Revision to the Academic Requirements for First Year PhD Comprehensive Exam in ECE

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The ECE Department's PhD graduate research program will be partitioned into five main areas of concentration and research:

1. ***Signals, Communication, and Imaging:*** Signal and Image Processing, Communications, Medical Imaging, Machine Learning
2. ***Integrated Electronics and Computer Engineering*****:** VLSI/IC Microelectronics, Computer Design/Architecture, Hardware Security, Machine Learning
3. ***Physical Electronics, Electromagnetism, and Quantum Engineering*****:** Superconductivity and Solid-State Electronics, Optoelectronics, Integrated Photonics, Microelectromechanics and Electrostatics
4. ***Audio and Acoustics*****:** Music Acoustics and Signal Processing, Acoustic Waves, Audio Electronics and Software Design
5. ***Robotics:*** Motion Planning, Navigation, Control, Estimation, Perception, Artificial Intelligence

From an evaluation perspective, the purpose of the First Year PhD Comprehensive Exam in ECE along with the graduate coursework requirements is twofold. The first goal is to assess the student's breadth of knowledge pertaining to the fundamental concepts in ECE. The second objective is to assess the student's potential to perform research while working in an area of concentration in ECE, as well as the student's ability to communicate their research (orally and in writing).

Starting Fall '21, all first year PhD students must satisfy the following (depth and breadth) requirements for continuation in the PhD program:

1. 4+2 Course Requirement: Upon joining the PhD program, a student should claim one of the above areas of concentration. A detailed list of courses falling under each area of concentration will be posted on the ECE Department's website; the list is also included below for convenience. All PhD students must take and pass 6 graduate level courses (400-level) during their first year of study. To satisfy the area depth requirement, 4 of these courses should be from their chosen area of concentration. To comply with the breadth of knowledge requirement, the 2 other courses should be selected from 2 different (out of the remaining 4) external areas of concentration. Some courses may be listed in more than one area, and these courses may be used to satisfy the breadth of knowledge requirement. The specific courses are to be selected by the students in agreement with their research advisors.

Students with no prior ECE background at the undergraduate or MS level should take the new entry-level graduate course ECE 402 - Electrical Engineering Fundamentals in the Fall of their first year of study. This 4-credit course *will count as one of the two courses required outside their area of concentration*. By inspecting the students' transcripts, the Graduate Admissions Committee can indicate who should take this course. Students with an MSc in EE degree will be exempt from this leveling requirement.

Under specific circumstances requiring approval from the student's PhD advisor and the ECE Graduate Committee, relevant courses from other programs (e.g., Mathematics or Computer Science) could be considered to satisfy the 4+2 Course Requirement. Likewise, if a core course deemed to be important to the student's training is not offered during their first year of studies (some ECE graduate courses are offered every other year), the student could petition to take it during their second year.

UR MS EE students that transition to the PhD program will have already taken 6 of our courses and should be exempt from additional coursework requirements. Students coming from other UR MS degree programs, like Physics and Optics, may have taken some of these courses but would most likely need to take at least a few more. For these cases (or if an UR MS EE student decides to change their area of concentration), additional course requirements should be set on a case-by-case basis. Incoming PhD students with an MS degree from other schools should complete the 4+2 Course Requirement outlined above. In very special circumstances, the Graduate Committee can approve a thoroughly justified petition to reduce the course load by a maximum of two courses on a case-by-case basis. All PhD students should take and pass the PhD Comprehensive Exam by the end of their first year of studies.

List of eligible courses from each area of concentration and research.

Signals, Communication, and Imaging:

- ECE 408 The Art of Machine Learning
- ECE 409 (CSC 446) Machine Learning
- ECE 410 Introduction to Augmented and Virtual Reality
- ECE 411 Selected Topics in Augmented and Virtual Reality
- ECE 412 Optimization for Machine Learning
- ECE 440 Introduction to Random Processes
- ECE 441 Detection & Estimation Theory
- ECE 442 Network Science Analytics
- ECE 443 Probabilistic Models for Inference and Estimation
- ECE 444 Digital Communications
- ECE 445 Wireless Communications
- ECE 446 Digital Signal Processing
- ECE 447 Introduction to Digital Image Processing Using Python
- ECE 448 Wireless Sensor Networks
- ECE 449 (CSC 449) Machine Vision
- ECE 450 Information Theory
- ECE 451 (BME451) Biomedical Ultrasound
- ECE 452 (BME 453) Medical Imaging-Theory and Implementation
- ECE 453 Ultrasound Imaging
- ECE 454 Quantum Information Processing
- ECE 457 Digital Video Processing
- ECE 472 Audio Signal Processing
- ECE 485 Inverse Problems in Imaging
- ECE 484 Machine Learning in Imaging

Integrated Electronics and Computer Engineering:

- ECE 400 Computer Organization
- ECE 401 Advanced Computer Architecture
- ECE 403 Advanced Computer Architecture for Machine Learning
- ECE 404 Multiprocessor Architecture
- ECE 405 Ising Machines: Principles and Practices
- ECE 408 The Art of Machine Learning
- ECE 409 (CSC 446) Machine Learning
- ECE 413 Intro. to Hardware Security

- ECE 425 Superconductivity and the Josephson Effect
- ECE 467 Superconductor Electronics
- ECE 429 Audio Electronics
- ECE 431 Computational Methods
- ECE 455 Software Analysis and Improvement
- ECE 460 Digital Radio Engineering
- ECE 461 Intro to VLSI
- ECE 462 Advanced CMOS VLSI Design
- ECE 463 VLSI Error Control Systems
- ECE 464 Fundamentals of VLSI Testing
- ECE 465/565 Performance Issues in VLSI/IC Design & Analysis
- ECE 466 RF and Microwave Integrated Circuits
- ECE 467 Advanced Analog Integrated Circuit Design
- ECE 468 Advanced Analog CMOS Integrated Circuit Design II
- ECE 469 High Speed Integrated Electronics

***Physical Electronics, Electromagnetism, and Quantum Engineering*:**

- ECE 420 Introduction to Quantum Information Science and Engineering
- ECE 421 (OPT 421) Optical Properties of Materials
- ECE 422 Nanoelectronic Devices
- ECE 423 Semiconductor Devices
- ECE 424 Intro to Cond Matter Physics
- ECE 426 (OPT 468) Integrated Photonics
- ECE 428 (OPT 425) Radiation and Detectors
- ECE 434 Microelectromechanical Systems
- ECE 435 Introduction to Opto-Electronics
- ECE 436 Nanophotonic and Nanomechanical Devices
- ECE 439 Electroacoustics, Audio Reproduction, and Spatial Audio
- ECE 454 Quantum Information Processing
- ECE 474 (BME 474) Biomed Sensors, Circuits & Instrumentation
- ECE 520 Spin-based electronics: theory, devices & applications

***Audio and Acoustics*:**

- ECE 429 Audio Electronics
- ECE 432 Acoustic Waves
- ECE 433 Musical Acoustics
- ECE 438 Nonlinear Acoustics
- ECE 439 Electroacoustics, Audio Reproduction, and Spatial Audio
- ECE 440 Introduction to Random Processes
- ECE 470 Digital Audio Effects
- ECE 471 Computational Models of Musical Processes
- ECE 472 Audio Signal Processing
- ECE 475 Audio Software Development I
- ECE 476 Audio Software Development II
- ECE 477 Computer Audition

Robotics:

- ECE 417 Robot Motion Planning and Manipulation (Required)
- ECE 418 Mobile Robot Estimation, Mapping, Navigation, and Interaction (Required)
- ECE 409 (CSC 446) Machine Learning
- ECE 440 Introduction to Random Processes
- ECE 443 Probabilistic Models for Inference and Estimation
- ECE 449 (CSC 449) Machine Vision

2. **Comprehensive Exam**: The PhD Comprehensive Exam evaluates the student's depth of knowledge and research capability in the chosen area of concentration, as well as their writing, communication, and presentation skills.

Each year, ~2 faculty per area of concentration will take on the responsibility to serve in the examination committees of all the students in that area (nominally, 2-4 students or even less). Maintaining a fixed committee to evaluate all exams in that particular year and area has the advantage of providing more consistent evaluation criteria across the student cohort. *The student's PhD advisor will be included in the committee*. This would allow the advisor to provide general recommendations to the student about the exam.

The proposed PhD Comprehensive Exam will consist of two intertwined parts: (i) submission of a written report; and (ii) an oral presentation to the exam committee followed by questioning.

Written Exam: The written exam requires the student to submit a report. The purpose of the written report is to assess a student's readiness and potential for PhD-caliber research. The report should demonstrate that the student has sufficient depth of knowledge in their intended area of concentration and research. The student's ability to understand and think critically about their research topic will be assessed, as well as their ability to communicate clearly and effectively in written English.

In terms of scope, the written report should be an in-depth review/study of a research paper/project assigned by the area exam committee. The choice of format (assigning papers to critique versus applied projects for the students to work on) is left to the discretion of the area exam committees. The same format should be adopted for all students in the concentration area any given year, and the final deliverable should always be a written report. The choice of the paper assigned can be informed by e.g., keywords defining subareas of interest submitted by the student or a recommendation made by the student's PhD advisor (for instance, so that the time spent working on the exam also contributes to the student's own research in their lab). In the submitted report, the student should provide a critical evaluation of the paper by means of thorough explanations of the key concepts and trade-offs, positioning in the context of related work (with adequate references) and provide insight into promising areas of future work (especially if the paper represents the state-of-the-art). The area exam committee members could provide additional specific information and guidelines of what is expected of the students when preparing the report.

As far as the format is concerned, the report should be submitted as a single PDF file not exceeding, say, 8 pages and using the format and style guidelines for submission to IEEE Transaction journals. This way, students will be nudged towards typing with LaTeX, while using a specific template they are likely to encounter down the road. The written material in the report should be independently generated by the student. The same applies to uncited figures, tables and code, whose original preparation is encouraged.

Regarding timeline, the project or paper assignment should be made by *~May 15* on the student's first year of PhD studies. The report should be submitted by the students by *~June 15*. With these revised dates, the written exam should not conflict with Spring semester coursework.

Oral Exam: The oral examination requires the student to prepare slides and give a short presentation explaining the contents of the written report to the members of the concentration area committee. A Q&A session will follow, providing a second instance to gauge whether the student possesses sufficient depth of knowledge in their intended area of concentration and research. Specific to the oral examination, the student's aptitudes to present and communicate research orally will be assessed, as well their ability to understand and answer questions effectively.

As far as the format is concerned, the oral component is conducted as a closed-door examination. The duration of the presentation should be ~30 minutes, followed by no more than 30 additional minutes of Q&A. The questions posed by the committee will be mostly about the contents of the written report and the ensuing presentation. Optionally, the committee can pose additional questions about ECE fundamentals within the area of concentration, including material from the first-year graduate courses taken by the student.

The oral examinations will be scheduled for the week of *~July 1st*. This should give enough time for the students to work on their presentations after submitting their reports, and for the committee members to read and grade the written exams.

In making the final PhD Comprehensive Exam Pass/Fail recommendation, the committee members will vote based on the student's performance in both parts of the examination (perhaps also considering the grades in their first-year courses and the PhD advisor's general appraisal of the student). The committee will notify the student of the result of the exam no later than a couple days after all exams are concluded, via an email copied to the Graduate Coordinator. Students have two chances to pass the PhD Comprehensive Exam (the second attempt can be scheduled sometime around *~August 15*, given the student plenty of time to incorporate the feedback received from the committee). A student that fails the exam twice will be removed from the PhD program, possibly graduating with an MSc degree given the credits gained from the 6 first-year courses plus additional research credits obtained during the Summer.