Computer Engineering Major

Peter Bowlin

A proposal to change the electrical and computer engineering major at CU Boulder to computer engineering only

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Dr. Davis,

Enclosed is a proposal to change the electrical and computer engineering major offered by the College of Engineering and Applied Science to computer engineering only. As a result of the large number of core classes required for this degree, there's little time for electives specific to the major. This in turn severely limits the number of choices students have in what classes they take and what areas they wish to specialize in.

Along with the name change, this proposal will introduce some curriculum changes with the goal of increasing computer engineering students' knowledge of digital computers and allowing them more freedom in selecting their upper division classes.

Thank you for your time and consideration. If you have any questions or concerns, don't hesitate to call me at 719-439-7174 or email me at peter.bowlin@colorado.edu.

Sincerely,

Peter Bowlin

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Abstract

Currently the Department of Electrical, Computer, and Energy Engineering at the University of Colorado at Boulder offers two undergraduate majors. Students can major in electrical engineering (EE), or they can major in electrical and computer engineering (ECE). These degrees are very similar, but ECE takes essentially all of the required classes from EE and adds even more, resulting in little time for elective classes. This limits the flexibility students have in what they study and makes it difficult for them to specialize. Another problem with combining these two majors is that some students, who may be more interested in computer engineering and not as interested in electrical engineering, are forced to take many credit hours of classes dealing with analog circuit design, classes that have limited relevance to designing computer systems.

To remedy this, ECE should be changed to computer engineering only, and changes should be made to the curriculum to reflect this difference. Some of the less important EE core classes focused on analog design can be removed, making room for more upper division computer engineering electives. This will give students who choose the major a more comprehensive view of it, and better prepare them to work in the field of computer engineering. In addition, it will help position the major more neatly between electrical engineering and computer science, both of which have significant overlap with computer engineering.

Introduction and Background

Computer engineering is an exciting and rapidly expanding field within the engineering discipline. Compared to some of the other engineering disciplines, such as mechanical or aerospace engineering, computer engineering is relatively new, with the first accredited computer engineering programs showing up only in the early 1970s (IEEE Computer Society). Computer engineering (CE), defined very briefly, is the analysis and design of computer hardware and software. "Computer" is very broadly defined in this case, and includes anything from a desktop PC to a cell phone to even something as simple as a digital watch. Needless to say, computers of all types have become extremely prevalent in modern society, and there seems little doubt this trend will continue. To truly understand what computer engineering is and why it's important, however, we first have to look at two other areas within engineering: electrical engineering and computer science.

Electrical engineering (EE) can be defined as the study and application of electricity, electronics, and electromagnetism. Upon examination, most aspects of electrical engineering that are practiced today fit into one of two categories: analog circuit design, and digital circuit design. Analog design is the older, more traditional area and includes things like electromagnetics, wave propagation, power electronics, and signal processing. All of these areas require the use of many of the same basic electrical devices such as resistors, capacitors, inductors, diodes, transistors (bipolar and MOSFET), etc. As a result, circuits classes, which cover the basics of these devices and their applications, are at the foundation of any electrical engineering curriculum. The other area within EE is digital circuit design, which is the basis for computer hardware. Digital circuits represent

data at discrete (as opposed to continuous) levels, usually 1 and 0. Digital circuits are created out of a combination of logic gates that implement Boolean logic functions such as NOT, AND, OR, etc. Although logic gates are created out of analog components such as CMOS transistors (a specific application of MOSFETs), most of the focus is on what can be created with these abstract logic gates, ignoring the underlying implementation.

Computer science (CS) can primarily be thought of as the study and design of computer software. Once again, this can be broken down into two rough categories: high level and low level software. High level software primarily refers to applications, for example programs like Microsoft Office, Internet browsers, media players, virus scanners, or games, just to name a few. In general, applications don't interact directly with the computer hardware, which means they require an operating system of some sort to run and are relatively platform independent, meaning they can be run on systems with varying hardware. Low level software, on the other hand, generally does interact directly with computer hardware, and would include things like operating systems for PCs or firmware for embedded computers such as those in cells phones or cars. You could also think of low level software as encompassing assembly language, which is the language a processor executes natively, and instruction sets (an instruction set is the set of instructions that make up an assembly language).

As you can see in Figure 1 below, computer engineering (CE) is really a combination of elements from electrical engineering and computer science, specifically digital circuit design and low level software.

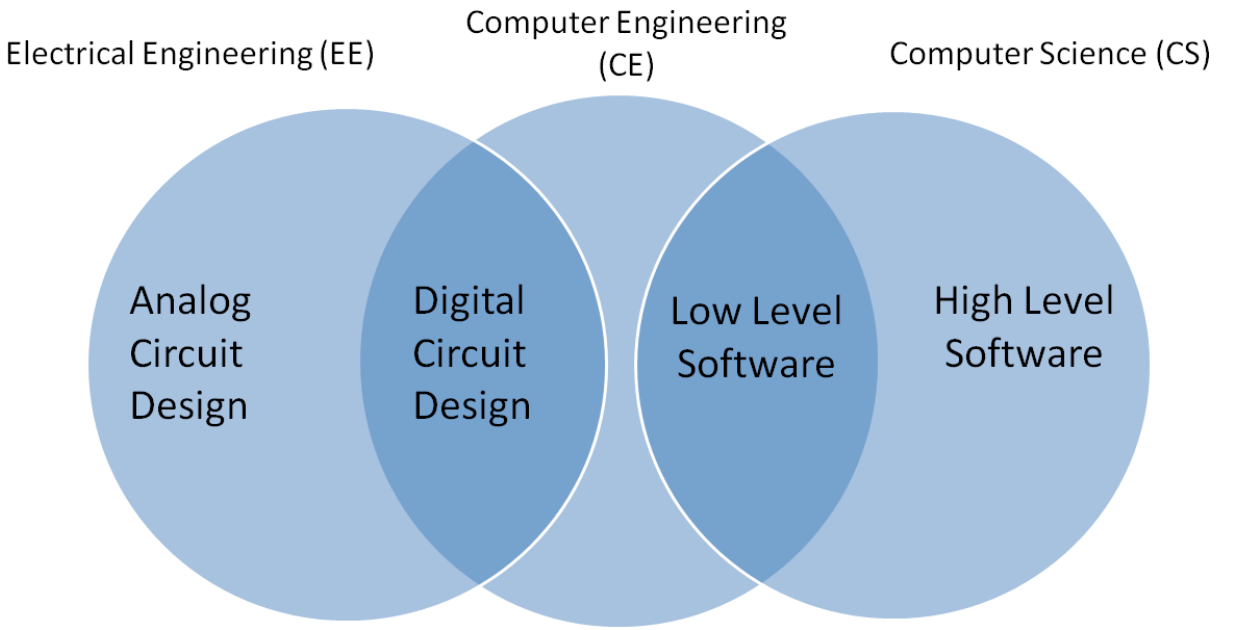

Figure 1

The reason for this is simply that a computer requires both of these elements to function. The fact that physical hardware is required is fairly obvious, but to make the hardware do anything useful, a stored program of some sort is equally necessary. As a result, it's only natural that computer engineers would strive to understand both of these areas as well as their integration, even if this means straddling two fairly different aspects of engineering.

Problem

Currently, the Department of Electrical, Computer, and Energy Engineering at the University of Colorado at Boulder offers two different majors. You can major in electrical engineering, or you can major in electrical *and* computer engineering. However, despite the fact that much of CE is software related, the current ECE degree is much more similar to and shares many more requirements with the EE degree than it does with the computer

science degree. Overall, this setup doesn't make a lot of sense when you consider what material is covered by EE and what is covered by ECE (see Figure 2), and it causes a couple of significant problems for students majoring in electrical and computer engineering.

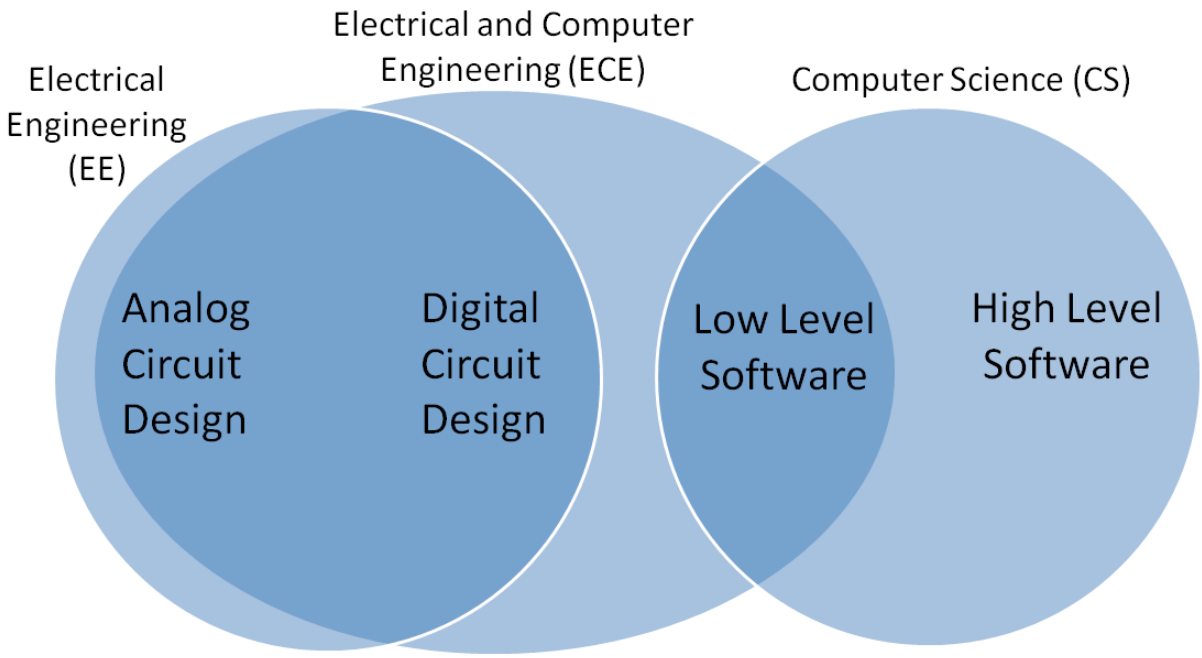

Figure 2. EE, ECE, and CS, the majors currently offered at the University of Colorado–Boulder

The first problem is that as a result of combining these two areas into one major, there end up being too many core classes. This, in turn, means there's very little time for the upper division elective classes that represent more specific areas within electrical and computer engineering. Currently, ECE majors take one freshman elective class (about 3 hours) and three upper division elective classes (about 9 hours), which total about 12 credit

hours. This is considerably lower than some of the other engineering majors offered by CU. For example, students majoring in only electrical engineering take about 23 credit hours of major-specific electives (Department of Electrical and Computer Engineering). For computer science majors, including the "track" classes they take (they choose one of seven different tracks), the number is about 37 hours (Department of Computer Science). Students majoring in applied math choose 24 credits of upper division classes from the applied math department and 24 credits of classes from other engineering departments, resulting in a total of 48 hours (Department of Applied Mathematics). As a result of taking so few electives, ECE majors are unable to take many classes in areas they're specifically interested in, and also find it more difficult to differentiate themselves from other students of the same major.

The second major problem with the current setup is that students who really just want to major in computer engineering are forced to also take a large number of electrical engineering classes that have less relevance to computer engineering. The degree to which this is the case varies a little depending on the class, but some examples would be classes like Electromagnetic Fields and Waves, Linear Systems, and Circuits 1, 2, and 3, all of which are focused almost entirely on the analog aspects of EE. In addition, these are all 5-credit-hour classes, meaning that these five alone account for almost 20% of the total credits required for the degree. While the analog aspects of EE covered in these classes do have some relevance to computer engineers, some of this time would be better spent increasing their knowledge of digital computers.

Proposal

The solution to these problems is remarkably straightforward – change the electrical and computer engineering major to *computer engineering only*, and make some changes to the curriculum to reflect this name change. Note that the electrical engineering major and curriculum will remain unchanged, so students wishing to pursue this field will still be free to do so. The changes will involve removing some of the core classes from the old ECE curriculum that aren't relevant to CE, adding an additional computer science class, and also making some significant changes to the way the upper division electives work. The logic behind all of these changes, and especially what classes to remove and what not to remove, is really about allowing students to take more upper division electives, and electives that are more relevant to computer engineering, rather than electrical engineering. The way the major-specific electives are currently set up, students choose one noncomputer theory course, one noncomputer lab course, and one software elective (see Figure 3 in the appendix for the current ECE curriculum). Almost all of the noncomputer electives require as a prerequisite Circuits 3, Electromagnetic Fields and Waves, or Linear Systems. Also, while the majority of these electives are not within the sphere of computer engineering, meaning they can be removed, there are a few of them that will be of interest.

The first class that can be removed is Circuits/Electronics 3. This class is primarily focused on a couple of different things. About the first 40% of the class is spent on diodes (a diode is a two-terminal circuit element) and their applications. Diodes are mainly used in the field of power electronics, which is why Circuits 3 is a prerequisite for electives like Energy Conversion I, Intro to Power Electronics, and Power Lab. These are all topics that

computer engineers usually aren't concerned with. The rest of the class is spent on two three-terminal circuit devices, MOSFETs and BJTs. Students learn about their internal workings and basic operation, and also about some of their applications. The main application covered is their use as the basis for AC signal amplifiers, another topic that doesn't have much relevance to computer engineers. As you may recall from the introduction, however, MOSFETs are also used to create CMOS transistors, which are used to create most digital (i.e., computer) hardware. While this might seem like a valid reason to keep Circuits 3 in the computer engineering curriculum, only the last two or three lectures of the course cover this application of MOSFETs, which is not enough to justify leaving things as they are now. Also, as was mentioned before, computer engineers are generally not concerned with this underlying implementation.

Another class that can be removed from the curriculum is Electromagnetic Fields and Waves (E & M for short). In some respects, this course is about explaining where a lot of the theory behind circuits and circuit elements comes from, and it covers things like electric fields, magnetic fields, transmission lines, and wave propagation. It's a precursor to upper division electives such as Electromagnetic Waves and Transmission, Intro to Optical Communication, and the lab electives that go along with these classes. As with Circuits 3, none of those electives will be of particular interest or relevance to most computer engineers, so there's no reason to keep this prerequisite class in the curriculum.

The last core class to be removed is General Physics 3. This class covers topics such as special relativity and quantum mechanics, which, once again, are of minimal use in designing computer systems. In addition, unlike Circuits 3 and E & M, Physics 3 is not

required for any of the old ECE elective classes. Finally, another reason to remove this class is that it requires having taken either Physics 2 or E & M. In other words, keeping this class would also require adding another 3-credit class, making a total of 6 credit hours that could be used for computer engineering electives instead.

There's also one core class that will be added with the new curriculum, CSCI 3104 – Algorithms, an existing class that is part of the core requirements for computer science majors. Currently ECE majors take two computer science classes: Computer Science I and CS II: Data Structures, both of which are also core classes for CS majors. The logic behind adding this third class is that it will give CE majors more programming experience, and it's also a prerequisite for some of the additional software electives that will be added, which we'll get to shortly.

The most drastic change to the curriculum will be the differences in the upper-division elective requirements. With the new curriculum, there will be two types of electives: hardware and software. Students will be required to take six total elective classes, for a total of about 18-20 credit hours. Also, they'll have to take at least two hardware elective classes and two software classes. Other than that, any combination will meet the requirements. This setup will give students a lot of freedom of choice in what they wish to study, and at the same prevent them from ignoring one category of electives. The hardware electives are as follows:

- ECEN 4138 – Control Systems Analysis
- ECEN 4532 – Digital Signal Processing Lab
- ECEN 4613 – Embedded Systems Design

- ECEN 4623 – Real-Time Embedded Systems
- ECEN 4632 – Digital Filtering
- ECEN 4633 – Hybrid Embedded Systems
- ECEN 4638 – Controls Lab
- ECEN 4693 – Adv. Computer Architecture (new undergraduate class)
- ECEN 4811 – Neural Sigs & Functional Brain Img.
- ECEN 4821 – Neural Systems & Physiological Ctrl.
- ECEN 4831 – Brains, Minds & Computers

As you may notice, many of these classes are taken from the existing list of noncomputer theory and lab courses (see Figure 2). The reason for keeping these courses specifically is that they'll be of more interest and relevance to computer engineers than the courses that were removed. While some of these areas may not involve the actual design of computer systems, in practice many will be implemented using a computer of some sort. For example, digital signal processing will usually be done using a special computer chip made for exactly that type of thing and programmed using a language such as C. Another example would be control systems, which are often applied in areas like robotics, something that is directly related to CE (a robot needs a computer of some sort to control it). However, both of these areas (digital signal processing and control systems) also require knowledge of linear systems, which is why that class remains in the new CE curriculum (along with Circuits 1 and 2, which are prerequisites) while Circuits 3 and E & M are removed. In addition to these classes carried over from the old curriculum, there are

four additional choices. The three embedded systems courses are logical choices, given that this is a core area within CE. For some reason, these classes are part of the EE curriculum but not the old ECE curriculum, which is one of its more glaring deficiencies. The only one of the above classes that isn't already in existence and offered by the ECEE department is Advanced Computer Architecture. However, there is already a graduate version of this class, so this will simply be another case where the undergraduate and graduate versions of the same class meet together.

Following this is the new list of software electives that will be available. Many of these are taken from the existing list of software electives, and the new ones are preexisting classes selected from the complete list of computer science electives, ones that should be of particular interest to computer engineers. Specifically, they're classes that deal more with low level software, rather than high level applications, as discussed in the introduction.

- ECEN 4553 – Compiler Construction
- ECEN 4583 – Software Systems Development
- CSCI 3155 – Principles of Programming Languages
- CSCI 3202 – Intro to Artificial Intelligence
- CSCI 3287 – Database & Information Systems
- CSCI 3308 – Software Engr Methods & Tools
- CSCI 3434 – Theory of Computation
- CSCI 3753 – Operating Systems
- CSCI 4113 – Unix Systems Administration

- CSCI 4123 – Network Lab
- CSCI 4202 – Artificial Intelligence 2
- CSCI 4229 – Computer Graphics
- CSCI 4273 – Network Systems
- CSCI 4322 – Things That Think
- CSCI 4576 – High-Performance Scientific Computing 1
- CSCI 4586 – High-Performance Scientific Computing 2
- CSCI 4753 – Computer Performance Modeling
- CSCI 4838 – User Interface Design

Benefits

Overall, this new curriculum will give CE majors a much more comprehensive view of computer engineering. Specifically, the added computer science class and revised electives will increase students' knowledge of both digital hardware and low level software, the two elements required to create a modern, functional computer. It will also give junior and senior level students more choice in what they study. On top of that, they'll no longer have to take quite so many EE classes that are focused on analog design and hence have less relevance to them. This, along with the other curriculum changes, will allow the computer engineering major to be more centered between electrical engineering and computer science than the ECE program is now.

This proposal will also bring some compelling benefits for the College of Engineering and Applied Science. As a result of the curriculum changes, the Department of Electrical, Computer, and Energy Engineering will produce better, more diverse

students. This means a higher reputation and national ranking for the University. As a result, more students will be attracted to the program, and tuition can be raised slightly. In addition, because computer engineering students will receive a better education and be more prepared for their careers, their average incomes will be higher, potentially resulting in more alumni dollars.

Counterarguments Addressed

There are some arguments against this solution, however. First of all, students' knowledge of the lowest level analog technology used to create digital circuits, such as CMOS transistors, will be decreased. Also, some of the knowledge of how digital circuits behave, particularly when run at very high clock speeds, will be lost because of the removal of the E & M class. While this may seem like critical knowledge, computer engineers are usually not very concerned with the underlying implementation and functionality of these components that make up digital circuits, and so it's not as important as might be assumed. The reason for this lack of concern is that designing hardware as part of a computer system is nearly always taken at least one, and often many, levels of abstraction higher. The designer is no longer dealing with something as minute as the CMOS transistors themselves, or even the Boolean logic gates created with the transistors. Of course, some people *do* need to concern themselves with such things, but this really is a separate area, and can safely be left up to the electrical engineers who specialize in it. Consequently, this will be a fairly minor loss, and is easily made up for by the fact that students will have a considerably better understanding of everything else related to digital hardware, as well as low level software.

The second potential drawback is that students no longer have the opportunity to get a degree in electrical *and* computer engineering simultaneously, and in the same amount of time as other engineering degrees. However, this is mitigated a lot by the fact that, even after the changes, the requirements for electrical engineering and computer engineering will still be very similar. Even if a student felt he or she just had to get both degrees, double majoring would add only about 19 credits on top of the 128 if electives were chosen correctly. In any case, the advantages offered by allowing students to specialize in whichever area they're truly interested in far outweigh this concern.

Another point worth considering – some people might suggest that an alternative solution to the one proposed here, besides simply leaving things the way they are, would be to remove computer engineering entirely. Electrical engineering and computer science would remain, and going back to the Venn diagram in the introduction, those two spheres together would encompass all four areas of interest, including digital circuit design and low level software. However, this line of thinking overlooks the advantages provided to a computer engineer when tasked with a computer engineering job. While the job may not involve actively designing *both* the hardware and software of a computer, the two are very much integrated. Someone who has majored in CE, and therefore has extensive knowledge of both these areas, will likely have a better understanding and be able to perform at a higher standard compared to an electrical engineer, who has good knowledge of the hardware but limited knowledge of the software, or a computer scientist, who has good knowledge of the software but limited hardware knowledge. Viewed from this perspective, offering a computer engineering degree, and having it separate from electrical engineering, makes a lot of sense.

Cost

Implementing this proposal would involve some minor administrative changes, such as rewriting the Department of Electrical, Computer, and Energy Engineering's help guide to reflect the curriculum changes and the name change from electrical and computer engineering to computer engineering only. No doubt there would be numerous other places the name would need to be changed across the University's systems. There is also the one new class, Advanced Computer Architecture, which might take a little work by one of the faculty to define what the standards would be for undergraduate students taking the class, as opposed to the graduate students who take the 5000 level version now. However, all of these things would most likely fall within the normal responsibilities of University employees or faculty. For example, writing a new help guide has to be done periodically anyway, and the University clearly has employees responsible for maintaining its various systems who could easily make minor changes such as the name change from ECE to CE. Defining the standards for Advanced Computer Architecture, assuming they even need to be different from those for the graduate version of the class, should also be a minor task, and easily completed by the professor who teaches it the first semester after the change. This means the overall cost of implementing this proposal should be negligible at worst. In fact, as discussed in the benefits section, it should result in a net increase in income for the University.

Conclusions

As it stands, students majoring in electrical and computer engineering at CU Boulder are burdened with an overabundance of core classes, denying them the additional

freedom of choice and opportunities for specialization they could have with more elective classes. Additionally, students who wish to concentrate simply on computer engineering are unable to do so, and are instead required to take many credit hours of classes dealing with analog design that won't be as relevant to them as computer hardware and software. Changing the major to computer engineering only, removing a few of the numerous EE classes focused on analog design, and adding more hours of computer engineering electives will make the degree more focused and complete. With the new curriculum, computer engineering will be neatly placed between electrical engineering and computer science, and students graduating with this degree will be exceptionally well prepared for all aspects of designing computer systems.

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Appendix

COURSES REQUIRED FOR B.S. IN *ELECTRICAL & COMPUTER ENGINEERING* (128 HOURS)

Math (16 hours)

APPM 1350	4	Calculus 1 for Engineers
APPM 1360	4	Calculus 2 for Engineers
APPM 2350	4	Calculus 3 for Engineers
APPM 2360	4	Linear Algebra & Diff. Equations

Science (12 hours)

CHEN 1211	3	General Chemistry for Engineers
CHEM 1221	2	General Chemistry Lab
PHYS 1110	4	General Physics 1
PHYS 2130	3	General Physics 3

Freshman Elective (3-5 hours) - freshmen choose one: ☐

ECEN 1400	3	Intro to Digital & Analog Elect
GEEN 1400	3	Freshman Projects
CHEM 1131	5	General Chemistry 2
PHYS 1120	4	General Physics 2
EBIO 1210	3	General Biology 1 *plus*
EBIO 1230	1	General Biology Lab 1
MCDB 1150	3	Intro to Molecular Biology *plus*
MCDB 1151	1	Intro to Molecular Biology Lab

Introductory freshman course from other engr. dept.

Freshman Seminar (1 hour) - freshmen choose one: ☐

ECEN 1100	1	Freshman Seminar *F*
GEEN 1500	1	Introduction to Engineering

Introductory freshman seminar from any engr. dept.

Computer Science (8 hours)

ECEN 1030	4	C Programming for EE/ECE
CSCI 2270	4	Data Structures

Electrical Engineering Core (38 hours)

ECEN 2120	5	Computers as Components
ECEN 2250	5	Circuits/Electronics 1
ECEN 2260	5	Circuits/Electronics 2
ECEN 3100	5	Digital Logic
ECEN 3250	5	Circuits/Electronics Lab 3
ECEN 3300	5	Linear Systems
ECEN 3400	5	Electromagnetic Fields & Waves
ECEN 3810	3	Introduction to Probability** *F*

** (may substitute MATH 4510 or APPM 3570 only)

Computer Engineering Core (6 hours)

ECEN 3703	3	Discrete Math for Comp. Engr. *S*
ECEN 4593	3	Computer Organization

*Students are not allowed to register for Capstone Laboratory until all Electrical Engineering Core courses and ECEN 4593 are passed with a grade of C- or better.

TOTAL HOURS = 128

Non-computer Theory Course (3 hours) - choose one: ☐

ECEN 3170	3	Energy Conversion *F*
ECEN 3320	3	Semiconductor Devices *F*
ECEN 3410	3	Electromagnetic Waves & Trans *F*
ECEN 4106	3	Photonics *F*
ECEN 4116	3	Intro. to Optical Communication *F*
ECEN 4138	3	Control Systems Analysis *F*
ECEN 4167	3	Energy Conversion 2 *S*
ECEN 4224	3	High Speed Digital Design *S*
ECEN 4242	3	Communication Theory *F*
ECEN 4345	3	Introduction to Solid State *S*
ECEN 4632	3	Digital Filtering *S*
ECEN 4645	3	Intro to Optical Electronics *S*
ECEN 4797	3	Introduction to Power Electronics *F*
ECEN 4811	3	Neural Sigs & Functional Brain Img. *S*
ECEN 4821	3	Neural Systems & Physiological Ctrl. S
ECEN 4827	3	Analog IC Design *F*
ECEN 4831	3	Brains, Minds & Computers *F*

Non-computer Lab Course (2-3 hours) choose one: ☐

ECEN 4375	3	Microstructures Lab *S, even years*
ECEN 4517	3	Power Lab *S*
ECEN 4532	3	Digital Signal Processing Lab *S*
ECEN 4606	3	Undergrad Optics Lab *F*
ECEN 4634	2	Microwave & RF Lab *F*
ECEN 4638	2	Controls Lab *F*
ECEN 4652	2	Communication Lab *F*

Capstone Design Lab

ECEN 4610	3	Capstone Laboratory* *(take F or S)*

Software Elective (3-4 hours) choose one: ☐

ECEN 4553	3	Intro. to Compiler Construction
ECEN 4583	3	Software System Development
CSCI 3287	3	Database & Information Systems
CSCI 3308	3	Software Engr. Methods & Tools
CSCI 3753	4	Operating Systems
CSCI 4273	3	Network Systems
CSCI 4576	4	High-Performance Scientific Comp 1
CSCI 4586	4	High-Performance Scientific Comp 2
CSCI 4753	3	Computer Performance Modeling

Humanities & Social Sciences (21 hours)

	12	A&S Core Lower division
	6	A&S Core Upper division
WRTG 3030	3	Writing on Science & Society or equiv.

(see page 15 for equiv. courses)

Free Electives (6 hours maximum)

Student's choice of courses up to a maximum of 6 credit hours.

Technical Electives (variable)

3000-level or above or approved Engineering, Math, or

Figure 3. Old ECE Curriculum (Department of Electrical and Computer Engineering)

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