peer to peer systems, distributed systems, and more. Moreover, students will obtain hands on experience with contemporary platforms and software used to implement Cloud computing concepts, such as: Spark, Hadoop, HDFS, big data databases like SQL or noSQL, virtualization systems, Kubernetes, Amazon Elastic Cloud Computing (EC2), Kafka.

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: 16:642:550.
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. 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. Emerging 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.

16:332:586 BIOSENSING AND BIOELECTRONICS (3)
This course covers state-of-the-art and emerging biosensors, biochips, microfluidics, which will be studied in the context of molecular diagnostics. Topics will include microfluidics and mass transfer limits, electrode-electrolyte interfaces, electrochemical noise processes, biosensor system level characterization, determination of performance parameters such as throughput, detection limit, and cost, integration of sensor with microfluidics, and electronic readout circuitry architectures, Novel nanobiosensors such as nanopores, nanowire FETS, surface plasmon resonance, surface enhanced Raman scattering, fluorescence and single molecule detection will also be covered.

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.

16:332:590 SOCIALLY COGNIZANT ROBOTICS (3)
This course covers the foundations of robotics and state-of-the-art developments so students can learn the expected trajectory of robot capabilities that will impact individuals and society. The course integrates technical foundations with cognitive and social sciences and student course projects will consider societal implications of robotics systems.

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.

16:332:640 ROBOTICS AND SOCIETY (3)
This course will examine the interplay of robotics technology and society. A sequence of foundational discussions will provide both technical and social science students with core skills for effective cross-disciplinary exploration. The course will examine the interaction between social and technical systems to consider how new and existing technologies affect and are affected by society and policy, as well as giving students an understanding of the ethics, unintended consequences, and social implications of robotics.

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.