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| University of Colorado Boulder Department of Electrical, Computer, and Energy Engineering |
| ECEE Help Guide 2017-2018 |
| Undergraduate Reference Guide |



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# Welcome to the ECEE Department!

## **Electrical, Computer & Energy Engineering Advising Contacts**

* Associate Chair of Undergraduate Education: Prof. Sean Shaheen (ECOT 256, 303-492-9627)
* Academic Advisors: Aaron Watenmaker (A-L) and Maura Hollister (M-Z)
* Schedule appointments online at [www.colorado.edu/mycuhub](http://www.colorado.edu/mycuhub).
* Course information and Career Advisors: Any ECEE faculty member
* Career Advising outside the department: Career Services Office (Center for Community N352, [www.colorado.edu/engineering/academics/career-services](http://www.colorado.edu/engineering/academics/career-services))

## **Departmental Resources and Opportunities**

* Knowledge Foundry Tutors
* Peer Mentor Program
* Concurrent BS/MS Program ([www.colorado.edu/ecee/undergraduate-program/degrees/bs-ms-degrees](http://www.colorado.edu/ecee/undergraduate-program/degrees/bs-ms-degrees))
* Minors and Certificates ([www.colorado.edu/ecee/undergraduate-program/degrees/minors](http://www.colorado.edu/ecee/undergraduate-program/degrees/minors))

## **Other Opportunities and Resources**

* Engineering Honors Program ([www.cuhonorsengineering.com](http://www.cuhonorsengineering.com))
* Engineers Without Borders ([www.colorado.edu/ewb](http://www.colorado.edu/ewb))
* Study Abroad ([www.colorado.edu/engineering-international](http://www.colorado.edu/engineering-international))
* Counseling and Psychiatric Services (CAPS)
	+ [www.colorado.edu/health/counseling](http://www.colorado.edu/health/counseling)
	+ Phone: 303-492/2277
	+ Locations: C4C, Wardenburg, and Williams Village
* Office of Victim Assistance (OVA)
	+ [www.colorado.edu/ova/contact-ova](http://www.colorado.edu/ova/contact-ova)
	+ Phone:303-492-8855
	+ Location: Center for Community, S440study
	+ Email: assist@colorado.edu
* Gender and Sexuality Center
	+ [www.colorado.edu/gsc](http://www.colorado.edu/gsc/)

# Electrical Engineering Curriculum

## Electrical Engineering Requirements

**A minimum grade of C- is required for any course that is a prerequisite for a subsequent course.**

These requirements are specific to students entering the university in fall 2017. If you matriculated prior to fall 2017, please connect with your Academic Advisor to understand your specific requirements.

### Math (19 hours)

Minimum grade of C- required:

* APPM 1350 Calculus 1 for Engineers (4) **(Recommended)**
	+ Or MATH 1300
* APPM 1360 Calculus 2 for Engineers (4) **(Recommended)**
	+ Or MATH 2300
* APPM 2350 Calculus 3 for Engineers (4) **(Recommended)**
	+ Or MATH 2400
* APPM 2360 Diff Equations w/ Linear Algebra (4) **(Recommended)**
	+ Or MATH 3130 AND MATH 3430
* ECEN 3810 Probability (3) **(Recommended)**
	+ Or APPM 3570, MATH 4510

### Physics (9 hours)

* PHYS 1110 General Physics 1 (4)
* PHYS 1120 General Physics 2 (4)
* PHYS 1140 Experimental Physics 1 (1)

### Freshman Elective (3-5 hours)

Choose One:

* ECEN 1400 Intro to Digital/Analog Elect. (3) **(Recommended)**
* GEEN 1400 Freshman Projects (3)
* \_\_\_\_\_\_\_\_\_\_ Freshman Projects from other Engr. Dept. (3)

### Freshman Seminar (1 hour)

Choose One:

* ECEN 1100 Freshman Seminar (1) **(Recommended)**
* COEN 1500 Introduction to Engineering (1)
* \_\_\_\_\_\_\_\_\_\_ Freshman Seminar from other Engr. Dept. (1)

### General Science Elective (3-5 hours)

Choose One:

* PHYS 2130 General Physics 3 (3)
* MCEN 3012 Thermodynamics (3)
* EBIO 1210 General Biology 1 (lab optional) (3)
* MCDB 1150 Intro to Molecular Biology (3)
* IPHY 3410 Intro to Human Anatomy (3)
* CHEN 1211 General Chemistry for Engineers (4)
	+ With or without CHEM 1221 General Chem. Lab (1)

### Computer Programing (5 hours)

* ECEN 1310 C Programming for EE/ECE (4) **(Recommended)**
	+ OR: CSCI 1300, CSCI 1310, CSCI 1320
* ECEN 1030/2310 Programming with Mathematical Software

### Sophomore Electives (6 hours)

Choose One

* ECEN 2410 Renewable Energy (3)
* ECEN 2420 Electronics for Wireless Communication (3)
* ECEN 2440 Applications of Embedded Systems (3)

### Electrical Engineering Core (18 hours)

* ECEN 2250 Intro to Circuits & Electronics (3)
* ECEN 2260 Circuits as Systems (3)
* ECEN 2270 Electronics Design Lab (3)
* ECEN 2350 Digital Logic (3)
* ECEN 3350 Programming of Digital Systems (3)
* ECEN 3360 Digital Design Lab (3)

### Advanced Analog Core (9 hours)

Minimum C- required:

* ECEN 3250 Microelectronics (3)
* ECEN 3300 Linear Systems (3)
* ECEN 3400 Fields (3)

### Track Courses (12 hours)

Must complete TWO tracks (See website for more details):

* ECEN 4011 Design of Implantable Devices (3)
* ECEN 2021 Engineering Apps in Medicine (3)
* ECEN 4242 Communication Theory (3)
* ECEN 4652 Communication Lab (3)
* ECEN 4652 Digital Signal Processing Lab (3)
* ECEN 4632 Intro to digital Filtering (3)
* ECEN 3410 EM Waves & Transmissions (3)
* ECEN 4634 Microwave/RF Lab (3)
* ECEN 3320 Semiconductor Devices (3)
* ECEN 4555 Prin. Of Energy Systems/Devices (3)
* ECEN 4005 Photovoltaic Devices (3)
* ECEN 4606 Undergrad Optics Lab (3)
* ECEN 4616 Optoelectronic System Design (3)
* ECEN 4106 Photonics (3)
* ECEN 4116 Intro to Optical Communication (3)
* ECEN 3170 Electromagnetic Energy Conservation 1 (3)
* ECEN 4167 Electromagnetic Energy Conversion 2 (3)
* ECEN 4797 Intro to Power Electronics (3)
* ECEN 4517 Renewable Power Electronics Lab (3)
* ECEN 4138 Control Systems Analysis (3)
* ECEN 4638 Controls Lab (3)
* ECEN 4341 Bio Electromagnetics (3)

### Technical Electives (typically 6-12 hours)

* Choose 3xxx/4xxx level courses housed in any Engr. Department or APPM, MATH,PHYS, ASTR, ATOC, CHEM, EBIO, ENVD, GEOG, IPHY, MCDB, PSYC.
* You may also elect to count up to 6 credits of 3xxx/4xxx level ECON, Business, or EMEN courses towards TE requirements.
* You may **not** choose: CSCI 4250/5250, MATH 4430, or ECEN 3070
* Note that you still must meet prerequisites for these courses!

#### Non-track ECEN Technical Electives for EE

* ECEN 4593 Computer Organization (3)
* ECEN 4653 Real-Time Digital Media Systems (3)
* ECEN 4224 High-Speed Digital Design (3)
* ECEN 4324 Fund. Of Microsystem Packaging (3)
* ECEN 4xxx Selected Special Topics (3)
* ECEN 4827 Analog IC Design (3)

### Capstone Design Lab (6 hours)

Minimum grade of C- required:

* ECEN 4610 Capstone Laboratory, Part 1 (3, Fall Only)
* ECEN 4620 Capstone Laboratory, Part 2 (3, Spring Only)

### Humanities & Social Sciences (18 hours)

* 1xxx/2xxx A&S Core Lower Division (9)
* 3xxx/4xxx A&S Core Upper Division (6)
* WRTG Approved Upper Division Writing (3)

### Free Electives (8 hours maximum)

* Student choice of courses

## Sample Schedule for Electrical Engineering Program

### Freshman Year

| Fall | Spring |
| --- | --- |
| Course | Title | Hours | Course | Title  | Hours |
| APPM 1350 | Calculus 1 | 4 | APPM 1360 | Calculus 2 | 4 |
| PHYS 1110 | Physics 1 | 4 | PHYS 1120 | Physics 2 | 4 |
| ECEN 1100 | Freshman Seminar (F)  | 1 | PHYS 1140 | Experimental Physics | 1 |
| ECEN 1400 | Freshman Elective\* | 3 | ECEN 1310 | C Programming for EE/ECE\* | 4 |
|  | Humanities/Social Sciences | 3 | ECEN xxxx | Programming with MATLAB | 1 |
|  |  TOTAL CREDIT HOURS | 15 |  | Humanities/Social Sciences | 3 |
|  |  |  |  |  TOTAL CREDIT HOURS | 16 |

### Sophomore Year

| Fall | Spring |
| --- | --- |
| Course | Title | Hours | Course | Title | Hours |
| APPM 2360 | Diff. Eq. with Linear Algebra | 4 | APPM 2350 | Calculus 3 | 4 |
| ECEN 24-- | Sophomore Elective 1 | 3 | ECEN 24-- | Sophomore Elective 2 | 3 |
| ECEN 2250 | Intro to Circuits & Electronics | 3 | ECEN 2260 | Circuits as Systems | 3 |
| ECEN 2350 | Digital Logic | 3 | ECEN 2270 | Electronics Design Lab | 3 |
|  | Humanities & Social Sciences | 3 |  | General Science Elective\*\* | 3 |
|  |  TOTAL CREDIT HOURS | 16 |  | TOTAL CREDIT HOURS | 16 |

### Junior Year

| Fall | Spring |
| --- | --- |
| Course | Title | Hours | Course | Title | Hours |
| ECEN 3350 | Programming of Digital Systems | 3 | ECEN 3360 | Digital Design Lab | 3 |
| ECEN 3810 | Probability\* (F)  | 3 | ECEN 3--- | Advanced Analog Core | 3 |
| ECEN 3--- | Advanced Analog Core | 3 |  | Track Course/Tech Electives\*\* | 6 |
| ECEN 3--- | Advanced Analog Core | 3 |  | Upper-division writing | 3 |
|  | Humanities & Social Sciences | 3 |  | Free Elective | 3 |
|  |  TOTAL CREDIT HOURS | 15 |  | TOTAL CREDIT HOURS | 18 |

### Senior Year

| Fall | Spring |
| --- | --- |
| Course | Title | Hours | Course | Title  | Hours |
| ECEN 4610 | Capstone Lab: Part 1 (F)  | 3 | ECEN 4260 | Capstone Lab: Part 2 (S) | 3 |
|  | Track Course/Technical Electives\*\* | 8 |  | Track Course/Tech Electives\*\* | 9 |
|  | Humanities & Social Sciences | 3 |  | Humanities/Social Sciences | 3 |
|  | Free Elective | 3 |  |  |  |
|  |  TOTAL CREDIT HOURS | 17 |  | TOTAL CREDIT HOURS | 15 |

# Electrical and Computer Engineering Curriculum

## Electrical and Computer Requirements

**A minimum grade of C- is required for any course that is a prerequisite for a subsequent course.**

These requirements are specific to students entering the university in fall 2017. If you matriculated prior to fall 2017, please connect with your Academic Advisor to understand your specific requirements.

### Math (19 hours)

Minimum grade of C- required:

* APPM 1350 Calculus 1 for Engineers (4) **(Recommended)**
	+ Or MATH 1300
* APPM 1360 Calculus 2 for Engineers (4) **(Recommended)**
	+ Or MATH 2300
* APPM 2350 Calculus 3 for Engineers (4) **(Recommended)**
	+ Or MATH 2400
* APPM 2360 Diff Equations w/ Linear Algebra (4) **(Recommended)**
	+ Or MATH 3130 AND MATH 3430
* ECEN 3810 Probability (3) **(Recommended)**
	+ Or APPM 3570, MATH 4510

### Physics (9 hours)

* PHYS 1110 General Physics 1 (4)
* PHYS 1120 General Physics 2 (4)
* PHYS 1140 Experimental Physics 1 (1)

### Freshman Elective (3-5 hours)

Choose One:

* ECEN 1400 Intro to Digital/Analog Elect. (3) **(Recommended)**
* GEEN 1400 Freshman Projects (3)
* \_\_\_\_\_\_\_\_\_\_ Freshman Projects from other Engr. Dept. (3)

### Freshman Seminar (1 hour)

Choose One:

* ECEN 1100 Freshman Seminar (1) **(Recommended)**
* COEN 1500 Introduction to Engineering (1)
* \_\_\_\_\_\_\_\_\_\_ Freshman Seminar from other Engr. Dept. (1)

### General Science Elective (3-5 hours)

* Choose One:
PHYS 2130 General Physics 3 (3)
* MCEN 3012 Thermodynamics (3)
* EBIO 1210 General Biology 1 (lab optional) (3)
* MCDB 1150 Intro to Molecular Biology (3)
* IPHY 3410 Intro to Human Anatomy (3)
* CHEN 1211 General Chemistry for Engineers (4)
	+ With or without CHEM 1221 General Chem. Lab (1)

### Computer Programing (5 hours)

* ECEN 1310 C Programming for EE/ECE (4) **(Recommended)**
	+ Or CSCI 1300, CSCI 1310, CSCI 1320
* ECEN 1030/2310 Programming with Mathematical Software

### Sophomore Electives (6 hours)

Choose One:

* ECEN 2410 Renewable Energy (3)
* ECEN 2420 Electronics for Wireless Communication (3)
* ECEN 2440 Applications of Embedded Systems (3)

### Electrical Engineering Core (18 hours)

* ECEN 2250 Intro to Circuits & Electronics (3)
* ECEN 2260 Circuits as Systems (3)
* ECEN 2270 Electronics Design Lab (3)
* ECEN 2350 Digital Logic (3)
* ECEN 3350 Programming of Digital Systems (3)
* ECEN 3360 Digital Design Lab (3)

### Computer Engineering Core (10 hours):

* ECEN 2703 Discrete Math for Comp. Engineers (3) **(Recommended)**
	+ Or APPM 3170, MATH 2001, CSCI 2824
* CSCI 2270 Data Structures (4)
* ECEN 4593
	+ Or ECEN 4002

### Advanced Analog Core (6 hours)

Minimum C- Required, Choose Two:

* ECEN 3250 Microelectronics (3)
* ECEN 3300 Linear Systems (3)
* ECEN 3400 Fields (3)

### Humanities & Social Sciences (18 hours):

* 1xxx/2xxx A&S Core Lower Division (9)
* 3xxx/4xxx A&S Core Upper Division (6)
* WRTG Approved Upper Division Writing (3)

### Track Courses (6 hours) ECEN 4011 Design of Implantable Devices (3)

Must complete ONE track (See website for more details):

* ECEN 2021 Engineering Apps in Medicine (3)
* ECEN 4242 Communication Theory (3)
* ECEN 4652 Communication Lab (3)
* ECEN 4652 Digital Signal Processing Lab (3)
* ECEN 4632 Intro to digital Filtering (3)
* ECEN 3410 EM Waves & Transmissions (3)
* ECEN 4634 Microwave/RF Lab (3)
* ECEN 3320 Semiconductor Devices (3)
* ECEN 4555 Prin. Of Energy Systems/Devices (3)
* ECEN 4005 Photovoltaic Devices (3)
* ECEN 4606 Undergrad Optics Lab (3)
* ECEN 4616 Optoelectronic System Design (3)
* ECEN 4106 Photonics (3)
* ECEN 4116 Intro to Optical Communication (3)
* ECEN 3170 Electromagnetic Energy Conservation 1 (3)
* ECEN 4167 Electromagnetic Energy Conversion 2 (3)
* ECEN 4797 Intro to Power Electronics (3)
* ECEN 4517 Renewable Power Electronics Lab (3)
* ECEN 4138 Control Systems Analysis (3)
* ECEN 4638 Controls Lab (3)
* ECEN 4341 Bio Electromagnetics (3)

### Technical Electives (typically 6-12 hours):

* Choose 3xxx/4xxx level courses housed in any Engr. Department OR APPM, MATH,PHYS, ASTR, ATOC, CHEM, EBIO, ENVD, GEOG, IPHY, MCDB, PSYC You may only elect to count up to 6 credits of 3xxx/4xxx level ECON, Business, or EMEN courses towards TE requirements.
* You may **not** choose: CSCI 4250/5250, MATH 4430, or ECEN 3070
* Note that you still must meet prerequisites for these courses!

#### Non-track ECEN Technical Electives for ECE:

* ECEN 4593 Computer Organization (3)
* ECEN 4653 Real-Time Digital Media Systems (3)
* ECEN 4224 High-Speed Digital Design (3)
* ECEN 4324 Fund. Of Microsystem Packaging (3)
* ECEN 4xxx Selected Special Topics (3)
* ECEN 4827 Analog IC Design (3)

### Software Electives (3-4 hours)

Choose One:

* ECEN 4313 Concurrent Programming
* ECEN 4613/ECEN 5613 Embedded Systems Design
* CSCI 3002 HCC Foundations/User-Centered Development & Design
* CSCI 3104 Algorithms
* CSCI 3287 Design and Analysis of Data Systems
* CSCI 3308 Software Development Methods and Tools
* CSCI 3753 Design and Analysis of Operating Systems
* CSCI 4446 Chaotic Dynamics
* TLEN 5842 Linux Systems Administration

If you find another class that you feel should meet the software elective that is not on this list it is your right, as a student, to petition for it to be counted.

### Capstone Design Lab (6 hours)

* ECEN 4610 Capstone Laboratory, Part 1 (3, Fall Only) (Minimum grade of C- required)
* ECEN 4620 Capstone Laboratory, Part 2 (3, Spring Only)

### Free Electives (8 hours maximum)

* Student choice of courses

## Sample Schedule for Electrical & Computer Engineering

### Freshman Year

| Fall | Spring |
| --- | --- |
| Course | Title | Hours | Course | Title  | Hours |
| APPM 1350 | Calculus 1 | 4 | APPM 1360 | Calculus 2 | 4 |
| PHYS 1110 | Physics 1 | 4 | PHYS 1120 | Physics 2 | 4 |
| ECEN 1100 | Freshman Seminar (F)  | 1 | PHYS 1140 | Experimental Physics | 1 |
| ECEN 1400 | Freshman Elective\* | 3 | ECEN 1310 | C Programming for EE/ECE\* | 4 |
|  | Humanities/Social Sciences | 3 | ECEN xxxx | Programming with MATLAB | 1 |
|  |  TOTAL CREDIT HOURS | 15 |  | Humanities/Social Sciences | 3 |
|  |  |  |  |  TOTAL CREDIT HOURS | 16 |

### Sophomore Year

| Fall | Spring |
| --- | --- |
| Course | Title | Hours | Course | Title | Hours |
| APPM 2360 | Diff. Eq. with Linear Algebra | 4 | APPM 2350 | Calculus 3 | 4 |
| ECEN 24-- | Sophomore Elective 1 | 3 | ECEN 2350 | Digital Logic | 3 |
| ECEN 2250 | Intro to Circuits & Electronics | 3 | ECEN 2260 | Circuits as Systems | 3 |
| ECEN 2703 | Discrete Mathematics (F) | 3 | ECEN 2270 | Electronics Design Lab | 3 |
|  | Humanities & Social Sciences | 3 |  | General Science Elective\*\* | 3 |
|  |  TOTAL CREDIT HOURS | 16 |  | TOTAL CREDIT HOURS | 16 |

### Junior Year

| Fall | Spring |
| --- | --- |
| Course | Title | Hours | Course | Title | Hours |
| ECEN 3350 | Programming of Digital Systems | 3 | ECEN 3360 | Digital Design Lab | 3 |
| ECEN 3810 | Probability\* (F)  | 3 | ECEN 3--- | Advanced Analog Core | 3 |
| ECEN 3--- | Advanced Analog Core | 3 |  | Software Elective | 3 |
| CSCI 2270 | Data Structures | 3 |  | Track Course/Tech Electives\*\* | 6 |
|  | Humanities & Social Sciences | 3 |  | Upper-division writing | 3 |
|  |  TOTAL CREDIT HOURS | 15 |  | TOTAL CREDIT HOURS | 18 |

### Senior Year

| Fall | Spring |
| --- | --- |
| Course | Title | Hours | Course | Title  | Hours |
| ECEN 4610 | Capstone Lab: Part 1 (F)  | 3 | ECEN 4260 | Capstone Lab: Part 2 (S) | 3 |
|  | Track Course/Tech Electives\*\* | 7 |  | Track Course/Tech Electives\*\* | 3 |
|  | Humanities & Social Sciences | 3 | ECEN 4593 | Computer Organization | 3 |
|  | Free Elective | 3 |  | Humanities/Social Sciences | 3 |
|  |  |  |  | Free Elective | 3 |
|  |  TOTAL CREDIT HOURS | 16 |  | TOTAL CREDIT HOURS | 15 |

##

### Miscellaneous Curriculum Notes

Students must earn a C- in any course considered a prerequisite for any subsequent course. This includes classes in the Math and Physics sequences, the Analog Core Electives, and Capstone Lab 1 ECEN 4610.

It is necessary that you take APPM 2360 (Differential Equations with Linear Algebra). Material covered in APPM 2360 will help you with ECEN 2250 and must be taken as a co-requisite if not taken prior to 2250. This will likely mean taking APPM 2360 before APPM 2350 (Calculus 3).

Because the curriculum is in transition, the numbers associated with the core courses may change. The course titles, however, should remain the same. Always check the schedule for the upcoming semester on the website.

# Other Important Publications and Links

* University of Colorado Catalog: Degree requirements, academic standards, administrative regulations, university policies and procedures - [www.colorado.edu/catalog](http://www.colorado.edu/catalog)
* College Information: College of Engineering & Applied Science requirements, rules and regulations - [www.colorado.edu/engineering](http://www.colorado.edu/engineering)
* Registrar’s Office : Deadlines, instructions for registration and drop/add, transcript requests, calendars – [www.colorado.edu/registrar](http://www.colorado.edu/registrar)

# Humanities and Social Sciences Requirements

Students must complete 15 credit hours of approved courses in the Humanities and Social Sciences and 3 credit hours of an approved upper-division writing course. These courses are all included in the 18 total hours required for Humanities & Social Sciences in the online degree audit in mycuinfo.

### Writing

3 credit hours of one of the following courses: HUEN 1010 (for first year freshmen only), WRTG 3030, WRTG 3035, PHYS 3035, HUEN 3100. Upper-division transfer courses approved by petition.

### Humanities and Social Sciences

18 credit hours of approved courses, 6 of those credits must be at the 3000 level or higher. Courses approved for the 18 credit-hour H&SS requirement:

See [www.colorado.edu/engineering/academics/policies/hss](http://www.colorado.edu/engineering/academics/policies/hss) for assistance in selecting approved courses. Students must petition for any exceptions.

Approval granted for any group of four courses that would count toward a minor field in any of the following departments in the College of Arts and Sciences: Economics, Ethnic Studies, History, Linguistics, Philosophy, Political Science, Religious Studies, or Women’s Studies. (Note: These courses satisfy H&SS credit **only** if taken as a group of four courses that would count toward a minor field.) For further information on minor fields, see [www.colorado.edu/advising/programs-requirements](http://www.colorado.edu/advising/programs-requirements).

# ECEN Track Courses

## Choosing Theory and Elective Track Courses

Because the range of engineering applications is so large, it is necessary for you to sample some areas of specialization. The areas chosen reflect the individual research interests and expertise of our faculty.

Each track lists prerequisite courses (normally from the ECEE core) and the courses that complete the track. As part of the curriculum requirements, EE majors must complete at least two tracks, while ECE majors must complete at least one track.

Should you develop an interest for further study, or would like to be involved in some independent work, you should consult one or more of the faculty listed. Faculty contact information is available on the ECEE web site.

Finally, be sure to consult the current University Course Catalog or the Course Schedule (found on a link from the front page of the department’s site) for course descriptions.

### Communications

* Core prerequisite: Linear Systems, ECEN 3300
* Courses: ECEN 4242 Communication Theory and ECEN 4652 Communication Lab
* Faculty advisors: E. Liu, P. Mathys, M. Varanasi

One of the most fascinating and important topics in electrical communications is the wireless transmission and reception of analog and digital signals. Early examples, most of which are still in use today, include wireless communication using Morse signals and AM (amplitude modulation) and FM (frequency modulation) radio broadcasts. Modern examples of wireless systems are satellite radio and TV, wireless LANs (local area networks), and cellular telephones.

All practical communication systems are affected by noise that is picked up during transmission, either by the communication channel itself or by the front-end of the receiver, and the signal-to-noise ratio (SNR) of the received signal is a crucial measure for the quality of a communication system. For analog systems quality is synonymous with high fidelity reproduction of the transmitted signal. For digital systems the main quality measure is the probability of bit or symbol error. Early on, the common perception was that in order to improve quality more transmit power was needed. But it is now recognized that putting intelligence in various forms of coding into communication systems is an energy-conscious and smart alternative. Most modern communication systems use digital symbols to represent signals, independent of whether the original signal, like speech or music, is analog or, like computer data, is already digital. Source coding, like MP3, for example, and error-control coding can be applied easily to digitally represented signals. However, most physical channels require a waveform that is continuous in time and in amplitude and is restricted to a specific frequency range for efficient signal transmission. Thus, important topics for the treatment of communication systems are the study of signal processing of both analog and digital signals and the conversion between analog and digital representations.

#### Representative Technical Applications

* Wireless and wired transmission of analog and digital data
* Reliable reception of analog and digital data
* Information storage and retrieval
* Telephone network, cell phones, data networks
* Coding for compression, error-control, and secrecy/privacy
* Radio and TV broadcasts

#### Representative Societal Applications

* Voice and data communication for personal and commercial purposes
* Digital storage of multimedia including audio, images, and movies
* Wireless communication networks for remote areas
* Communications for rescue missions and disaster recovery

### Digital Signal Processing

* Core prerequisite: Linear Systems, ECEN 3300
* Courses: ECEN 4632 Digital Filtering and ECEN 4532 Digital Signal Processing Laboratory
* Faculty advisors: F. Meyer

Digital Signal Processing became possible when digital computers came into existence and then became cheap enough to be considered components. Almost all the classical analog signal processing applications (like telephones, radio sets, signal generators, and oscilloscopes) can now be done digitally. DSP is done in real time or offline; it is done on one-dimensional signals like audio, and two-dimensional signals like images. Embedded processors for doing DSP are found in cell phones, audio players, digital cameras, automobile engines, braking control systems, and medical instruments. Examples of applications on large computers include seismic exploration, geophysical mapping, motion picture animation, and medical imaging. The range of application is enormous.

To study Digital Signal Processing, it is necessary to have a good grounding in discrete-time linear systems and time-frequency transformations. The essential pre-requisite for the senior DSP theory and lab courses is the Linear Systems Core course. In addition, real-time applications require experience with assembly language code development. Offline processing requires the use of high-level application languages like MATLAB. DSP is a good area for those who enjoy the design and development of algorithms, applied mathematics, and applications. Students who intend to complete degrees in both EE and Music will find the DSP lab course especially interesting.

#### Representative Technical Applications

* Audio generation, coding, reproduction, and enhancement
* Image Processing, enhancement, coding, and pattern recognition
* Video analysis, coding and decoding
* Wireless Communications modulation and demodulation
* The Design of dedicated DSP processors
* The use of DSP in feedback control

#### Representative Societal Applications

* Aids for human speech and hearing
* Aids for human vision
* Medical instruments which can see into the body and the brain
* Environmental analysis using remote sensing data

### Dynamics and Controls

* Core prerequisite: Linear Systems, ECEN 3300
* Courses: ECEN 4138 Control Systems Analysis and ECEN 4638 Control Systems Laboratory
* Faculty advisors: J. Hauser, J. Marden, D. Meyer, L. Pao

Safe airplanes and vehicles, minimally invasive surgery, reliable manufacturing, computer-assisted physical rehabilitation—these all have automatic control and robotics as core technologies. Automatic control has been a key technological component since the middle of the 20th century, and with the advent of fast computers, nearly any device that moves or has dynamics has an embedded digital controller. Moreover, robotic applications have found their way into more than just automotive manufacturing. We now see robotic devices in medical, defense, and renewable power industries. Students wishing to pursue these areas will increasingly need expertise in the robotics and control areas.

To study robotics and control, students need to have taken Linear Systems Analysis (ECEN 3300) and the controls sequence early. If possible, students should take ECEN 3300 by their Spring junior term so that they can take ECEN 4138/4638 in their Fall/spring senior term. This will allow them to take a senior robotics elective. Many students find that a course in matrix methods (typically offered through the Applied Mathematics Department) is helpful in robotics and control. Other relevant courses include embedded systems and power electronics, both of which play significant roles in autonomous, robotic systems.

#### Representative Technical Applications

* Haptic rendering for minimally-invasive surgery
* Motion planning in uncertain environments, such as the NASA Mars rover
* Flight control of aggressive aircraft
* Reconfigurable manufacturing
* Image recognition and autonomous response
* Fast and precise control of atomic force & near field scanning optical microscopes

#### Representative Societal Applications

* Safe transportation
* Precise medical treatment and rehabilitation
* Efficient energy usage

### Electromagnetics, RF and Microwaves

* Core prerequisite: Electromagnetic Fields, ECEN 3400
* Courses: ECEN 3410 Electromagnetic Waves and Transmission and ECEN 4634 RF & Microwave Laboratory
* Faculty advisors: D. Filipovic, A. Gasiewski, E. Kuester, M. Piket-May, Z. Popovic

The origins of electromagnetics can be traced to the earliest days of human existence. Fear and fascination with many natural phenomena including lightning lingered for thousands of years until sound physical understandings were developed. Ancient Greeks noticed that rubbing fur against amber (‘electron’ in Greek language) caused attraction between the two. The 20th century archeological findings indicate that the first battery was made in old Iraq in 3rd century BC. Many scientists and free thinking minds over the last 300 years, including Benjamin Franklin, Michael Faraday, Nikola Tesla, James Clerk Maxwell, Heinrich Hertz and others have contributed to tremendous advances in electromagnetics, and by application of electromagnetics, to electrical and electronic engineering as a whole. Try to imagine life without electrical signals, power, and modern electronic materials: radio, TV, phones, air travel, refrigeration, etc... would be virtually impossible.

The CU Electromagnetics, RF and Microwave focus area provides the necessary foundation for understanding the phenomena of electricity, magnetism and radio waves, and facilitates the engineering of a wide range of RF and microwave components, devices, sub-systems, and systems. EM theory, design, measurements and fabrication are covered on a level that enables a career in industry, government, or further education on a master or doctoral level. A background in mathematics and elementary circuits are needed. The low-frequency part of this track is the foundation for circuit theory, while the high-frequency portion merges with the optics track.

#### Representative Technical Applications

* Generation, transmission, propagation, and reception of radio waves
* Wireless, satellite, and cable communications, including radio and television
* Antennas for cell phones, vehicles, space exploration, navigation, and sensing
* RF and microwave transmitters and receivers
* Microwave transmission lines, amplifiers, oscillators, resonators, and filters
* Radar, concealed weapon and buried object detection; stealth design
* Remote sensing of Earth and planetary surfaces, oceans, atmospheres, and cryospheres
* RF tagging, telemetry, therapeutic and industrial heating
* Acoustic sensing and communications; seismic sensing

#### Representative Societal Applications

* Wireless communications and networking
* Medical instrumentation, diagnostics, treatment and therapeutics
* Alternative energy resources – wireless power harvesting
* Environment sensing, monitoring, and forecasting
* Border control, defense, homeland security

#### Possible follow-on courses

* ECEN 5114 Waveguides and Transmission Lines
* ECEN 5134 Electromagnetic Radiation and Antennas
* ECEN 5104 Computer-Aided Microwave Circuit Design
* ECEN 5254 Radar and Remote Sensing

### Nanostructure Materials & Devices

* Prerequisites: Microelectronics, ECEN 3250 (Modern Physics PHYS 2130 recommended)
* Courses (choose two to complete the track): ECEN 3320 Semiconductor Devices, ECEN 4555 Principles of Energy Systems & Devices (requires PHYS 2130 but not ECEN 3250) and ECEN 4005 Photovoltaic Devices
* Faculty advisors: J. Gopinath, G. Moddel, W. Park, S. Shaheen, B. Van Zeghbroeck

Materials and device electronics dominated technological advances in the 20th century, and are advancing at an accelerated rate in the 21st century. Early electronics used the vacuum tube, but about 50 years ago this gave way to solid state electronics based on semiconductors. This enabled the growth of the microelectronics industry, integrated circuits, superconductor devices, and more recently practical use of solar cells. Virtually all audio, video, communications, computing and more recently aerospace and automotive technologies are based on microelectronic devices. During the last few years, nanostructured materials and nano-scale (below 1 micron) devices have allowed the fabrication of devices that were not even dreamed of earlier.

Nanostructures is based upon a solid understanding of modern physics as well as a “feel” for physical structures. In addition to the physics courses required for the EE degree, it would be useful to take PHYS 2130 Modern Physics as early as possible. The stepping-off point to junior and senior-level nanostructures courses is ECEN 3250 Microelectronics. ECEN 3320 Semiconductor Devices, ECEN 4555 Principles of Energy Systems & Devices (ECEN 3250 not required), and ECEN 4005 Photovoltaic Devices can be taken in any order. Semiconductor Devices and Photovoltaic Devices use underlying physics to develop an understanding of electronics and solar cell technology. Principles of Energy Systems & Devices develops thermodynamics concepts to explore energy technologies.

#### Representative Technical Applications

* Lower-power portable devices
* Lasers and solid-state lighting devices
* Flat-panel displays
* Solar cells
* Energy conversion devices and systems
* Higher-density computers and memories
* Digital cameras and photodetectors

#### Representative Societal Applications

* Alternative energy devices
* Internet, communications and entertainment
* Nano-scale electronic devices for medical implants
* Medical imaging, cancer detection and therapeutics

### Neural and Biomedical Engineering

* Core prerequisite: Circuits as Systems, ECEN 2260
* Courses (choose two to complete the track): ECEN 4011 Design of Implantable Medical Devices, ECEN 4021 Engineering Applications in Medicine and ECEN 4053 Assistive Technologies for People with Disabilities
* Faculty advisors: M. Lightner, R. Mihran

The roots of electrical engineering and neuroscience both go back to the late 18th century when scientific debates as to the fundamental nature of electricity and its role in the neural control of muscle activity were raging. For example, the Italian physiologist and anatomist Luigi Galvani built a sensitive device (subsequently known as a Galvanometer) used it to, he claimed, detect electrical activity in active frog muscles. His fellow Italian, physicist Alessandro Volta, however, disputed this and suggested instead that the electrical potentials (subsequently known as Voltages) that Galvani registered were due to the interface of metal wires with the muscle tissue. To prove his point Volta showed that you could generate voltages simply by interfacing metal plates with salt solutions—and in so doing he invented the battery! History would prove that both Galvani and Volta were correct in their own context and ever since progress in electrical and neural sciences has been intrinsically linked.

Today, this strong linkage between ECE and Neural Sciences has re-emerged as a field called Neural Engineering or Neurotechnology, and it is well represented in the course offerings open to junior and senior (as well as first-year graduate) EE/ECE students.

The NE track does not require any previous coursework in biology. The courses listed above are designed to be comprehensible to engineering students with no prior biological background.

#### Representative Technical Applications

* Measurements of biomedically important signals
* Algorithms for biomedical signal processing and display
* Technologies for imaging body anatomy (MRI, CAT, etc.) and imaging neuroelectric activity patterns (FMRI, etc.)
* Studying the molecular and cellular basis of bioelectrical phenomena
* Applying control theory and signal flow concepts to physiological systems
* Quantifying and understanding the biological effects of electromagnetic fields
* Modeling the genesis and propagation of neuromagnetic fields
* Improving neurosurgical techniques such as Deep Brain Stimulation

#### Representative Societal Applications

* Improved diagnoses and treatment for cardiac, vascular, and pulmonary diseases.
* Improved diagnoses and treatment for neural diseases.
* Development of assistive devices for cognitive disabilities
* Development of brain controlled prostheses for disabled patients.
* Better understanding of health risks (or lack thereof) posed by EMF devices.
* Refinement of "artificial intelligence" to be more like actual cognitive function.

### Optics and Photonics

* Core prerequisite: ECEN 3400 Electromagnetic Fields & Waves and ECEN 3300 Linear Systems
* Courses: ECEN 4606 Undergraduate Optics Lab and ECEN 4616 Optoelectronic System Design
* Faculty advisors: J. Gopinath, R. McLeod, A. Mickelson, R. Piestun, M. Popovic, K. Wagner

From LCD displays and CMOS cameras, fiber optics and telecommunications, to medical and astronomical imaging, optics and photonics are critical to many modern technologies. Based on the science of light, optics and photonics are at the confluence of electrical and optical engineering with applied physics. Iconic developments that are prevalent in daily life such as the laser, holography, liquid crystal displays, charge coupled device (CCD) detectors, and fiber optics are being extended by CU faculty into future applications such as silicon photonics, computational imaging, nano-lithography, biophotonics, femtosecond lasers, and quantum and optical computing.

The study of Optics and Photonics requires a background in electromagnetic fields and waves and the interaction of light with matter, as well as the system viewpoint of linear systems and communication theory. Thus, both fields and linear systems are required prerequisites of the Photonics Theory/Lab senior electives.. Theory courses in either Photonics, Optics, Optical Electronics, or Optical Systems Design can be followed with more advanced courses such as Physical or Fourier optics or others offered in the department of ECEE.

#### Representative Technical Applications

* Laser diodes, solid state lasers, tunable lasers, ultrafast lasers, and other novel light sources
* Holography for display and storage, interferometric metrology
* Fiber optic components, lasers, detectors, amplifiers, modulators
* Microscopes, Telescopes, Spectrometers, Polarimeters, Interferometers
* Quantum optics, quantum encryption, quantum information processing
* Nonlinear optics based information processing, frequency conversion

#### Representative Societal Applications

* Optical data storage (CDs, DVDs, holographic storage)
* Fiber optic communication (internet backbone, fiber to the home)
* Imaging (digital cameras for consumer, microscopy, medical, defense, astronomy applications)
* Displays (for computers, portable devices, video and art, including 3-D displays)
* Electronic-photonic circuits (next generation ICs and planar lightwave integrated circuits)
* Lasers sources (precision metrology, spectroscopy, time and frequency standards)
* Energy conversion (semiconductor and organic solar cells)

#### Alternate Theory Course

* ECEN 4645 Optical Electronics

#### Advanced follow-on courses

* ECEN 5696 Fourier Optics and Imaging
* ECEN 5156 Physical Optics
* ECEN 5166 Guided Wave Optics

### Power Electronics

* Core prerequisite: ECEN 3250 Microelectronics
* Courses: ECEN 4797 Introduction to Power Electronics and ECEN 4517 Power Electronics Laboratory
* Faculty advisors: K. Afridi, R. Erickson, D. Maksimovic

Although vast majority of electronic signal processing and computing is now performed digitally, signal and power generation and delivery remain fundamentally analog. Interfaces between sensors such as microphones, temperature, motion or optical sensors and digital computers involve analog signal conditioning and analog-to-digital conversion. Similarly, digital computer outputs, such as audio or communication signals must be ultimately converted to real-world analog signals via digital-to-analog converters. All electronic systems require efficient, tightly regulated power supplies. Advances in power electronics have enabled improved operating life of battery powered electronics, significant energy savings and reductions in size and cost in all electronic systems, as well as more effective utilization of renewable energy sources such as wind or solar. Performance of systems ranging from cell phones to audio or video players, to medical instrumentation, measurement devices, or renewable energy systems is often determined by the noise, bandwidth or efficiency of analog and power microelectronics.

Basic understanding of transistors and other semiconductor devices, as well as circuit analysis techniques in time and frequency domains, are necessary to learn about circuit design techniques in microelectronics. ECEN 2250, ECEN 2260 and ECEN 3250 are therefore essential prerequisites for the senior power electronics and analog integrated circuit design courses. In the Introduction to Power Electronics and the Power Electronics Laboratory, we address analysis, modeling and design of switched-mode power conversion circuits capable of supplying arbitrary tightly regulated voltages and currents at very high efficiencies. The lab culminates with a project where students design, build and test power electronics for a complete solar power system. Analog Integrated Circuits Design addresses transistor-level circuit design of current and voltage references, amplifiers, comparators, analog-to-digital and digital-to-analog converters with numerous applications in audio, video, radio-frequency and sensor interfaces. Microelectronics is a good area for those who enjoy hands-on circuit design, experimentation, and applications.

#### Representative Technical Applications

* Efficient electrical power processing and power management
* Signal conditioning, analog-to-digital and digital-to-analog conversion
* Audio, video, radio-frequency and sensor interfaces

#### Representative Societal Applications

* Energy efficiency and energy savings
* Effective utilization of renewable energy sources
* Computing and communication infrastructure
* Sensors and instrumentation: environmental, medical, industrial

### Renewable Energy

* Core prerequisite: ECEN 2260 Circuits as Systems
* Courses: ECEN 3170 Electromagnetic Energy Conversion I (co-requisite ECEN 3250 Microelectronics) and ECEN 4167 Electromagnetic Energy Conversion II
* Faculty advisors: H. Hilgers (adjunct faculty)

Renewable energy was established as a new field about 20 years ago with the design of wind and photovoltaic power plants. Although in some areas great progress has been made, it is still insufficient to cover the electric energy needs of our nation which requires a total installed power capacity of about 800GW with a spinning reserve of about 80GW. The latter is required because the electricity consumed by residential, commercial and industrial loads must be generated at the very moment when consummation occurs. This requirement cannot be met by renewable energies alone because they are intermittent in their energy production and even meteorological forecasts cannot alleviate this problem. In addition, the change of the wind, for example, may result in the loss of 60MW per minute. This loss of generation capacity can only be covered either by conventional plants (e.g., natural gas or coal-fired plants) or by energy storage facilities, and to a lesser extent by nuclear plants which serve mostly as base load plants due to the long thermal time constants of the nuclear reactor.

Applications range from the development of new algorithms for the control of distributed systems (DG), load flow analyses for fundamental and harmonics as required by power system control centers, the development of emergency operational procedures in case of brown- or blackouts, the interaction of renewable plants with energy storage plants. From the Dutch experiences one can conclude that renewable energy of 30% of the entire required power, that is, in our nation’s case 240GW, poses tremendous control problems. Needless to say, the range of application is enormous.

To study renewable energy systems, it is necessary to have a good grounding in basic laws and theorems of electrical engineering. The prerequisite for the sophomore, senior, and cross-listed graduate courses is Circuits and Electronics 1 and 3. In addition, real-time applications require some experience in computer languages such as Quick Basic, C++, D/D, D/A and A/D converters, and other soft- and hardware. Off-line processing requires the use of high-level application languages like MATLAB, MATHEMATICA and SPICE. The renewable energy field is a good area for those who want to contribute to solving the problems of society and who enjoy the design and development of power system and power electronic components, applied mathematics, and applications.

#### Representative Technical Applications

* Renewable energy sources such as wind- photovoltaic and co-generation
* Large-scale energy storage to mitigate intermittent nature of renewable sources: design of pumped-storage hydro plants, compressed air storage plants, emergency and standby power supplies, and uninterruptible power supplies for data processing equipment
* Design of large-scale machines, rectifiers and inverters
* AC and DC transmission of electrical energy, voltage- and frequency control of systems with distributed generation
* Energy conservation
* Replacement of internal combustion engine (IC) by electric drives based on either fuel cells or batteries/supercapacitors

#### Representative Societal Applications

* Reduction of particulates, sulfur and carbon dioxide emissions
* Providing fuel (electricity from renewable sources) for public and individual transportation

# Graduation Checklist

* Successfully complete a minimum of 128 semester credit hours according to the curriculum in effect at the time the student was officially admitted to the EEEN or ECEN degree program. The last 45 credit hours must be earned as a degree student in classes at the Boulder campus after admission to the College of Engineering and Applied Science unless exempted by prior petition.
* Achieve a cumulative grade point average of 2.25 or better in all courses taken at the University of Colorado (all campuses) as well as a grade point average of 2.25 or better in all courses taken from, or cross listed in, the Department of Electrical, Computer, and Energy Engineering.
* Satisfy any outstanding MAPS deficiencies. These deficiencies should have been resolved in the first year or two of enrollment in the College, but students cannot graduate without having met the basic requirements in effect at the time of their admission.
* Meet with the Undergraduate Advisor two semesters prior to intended graduation for a comprehensive review and approval of remaining courses needed to satisfy graduation requirements.
* Complete the Application for Graduation online using MyCuInfo. Deadlines for completion of the application process will be announced by the Registrar’s Office, the Engineering Dean and the Undergraduate Advisor.
* If you are completing a minor, a Minor Completion form must be submitted to the Undergraduate Staff Advisor’s Office prior to graduation.

It is the **responsibility of each student** to be certain that they have met all degree requirements and to keep the Department informed of any change in graduation plans.