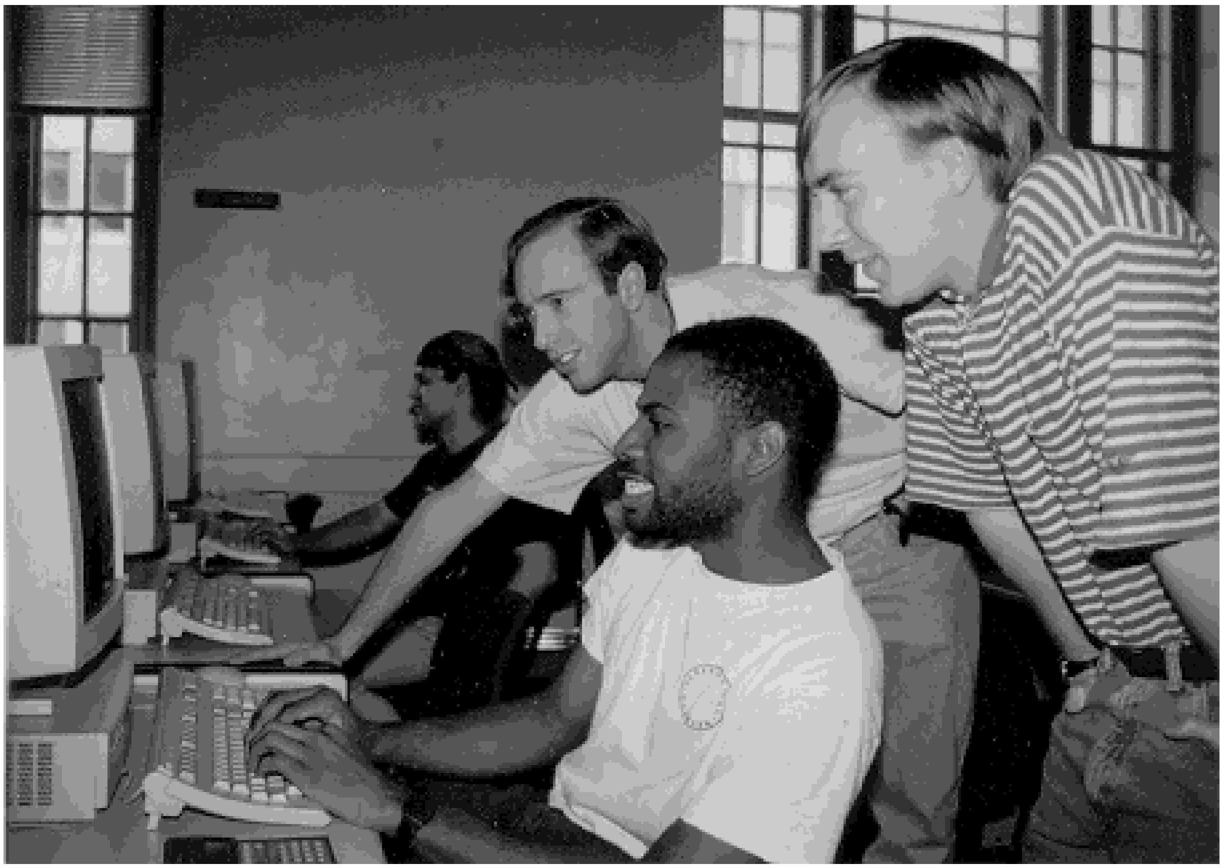


ECE students working together.

CHAPTER 5

New Curriculum: Detailed Requirements, Example Paths

We now turn to a more student-oriented view of the new curriculum. One obvious question to address is: exactly what must one take to get the B.S.E.C.E. degree at Carnegie Mellon? We revisit the curriculum, this time laying out precisely all the requirements. A second question is: what alternatives are available as students plan to allocate their electives among various technical and nontechnical topics? As a part of the curriculum design process, the Wipe the Slate Clean Committee constructed example curriculum *templates*, each illustrating–albeit at that time approximately–a different path to a four year bachelor's degree in electrical and computer engineering comprising eight semesters with four courses per semester. We offer a few of these templates here, now revised in light of current requirements, to suggest ways in which the flexibility of the new curriculum can serve the needs of different students with different preparation and aspirations.

Detailed Curriculum Requirements

To begin, we enumerate the requirements and constraints specified in the new ECE curriculum.

General Education Requirements

Eight courses in all, comprising:

- One course chosen from a list of designated *writing and expression* courses.
- One course chosen from a list of designated *humanistic studies* courses.
- One course chosen from a list of designated *cognition and institutions* courses.
- Three more advanced courses, constituting again a *depth* sequence, chosen from among nontechnical courses in humanities, social sciences, foreign language or fine arts.
- Two freely chosen nontechnical courses from humanities, social sciences, foreign language or fine arts.

Mathematics, Science and Computer Programming Requirements

Eleven required courses in all, comprising:

- *Computing Skills Workshop* (required of all freshmen in the college of engineering)
- *Introduction to Programming and Computer Science* (corequisite for *Introduction to ECE*)
- *Calculus I* (corequisite for *Introduction to ECE*)
- *Calculus II*
- *Physics I* (corequisite to most other CIT engineering department's freshman *Introduction to Engineering* course)
- *Physics II*
- *Linear Algebra* or *Mathematical Foundations of Electrical Engineering* (corequisite for *Fundamentals of Electrical Engineering*)
- *Introduction to Modern (Discrete) Mathematics* (corequisite for *Fundamentals of Computer Engineering*)
- *Probability and Random Processes*

Plus two more elective courses, constrained as follows:

- Two math/science electives, satisfied by any course beyond the elementary level in mathematics, physics, biology, chemistry, statistics, except those specifically aimed at a nontechnical audience.

Freshman Engineering Requirements

Two requirements for obtaining a B.S.E.C.E. are:

- The ECE freshman course, *Introduction to Electrical and Computer Engineering*, must be taken by ECE majors, although it may be taken as late as the fall semester of the sophomore year.
- One additional "Introduction to Engineering" course offered by another department in the college of engineering.

For completeness, a list of all freshman introductory engineering courses offered in the college of engineering follows. Each course is permitted to have one science and one mathematics corequisite:

- *Introduction to Chemical Engineering* (corequisites *Modern Chemistry I* and *Calculus I*)
- *Innovation and Design in Civil Engineering* (corequisites *Physics for Engineering Students I* and *Calculus I*)
- *Introduction to Electrical and Computer Engineering* (corequisites *Introduction to Computer Programming* and *Calculus I*)
- *Introduction to Engineering and Public Policy* (corequisites *Physics for Engineering Students I* and *Calculus I*)
- *Fundamentals of Mechanical Engineering* (corequisites *Physics for Engineering Students I* and *Calculus I*)
- *Materials in Engineering* (corequisites *Physics for Engineering Students I* and *Calculus I*)

ECE Core Requirements

There are only two required core courses past the required freshman *Introduction to ECE* class:

- *Fundamentals of Electrical Engineering* (corequisite *Linear Algebra* or *Mathematical Foundations of Electrical Engineering*)
- *Fundamentals of Computer Engineering* (corequisite *Introduction to Modern Math*)

ECE Breadth Requirements

Students must take at least one first-level course in each of three of the five basic areas of ECE*:*

- *Applied Physics*
- *Signals and Systems*
- *Circuits*
- *Computer Hardware*
- *Computer Software*: These courses are all offered by the Computer Science Department, with whom we maintain a reciprocal relationship: computer science students take several hardware-oriented ECE classes, and ECE students may elect to take software-oriented computer science classes.)

Engineering Coverage, Depth and Design Requirements

At least three more courses must be taken from the areas defined in the ECE breadth requirement. These courses must be chosen so that two additional requirements, the depth and design requirements, are satisfied.

To satisfy the depth requirement, students must take at least one course that has, as a prerequisite, one of the courses used to meet the breadth requirement.

To satisfy the design requirement, students must complete one course from a list of designated capstone design courses. In some cases, a single course can satisfy both the depth and design requirements.

Engineering Elective

Students must complete one additional technical course beyond the elementary level chosen from among any courses in the College of Engineering or School of Computer Science.

Free Electives

Students may choose up to 4.5 classes (at Carnegie Mellon, this is 54 units) arbitrarily from among any graded courses offered by any degree-granting department.

Overload Policy, QPA Policy

The term “overload” refers to the maximum number of units per semester a typical student is allowed to carry without getting special permission. An overload is defined as any schedule with more than 54 units (three 12-unit classes and two 9-unit classes) in one semester. Only students who have achieved a QPA of 3.5 out of 4.0 in the previous semester may overload.

To graduate, students must maintain a 2.0 QPA in the set of courses used to satisfy the ECE freshman, ECE core, breadth, depth, coverage and design requirements.

Curriculum Templates: Example Paths through ECE

We now turn to the larger picture: what options do students have to tailor their course elections to their aspirations and goals within our new curriculum? We offer a broad set of different scenarios in the following sections.

First, however, a bit of notation should be explained. ECE courses, and courses in other departments such as Computer Science that are considered to be in core ECE areas, appear in **bold print** with the appropriate title in the following curriculum templates. All other courses appear as regular print. The number in parentheses in each box represents the units of each course.

A Traditional Electrical Engineering Curriculum

Perhaps the first observation to make is that a flexible curriculum in no way prevents a student from choosing a “traditional” sequence of courses. Hence, the course template in FIGURE 12 shows how a conventional electrical engineering program–conventional except, of course, for the existence of real engineering classes in the freshman year–can be constructed within the constraints of the proposed ECE curriculum. This template shows the student pursuing the usual component of mathematics, physics, computer programming and ECE fundamentals classes, as well as substantial breadth and depth in electromagnetics, circuits, signals and systems, and solid state. By the standards of any traditional electrical engineering curriculum, this is an exceptionally broad, solid plan of study. This program, or something similar, would be the “default” program suggested by an adviser to a student who is interested in traditional electrical engineering without more specific interest areas. It should be emphasized that this is only one of many possible course selections that could be used to construct a curriculum with traditional electrical engineering emphasis.

FIGURE 12. A Traditional Electrical Engineer

FRESHMAN	**FALL**	General Education (9)	**Introduction to ECE (12)**	**Computer Science Intro Programming (10)**	Calculus I (10)	Computing Skills Workshop (3)
	SPRING	General Education (9)	Materials in Engineering (12)	Physics I (12)	Calculus II (10)	
SOPHOMORE	**FALL**	General Education (9)	**Fundamentals of Electrical Eng (12)**	Physics II (12)	Mathematical Foundations of EE (12)	
	SPRING	General Education (9)	**Fundamentals of Computer Eng (12)**	**Engineering Electromagnetics I (12)**	Modern Math (9)	Biology (9)
JUNIOR	**FALL**	General Education (9)	**Digital Circuits (12)**	**Engineering Electromagnetics II (12)**	Chemistry I (10)	
	SPRING	General Education (9)	**Analog Circuits (12)**	**Semiconductor Devices I (12)**	**Signals and Systems (12)**	**C/Unix Skills (3)**
SENIOR	**FALL**	General Education (9)	**Analog IC Design (12)**	**Semiconductor Devices II (12)**	Probability / Statistics (9)	
	SPRING	General Education (9)	**Senior Project (12)**	**Fundamentals of Communication Systems (12)**	**Computer Control Systems Design Lab (12)**	

A Traditional Computer Engineering Curriculum

A “traditional” computer engineering plan of study can also be formulated within the framework of the proposed ECE curriculum. Following the usual mathematics, physics, introductory programming and ECE fundamentals classes, the computer engineering student pursues a variety of computer hardware and computer software topics. Note that the ECE breadth requirement (which mandates that students elect one course in three of the five different ECE breadth areas) will not permit a course of study so narrow that only hardware-related topics, or only software-related topics are selected to the exclusion of other areas. Here, the breadth requirement means that even after taking courses in the computer hardware and computer software areas, a third area must be selected for study. In the template shown in FIGURE 13, the student attains this breadth in the circuits area, after having acquired the necessary preparation in the *Fundamentals of EE* class required of all ECE students. The senior year culminates in a capstone design project in digital systems design, along with yet more depth and breadth in signals and systems, software and hardware. Again, by the standards of any traditional computer engineering program, this is a solid and well-balanced course of study. It should again be emphasized that this is only one of many possible course selections that could be used to construct a curriculum with traditional computer engineering emphasis.

FIGURE 13. A Traditional Computer Engineer

FRESHMAN	**FALL**	General Education (9)	**Introduction to ECE (12)**	**Computer Science Intro Programming (10)**	Calculus I (10)	Computing Skills Workshop (3)
	SPRING	General Education (9)	Fundamentals of Mechanical Eng (12)	Physics I (12)	Calculus II (10)	
SOPHOMORE	**FALL**	General Education (9)	**Fundamentals of Computer Eng (12)**	Physics II (12)	Modern Math (9)	
	SPRING	General Education (9)	**Fundamentals of Electrical Eng (12)**	**Fundamentals of Computer Science I (12)**	Linear Algebra (9)	**C/Unix Skills (3)**
JUNIOR	**FALL**	General Education (9)	**Computer Architecture (12)**	**Fundamentals of Computer Science II (12)**	**Digital Circuits (12)**	Probability / Statistics (9)
	SPRING	General Education (9)	**Concurrency and Real-time Systems (12)**	**Intro to Computer-Aided Digital Design (12)**	Numerical Methods (9)	
SENIOR	**FALL**	General Education (9)	**Senior Project (6)**	**Advanced Digital Design Project (12)**	**Introduction to Telecommunication Networks (12)**	
	SPRING	General Education (9)	**Superscalar Processor Design (12)**	**Signals and Systems I (12)**	**Operating Systems (12)**	Discrete Math (9)

A Novel Preparatory Curriculum: The ECE Generalist

We have seen that the flexibility inherent in the proposed ECE curriculum does not preclude traditional avenues of study. Now let us consider instead new avenues of study that it creates. One possibility is illustrated by the course template shown in FIGURE 14 that we call a "preparatory curriculum." Such a curriculum has exactly the same connotation that a traditional liberal arts curriculum usually carries: a broad, solid course of study emphasizing a variety of different areas that is worthy of a degree in itself, but undertaken specifically as preparation for a subsequent professional degree. It has become increasingly obvious in recent years that not all students who pursue a bachelor's degree in ECE actually remain electrical or computer engineers for the rest of their lives. Moreover, we are seeing significantly more students who consciously choose an engineering degree as preparation for post-graduate study in other professional disciplines such as law, business or medicine. In the past, such preparatory curricula were, it seems, exclusively undertaken under the rather broad umbrella of liberal arts. We are specifically interested now in supporting an ECE degree as a general preprofessional degree–but without compromising the integrity of the ECE bachelor's degree itself.

The plan of study shown here is one middle-ground approach. Observe that this student still takes the usual mathematics, physics, computer programming and ECE fundamentals classes. In addition, the breadth, depth, ECE content and capstone design requirements are met, in this case with a combination of courses in signals and systems, circuits, computer hardware and computer software. Note that the emphasis in such a curriculum is breadth of experience, and exposure to many different technical topics. Nevertheless, the result is not a weak or simplified program, but rather, a program for what might be called the "ECE Core Generalist." Significant here is that the curriculum still leaves room for six free elective courses, in addition to Carnegie Mellon's already stronger-than-average requirement of eight general education (humanities, social sciences, fine arts) classes. With appropriate choices among these nontechnical classes, a very strong preparatory program can be created. In the example shown, we have populated the elective courses with economics, biology and a foreign language. Of course, some of these elective choices could also be accomplished within the eight general education courses themselves; the point worth noting is that taken together, the general education and elective slots provide considerable flexibility. With appropriate course choices, this course of study will produce students with a solid background in ECE core material, along with good preparation for further study in, for example, business or law.

FIGURE 14. An ECE Core Generalist

FRESHMAN	FALL	General Education (9)	**Introduction to ECE (12)**	**Computer Science Intro Programming (10)**	Calculus I (10)	Computing Skills Workshop (3)
	SPRING	General Education (9)	Introduction to Eng and Public Policy (12)	Physics I (12)	Calculus II (10)	
SOPHOMORE	FALL	General Education (9)	**Fundamentals of Electrical Eng (12)**	Physics II (12)	Linear Algebra (9)	Modern Chemistry I (10)
	SPRING	General Education (9)	**Fundamentals of Computer Eng (12)**	Modern Math (9)	**Fundamentals of Computer Science I (12)**	
JUNIOR	FALL	General Education (9)	**Computer Architecture (12)**	**Digital Circuits (12)**	Foreign Language I (9)	Probability / Statistics (9)
	SPRING	General Education (9)	**Signals and Systems (12)**	**Analog Circuits (12)**	Foreign Language II (9)	Biology I (9)
SENIOR	FALL	General Education (9)	**Intro to Telecommunications Networks (12)**	Economics I (9)	Foreign Language III (9)	
	SPRING	General Education (9)	**Digital Communications and Signal Processing Design(12)**	Economics II (9)	Foreign Language IV (9)	

Alternatively, the new curriculum permits a much broader curriculum within ECE than was previously possible. The breadth, depth, design, coverage and free electives taken together give more than 13 courses that may be chosen to span the entire range of areas within the department. Such a program might be called the “ECE Technical Generalist.” An example of such a curriculum is shown in FIGURE 15. A student following this curriculum would be well prepared for interdisciplinary engineering projects, as well as further study in engineering management, business or law.

FIGURE 15. An ECE Technical Generalist

FRESHMAN	**FALL**	General Education (9)	**Introduction to ECE (12)**	**Computer Science Intro Programming (10)**	Calculus I (10)	Computing Skills Workshop (3)
	SPRING	General Education (9)	Materials in Engineering (12)	Physics I (12)	Calculus II (10)	
SOPHOMORE	**FALL**	General Education (9)	**Fundamentals of Electrical Eng (12)**	Physics II (12)	Mathematical Foundations of EE (12)	
	SPRING	General Education (9)	**Fundamentals of Computer Eng (12)**	**Signals and Systems (12)**	Modern Math (9)	Biology I (9)
JUNIOR	**FALL**	General Education (9)	**Fundamentals of Computer Science I (12)**	**Digital Circuits (12)**	Modern Chemistry I (10)	
	SPRING	General Education (9)	**Semiconductor Devices I (12)**	**Analog Circuits (12)**	**Engineering Electromagnetics I (12)**	**C/Unix Skills (3)**
SENIOR	**FALL**	General Education (9)	**Analog IC Design (12)**	**Computer Architecture (12)**	Probability / Statistics (9)	
	SPRING	General Education (9)	**Senior Project (12)**	**Concurrency and Real-Time Systems (12)**	**Computer Control Systems Design Laboratory (12)**	

A Focused Preparatory Curriculum: The Premedical Student

This template shown in FIGURE 16 is a more specific example of the Core-Generalist template presented in FIGURE 14 in the previous section. The student in this program is specifically tailoring an ECE program toward a career in medicine. Notice, for example, the choice of the *Introduction to Chemical Engineering* class as a freshman engineering elective (in addition to the *Introduction to ECE* freshman course). This requires a chemistry class as a corequisite, which displaces a General Education class to the spring of the sophomore year. In addition to the usual mathematics, physics, programming and ECE fundamentals classes, this student pursues breadth in signals and systems, circuits and computer software. Depth in signals and systems ultimately leads to a capstone design course in controls and instrumentation. Observe that it is possible to pursue a fairly traditional ECE core that also meshes nicely with the overall interest in medicine. In particular, using the elective slots, this student manages to take three biology classes and five chemistry or chemical engineering classes, to strengthen preparation for medical school. (Note: this curriculum is for illustration only; no assurance is given that the requirements of any given medical school are satisfied.)

FIGURE 16. An ECE Premedical Student

FRESHMAN	**FALL**	General Education (9)	**Introduction to ECE (12)**	**Computer Science Intro Programming (10)**	Calculus I (10)	Computing Skills Workshop (3)
	SPRING	Modern Chemistry I (10)	Introduction to Chemical Engineering (12)	Physics I (12)	Calculus II (10)	
SOPHOMORE	**FALL**	General Education (9)	**Fundamentals of Electrical Eng (12)**	Physics II (12)	Mathematical Foundations of EE (12)	Chemistry II (10)
	SPRING	General Education (9)	**Fundamentals of Computer Eng (12)**	Modern Math (9)	General Education (9)	Bio-Statistics (9)
JUNIOR	**FALL**	General Education (9)	**Signals and Systems I (12)**	Biology I (9)	**Fundamentals of Computer Science I (12)**	Organic Chemistry I (9)
	SPRING	General Education (9)	**Digital Communications and Signal Processing Design (12)**	**Analog Circuits (12)**	Bio-Chemistry I (9)	
SENIOR	**FALL**	General Education (9)	**Fundamentals of Control (12)**	Biology II (9)	Genetics (9)	
	SPRING	General Education (9)	**Computer Control Systems Design Lab (12)**	**Engineering Electromagnetics I (12)**	Organic Chemistry II (9)	

A Curriculum with One Year of Study Abroad

Carnegie Mellon has recently strengthened its commitment to the concept of spending one year abroad during undergraduate studies. Foreign study can be extremely rewarding, but structural impediments in an overly rigid curriculum can render such plans unattractive to even the most committed student. The template shown in FIGURE 17 is merely one example of how this might be accommodated in the new ECE curriculum. Using the flexibility in the proposed curriculum, we have “stacked” the junior and senior years as shown here. During the junior year spent abroad, this student emphasizes humanities and foreign language studies. Upon returning, the student plunges back into a technical program, in this example, a plan of study emphasizing computer hardware, with breadth in computer software, circuits, and signals and systems. Of course, other strategies are possible, but the point to note is that the proposed curriculum can adapt itself to those students intent on pursuing foreign studies.

FIGURE 17. An ECE Student Who Studies Abroad for One Year

FRESHMAN	**FALL**	General Education (9)	**Introduction to ECE (12)**	**Computer Science Intro Programming (10)**	Calculus I (10)	Computing Skills Workshop (3)
	SPRING	General Education (9)	Introduction to Eng and Public Policy (12)	Physics I (12)	Calculus II (10)	C/Unix Skills (3)
SOPHOMORE	**FALL**	General Education (9)	**Fundamentals of Electrical Eng (12)**	Physics II (12)	Linear Algebra (9)	Probability / Statistics (9)
	SPRING	General Education (9)	**Fundamentals of Computer Eng (12)**	Modern Math (9)	**Signals and Systems (12)**	Modern Chemistry I (10)
JUNIOR YEAR ABROAD	**FALL**	General Education (9)	Foreign Language I (9)	Foreign Language II (9)	General Education (9)	
	SPRING	General Education (9)	Foreign Language III (9)	Math/Science (9)	General Education (9)	
SENIOR	**FALL**	**Fundamentals of Computer Science I (12)**	**Computer Architecture (12)**	**Introduction to Telecommunication Networks (12)**	**Digital Circuits (12)**	
	SPRING	**Fundamentals of Computer Science II (12)**	**Concurrency and Real-Time Computing (12)**	**Computer Control Systems Design Lab (12)**	**Semiconductor Devices I (12)**	

A Curriculum with Specific Technical Focus: The CAD / VLSI Designer

The flexibility in the new ECE curriculum allows an ECE bachelor's program to be used as preparation for other post-graduate professional studies. However, the skeptical reader should not jump to the conclusion that the new ECE curriculum is thus specifically tailored to those students who will not pursue engineering as their livelihood, to the detriment of those who will actually become practicing electrical and computer engineers. The critical attribute of a flexible curriculum is that it can adapt to a variety of students. Accordingly, we now consider yet another kind of curriculum: the "focused" program of study that emphasizes particular technical strengths at Carnegie Mellon.

The template shown in FIGURE 18 focuses on Computer-Aided Design (CAD) for Very Large Scale Integrated Circuits (VLSI). Carnegie Mellon's ECE Department houses the Center for Electronic Design Automation, an internationally recognized leader in this area, and a number of our faculty devote their research to its problems. The plan of study illustrated here has substantial breadth and depth in the areas of circuits, computer software and computer hardware. The senior year culminates in a capstone design course in VLSI design that integrates all these skills. In addition, the senior year is also used to attain CAD-specific depth, as well as general breadth in signals and systems and computer architecture. Note that this highly focused plan of study sacrifices none of the general breadth or exposure one would expect of a strong undergraduate ECE degree.

FIGURE 18. A CAD/VLSI Designer

FRESHMAN	**FALL**	General Education (9)	**Introduction to ECE (12)**	**Computer Science Intro Programming (10)**	Calculus I (10)	Computing Skills Workshop (3)
	SPRING	General Education (9)	Fundamentals of Mechanical Engineering (12)	Physics I (12)	Calculus II (10)	
SOPHOMORE	**FALL**	General Education (9)	**Fundamentals of Computer Eng (12)**	Physics II (12)	Modern Math (9)	
	SPRING	General Education (9)	**Fundamentals of Electrical Eng (12)**	Linear Algebra (9)	**Fundamentals of Computer Science I (12)**	**C/Unix Skills (3)**
JUNIOR	**FALL**	General Education (9)	**Digital Circuits (12)**	**Computer Architecture (12)**	**Fundamentals of Computer Science II (12)**	Probability / Statistics (9)
	SPRING	General Education (9)	**Introduction to Computer-Aided Digital Design (12)**	**Analog Circuits (12)**	**Computer Science Algorithms (9)**	Numerical Methods (9)
SENIOR	**FALL**	General Education (9)	**Signals and Systems (12)**	**Discrete Math (9)**	**VLSI CAD: Logic to Layout (12)**	
	SPRING	General Education (9)	**Integrated Circuit Design Project (12)**	**Superscalar Processor Design (12)**	**Physical Design for VLSI (12)**	

Another Curriculum with Technical Focus: The Data Storage Systems Designer

FIGURE 19 shows a template for a plan of study that focuses on data storage systems, with particular emphasis on magnetic recording media and the computer applications that use these media. This program is another example of a focused technical curriculum that exploits particular strengths at Carnegie Mellon. The ECE Department houses a National Science Foundation-supported engineering research center called the Data Storage Systems Center. This center is the focus of interdisciplinary work on a variety of topics in data storage, from the material properties of magnetic media to the architecture of distributed file systems for computer networks. The template shown here is an example of how the new ECE curriculum can support interdisciplinary studies, surmounting some of the barriers between disciplines. The interesting feature of this course of study is its two seemingly disparate areas of concentration: magnetic media and computer systems. Normally, one just does not expect a student to take courses in, say, device physics and computer operating systems. And yet, engineers with precisely such an interdisciplinary background would be ideally positioned to understand and attack the interesting problems in data storage system design. This student achieves breadth in applied physics, circuits, signals and systems and computer software, as well as depth in relevant physics- and computer-related topics. The senior year culminates in a capstone design project in data storage systems.

FIGURE 19. A Data Storage Systems Designer

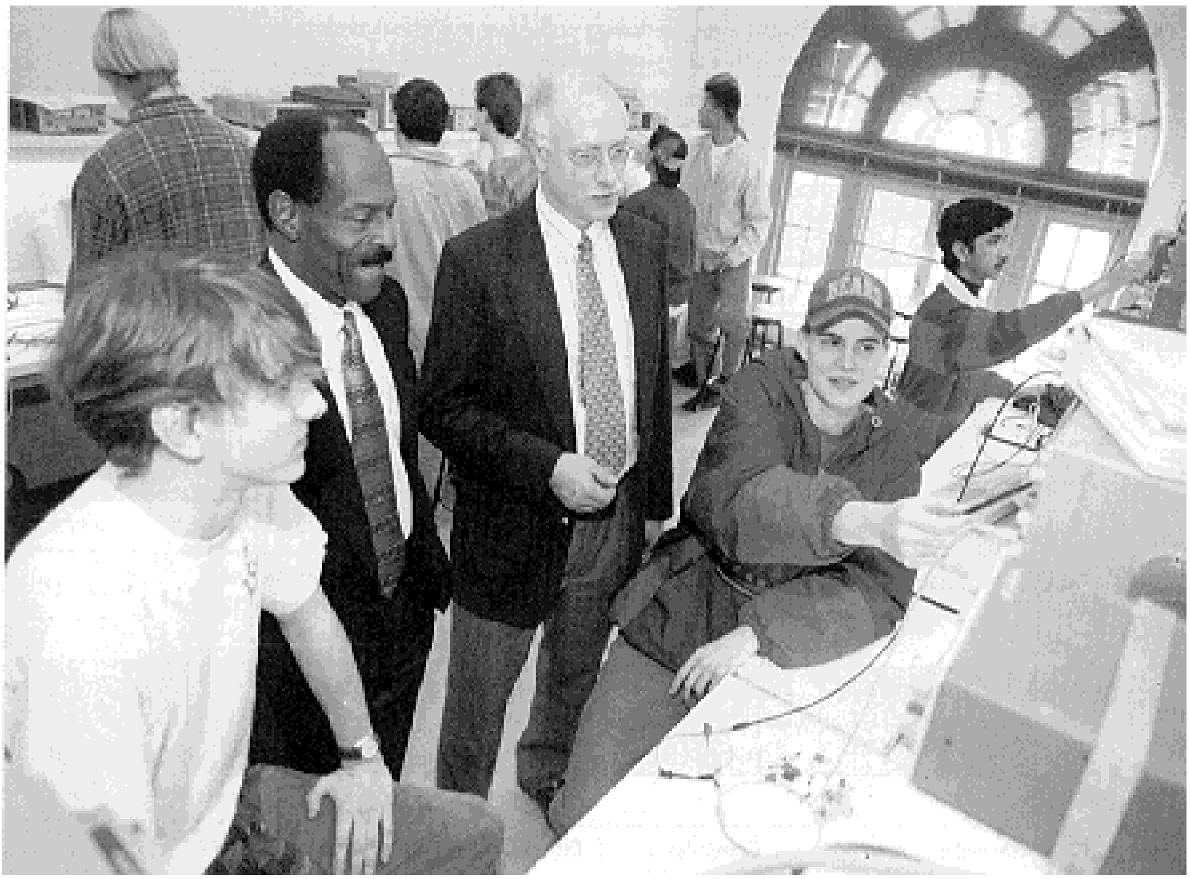
FRESHMAN	**FALL**	General Education (9)	**Introduction to ECE (12)**	**Computer Science Intro Programming (10)**	Calculus I (10)	Computing Skills Workshop (3)
	SPRING	General Education (9)	Materials in Engineering (12)	Physics I (12)	Calculus II (10)	
SOPHOMORE	**FALL**	General Education (9)	**Fundamentals of Electrical Eng (12)**	Physics II (12)	Linear Algebra (9)	
	SPRING	General Education (9)	**Fundamentals of Computer Eng (12)**	Modern Math (9)	Calculus in 3-Dimensions (9)	Chemistry I (10)
JUNIOR	**FALL**	General Education (9)	Materials Science I (9)	**Signals and Systems (12)**	**Fundamentals of Computer Science I (12)**	Probability / Statistics (9)
	SPRING	General Education (9)	**Engineering Electromagnetics I (12)**	**Introduction to Data Storage Systems (12)**	**Fundamentals of Computer Science II (12)**	**Fundamentals of Computer Science II (12)**
SENIOR	**FALL**	General Education (9)	**Engineering Electromagnetics II (12)**	**Data Storage Systems Lab (12)**	**Fundamentals of Controls (12)**	
	SPRING	General Education (9)	**Analog Circuits (12)**	Materials Science II (9)	**Computer Science Operating Systems (12)**	

A Program for the Late Starter

All CIT incoming freshmen must take two introductory engineering courses during their freshman year. It is possible that a student may not take the introductory ECE course during the freshman year but still decide to purse an ECE degree. The template shown in FIGURE 20 shows a program that accommodates such a student.

FIGURE 20. A Late Starting ECE Student

FRESHMAN	FALL	General Education (9)	Foundations of Mechanical Eng (12)	Physics I (12)	Calculus I (10)	Computing Skills Workshop (3)
	SPRING	General Education (9)	Materials in Engineering (12)	Physics II (12)	Calculus II (10)	
SOPHOMORE	FALL	General Education (9)	**Introduction to ECE (12)**	Differential Equations (9)	**Computer Science Intro Programming (10)**	Probability / Statistics (9)
	SPRING	General Education (9)	**Fundamentals of Electrical Eng (12)**	Linear Algebra (9)	Modern Math (9)	Biology (9)
JUNIOR	FALL	General Education (9)	**Fundamentals of Computer Eng (12)**	**Intro to Telecommunications Networks (12)**	**Signals and Systems (12)**	
	SPRING	General Education (9)	**Fundamentals of Computer Science I (12)**	**Semiconductor Devices I (12)**	**Fundamentals of Communication Systems (12)**	
SENIOR	FALL	General Education (9)	**Computer Architecture (12)**	**Digital Circuits (12)**	**Semiconductor Devices II (12)**	
	SPRING	General Education (9)	**Senior Project (6)**	**Analog Circuits (12)**	**Computer Control Systems Design Lab (12)**	



Hewlett-Packard representatives, Al Moyé and Bob Haye, viewing donated equipment.

CHAPTER 6

CMU ECE Class of 1995: Data and Analysis

Implementation of the new ECE curriculum began in the fall semester of 1991. The first class of graduates will finish in the spring of 1995. Hence, some obvious questions, *e.g.*, employer response to our new graduates, cannot yet be answered as of this writing. However, over the last year we have begun to gather data–both anecdotal and quantitative–about the impact of the new curriculum and how our students are navigating its manifold elective choices. We offer some preliminary data and analysis in this chapter.

First Impressions

To date, four cohorts of students have entered the new ECE curriculum, entering in the fall of 1991, 1992, 1993 and 1994 respectively. Each cohort had roughly 150 students. The most advanced typical student is now finishing the senior year of his or her curriculum. Although a few students have finished ahead of schedule, we still have insufficient data about graduates from the curriculum. However, we have a wealth of anecdotal impressions about the first three of these cohorts.

On the qualitative side, perhaps the most common observation is that the entering students are enthusiastic about starting real engineering classes in their first semester. They also simply appreciate the attention being paid to them by their actual chosen departments in their first year, as opposed to the older curriculum in which ECE played no role until late in the second year. There is also evidence that students are using the freshman engineering courses offered by each department to help select their major, or at least, to decide which majors they do not wish to pursue. At least a few students have switched majors from their original choice after sampling the introductory freshman course offered by that department. An unexpected positive side effect of teaching engineering early is that some students have actually been able to land engineering jobs during the summer after their freshman year.

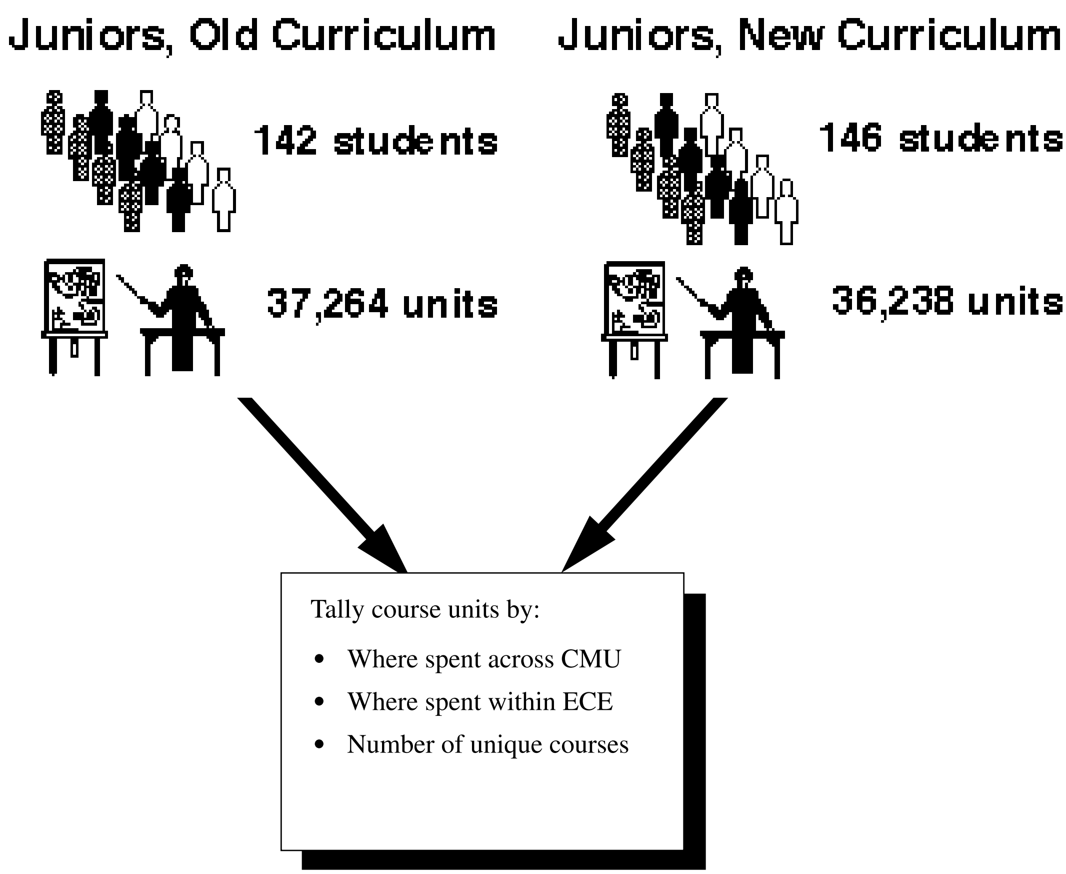
The second year's *Fundamentals of EE* and *Fundamentals of CE* classes also appear to be succeeding–although mathematics coverage remains an issue we are working to address (see Chapter 4). The extra facility in the laboratory gained during the freshman year helps considerably, allowing more interesting labs earlier in the curriculum. There is also evidence of students making active choices to select one or another of these courses early in the second year, to attain the prerequisites necessary to elect an ECE breadth course in the second half of the year. One common example is the election of *Fundamentals of EE* in the first half of the year, followed by *Signals and Systems* in the second half. Again, students especially like the idea of being able to elect real engineering classes early in the curriculum, and often use this flexibility to get an early start on their breadth electives, rather than taking a free elective in their sophomore year. We had originally envisioned this unconstrained slot in the sophomore year as a free elective, as illustrated in FIGURE 2 on page 22. Instead, students often prefer getting into an ECE breadth class as early as possible.

Impact on Course Choices

To answer questions about what students are actually doing with their newfound flexibility in this curriculum, we performed an experiment illustrated in FIGURE 21. Two populations of students were identified for comparison:

- Students in the graduating class of 1992 who were juniors during the 1990-1991 academic year and whose previous three years of courses were taken in the *old* (pre-1991 version) ECE curriculum.
- Students in the graduating class of 1995 who were juniors during the 1993-1994 academic year and whose previous three years of courses were taken in the *new* ECE curriculum.

FIGURE 21. **Experiment to Compare Course Elections Between Old and New ECE Curricula**



We looked at all the courses elected over the preceding three years in each population of students, and counted where (department and college at Carnegie Mellon) each course was taken, and for how many units of credit. At Carnegie Mellon, typical courses range from 9 to 12 units, the number representing the estimated hourly workload of the class. In the old curriculum, the typical workload was between 44 and 54 units per semester; in the new curriculum the target is for this to be 45 units per semester. The old curriculum required 388 units to complete the bachelor's degree; the new curriculum requires 360, a reduction of essentially 2.5 classes. The data provide an interesting picture of how students are reacting to the new curriculum.

FIGURE 22 tallies the number of units elected within ECE, and across the various colleges of Carnegie Mellon. One obvious fact is that, despite the flexibility to avoid some ECE courses, students are still spending most of their units inside ECE; there is no mass flight to easier courses. Election of courses in engineering outside ECE is down, primarily due to the elimination of old requirements to elect a few *ad hoc* courses in other engineering departments, *e.g.*, thermodynamics, statics and so forth. The new curriculum requires all students to take two introductory courses in the freshman year, one of which is usually in the student's major area–*Introduction to ECE* for our students. Election of computer science courses is up. There was always an unmet demand in the old curriculum by non-CE students to take more computer-related courses, but it was extremely difficult to fit them in. This appears to have been resolved in the new curriculum. Election of math/science classes is slightly down due to some changes in the required courses, *e.g.*, three 9-unit physics courses were replaced by two 12-unit courses, and the chemistry requirement was eliminated altogether.

There are also some interesting lower-level changes not apparent in this chart. For example, FIGURE 23 shows the number of unique, *i.e.*, *different* courses elected by the two populations. Students in the new curriculum are taking a wider variety of courses.

FIGURE 24 refines the data related to ECE-specific courses in the top two bars of the chart of FIGURE 22. Here, each course elected in ECE has been tallied based on the relevant ECE breadth area, as defined by the new curriculum. Courses in the old curriculum were matched to their best fit in the new curriculum. In addition, the freshman *Introduction to Electrical and Computer Engineering* was arbitrarily counted as being half in the computer hardware area and half in the circuits area. FIGURE 24 shows where the 1994 juniors chose to exercise their flexibility within the new curriculum, versus the mix of required and elective courses for 1991 juniors in the old curriculum.

FIGURE 22. **Comparative Course Elections: Across Carnegie Mellon Colleges**

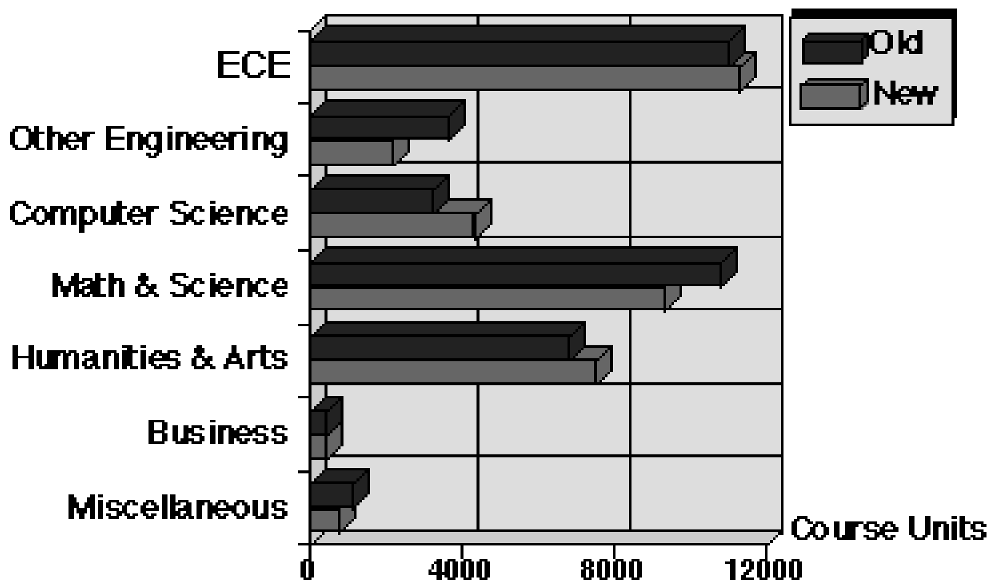


FIGURE 23. **Comparative Course Elections: Unique (Different) Courses**

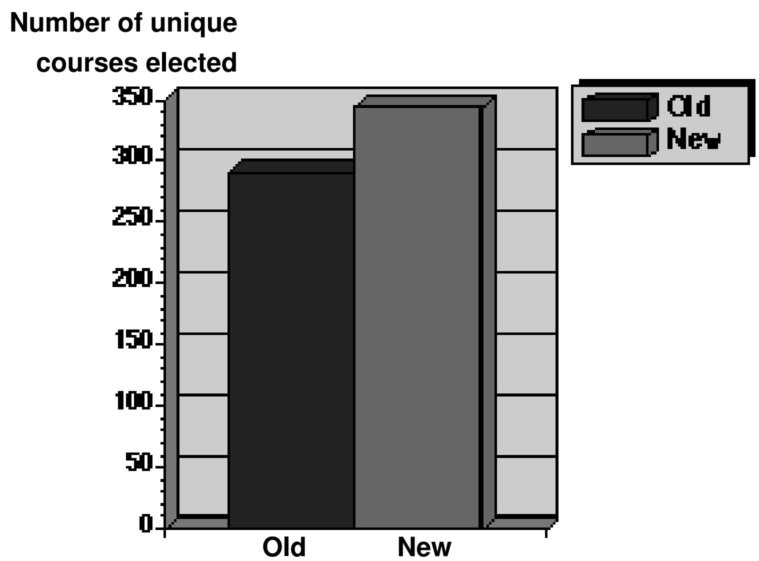
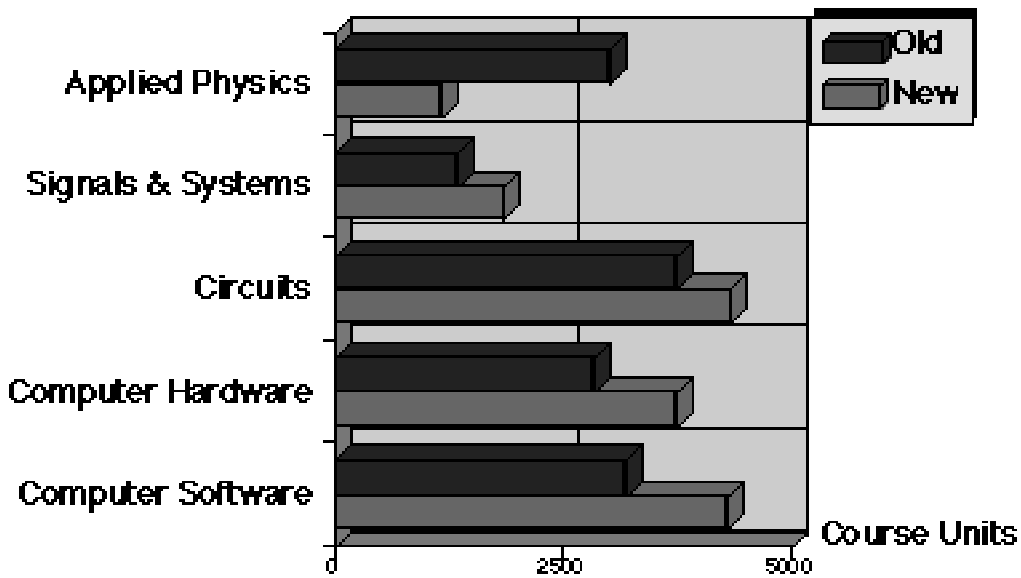


FIGURE 24. **Comparative Course Elections: Across ECE Breadth Areas**



Again, there are several interesting observations. Election of applied physics courses is down substantially. In part this reflects the elimination of a required solid state devices class for all students (electrical engineering and computer engineering) in the 1991 curriculum, and of required electromagnetics courses for electrical engineers. More interesting though is the choice of courses in the new curriculum. The elective solid state breadth course in this area has seen its enrollment increase nearly 50 percent in comparison with the old introductory solid state course. More students are now electing to sample the applied physics area via the solid state course, instead of via the electromagnetics course. Conversely, enrollment in electromagnetics courses has fallen by about 50 percent, though there is some evidence that the prerequisite of an extra calculus class (3-D methods) is making electromagnetics less attractive. (See again our discussion of the motivations for the proposed *Mathematical Foundations of EE* class, Chapter 4, page 58.) It has also been suggested that the lack of recently offered advanced design-oriented capstone classes in this area that pull students toward electromagnetics is also a contributing factor; new capstone design classes planned for this area (*e.g.*, microwave design) might change this.

Election of signals and systems courses is up, primarily due to the popularity of the introduction breadth course in this area as a first ECE course beyond the *Fundamentals of Electrical Engineering* requirement. Circuits units are also up, due in some part to counting freshman *Fundamentals of ECE* partly in this area, as well as *Fundamentals of Electrical Engineering*, both of which are required. Computer hardware units are up, again for a similar reason due to *Fundamentals of ECE* and *Fundamentals of Computer Engineering*. Computer software elections are also up strongly, reflecting continued interest in programming classes that now more easily fit into the schedules of ECE students who are not specifically trying to become computer engineers.

Overall, there is still substantial breadth of course elections among the ECE topical areas, and among Carnegie Mellon colleges, albeit with some shifts in emphasis. None of the worst-case scenarios we might have imagined–mass flight from difficult courses, for example–have come to pass. Most students continue to elect challenging courses, now somewhat more widely distributed across ECE’s breadth.

CHAPTER 7

Integrated M.S./B.S. Degrees Program

One entirely unexpected recent spin-off of our curriculum design efforts is the recent creation of an integrated master's degree in ECE. We briefly discuss the motivation and current structure of this program in this chapter.

Motivation

There has been widespread discussion about how the best among our undergraduate students typically elect graduate school, but the solid middle-of-the-curve student typically enters industry immediately–despite the fact that another year of course and project work would be immensely helpful to that student's career. Similar to the model now in place within Electrical Engineering and Computer Science at MIT, our program offers automatic admission to students who achieve a specified minimum grade point average over certain courses and ECE breadth areas.

The primary purpose of the new Integrated M.S./B.S. Degrees program is to provide students with superior breadth and depth of technical material, which will better prepare them for careers in industry. The program normally requires an additional year of coursework beyond the bachelor's degree requirements. However, students who pursue the Integrated M.S./B.S. Degrees substantially enhance their readiness to contribute in an industrial position. The advanced education attainable via the program is likely to be better integrated and more sophisticated than the further education pursued at “local” colleges or universities as a part-time or evening student.

Requirements

This program is available to all undergraduates who maintain a cumulative QPA of 3.0 out of 4.0. No course with a grade lower than C is counted toward the master’s degree requirements for the integrated degree.

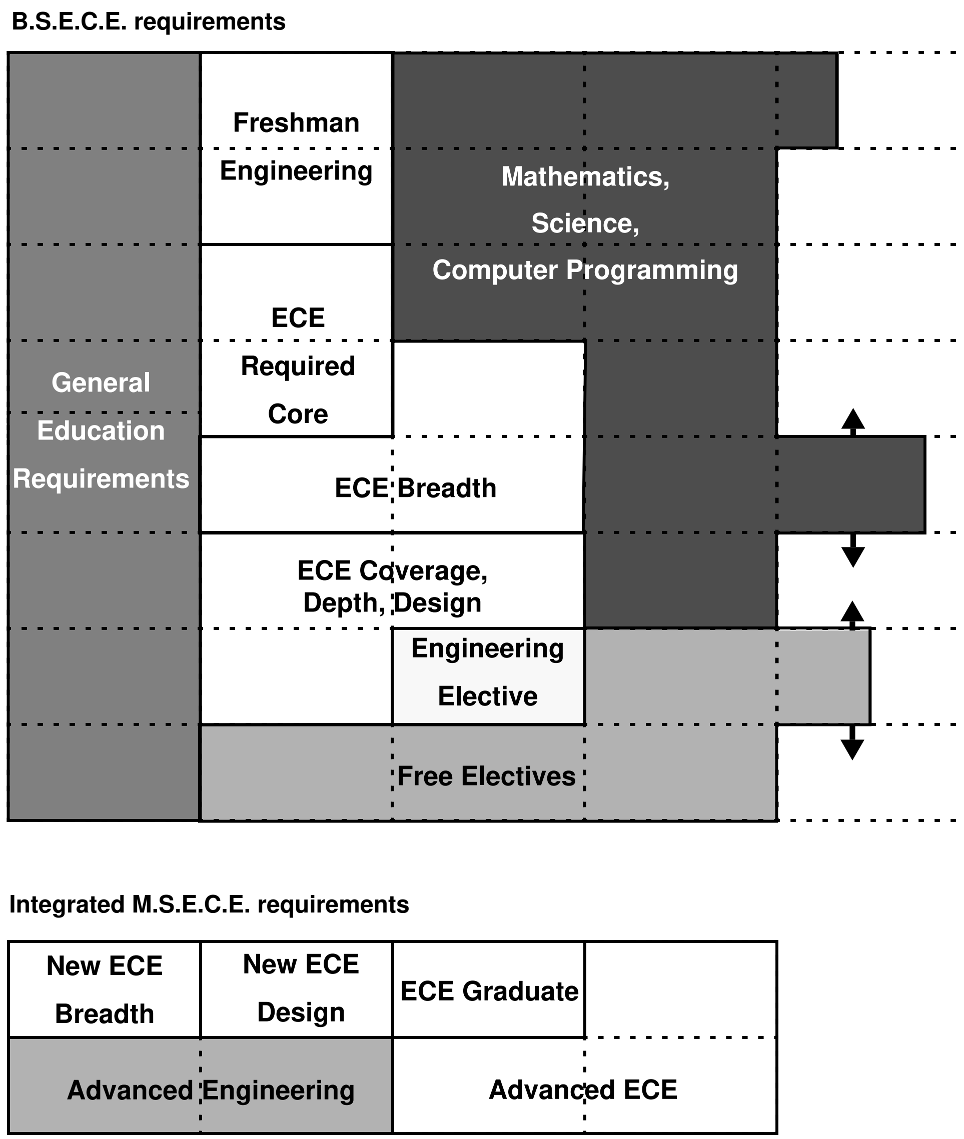
The following are the additional requirements for the Integrated M.S./B.S. Degrees over and above the requirements for the bachelor’s degree. Note, no course can be counted as satisfying more than one of the requirements listed below and no course used to satisfy the basic bachelor’s degree requirements can be used to satisfy one of the requirements listed below. The requirements total 96 units (nominally eight 12-unit courses).

1. **Breadth Requirement (12 units):** To increase the breadth in ECE, students must take 12 units of course work in a “new” area–an area in which they have not already taken an introductory course (this makes four breadth areas rather than the three required for the bachelor’s degree).
2. **Additional Design Capstone Requirement (12 units):** To further prepare students for engineering design work, they must take an additional course from the list of acceptable engineering design capstone courses (this makes two design capstone courses rather than the one required for the bachelor’s degree). Both design capstones can be in the same area or in different areas.
3. **ECE Graduate Course Work (12 units):** Any mezzanine-level senior-graduate or higher course(s) can be used to satisfy this requirement. (Within ECE these are numbered as 18-5xx courses.)
4. **Advanced ECE Course Work (36 units):** Any graduate-level or higher courses can be used to satisfy this requirement. (Within ECE these are numbered as 18-7xx courses.)
5. **Advanced Engineering Course Work (24 units):** Any graduate-level (18-7xx) advanced courses in ECE or any courses drawn from a list of designated non-ECE advanced engineering courses can be used to satisfy this requirement.

Up to 15 units of graduate project can be used in place of any of the course work from areas 3, 4 or 5 listed above. The graduate project must contain substantial design and/or research experience. Graduate projects must be proposed (one page abstract describing project), supported by a faculty adviser and approved by the ECE Graduate Education Committee.

A final, salient point here was the unexpected ease of extending our undergraduate B.S.E.C.E. program to become an integrated master's program. FIGURE 25 again shows the overall structure of the ECE undergraduate degree, now with the requirements of the Integrated M.S./B.S. added.

FIGURE 25. Integrating Master's Requirements into ECE Bachelor's Degree



CHAPTER 8

Summary

Curriculum Evolution: 1991 to 1995

In the fall of 1991, after approximately two years of work, a novel electrical and computer engineering curriculum was implemented at Carnegie Mellon. The curriculum features a small core of required classes, engineering courses beginning in the freshman year, area requirements in place of specific course requirements, mandates on breadth, depth, coverage and design, and a unified electrical and computer engineering bachelor's degree.

Four cohorts of students are in the pipeline of the new curriculum to date; the first class will graduate in 1995. Measurements suggest that even with large amounts of flexibility, students continue to elect difficult, broad courses of study. We believe that flexibility in the election of courses, avoidance of rigid requirements and notions of exposure to all "critical" topics, and tolerance of students with widely varying preparation and aspirations are the essential features of the curriculum. In 1994 the curriculum was extended to incorporate the Integrated M.S./B.S. ECE Degrees. Four years into the new curriculum, we still have high rankings in the national media, *e.g.*, [15].

Rather than being a divisive exercise, we believe that our overall curriculum design process, including an analysis of the problems to address and the generation of some basic guiding principles to solve these problems, was a useful exercise in involving all of our faculty in the evolution of the curriculum. Somewhat to our surprise, the curriculum and its design philosophy continue to be widely discussed outside of Carnegie Mellon, *e.g.*, [2] [3] [4] [5]. Several hundred copies of the original curriculum design document [1] were requested from colleagues around the world. In this document, we have revisited some of this same material, but tried to offer some additional insights (and hindsights) on that design process, some analysis of its impact on our students and some guidance to others undertaking this important task.

Acknowledgments

The new ECE curriculum was originally designed by the Wipe the Slate Clean Committee, whose membership included ECE faculty L. Richard Carley, Stephen W. Director, James F. Hoburg, Pradeep K. Khosla, B. V. K. Vijaya Kumar, Ronald A. Rohrer, Rob A. Rutenbar (Chair), T. Ehud Schlesinger, Daniel D. Stancil, Jay K. Strosnider and Donald E. Thomas. Professor Ronald P. Bianchini is the principal architect of the course planning software mentioned in Chapter 3. Much of the early implementation of the curriculum was overseen by Professors James F. Hoburg and Daniel D. Stancil. The current evolution of the curriculum is being overseen by Professor B. V. K. Vijaya Kumar. Professor Charles P. Neuman is coordinating the department's revised advising strategy. Contributors to this document were ECE Professors L. Richard Carley, Stephen W. Director, James F. Hoburg, Pradeep K. Khosla, B. V. K. Vijaya Kumar, Charles P. Neuman, Ronald A. Rohrer, Rob A. Rutenbar, Daniel D. Stancil, Sarosh Talukdar and Robert M. White. Professors
B. V. K. Vijaya Kumar, Rob A. Rutenbar and Daniel D. Stancil edited this revision. Sandra Salmonsen assisted with the production of this document.

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APPENDIX A

Complete ECE Undergraduate Course List

We provide here complete new lists of the courses that satisfy the various requirements of the ECE curriculum with the exception of courses in the humanities and arts used to satisfy the general education requirements. However, it is important to emphasize that the curriculum is still evolving, especially for the upper-division classes.

ECE Course Lists, by Area

In the following lists, courses satisfy one or more of the ECE requirements as indicated by the symbols: B = Breadth, Ds = Design, Co = Coverage, Dp = Depth.

Courses within ECE are numbered 18-xxx. Courses from other departments start with numbers other than 18. Some relevant other departments are:

- *Computer Science*, 15-xxx
- *Mathematics*, 21-xxx
- *Physics*, 33-xxx
- *Statistics*, 36-xxx
- *College of Engineering*, interdisciplinary, 39-xxx

Mathematics, Science and Computer Programming Requirements

	Units
• 99-101 *Computing Skills Workshop*	3
• 15-127 *Introduction to Programming and Computer Science* (corequisite to *Intro. to ECE)*	10
• 21-121 *Calculus I*	10
• 21-122 *Calculus II*	10
• 21-241 *Linear Algebra* (possible corequisite to *Fund. of EE*)	9
• 21-127 *Introduction to Modern Mathematics* (corequisite to *Fund. of CE*)	9
• 33-106 *Physics for Engineering Students I*	12
• 33-107 *Physics for Engineering Students II*	12
• xx-xxx *Math/Science Elective* (see below)	9

The math/science elective may be satisfied by any course in biology, chemistry or physics, or any 200 level course or higher in mathematics or statistics except for certain courses intended exclusively for nontechnical majors. Some suggested math courses of interest to electrical and computer engineers are:

• 21-259 *Calculus in Three Dimensions*	9
• 21-260 *Differential Equations*	9
• 36-217 *Probability Theory and Random Processes*	9
• 36-220 *Engineering Statistics and Quality Control*	9
• 36-225 *Introduction to Probability and Statistics I*	9
• 36-226 *Introduction to Probability and Statistics II*	

Any of the last four courses listed above (36-xxx) can be used to satisfy the probability/statistics requirement.

Freshman Engineering and ECE Core

• 18-100 *Introduction to Electrical and Computer Engineering*	12
• 18-220 *Fundamentals of Electrical Engineering*	12
• 18-240 *Fundamentals of Computer Engineering*	12

Applied Physics

•	18-303 *Engineering Electromagnetics I* (B, Co)	12
•	18-304 *Engineering Electromagnetics II* (Dp, Co)	12
•	18-311 *Semiconductor Devices I* (B, Co)	12
•	18-312 *Semiconductor Devices II* (Dp, Co)	12
•	18-316 *Introduction to Data Storage Systems Technology* (B, Co)	12
•	18-400 *High Frequency System Design* (Ds, Co)	12
•	18-405 *Computer-Aided Design of Electromagnetic Systems* (Ds, Co)	12
•	18-501 *Electromechanics* (Dp, Co)	12
•	18-517 *Data Storage Systems Measurement Design Laboratory* (Ds, Co)	12
•	18-701 *Electromagnetic Field Theory* (Co)	12
•	18-702 *Finite Element Methods in Electrical Engineering* (Co)	12
•	18-708 *High Frequency Engineering* (Co)	12
•	18-711 *Solid State Electronics* (Co)	12
•	18-712 *Microwave and Optical Magnetics* (Co)	12
•	18-713 *Fundamentals of Carrier Transport* (Co)	12
•	18-714 *Introduction to Superconducting Devices* (Co)	12
•	18-715 *Physics of Applied Magnetism* (Dp, Co)	12
•	18-716 *Advanced Applied Magnetism* (Co)	12

Signals and Systems

•	18-370 *Fundamentals of Control* (Dp, Co)	12
•	18-373 *Computer-Controlled Testing and Measurement System Design* (Ds, Co)	12
•	18/15-384 *Artificial Intelligence: Robotic Manipulation* (Co)	9
•	18-396 *Signals and System*s (B, Co)	12
•	18-474 *Computer Control Systems Design Laboratory* (Ds, Co)	12
•	18-550 *Fundamentals of Communications Systems* (Dp, Co)	12

- 18-551 *Digital Communications and Signal Processing System Design* (Dp, Ds, Co) 12
- 18-575 *Control Systems Design* (Ds, Co) 12
- 18-751 *Applied Stochastic Processes* (Co) 12
- 18-752 *Estimation, Detection and Identification* (Co) 12
- 18-754 *Error Control Coding: Theory and Applications* (Co) 12
- 18-756 *Circuit Switching & Packet Switching* (Co) 12
- 18-757 *Principles of Broadband Communication* (Co) 12
- 18-771 *Linear Systems* (Co) 12
- 18-772 *Multivariable Control* (Co) 12
- 18-773 *System Identification and Adaptive Control* (Co) 12
- 18-774 *Digital Control* (Co) 12
- 18-775 *Optimal Control* (Co) 12
- 18-776 *Nonlinear Control Systems* (Co) 12
- 18-777 *Model Predictive Control* (Co) 12
- 18-778 *Discrete Event Systems* (Co) 12
- 18-791 *Digital Signal Processing I* (Dp, Co) 12
- 18-792 *Digital Signal Processing II* (Dp, Co) 12
- 18-793 *Optical Image and Radar Processing* (Co) 12
- 18-794 *Pattern Recognition Theory* (Co) 12
- 18-796 *Numerical Optimization Methods* (Co) 12

Circuits

- 18-321 *Analysis and Design of Analog Circuits* (B, Co) 12
- 18-322 *Analysis and Design of Digital Circuits* (B, Co) 12
- 18-523 *Analog Integrated Circuit Design* (Dp, Ds, Co) 12
- 18-525 *Integrated Circuit Design Project* (Dp, Ds, Co) 12
- 18-723 *Advanced Analog Integrated Circuit Design* (Co) 12
- 18-725 D*igital Integrated Circuit Design* (Ds, Co) 12

- 18-728 *Applications of Analog Integrated Circuits* (Ds, Co) 12
- 18-762 *Circuit Simulation: Theory and Practice* (Co) 12

Computer Hardware

- 18-345 *Introduction to Telecommunications Networking* (B, Co) 12
- 18-347 *Introduction to Computer Architecture* (B, Co) 12
- 18-349 *Concurrency and Real-Time Systems* (B, Co) 12
- 18-360 *Introduction to Computer-Aided Digital Design* (B, Co) 12
- 18-545 *Advanced Digital Design Project* (Dp, Ds, Co) 12
- 18-547 *Superscalar Processor Design* (Dp, Co) 12
- 18-549 *Time Critical Computing Systems* (Dp, Co) 12
- 18-742 *Advanced Computer Architecture* (Co) 12
- 18-746 *Parallel Processing* (Dp, Co) 12
- 18-748 *Dependable System Design* (Dp, Co) 12
- 18-760 *VLSI CAD: Logic to Layout* (Dp, Co) 12
- 18-761 *VLSI CAD: Layout to Manufacturing* (Co) 12
- 18-763 *Physical CAD for VLSI* (Co) 12

Computer Software

- 15-211 *Fundamental Structures of Computer Science I* (B, Co) 12
- 15-212 *Fundamental Structures of Computer Science II* (Dp, Co) 12
- 15-312 *Programming Languages Design and Processing* (Co) 9
- 15-381 *Artificial Intelligence: Representation and Problem Solving* (Co) 9
- 15-385 *Artificial Intelligence: Computer Vision* (Co) 9
- 15-411 *Compiler Design* (Co) 12
- 15-412 *Operating Systems* (Co) 12
- 15-413 *Software Engineering* (Ds, Co) 12
- 15-414 *Structured Programming and Problem Solving* (Co) 9
- 15-451 *Algorithms* (Co) 9
- 15-453 *Formal Languages and Automata* (Co) 9

- 15-462 *Computer Graphics* (Co) 9
- 15-612 *Distributed Systems* (Co) 12

Professional, Policy and Interdisciplinary Topics

- 18-480 *Senior Seminar* 0
- 18-482 *Telecommunications: Technology, Policy and Management* (Co) 12
- 18-483 *Civilian and Military Applications of Space* (Co) 12
- 18-489 *Basic Trends in the Evolution of Modern Microelectronics* (Co) 12
- 39-405 *Engineering Design: The Creation of Products and Process* (Ds, Co) 12

Undergraduate Projects

- 18-231 *Sophomore Project-Fall* (Co) variable
- 18-232 *Sophomore Project-Spring* (Co) variable
- 18-331 *Junior Project-Fall* (Co) variable
- 18-332 *Junior Project-Spring* (Co) variable
- 18-431 *Senior Project-Fall* (Co) variable
- 18-432 *Senior Project-Spring* (Co) variable
- 18-439 *Special Topics in ECE* (Co) variable
- 39-500 *CIT Honors Research Project* (Ds, Co) variable

ECE Course Descriptions, by Course Number

18-100
Introduction to Electrical and Computer Engineering **Fall and Spring: 12 units**

The goals of the introductory course are: to introduce basic concepts in electrical and computer engineering in an integrated manner; to motivate basic concepts in the context of real applications; to illustrate a logical way of thinking about problems and their solutions; and to convey the excitement of the field. These goals are attained through analysis, construction and testing of an electromechanical system (*e.g.* a robot) that incorporates concepts from a broad range of areas within Electrical and Computer Engineering. Some of the specific topics that will be covered include system decomposition, real and ideal sources, Kirchhoff's and Ohm's Laws, Linear and Nonlinear circuit elements, Ideal Op-Amp characteristics, combinational logic circuits, Karnaugh Maps and Flip-Flops. The course will culminate in a final project that will provide an opportunity for creative design. 3 hr. lec., 1 hr. rec., 3 hr. lab. Corequisites: 15-127 and 21-121.

18-113
Basic Electrical Engineering **Spring: 9 units**

The objective of this course is to provide solid understanding of the basic sciences underlying electrical circuits; dielectric and magnetic devices, rotating machinery, and the development of capacity to apply this science with creative skill in a variety of applications selected from the fields of electrical engineering. 2 hrs. lec., 3 hrs. lab. Prerequisites: junior standing in Mechanical Engineering, 33-107, 24-245.

18-200
Mathematical Foundations of Electrical Engineering **Fall: 12 units**

This course covers topics from engineering mathematics that serve as foundations for descriptions of electrical engineering devices and systems. It has four major parts: (1) Complex analysis, including complex numbers and complex analytic functions; (2) Ordinary differential equations of first- and second-order; (3) Linear algebra, including matrices, vectors and determinants; (4) Vector calculus, including the vector differential operators gradient, divergence and curl, and vector integral calculus, including multiple integrations and integral theorems. 3 hrs., 1.5 hrs. rec. Prerequisite: 21-122.

18-220
Fundamentals of Electrical Engineering:
Introductory Circuit Analysis **Fall and Spring: 12 units**

The course thoroughly covers the fundamentals of linear circuit analysis necessary to perform design of digital and analog electronic circuits: Kirchhoff's Voltage and Current Laws; Superposition and Convolution; Series, Parallel and Ladder Circuit Analysis; Thevenin's and Norton's Theorems; Natural Frequencies; Circuit Partitioning; Nodal Analysis; Fourier series representation of periodic signals and frequency domain analysis. This course will cover these principles thoroughly in the context of the transient and sinusoidal steady state analysis of RLC circuits. Theoretical investigations presented in the class will be reinforced with laboratory experiments. A recurring motivational theme throughout the course is the study of high performance digital system switching speed limitations imposed by electronic circuit interconnects. 3 hrs. lec., 1 hr. rec., 3 hrs. lab. (every other week). Prerequisite: 18-100. Corequisite: 21-241, or 18-200.

18-231 **Fall: Variable units**
18-232 **Spring: Variable units**
Sophomore Projects

Experience in independent planning and conduct of engineering research, development or design projects, usually in concert with the research interests and programs of individual faculty members. Prerequisite: sophomore standing in Electrical and Computer Engineering.

18-240
Fundamentals of
Computer Engineering **Fall and Spring: 12 units**

This course introduces basic issues in design and verification of modern digital systems. Topics include: Boolean algebra, digital number systems and computer arithmetic, combinational logic design and simplification, sequential logic design and optimization, register-transfer abstractions of digital systems, basic machine organization and instruction set issues, assembly language programming and debugging, and microprogramming. Emphasis is on the fundamentals, the levels of abstraction that allow designers to cope with hugely complex systems and connections to practical hardware implementation problems. Students will use computer-aided digital design software and actual hardware implementation laboratories to learn about real digital systems. 3 hrs. lec., 1 hr. rec., 3 hrs. lab. Prerequisite: 18-100, Corequisite: 21-127.

18-303
Engineering Electromagnetics I — Spring: 12 units

The objective of this and the subsequent course is to develop an understanding of fundamental electromagnetic principles and of electromagnetic field analysis methods. Maxwell’s Equations in integral and differential forms, boundary conditions; Electroquasistatics, potential and voltage, Poisson’s equation; Method of images; Capacitance; Laplace’s equation, solutions in Cartesian, polar and spherical coordinates, numerical methods; Conduction; Polarization; Magnetoquasistatics, vector potential, Biot-Savart Law; Induced voltages as described by Faraday’s Law, inductance; Magnetization, magnetic circuits; Numerical simulation laboratory and projects. 3 hrs. lec., 2 hr. rec., lab additional. Prerequisites: 18-220 and 21-259 or 18-200.

18-304
Engineering Electromagnetics II — Fall: 12 units

Maxwell’s equations, differential and integral forms; Energy conservation, Poynting Theorem; Plane waves; TEM waves on 2-conductor transmission lines, sinusoidal steady state, Smith Chart, reflection and transmission of transients at discontinuities; Modal description of waveguides and cavities; Radiation, antennas; Numerical simulation laboratory and projects. 3 hrs. lec., 2 hr. rec., lab additional. Prerequisite: 18-303.

18-311
Semiconductor Devices I — Spring: 12 units

In this course students will build a fiber optic communication system, capable of transmitting and receiving amplitude-modulated audio information over a glass optical link. The fundamental concepts central to understanding, applying and modeling electronic devices are introduced and studied in the laboratory using this system. The goal is to develop an understanding of the operation of semiconductor devices, both electronic and optical, in terms of relevant physical concepts and to apply these devices in practical circuits.

Devices studied in this course include bipolar junction transistors, PN diodes, Zener diodes, photodetectors, light emitting diodes, glass optical fibers and Schottky diodes. The fundamental physical principles governing their operation, how to use them in circuits by applying the appropriate DC and AC voltages, and how to predict the performance of the circuit using simple models and approximations, will be covered.

The description of the fundamental principles will make use of energy band theory, and will include the following topics: electron and hole generation in solids; carrier transport (drift and diffusion); carrier mobility; doping and conductivity; band diagrams; Fermi level and energy distribution functions; carrier recombination; generation, transmission and absorption of light in solids as a function of wavelength; minority carrier diffusion equation; PN junction electrostatics and carrier transport. 3 hrs. lect., l hr. rec., 3 hrs. lab. Prerequisite: 18-220.

18-312
Semiconductor Devices II **Fall: 12 units**

This course, a continuation of *Semiconductor Devices I*, will focus on the physics and operation of field effect devices, including MOS capacitors, MOSFET's, JFET's and MESFET's, as well as more advanced devices, such as charge coupled devices (CCD's), metal-semiconductor junctions and heterostructure transistors. The course will begin with a thorough description of the MOS capacitor: electron affinity and metal work functions; accumulation, depletion, weak and strong inversion regimes; flatband and threshold voltage; ionic, fixed, oxide trapped, and interface trapped charges and their effects; high and low frequency capacitance-voltage measurements. We will then develop and solve the charge transport equations for the MOSFET to obtain terminal I-V curves. Nonidealities encountered in modern field effect devices, such as the narrow width effect, drain induced barrier lowering, hot carrier generation, *etc.*, will be investigated in detail. The course will conclude with similar treatments of other technologically important semiconductor electronic devices. 3 hrs. lect., 1 hr. rec., Prerequisite: 18-311.

18-316
Introduction to Data Storage
Systems Technology **Spring: 12 units**

This course teaches the fundamentals of magnetic and optical recording technology as used in data storage systems, audio and video recording. It begins with a description of the fundamental properties of magnetic materials. The origins of magnetism, demagnetizing fields, anisotropy, magnetostriction, domains and coercivity are explained. With this as a basis, the operation of magnetic and magneto-optical recording devices such as rigid and floppy disk drives, tape recorders, compact disk players and optical disk drives is explained. 4 hrs. rec. Prerequisites: 33-107 and 18-200 or 21-259.

18-321
Analysis and Design of Analog Circuits **Spring: 12 units**

The purpose of this course is to introduce the student to the fundamentals of the analysis and design of basic analog circuits. Topics to be covered include: DC bias calculations and circuits, MOSFET and BJT large- and small-signal device models, small-signal gain and frequency response characteristics of single-stage amplifiers, operational amplifier design, basic theory of feedback amplifiers, frequency stability and compensation techniques, large-signal characteristics and nonidealities. In the hardware laboratory, the student will gain experience designing and implementing analog circuits, and comparing actual to simulated performance using the SPICE circuit simulation program. The analysis and design of analog circuits incorporating both Bipolar and CMOS technologies will be considered. 3 hrs. lec., 1 hr. rec., 3 hrs. lab. Prerequisite: 18-220.

18-322
Analysis and Design of Digital Circuits **Fall: 12 units**

The purpose of this course is to introduce the student to the fundamentals of the analysis and design of basic digital circuits. Topics to be covered include: MOSFET and BJT large-signal device models, propagation delay calculations, MOS and BJT combinational and sequential gates, physical layout techniques, semiconductor memories, programmable logic arrays, pulse-generation techniques, and TTL and ECL technologies. The necessity of circuit simulation (SPICE), timing simulation (COSMOS) and physical layout (MAGIC) computer tools is stressed. The lab includes the design, analysis, layout and verification of a digital system such as a simple microprocessor. 3 hrs. lec., 1 hr. rec., 3 hrs. lab. Prerequisites: 18-220 and 18-240.

18-323
Analog Filter Design **Offered intermittently: 12 units**

Analog filtering is an indispensable aspect of signal processing. Passive filters for high frequency applications and active filters employing inexpensive operational amplifiers are emphasized in both the theory and laboratory/project portions of the course. Specific topics to be covered are the following: Overview of Analog Filter Design; Review of Resistor Operational Amplifier Circuits; Butterworth and Chebyshev Low Pass Filter Approximations; Frequency Scaling; Active Circuit Realizations of Low Pass Filters; High Pass Filter Specification; Low Pass to High Pass Transformation; Active Circuit Realizations of High Pass Filters; Inverse Chebyshev Approximation; Cauer Filters; Low Pass to Band Pass and Band Stop Transformations; Active Circuit Realization of Band Pass and Band Stop Filters;

Passive Filter Design; Sensitivity; Active Circuit Equivalents for Passive Filter Elements; State Variable Forms of Filter Design; Delay Filters; Switched Capacitor Filters. This course will be conducted as a series of design exercises, each starting with a solution in theory and ending with a practical realization in the laboratory. 3 hrs. rec., 3 hrs. lab. Prerequisites: 18-220, 18-396, 18-321.

18-331 — Fall: Variable units
18-332 — Spring: Variable units
Junior Projects

Experience in independent planning and conduct of engineering research, development or design projects, usually in concert with the research interests and programs of individual faculty members. Prerequisite: junior standing in Electrical and Computer Engineering.

18-342
C/Unix Survival Skills — Spring: 3 units

This course provides a practical introduction to C programming in the Unix workstation environment for students who will not be exposed to it in advanced computer science courses. Lectures will focus on C itself, Unix and Unix Utilities (csh, make, awk, grep, etc.). Example applications will be drawn from the breadth areas of the ECE curriculum. A secondary focus of the course will be software engineering (portability, reuse, *etc.*) for engineering/scientific programs. Particular attention will be paid to software engineering issues and how they complement/conflict with rapid software prototyping. Weekly programming labs will form the keystone of the work. Most labs will be short (1-2 hours) and will introduce a broad spectrum of tools. A few larger programs will be built over multiple weeks. Upon completion of the course students should be familiar with techniques and tools for engineering practical programs in C under Unix. Prerequisite: 15-127.

18-345
Introduction to Telecommunication Networks — Fall or Spring:12 units

This course introduces the fundamental concepts of telecommunication networks. Underlying engineering principles of telephone networks, computer networks and integrated digital networks are discussed. Topics in the course include: telephone and data networks overview; OSI layers; data link protocol; flow control, congestion control, routing; local area networks (Ethernet, Token Ring, FDDI); transport layer; introduction to high-speed networks; performance evaluation techniques. 4 hrs. lec. Prerequisite: 36-217.

18-347/15-347
Introduction to Computer Architecture — Fall: 12 units

The goal of this course is to develop an understanding of the structure and operation of contemporary computer systems from the instruction set architecture level through the register transfer implementation level. We explore: theory of computation, levels of abstraction, instruction set design, assembly language programming, processor data paths, data path control, pipeline design, design of memory hierarchies, memory management, input/output. Several of the principles presented in lecture are reinforced through laboratory projects including assembly language programming, evaluation of instruction set architectures by benchmarks, behavioral simulation of an instruction set architecture, and design/simulation of a register transfer implementation of an instruction set architecture. A contemporary behavioral/functional/logical simulator will be used for the laboratory projects. 3 hrs. lec., 3 hrs. lab. Prerequisite: 18-240. Corequisite: 15-211.

18-349
Concurrency and Real-Time Systems — Spring: 12 units

This course teaches the fundamentals of concurrency and time constrained computing both at the hardware and software levels. These notions are developed through the study and implementation of real-time systems. The fundamental problems and issues of timing correctness, synchronization, deadlock and contention are described. Solutions to these problems, which have evolved in the software realm, are presented along with the hardware required to implement these solutions. Topics include real-time interrupt driven systems; concurrency in digital systems; synchronous, asynchronous and self-timed systems; and hardware and software synchronization mechanisms. 3 hrs. rec., 3 hrs. lab. Prerequisites: 18-240 and 15-211.

18-360
Introduction to Computer-Aided Digital Design — Spring: 12 units

The design of digital integrated circuits (ICs) has grown in complexity to where typical designs have several hundred thousand transistors and leading-edge ICs have several million. Computer-aided design tools are required for designers to produce such complex systems in an economically productive manner. This course introduces the techniques of modeling digital systems at various levels of abstraction and computer-aided design algorithms that are applied to these models to support design and analysis tasks. The course covers modeling through the use of a modern hardware description language. The language is used to model an IC in the early stages of design using behavioral modeling techniques and in later stages using structural modeling techniques. The course will cover: synthesis algorithms, which produce structural designs from the behavioral; physical design, which is used to map the synthesized logic design onto physical IC area; simulation, which is used at several levels of abstraction to analyze a design; and testing, which is used to determine if a manufactured design is correct. Prerequisites: 18-240 and 15-211.

18-370
Fundamentals of Control **Fall: 12 units**

An introduction to the fundamental principles and methodologies of classical feedback control and its application. Emphasis is on problem formulation and the analysis and synthesis of servomechanisms using frequency and time domain techniques. Topics include analytical, graphical and computer-aided (MATLAB) techniques for analyzing and designing automatic control systems; analysis of performance, stability criteria, realizability and speed of response; compensation methods in the frequency domain, root-locus and frequency response design and pole-zero synthesis techniques; robust controller design; systems with delay and computer control systems; transfer function and state space modeling of linear dynamic systems; nonlinearities in control systems; and control engineering software (MATLAB). 3 hrs. lec., 1.5 hrs. rec., 3 hrs. MATLAB lab. Prerequisite: 18-396.

18-371
Design Optimization Techniques **Offered intermittently: 12 units**

This course introduces the student to the concepts and techniques of design optimization by computers using various proven methods, both algorithmic and heuristic. The need to acquire each optimization tool is demonstrated through a design exercise of an actual device or system. The tools covered include modeling of engineering problems, matrix solution of linear equations, unconstrained quadratic optimization with and without constraints, nonlinear problems, mathematical programming techniques, Newton-Raphson methods, and nonlinear and geometric programming algorithms. Design exercises will include iron-core inductors, transformers, thermal power plants, servo systems and economic dispatch of power plants. 4.5 hrs. rec. Prerequisite: 21-341.

18-373
Computer-Controlled Testing and Measurement System Design **Offered intermittently: 12 units**

The aim of this course is to familiarize the student with the fundamentals of measurements, data acquisition, control and the role of a microcomputer in carrying out these activities. This course will consist of lectures and extensive laboratory experiments and a final project. Of special interest will be the following areas: sensors, measurement techniques, signal transmission methods, noise sources and noise suppression, signal conditioning techniques, fundamentals of computer control, A/D and D/A conversion techniques, sampling and data compression, and error analysis in experiments. In general, the course will concentrate on the use of a microcomputer in obtaining measurement data for the purposes of testing and control. The course has a practical slant and is intended to give the student a cohesive understanding of the relationships amongst different areas of electrical and computer engineering and their application in practice. 3 hrs. rec., 3 hrs. lab. Prerequisite: 18-220 or 18-113 or permission of instructor.

18-384/15-384
Artificial Intelligence: Robotic Manipulation **Fall: 9 units**

Foundations and principles of robotic manipulation. Topics include computational models of objects and motion, the mechanics of robotic manipulators, the structure of manipulator control systems, planning and programming of robot actions. Prerequisites: 21-122 or permission of the instructor.

18-396
Signals and Systems **Fall and Spring: 12 units**

This course is a breadth course that is also a prerequisite for most courses in communications, signal processing and control systems. The objective of this course is to provide students with an integrated understanding of the relationships between mathematical tools and properties of real signals and systems. This is accomplished by motivating lectures and recitation problems using demonstrations and laboratory assignments that cover such topics as radio transmission and reception, audio synthesizers, CDs, image processing and prosthetic devices. In the course of the semester, students are introduced to industry-standard computing and simulation tools that will be used in subsequent courses. Continuous and discrete-time signals and systems are treated in a unified manner through the concept of sampling. The course covers the basic concepts and tools needed to perform time and transform domain analyses of signals and linear time-invariant systems, including: unit impulse response and convolution; Fourier transforms and filtering;

Laplace transforms, feedback and stability; and a brief introduction to z-transforms in the context of digital filtering. Prerequisite: 18-220.

18-400
High Frequency System Design **Offered intermittently: 12 units**

This course is intended to familiarize students with the characteristics of various radio frequency / microwave components and the design of representative systems. Waveguide components are available at X-band (8.20-12.40 GHz) and K-band (18.0-26.5 GHz). These include oscillators, attenuators, phase shifters, wavemeters, directional couplers, circulators, isolators, horns, detectors, *etc.* For example, an intruder alarm system (Doppler radar) can be designed, constructed and tested at both X- and K-bands. Various coaxial components enable operation down to several 100 MHz at least. An RF / microwave sweeper ranging up to 12 GHz is available. Planar transmission line circuitry (microstrip) can be fabricated. CAD programs are available for laying out and analyzing microstrip circuitry. At frequencies of 4 GHz or so, various resonators, filters and directional couplers can be designed, constructed and tested. Microwave amplifiers can be designed and constructed at frequencies up to 4 GHz using drop-in components on wafers and PC boards. 2 hrs. rec., 3 hrs. lab. Prerequisite: 18-304 or equivalent or permission of the instructor.

18-405
Computer-Aided Design of
Electromagnetic Systems **Offered intermittently: 12 units**

This course employs field theory based CAD tools to simulate the behavior of electromagnetic systems. Students learn to use finite element computer programs to determine the electric and magnetic fields in printed circuit boards and in other high-speed digital and microwave devices. Course topics include: Electromagnetics CAD; finite element methods; finite element mesh generation; electrostatics and magnetostatics of PCB and IC interconnects; capacitance and inductance matrices; cross-talk, insertion loss and return loss; dispersion; eddy currents and skin effect; use of CAD packages for computing signal characteristics; microwave CAD; S matrices; use of the Hewlett-Packard High-Frequency Structure Simulator; hybrid and MMIC microwave design; propagation of optical signals; modal characteristics of optical ICs. 2 hrs. rec., 3 hrs. lab. Prerequisite: 18-304.

18-431 **Fall: Variable units**
18-432 **Spring: Variable units**
Senior Projects

Experience in independent planning and conduct of engineering research, development, or design projects, usually in concert with the research interests and programs of individual faculty members. Prerequisite: senior standing in Electrical and Computer Engineering.

18-439
Special Topics in Electrical and Computer Engineering **Fall or Spring: Variable units**

Offered from time to time on topics of current interest. Specific details will be announced prior to registration.

18-474
Computer Control Systems Design Laboratory **Spring: 12 units**

A senior design elective in Electrical and Computer Engineering focusing on issues in the design of feedback control systems using digital computers. Lectures and laboratory experiments cover basic switching control methods, collection and analysis of data for modeling system dynamics, PID control, design methodologies for setpoint control and disturbance rejection, state variable feedback, dynamic state observers and methods for adaptive control. Major emphasis is placed on a project involving the analysis, design and implementation of a computer control system developed by each lab group. 2 hrs. rec., 3 hrs. lab. Prerequisite: senior standing in Electrical and Computer Engineering.

18-480
Senior Seminar **Fall: 0 units**

The senior seminar provides students with information that should be of use in making the transition from undergraduate studies to graduate life. The seminar features discussions led by faculty members and invited guests, with student participation in the discussions. 1 hr. lec./rec. Prerequisite: senior standing in Electrical and Computer Engineering.

18-481
Analysis, Synthesis and Evaluation **Offered intermittently: 12 units**

Analysis, synthesis and evaluation in the context of realistic engineering situations. The student learns through practice to formulate and solve problems that require the application of skills, which include modeling, analyses that range from mathematical to heuristic, experimental methods, inventing, making judgments of value and need, making decisions and recommendations, and producing an engineering report containing an analysis of the problem and an evaluation of the solution. 3 hrs. lec., 3 hrs. lab. Prerequisite: senior standing in Electrical and Computer Engineering.

18-482/19-402
Telecommunications: Technology,
Policy and Management **Fall: 12 units**

This course provides a comprehensive introduction to basic principles of telecommunications technology and the telephone network, and the legal, economic and regulatory environment of the telecommunications industry. Role of new technologies such as fiber, integrated digital networks, computer communications and information services. Common carrier law and the economics of natural monopoly as the basis for regulation of the telecommunications industry. Issues of competition, monopoly and technical standards. Spectrum allocation and management. International communications and transborder data flow. Special emphasis on how the new technologies have altered and are altered by regulation. Prerequisites: 73-100, junior or senior standing.

18-483/19-430
Civilian and Military Applications of Space **Spring: 12 units**

Space is an arena of growing activity and importance. The use in space puts specific requirements on the technology of remote sensing and communication. Furthermore, the access to space requires rocket engines. Operation in space supposes the ability of controlling automatically the attitude of spacecraft. Navigation and guidance requires a very large and powerful infrastructure. Most space endeavors are very ambitious and long-term projects. The cost of space projects are often easier to estimate than the benefit. The goal of this course is to penetrate somewhat in the world of space policy dilemmas by studying the interface between the technology and what space programs could or try to accomplish. 3 hrs. lec. Prerequisites: junior standing in engineering or science.

18-489
Basic Trends in the Evolution of Modern Microelectronics **Offered intermittently: 12 units**

Recent rapid changes and future trends in the evolution of the microelectronics are determined by three factors: market needs, manufacturing capabilities and efficiency of design. Each of them has its own dynamics and limitations. Understanding all of them is necessary to explain the current structure of the microelectronics industry and to predict future developments in the areas of IC technology, design and CAD tools. The goal of this lecture is to introduce technical aspects related to the above mentioned three areas. Prerequisite: 18-322.

18-501
Electromechanics **Offered intermittently: 12 units**

This course provides a broadly based introduction to interactions between mechanical media and electromagnetic fields. Attention is focused on the electromechanical dynamics of lumped-parameter systems, wherein electrical and mechanical subsystems may be modeled in terms of discrete elements. Interactions of quasistatic electric and magnetic fields with moving media are described and exemplified. Unifying examples are drawn from a wide range of technological applications, including energy conversion in synchronous, induction and commutator rotating machines, electromechanical relays, a capacitor microphone and speaker, and a feedback-controlled magnetic levitation system. 4.5 hrs. rec. Prerequisite: 18-303.

18-517
Data Storage Systems Measurement and Design Laboratory **Fall: 12 units**

This course is designed to provide students with an opportunity to gain hands-on experience in designing and carrying out a small research project on storage devices such as a disk drive, or an optical recording device. The students will be taught the principles of operation of a variety of magnetic measurement devices including magnetometers, hysteresis loop tracers and magnetic and magneto-optic recording device testers. Having learned the use of these instruments, students will select, design and carry out a research project related to storage technology in the research labs of the Data Storage Systems Center. 1.5 hr. rec., 10.5 hrs. lab scheduled at student’s convenience. Prerequisites: 33-107 and 18-200 or 21-259.

18-523
Analog Integrated Circuit Design **Offered intermittently: 12 units**

Advanced techniques for the design of analog integrated circuits. Emphasis will be placed on the design process. Design issues associated with both MOS and BJTs devices will be explored. Students will be expected to design and simulate several projects. Topics will be selected from the following: modeling of basic IC components (in MOS & BJT processes), wideband amplifier design, operational amplifier design, the design of switched-capacitor circuits, the design and analysis of phase locked loops, analog-to-digital conversion techniques (including the design of sample-and-hold amplifiers), and digital-to-analog conversion techniques. 4 hrs. lec., 3 hrs. lab. Prerequisites: 18-321 and 18-322 or equivalent with permission of instructor.

18-525
Integrated Circuit Design Project **Spring: 12 units**

The purpose of this course is to study the design process of VLSI circuits. The first part of the course will be devoted to the standard cell design methodologies. Major emphasis will be put on layout design, circuit and parasitic element extraction and verification of circuit performance via simulation tools. In the second part of the course, students will design functional blocks of digital ICs and verify their performance using such simulators as COSMOS and SPICE. The collection of these functional blocks will constitute a multiproject chip, which will be submitted for fabrication to MOSIS. 4 hrs. rec., 3 hrs. lab. Prerequisite: 18-322.

18-545
Advanced Digital Design Project **Fall: 12 units**

This is a project oriented course on advanced digital design. It provides the background needed for developing design skills of large digital systems at a professional level. The course covers fundamental design principles and extensive pragmatic implementation considerations. A substantial project will be designed and built by each project group of three students. A typical project is a single-board microprocessor that is implemented for a specified general purpose instruction set or special purpose embedded application, such as a network controller. Contemporary building blocks and design tools will be used, including programmable logic devices (PLDs), advanced field programmable gate arrays (FPGAs), schematic capture, Verilog simulation and PLD design tools. Industry standard practices of interim design reviews and final project presentations are followed. 3 hrs. lec., 3 hrs. lab. Prerequisites: 18-347 or 18-349, 15-212.

18-547
Superscalar Processor Design **Fall: 12 units**

This course presents the fundamental principles, critical issues and latest techniques involved in the design of advanced modern processors. The course emphasizes the design of processors capable of extracting and exploiting instruction level parallelism (ILP). The topics covered include: arithmetic (floating-point) unit design; design space exploration via profiling and trace-driven simulation; microcoded CISC and pipelined RISC processors; instruction level parallel processing (ILPP) principles; superpipelined, superscalar, and VLIW (very long instruction word) processors; dynamic (run-time hardware) and static (compile-time software) techniques for achieving ILPP; aggressive instruction scheduling and machine-dependent code optimization. This course also incorporates case studies of a number of ILP processors *e.g.* IBM RS/6000, Motorola PowerPC and DEC Alpha, and the use of software tools in experimenting with performance evaluation, machine simulation and code transformation. 3 hrs. lec. Prerequisites: 18-347 and 15-212.

18-549
Time Critical Computing Systems **Spring: 12 units**

The analysis and design of time critical computing systems is emphasized in this course. Engineering skills necessary to build embedded/multimedia systems are presented. This course includes a significant project where students will build/analyze a system. Typical systems include control systems, signal processing systems, and multimedia systems. A real-time scheduling theoretic approach will be used to quantitatively explore the design space. Performance models will be developed to explore the hardware/software boundary issues for the following subsystems: CPU's, buses, disks arrays, LANs, switching networks, and video/graphics/rendering subsystems. 4 hrs. rec. Prerequisites: 18-240, 15-212 and (18-349 or 15-412).

18-550
Fundamentals of Communication Systems **Fall or Spring: 12 units**

A general introduction to analog and digital communications. Review of relevant aspects of linear systems and probability theories. Fourier analysis. Analog modulation systems: amplitude modulation (AM), frequency and phase modulation (FM and PM) and pulse amplitude modulation (PAM). Digital modulation systems: pulse code modulation (PCM), delta and differential PCM. For each modulation system, the course covers the basic structure of the transmitter and receiver, the trade-offs between bandwidth/data rates requirements and signal to noise ratio for desired levels of performance and waveform design. Applications are drawn from broadcasting (radio and TV), telephone networks (multiplexing), satellite communications, radar, digital communications (matched filter and optimal detection). Time permitting, the course will cover error detection and correction and elements of information theory. 3 hrs. lec., 1.5 hrs. rec. Prerequisites: 18-396, 36-217.

18-551
Digital Communications and Signal Processing Systems Design **Spring: 12 units**

This course provides students with a rich, integrated design experience in the area of digital communications and signal processing systems. Lectures will highlight component blocks needed to produce a viable systems technology. Labs early in the semester will be used to explore the use of standard instrumentation and simulation tools in the context of the development and performance of these component blocks. Homework will be used to develop the students' skills at using "back-of-the-envelope" calculations to ascertain the validity of their simulation and/or experimental results. Recitations will be used to help students in proposing, planning and designing their final project. Topics include: multimedia signals including speech and music, digital communication systems, FFT and practical digital Fourier analysis, voiceband modems, linear prediction, adaptive FIR filters, wireless HDTV, MPEG, Data Storage, CD, *etc.* 3 hrs. lec. Prerequisite: 18-396.

18-575
Control System Design **Spring: 12 units**

A senior design elective in Electrical and Computer Engineering integrating the computer-aided analysis and design of feedback control systems from both the classical (transfer function) and modern (state-space) points of view. The perspective spans the dynamic modeling of physical systems and the analysis and computer-aided design (utilizing MATLAB) of linear and nonlinear, continuous-time and discrete-time, robust multivariable feedback systems. In illustrating the centrality of numerical linear algebra in control engineering, case studies are selected from pole placement, linear-quadratic design and Kalman filtering. A significant emphasis is placed upon student selected design projects. 4 hrs. lec., 3 hrs. MATLAB lab. Prerequisite: 18-370 or equivalent.

Graduate Courses, by Number and Name

The following graduate courses are available to undergraduate students who have appropriate prerequisites. Descriptions of these graduate courses may be found in the graduate catalog of the Department of Electrical and Computer Engineering.

- 18-701 *Electromagnetic Field Theory*
- 18-702 *Numerical Methods in Electromagnetics*
- 18-708 *High Frequency Engineering*
- 18-711 *Solid State Electronics*
- 18-712 *Microwave and Optical Magnetics*
- 18-713 *Fundamentals of Carrier Transport*
- 18-714 *Introduction to Superconducting Devices*
- 18-715 *Physics of Applied Magnetism*
- 18-716 *Advanced Applied Magnetism*
- 18-723 *Advanced Analog Integrated Circuit Design*
- 18-725 *Digital Integrated Circuit Design*
- 18-728 *Applications of Analog Integrated Circuits*
- 18-742 *Advanced Computer Architecture*
- 18-746 *Parallel Processing*
- 18-748 *Dependable System Design*
- 18-751 *Applied Stochastic Processes*
- 18-752 *Estimation, Detection and Identification*
- 18-754 *Error Control Coding: Theory and Applications*
- 18-756 *Packet Switching and Computer Networks*
- 18-757 *Principles of Broadband Networks*
- 18-760 *VLSI CAD: Logic to Layout*
- 18-761 *VLSI CAD: Layout to Manufacturing*
- 18-762 *Circuit Simulation: Theory and Practice*
- 18-763 *Physical CAD for VLSI*
- 18-771 *Linear Systems*
- 18-772 *Multivariable Control Systems*

- 18-773 *Adaptive Control*
- 18-774 *Digital Control*
- 18-775 *Optimal and Stochastic Control*
- 18-776 *Nonlinear Control Systems*
- 18-777 *Model Predictive Control*
- 18-778 *Discrete Event Systems*
- 18-791 *Digital Signal Processing I*
- 18-792 *Digital Signal Processing II*
- 18-793 *Optical Image and Radar Processing*
- 18-794 *Pattern Recognition Theory*
- 18-795 *Sensory Processes: Perception & Psychophysics*
- 18-796 *Numerical Optimization Methods*
- 18-809 *Special Topics in Electromagnetics*
- 18-813 *Optical Electronics*
- 18-815 *Integrated Circuit Fabrication Processes*
- 18-816 *Magnetic and Optical Data Storage*
- 18-819 *Special Topics in Solid State Devices*
- 18-828 *Design and Testing of Analog Integrated Circuits*
- 18-829 *Special Topics in Circuits*
- 18-846 *Theory of Distributed Systems*
- 18-845 *Computer Engineering Applied Graph Theory*
- 18-849 *Special Topics in Computer Engineering*
- 18-859 *Special Topics in Communications*
- 18-869 *Special Topics in Computer-Aided Design*
- 18-879 *Special Topics in Systems and Control*
- 18-899 *Special Topics in Signal Processing*