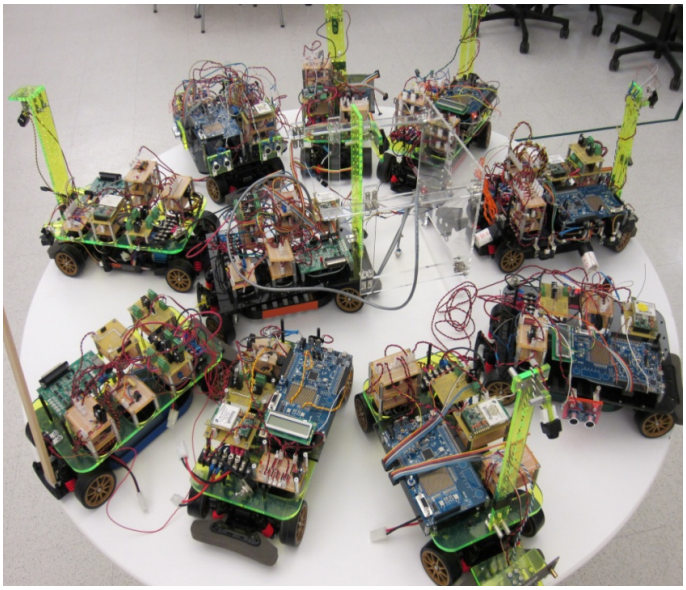
PRINCETON
Electrical
Engineering

Electrical Engineering Handbook

Academic Year 2015-2016



Communications Network Optical Devices Energy Robotics Control Information Security Computer Systems Software Electronic Computer Aided Design Solid State Physics Computer Architecture Biomedical Applications

Photonics Computer Design Real-time Computing Microelectronics Circuits Electronic Optoelectronic Materials Computational Signal Processing

Upated September, 2015

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TO PROSPECTIVE MAJORS

On behalf of the faculty of the Department of Electrical Engineering, my warmest welcome. This booklet outlines the academic programs available within the department. I encourage you to follow up your reading of this material through discussions with department faculty and students and exploration of the department's web pages. The most important things you need to know are the distinctive features of our undergraduate program:

- Rigorous training in engineering fundamentals
- Exposure to modern applications and recent research results
- Participation in independent study/research
- Required completion of seven courses from a wide range of elective courses in the liberal arts, with the flexibility to take up to twelve electives from outside engineering

At the same time, our program provides the opportunity to:

- Combine studies in electrical engineering with a wide variety of other fields such as biology, economics, computer science, neuroscience, and physics
- Complete one of Princeton's many Certificate Programs
- Take courses in entrepreneurship and engineering management
- Participate in a junior-year exchange program with Oxford University or spend a semester abroad studying at another institution

A key feature of the program is the opportunity to participate in research, either on a project of your design or a project in a faculty member's research laboratory. Students may enroll in independent research as early as the sophomore year. The Department provides bench space and has a dedicated fund to support students' independent projects. The Department also has funds available to support students attending domestic engineering conferences, whether to present research results or simply to take advantage of valuable professional development opportunities. There is also funding specific to those students whose projects have an innovative and entrepreneurial focus.

Our program has been carefully designed to prepare our graduates to excel in engineering innovation and in life-long learning. The program also offers outstanding preparation for professions in business, finance, government, law, and medicine. Recent graduates have gone on to work in a wide range of fields – a set of representative examples is given on the department website. A significant percentage of our graduates go on to study at the top graduate and professional schools in the country.

In the pages that follow, you will find the ELE Department course requirements and outlines of some typical academic programs pursued by majors. The Department cannot be described with a few facts and figures. It encompasses a vast range of topics and activities reflecting the diverse nature of the field and the varied interests of the students and faculty. I encourage you to visit the department's facilities and to meet with both students and faculty. We are happy to discuss your interests and career plans, to answer questions about our academic programs, and to help you design a course of study that best meets your individual interests.

Prospective ELE majors should see me first for a general discussion about departmental programs and procedures, and for selection of a faculty advisor. After our meeting, your faculty advisor will take responsibility for assisting you with academic decisions and approving your course selections.

Andrew Houck, Departmental Representative
B-424 Engineering Quadrangle, aahouck@princeton.edu

1. General Information

1.1 Overall structure

The Department offers a four-year degree program leading to an ABET-accredited Bachelor of Science in Engineering degree[1]. After entering the Department as majors, students embark on a rigorous plan of study to acquire mastery of core knowledge in electrical engineering. The program begins with a set of introductory foundation courses (information, circuits, devices, and digital logic). The intent of these courses is to provide essential knowledge for upper-level elective courses and to expose majors to the breadth of this exciting discipline. This foundation is built upon with two core preparatory and design courses, followed by a set of department electives that support the concentration area of your choice. Possible areas of concentration range from theoretical topics (such as communications and network theory) to more experimental and design topics (such as advanced biomedical circuits). Students tailor their areas of concentration in consultation with their faculty program advisors.

In addition to the concentration, students are required to participate in at least one semester of independent research, normally in the senior year. However, many students enroll in additional independent study beyond this minimum requirement.

The program's flexibility allows students to create a tailored program to suit their interests. For example, ELE majors may combine their program with studies in biology, computer science, economics, energy, materials science, management, neuroscience, public policy, physics, or several other fields. Many majors combine their study of electrical engineering with one of the many interdisciplinary certificate programs offered at Princeton.

1.2 Faculty Advisors

The ELE Departmental Representative is the faculty advisor for all sophomore and upperclass students in the department. In addition, each student is assigned a faculty program advisor to consult in more detail concerning both academic program matters and career advice. Students see their program advisors each semester to review their progress towards graduation and to have their course selections approved. Subsequent course changes should be discussed with the program advisor, as the advisor's signature is required on any course-change forms submitted to the Registrar. All seniors should also discuss any course changes with the Departmental Representative and also obtain his signature on the course-change forms. The program advisors for the various classes are as follows:

Class of 2016: P. Cuff (B316), S. Lyon (B428), K. Sengupta (B216), S. Verdu (B308)
Class of 2017: N. Jha (B220), P. Ramadge (B222), J. Sturm (320 Bowen Hall), G. Wysocki (B324)
Class of 2018: Abbe (B322), Chou (B412), Lee (B218), Shayegan (B408), Tureci (B312)

1.3 Certificate and Special Programs

Various ELE faculty serve as coordinating faculty for special programs offered by the university. Some of these programs offer certificates. If you enroll (or wish to enroll) in any of these programs, you may find it helpful to consult the appropriate faculty in addition to your faculty program advisor for help in planning your curriculum.

Certificate Program:	**Coordinating Faculty**
Engineering Biology:	See UG Coordinator
Engineering and Management Systems:	See UG Coordinator
Engineering Physics:	A. Kahn/S.Lyon
Technology and Society	M. Chiang/S. Malik
Materials Science and Engineering:	C. Gmachl/J. Sturm
Woodrow Wilson Certificate:	See UG Coordinator
Environmental Studies:	S. Wagner
Robotics and Intelligent Systems:	S. Kulkarni/S. Lyon

[1] Engineering Accreditation Commission of ABET, http://www.abet.org.

Applications of Computing:	S. Malik/M. Chiang
Applied and Computational Mathematics:	S. Verdu/E. Abbe
Sustainable Energy	B. Rand
Statistics and Machine Learning	P. Ramadge

2. University and General B.S.E Requirements:

2.1 Writing Requirement
A 100-level course in the subject area of WRI.

2.2 Courses
Thirty-six courses are required for completion of the B.S.E degree in a 4-year program (or 28 courses for a 3-year program for students granted advanced standing).

2.3 Distribution Area Requirements
Minimum of seven courses in the humanities and social sciences. The humanities and social science courses must include one course in four of the following six areas: Epistemology and Cognition (EC), Ethical Thought and Moral Values (EM), Historical Analysis (HA), Literature and the Arts (LA), Social Analysis (SA), and Foreign Language (at the 107/108 level or above).

2.4 Math and Science Requirements
All B.S.E students must complete: MAT 103, MAT 104, (MAT 201 or MAT 203), and (MAT 202 or MAT 204 or equivalent); (PHY 103 or PHY 105) and (PHY 104 or PHY 106 or equivalent); CHM 207 or (CHM 201/201A or equivalent). Requirements cannot be taken P/D/F or audit, but may be met by advanced placement.

2.5 Computer Proficiency
The computer proficiency requirement can be fulfilled by taking COS 126 or by advanced placement. The requirement may not be taken P/D/F or audit.

2.6 Transfer of Credit
At most four courses, excluding programs such as study abroad, may be applied to the 36 required courses.

3. ELE Program Requirements

3.1 Foundation
All ELE majors are required to take:

- ELE 201 **Information and Signals**
- ELE 203 **Electronic Circuit Design, Analysis and Implementation**
- ELE 206 **Contemporary Logic Design**
- ELE 208 **Electronic and Photonic Devices**

This requirement is normally satisfied by the end of the sophomore year. In some instances, students with prior exposure to similar material may test out of one or more of these courses. In such cases, an upperlevel ELE course in the same general area must be substituted for the course before graduation. The substituted course cannot be used to satisfy any other requirement.

3.2 Core
Two upperclass courses are required of all ELE majors:

- ELE 301 **Designing Real Systems**
- ELE 302 **Building Real Systems**

This requirement is normally satisfied by the end of the junior year.

3.3 Mathematics
At least one additional upperclass (300 level or higher) math course. Examples include: MAE305/MAT301, MAE306/MAT302, ORF309*/MAT309, COS 340. This may not count towards the concentration requirement, the breadth requirement or as a Departmental requirement (See 3.6). Additional upperclass math courses may be used for that purpose.

3.4 Breadth
At least one department elective course, 300-level or above, in an area distinct from your area of concentration. The following courses are also possible: COS 318, 320, 333, 402, 426, 429, 432, 441,461; PHY 208/305 – must take both PHY208 and PHY 305 (counts as one). Note: ORF309 cannot be used to satisfy this requirement. Of special note: TigerHub states you need one course each in two areas. One of your concentration courses will serve as one of the two needed. This means you need one course outside of concentration and the other course will naturally fall into your concentration. The departmental representative is the final authority on whether or not a course can fulfill a requirement.

3.5 Engineering Science
An engineering course with a significant scientific component must be taken outside of ELE to satisfy this requirement. Many courses can be used to satisfy this requirement; note, however, that a course comprised largely of mathematics or applied mathematics does not satisfy the requirement. The course used to satisfy the Engineering Science requirement cannot also be used to satisfy the concentration requirement or the breadth requirement, nor can it be counted as a Departmental requirement. The following is a non-exhaustive list of possibilities: COS 217, 226, 320, 402, 423, 425, 444, 451, 487; MAE 206, 221, 222, 324, 328, 344, 345, 433, 434; CEE 205, 303, 305, 471; MSE 301, 302; CBE 245, 246, 341, 415, 445, 447; ORF 307, 311, 405, 406, 417.

3.6 Balance and Completeness
ELE students must take at least two upperclass technical courses in each of the last four semesters. These 300-level-or-higher courses are called Departmental courses. Of the eight Departmental courses, at least five must be ELE courses. The remaining three courses can be taken in CEE, CHM, CBE, COS, EEB, ELE, MAE, MAT, MOL, MSE, ORF or PHY. Courses outside electrical engineering counted towards this requirement must be closely related to the student's academic program.

3.7 Design
In the junior year, ELE 302 takes each student through all phases of a design project, emphasizing hands-on experience while providing classroom guidance. In addition, at least one upperclass ELE course with substantial engineering design content must be selected from the following: ELE 352, 375, 404,454, 462, 465, 475, 482, COS 426, 436. This requirement may also be satisfied with junior or senior independent work, if that work contains *a substantial design component.*

3.8 Concentration
Each student must develop depth in a coherent area of concentration in the department by completing three courses in one concentration area. Concentrations may be interdisciplinary and include courses from other departments in the School of Engineering and Applied Sciences (SEAS), as well as from related fields such as biology, chemistry, neuroscience, physics, and others. However, the courses must form a coherent theme and normally two of the courses will be ELE courses or designated equivalents. ORF 309/MAT 309 may be used to satisfy either the upperclass mathematics requirement or the concentration requirement, but not both.

Graduate courses (500 level) are open to undergraduates after the completion of a permission form containing the signatures of instructor and departmental representative. The permission form is available from the undergraduate coordinator or you can download at http://registrar.princeton.edu/student-services/.

Table 1: Example ELE Undergraduate Concentrations

Communications and Networks
(c1) ORF 309 Probability**
(c2, c3) Two courses from:
ELE 381 Networks: Friends, Dollars, and Bytes
ELE 386 Cyber Security
ELE 454 Photonics and Light Wave Communications
ELE 486 Transmission and Compression of Information
COS 432 Information Security
COS 461 Computer Networks

Computer Systems and Software
(c1) ELE 375 Computer Architecture and Organization
(c2) one course from:
ELE 475 Computer Architecture
ELE 482 Digital Signal Processing
(c3) one course from:
COS 318 Operating Systems
COS 320 Compiling Techniques
COS 425 Database & Information Management Systems
COS 426 Computer Graphics
COS 435 Information Retrieval, Discovery, & Delivery

Information and Security
(c1) ELE 386 Cyber Security
(c2, c3) Two courses from:
ELE 381 Networks: Friends, Money and Bytes
ELE 454 Photonics and Light Wave Communications
ELE 486 Transmission and Compression Information
ELE 488 Image Processing
COS 402 Artificial Intelligence
COS 432 Information Security
COS 433 Cryptography
COS 461 Computer Networks

Biomedical Applications
(c1) ELE 404 Electronic Circuits for Biomedical Applications
(c2) ELE 488 Image Processing
(c3) One course from:
ELE 352 Physical Optics
ELE 455 Mid-infrared Tech. for Health & Environment
ELE 480 Analysis of fMRI Data
COS 455 Intro. Genomics & Comp. Molecular Biology
MAE 344 Intro. Bioengineering and Medical Devices
NEU 437 Computational Neuroscience
PHY 412 Biological Physics

Computer Architecture
(c1) ELE 375 Computer Architecture and Organization
(c2) ELE 475 Computer Architecture
(c3) One course from:
ELE 386 Cyber Security
ELE 396 Introduction to Quantum Computing
ELE 461 Design with Nanotechnologies
ELE 462 Design of Large-Scale Integrated Systems
ELE 465 Switching and Sequential Systems

Electronic and Optoelectronic Materials
(c1) ELE 342 Physical Principles of Electronic Devices*
(c2, c3) Two courses from:
ELE 341 Solid-State Devices
ELE 441 Solid-State Physics I
ELE 442 Solid-State Physics II
MSE 301 Materials Science and Engineering
CHM 305 The Quantum World
MAE 324 Structure and Properties of Materials

Microelectronics and Circuits
(c1) ELE 341 Solid-State Devices
(c2) ELE 462 Design of Large-Scale Integrated Systems
(c3) One course from:
ELE 404 Electronic Circuit Analysis for Biomedical Applications
ELE 461 Design with Nanotechnologies

Photonics
(c1) ELE 351 Electromagnetic Field Theory and Optics
(c2) ELE 352 Physical Optics
(c3) One course from:
ELE 341 Solid-State Devices
ELE 453 Optical Electronics
ELE 454 Photonics and Light Wave Communications

Solid State Electronic and Optical Devices
(c1) ELE 341 Solid-State Devices
(c2, c3) Two courses from:
ELE 342 Physical Principles of Electronic Devices*
ELE 351 Electromagnetic Field Theory and Optics Applications
ELE 404 Electronic Circuits for Biomedical Applications
ELE 431 Solar Energy Conversion
ELE 453 Optical Electronics

Computational Signal Processing
(c1) ORF 309 Probability**
(c2, c3) Two courses from:
ELE 396 Introduction to Quantum Computing
ELE 482 Digital Signal Processing
ELE 488 Image Processing
COS 402 Artificial Intelligence
COS 426 Computer Graphics
COS 429 Computer Vision

* or PHY 208 and 305 counted as one course for the concentration requirement **ORF 309/MAT 309 satisfies the upperclass Mathematics requirement or the concentration requirement, but not both. The above table is not exhaustive. Other possible concentrations include: **Energy, Robotics and Control**, **Electronic Computer-Aided-Design, Computer Design**, **Real-time Computing**, **Solid State Physics.**

3.9 Independent Work

Independent projects or research projects outside of normal structured lecture or laboratory courses are a valuable educational experience. Such projects are extremely challenging on both a personal and academic level, but are also extremely fulfilling. Requirements include both written documents and an oral presentation. Independent work cannot be used to fulfill the breadth or concentration requirements.

A Senior Thesis is required. You must have both an advisor and a second reader. The department does not require a bound copy of the thesis. You will be required to submit a pdf of your thesis on the Senior Thesis due date mandated by the University.

3.10 Ethics and Social Context

Successful engineering innovation is fostered by core technical excellence, exposure to the latest developments in the discipline, *and an appreciation of the economic, ethical, societal, and cultural context within which engineering operates*. The department encourages majors to draw from the liberal arts programs for grounding in the social context vital to solving the technological challenges of the future. By doing so, electrical engineering graduates will find their education to be a strong foundation for professional responsibility and career development.

4. Generic ELE Study Program and Specific Sample

4.1 Two Generic Example Programs

Two sample programs of study are given below. "Departmental Elective" and "Technical Elective" are technical courses, normally either Electrical Engineering, Computer Science, Mathematics, Physics, other engineering courses, or courses that form part of a coherent pattern of study for students emphasizing special programs in areas such as engineering and management systems, engineering physics, or engineering biology. Courses labeled "Elective" are free-choice elective courses selected from department or other technical courses, entrepreneurship courses or humanities/social science courses.

Generic Example 1: No Advanced Placement in Math/Physics/Chemistry	
Freshman Year	
Math 103: Calculus Physics 103: Mechanics Chem 207: Materials Chemistry Elective: writing requirement	Math 104: Calculus Physics 104: Elect. & Magnetism COS 126: Computer Science Elective: humanities/social science Elective: humanities/social science
Sophomore Year	
Math 203: Multivariable Calculus ELE 203 Electronic Circuit Design, Analysis and Implementation ELE 206: Contemporary Logic Design Elective Elective: humanities/social science	Math 204: Linear Algebra ELE 201: Information and Signals ELE 208: Electronic and Photonic Devices Elective Elective: humanities/social science
Junior Year	
ELE 301: Designing Real Systems Departmental Elective Upper Level Math Elective Elective Elective: humanities/social science	ELE 302: Building Real Systems Departmental Elective Technical Elective Elective: humanities/social science
Senior Year	
Departmental Elective Departmental Elective Elective: humanities/social science Elective: Independent Research	Departmental Elective Departmental Elective Elective Elective

Generic Example 2: One Course Advanced Placement in Math	
Freshman Year	
Math 104: Calculus Physics 103: Mechanics Chem 207: Materials Chemistry Elective: writing requirement	Math 203: Multivariable Calculus Physics 104: Elect. & Magnetism COS 126: Computer Science Elective: humanities/social science Elective: humanities/social science
Sophomore Year	
Math 204: Linear Algebra ELE 203: Electronic Circuit Design, Analysis and Implementation ELE 206: Contemporary Logic Design Elective Elective: humanities/social science	ELE 201: Information and Signals ELE 208: Electronic and Photonic Devices Upper Level Math Elective Elective Elective: humanities/social science
Junior Year	
ELE 301: Designing Real Systems Departmental Elective Technical Elective Elective Elective: humanities/social science	ELE 302: Building Real Systems Departmental Elective Elective: humanities/social science Elective: humanities/social science
Senior Year	
Departmental Elective Departmental Elective Elective: humanities/social science Elective: Independent Research	Departmental Elective Departmental Elective Elective Elective

4.2 Specific Example Program: Communications and Networks with EMS Certificate

In the example below, the following abbreviations are used:

b:	Breadth in ELE	c1, c2, c3:	Concentration in ELE
D:	Departmental	d:	Engineering Design
e:	Engineering Science	m:	Upperclass Mathematics
p:	Certificate requirement		

Specific Example: One Course Advanced Placement in Math Communications and Networks Concentration with EMS Certificate	
Freshman Year	
Math 104: Calculus Physics 103: Mechanics Chem 207: Materials Chemistry Elective: writing requirement	Math 203: Multivariable Calculus Physics 104: Elect. & Magnetism COS 126: Computer Science Econ 100: Description & Analysis of Price Systems (p) Elective: humanities/social science
Sophomore Year	
Math 204: Linear Algebra ELE 203: Electronic Circuit Design, Analysis and Implementation ELE 206: Contemporary Logic Design ORF 245: Fund. of Engineering Statistics (p) Elective: humanities/social science	ELE 201: Information and Signals ELE 208: Electronic and Photonic Devices Upper Level Math Elective ORF 307: Optimization (p,e) Elective: humanities/social science
Junior Year	
ELE 301: Designing Real Systems (D) ELE 375: Computer Arch. & Org. (D,b,d) ORF 309: Probability (c1,p) Elective Elective: humanities/social science	ELE 302: Building Real Systems (D) ELE 482: Digital Sig. Processing (D) Elective: humanities/social science Elective: humanities/social science
Senior Year	
ELE 488: Image Processing (D,c2) ORF 411: Operations & Inform. Eng. (D,d,p) ELE 497: Independent Research Elective	ELE 486: Digital Communications (D,c3) ORF 417: Dynamic Programming (D,p) Elective Elective: humanities/social science

5. Miscellany

5.1 Academic Progress

The B.S.E degree in Electrical Engineering requires a minimum performance level. Students are expected to maintain a C average in their Sophomore ELE program courses as well as in the Departmental courses in the Junior and Senior years. Should a student drop below a C average, the department will recommend an appropriate action to the University Faculty Committee on Examinations and Standing. The resulting action will be the issuing of an Academic Warning or the requirement of withdrawal from the University.

5.2 Honors

The "Departmental Standing," which determines eligibility for graduation and the eligibility for the awarding of graduation Honors, is based on the average grade of the eight of the Departmental courses with the best grades. At least a C average is required for graduation and a B+ average is required to be eligible for consideration for Honors. The awarding of Honors, High Honors, and Highest Honors is determined by a vote of the faculty based on performance in all technical courses. Typically, independent project and thesis work are also given special consideration when awarding Honors.

5.3 Interdisciplinary Programs

Interested students may combine their work in ELE with coursework in other departments through interdisciplinary Certificate Programs such as Engineering and Management Systems, Engineering Physics, Materials Science and Engineering, Engineering Biology, Environmental Studies, Applied and Computational Math, and the Woodrow Wilson School. (WWS is by application only) Students fulfilling a Certificate Program will receive a special certificate upon graduation. Majors should consult with their advisors to develop an ELE program that best combines their ELE interest with the interdisciplinary program. Additional material on a Certificate Program may be obtained by contacting the Director of the Program (listed in the Undergraduate Announcement).

5.4 Independent Research Funding

The Electrical Engineering Department, the School of Engineering and Applied Science and the Dean of the College's office offer funding opportunities for independent projects requiring financial support for acquisition of data or other special requirements. Funding requests require the submission of a detailed proposal and budget. Details are available in the Undergraduate Office.

5.5 The Fund for Excellence in Electrical Engineering

Funds from this endowed gift to the department are available to support students attending an engineering conference held in the USA or Canada. Students must submit a detailed request for funding well in advance of registering or traveling to the conference. Details are available in the Undergraduate Office.

5.6 Undergraduate Travel

http://travel.princeton.edu/undergraduate-students