Department of Electrical and Computer Engineering

231 Kaufman Hall
757-683-3741
http://www.odu.edu/ece/

Oscar González, Chair Chunsheng Xin, Graduate Program Director,
Electrical & Computer Engineering Christian Zemlin, Graduate Program
Director, Biomedical Engineering Hongyi Wu, Graduate Program Director,
Doctor of Engineering, Cybersecurity

Department Description

The Department of Electrical and Computer Engineering strives to provide the highest quality engineering education at the undergraduate and graduate levels, to engage in scholarly research at the forefront of electrical, computer, and biomedical engineering, and to serve the professions of electrical, computer, and biomedical engineering. The department has strong graduate and research programs providing a high quality and broad-based education that prepares graduates for successful professional careers and a lifetime of learning. The Electrical & Computer Engineering Department also administers the Biomedical Engineering degree programs described in the Biomedical Engineering section at the end of this page.

Electrical and Computer Engineering graduate studies encompass four broad areas:
1. systems
2. signal and image processing
3. physical electronics
4. computer engineering

Special Facilities

The research laboratories and institutes directly associated with the department include the Advanced Signal Processing in Engineering and Neuroscience Lab (ASPEN), the Applied Plasma Technology Laboratory (AFTL), the Cardiac Electrophysiology Laboratory, the Cybersecurity, Communications & Networking Innovation (CCNI) Laboratory, the Medical Imaging, Diagnosis & Analysis (MIDA) Laboratory, the Plasma Engineering & Medicine Institute (PEMI), the Systems Analysis of Metabolic Physiology and Exercise (SAMPE) Laboratory, the Systems Research Laboratory, the Virginia Institute for Photovoltaics (VIPV), the Vision Lab, and the Virginia Institute for Vision Analysis (VIVA). In addition, the department has strong ties to the Applied Research Center at the Jefferson National Laboratory and to the Frank Reidy Research Center for Bioelectrics. These research facilities position the department for national leadership in several areas and as a leading institution of research and higher education in the southeastern United States.

List of Degrees and Certificate

The department offers the following Electrical and Computer Engineering graduate degrees:

- Master of Science, Engineering - Electrical and Computer Engineering (Traditional and Online Formats)
- Doctor of Philosophy, Engineering - Electrical and Computer Engineering
- Doctor of Engineering, Electrical and Computer Engineering

The department also offers the following Biomedical Engineering graduate degrees and certificate:

- Master of Engineering - Biomedical Engineering
- Master of Science, Engineering - Biomedical Engineering
- Doctor of Philosophy, Engineering - Biomedical Engineering
- Advanced Engineering Certificate - Biomedical Engineering

The department also offers the following Cybersecurity graduate degree.

- Doctor of Engineering, Cybersecurity

Master of Science, Engineering, Electrical and Computer Engineering

Degree Description

The Department of Electrical and Computer Engineering offers the Master of Science (M.S.) graduate degree program. It requires a minimum of 30 credit hours of graduate study. The credit hours are obtained through a combination of graduate coursework and thesis research. Full-time and part-time students may complete coursework through a combination of on-campus and distance learning courses. The distance learning courses are available synchronously at the higher education centers and can be broadcast to any computer with a high speed Internet connection. These distance learning courses can also accommodate asynchronous students. Full details on all requirements for graduating with a Master's degree are outlined in a separate section that follows the admission information.

Admission Information

Applicants are expected to hold a B.S. degree in electrical engineering (EE) or computer engineering (CpE) from an accredited institution. Applicants are also expected to have a minimum grade point average of 3.0 (on a 4.0 scale) in both the baccalaureate major area (EE or CpE) and overall. Applicants with a GPA below a 3.0 may be considered for provisional admission, which may require additional prerequisite courses in addition to the graduate degree requirements. The applications are submitted through the Office of Admissions of Old Dominion University. Together with the completed application form, two letters of recommendation from former instructors or employment supervisors, transcripts from all colleges and universities attended, GRE scores, a resume, and a personal statement of objectives are required. TOEFL scores are also required for international applicants. Applicants with academic degrees in areas other than electrical and computer engineering will be considered. Those with degrees in math, physics, computer science, or other engineering fields are encouraged to apply. The linked Bachelor's/Master's degree program in the Frank Batten College of Engineering and Technology at Old Dominion University is designed to provide an opportunity for exceptionally qualified engineering undergraduate students to obtain both a bachelor's and a master's degree in Electrical and Computer Engineering. Typically undergraduate students apply at the end of their junior year for admission to the linked programs.

Accepted students from disciplines other than EE or CpE are required to complete a number of leveling courses to meet prerequisites for graduate studies. All students are required to have one year of college chemistry and one year of calculus-based college physics in addition to Calculus III and Differential Equations courses. Students at Old Dominion University may complete the leveling requirement by earning a minor in electrical or computer engineering with a GPA of 3.0 or greater. Students that have not earned a minor need to meet with the graduate program director to prepare a course plan and determine which pre-requisite courses are needed. In general, three to four leveling courses are needed and they are chosen from the following lists.

List of Possible Courses to Meet the Leveling Requirement

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECE 202</td>
<td>Circuit Analysis II</td>
<td>3</td>
</tr>
<tr>
<td>ECE 241</td>
<td>Fundamentals of Computer Engineering</td>
<td>4</td>
</tr>
<tr>
<td>ECE 302</td>
<td>Linear System Analysis</td>
<td>3</td>
</tr>
<tr>
<td>ECE 303</td>
<td>Introduction to Electrical Power</td>
<td>3</td>
</tr>
<tr>
<td>ECE 304</td>
<td>Probability, Statistics, and Reliability</td>
<td>3</td>
</tr>
<tr>
<td>ECE 313</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>ECE 323</td>
<td>Electromagnetics</td>
<td>3</td>
</tr>
<tr>
<td>ECE 332</td>
<td>Microelectronic Materials and Processes</td>
<td>3</td>
</tr>
</tbody>
</table>

1Department of Electrical and Computer Engineering
Students interested in taking computer engineering graduate courses may need to take additional leveling computer science courses as indicated below.

**List of Possible Computer Science Courses to Meet the Leveling Requirements**

- CS 350 Introduction to Software Engineering 3
- CS 361 Data Structures and Algorithms 3
- CS 381 Introduction to Discrete Structures 3

**Degree Requirements**

The M.S. degree requires a minimum of 30 credit hours of graduate study.

The M.S. degree thesis option requires a minimum of 24 credit hours of courses (not including the Graduate Seminar), at least 1 credit hour of Graduate Seminar (ECE 731), and 6 credit hours of thesis along with the oral thesis defense examination. Continuation in the M.S. program thesis option is contingent upon identifying a MS thesis advisor after completing 18 credit hours of coursework (which coincides approximately with the end of the second semester of study for full-time students).

The M.S. degree project option requires a minimum of 27 credit hours of courses (not including the Graduate Seminar) and 3 credit hours of Master's project course (ECE 698) that includes an oral defense examination.

The M.S. degree course option requires a minimum of 30 credit hours of courses (not including the Graduate Seminar) and a written comprehensive examination at the end of the course work. The examination is offered every fall and spring semesters, and the student needs to pass the examination in no more than two attempts. The second attempt, if necessary, should be taken at the next offered examination.

The M.S. program is available to full-time and part-time students seeking to improve their professional skills in electrical and computer engineering. Students are required to complete at least one course that meets the department's mathematics requirement. The current list of courses that meet this requirement is given next.

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECE 601</td>
<td>Linear Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECE 611</td>
<td>Numerical Methods in Engineering Analysis</td>
<td>3</td>
</tr>
<tr>
<td>ECE 623</td>
<td>Electromagnetism</td>
<td>3</td>
</tr>
<tr>
<td>ECE 651</td>
<td>Statistical Analysis and Simulation</td>
<td>3</td>
</tr>
</tbody>
</table>

The remaining courses are chosen to meet the student's career objectives. To earn a master's degree, a student needs to take at least five courses at the 600 or higher level, and no more than three courses at the 500 level. Also, no more than three graduate courses can be taken in other departments. All course selections must be reviewed by the graduate program director, and for M.S. thesis option students' course selection should be made in coordination with the students' research/thesis advisor. The graduate course descriptions are included in the graduate catalog and are also listed on the department's website. Additional graduate courses are offered through the Commonwealth Graduate Engineering Program and the Virginia Consortium for Engineering and Science. All funded Master's students are required to attend Graduate Seminar (ECE 731).

**Doctor of Philosophy, Engineering**

**Degree Description**

The Department offers a strong doctoral program leading to the Doctor of Philosophy (Ph.D.), Engineering degree. The Ph.D. degree is awarded to candidates who have displayed an in-depth understanding of the subject matter and demonstrated the ability to make an original contribution to knowledge in their chosen field of specialty. A very important component of the Ph.D. degree is the original research pursued by the student which culminates in a written dissertation, as well as an oral defense of this work. Ph.D. students usually publish the result of their research in highly reputable nationally and internationally refereed journals. In addition, the students are expected to present their work at national and international conferences.

**Admission Requirements**

Applicants to a doctoral degree in electrical and computer engineering are expected to have completed a master's degree in electrical engineering and/or computer engineering or a closely related technical field with a minimum grade point average of 3.5 (on a 4.0 scale) in graduate course work. The applications are submitted through the Office of Admissions at Old Dominion University. Together with the completed application form, three letters of recommendation, transcripts from all colleges and universities attended, GRE scores, a resume, and a personal statement of objectives are required. TOEFL scores are required for international applicants. At least two of the recommendation letters should be submitted by faculty or work supervisor familiar with the applicant's graduate work. The Frank Batten College of Engineering and Technology at Old Dominion University has the Direct Bachelor-to-Ph.D. and Integrated Bachelor/Ph.D. programs that allow exceptionally well-qualified undergraduate students to apply for admission directly to a Ph.D. program. The programs are described in the college section of the catalog.

**Degree Requirements**

The Ph.D. degree requires:

- 24 credit hours of graduate-level courses beyond the master's degree (not including Graduate Seminar),
- 24 research credit hours,
- successful completion of a written diagnostic examination,
- successful completion of written and oral candidacy examinations,
- successful completion of a dissertation research proposal, and
- successful completion and public defense of a dissertation.

The eight graduate-level courses are chosen together with the research adviser, and approved by the graduate program director. At least 1 credit hour of Graduate Seminar (ECE 831) is required too. It is required that at least three-fifths of the coursework (not including ECE 831) be completed at the 800 level, and no more than three graduate courses can be taken in other departments. Additional course work or appropriate research background may be required to meet prerequisites for courses or in preparation for the diagnostic examination. All funded students are required to enroll in ECE 831. The graduate course descriptions are included in the catalog and are also listed on the department's website. Additional graduate courses are offered through the Commonwealth Graduate Engineering Program and the Virginia Consortium for Engineering and Science. All funded Ph.D. students are required to attend Graduate Seminar (ECE 831).

All Ph.D. students are required to take the department's Ph.D. Diagnostic Examination for the first time before the end of their second semester in the Ph.D. program. The examination is offered every fall and spring semesters, and the student needs to pass the examination in no more than two attempts. The second attempt, if necessary, should be taken at the next offered examination. The topics for the examination and samples of previous examinations are posted in the department's website. The examination rules are given on the first page of each examination.

It is required that the written and oral candidacy examinations be taken in the semester when a student is completing the graduate course work or during the following semester. Once a student has completed the course work, passed the candidacy examinations, and has gained approval for the research proposal, the student advances to candidacy. It is a university requirement that students who have advanced to candidacy be enrolled for at least one credit hour every fall, spring, and summer until graduation.

**Doctor of Engineering, Electrical and Computer Engineering**

The Department offers a Doctor of Engineering (D.Eng.) degree with concentration in Electrical and Computer Engineering in accordance with
the admission criteria and degree requirements specified in the Frank Batten College of Engineering and Technology section in this catalog. The curriculum of this concentration consists of 18 credit hours of ECE 600 and 800 level courses as core courses, 18 credit hours of graduate coursework in the area of specialization and 12 credit hours of applied doctoral project. The courses need approval of the advisor and the graduate program director. Among the total 36 credit hours of coursework, no more than five graduate courses can be taken in other departments.

Cybersecurity Engineering Program
Hongyi Wu, Graduate Program Director, Doctor of Engineering, Cybersecurity
231 Kaufman Hall
757-683-4586
www.odu.edu/eng/

Doctor of Engineering, Cybersecurity

The Department offers a Doctor of Engineering (D.Eng.) degree with concentration in Cybersecurity in accordance with the admission criteria and degree requirements specified in the Frank Batten College of Engineering and Technology section in this catalog.

A minimum of 48 hours of graduate work beyond the master's degree is required including:

- 18 credit hours of core courses
- At least 18 credit hours of graduate coursework in the student's area of specialization
- At least 12 credit hours for the applied doctoral project

Among the total 36 credit hours of coursework, no more than five courses can be taken from departments or programs other than CYSE, ECE, MSIM, and ENMA. At least three-fifths of the coursework must be at the 800-level.

Curriculum

Core Courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENMA 604</td>
<td>Project Management</td>
<td>3</td>
</tr>
<tr>
<td>ENGN 611</td>
<td>Financial Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ENGN 612</td>
<td>Analysis of Organizational Systems</td>
<td>3</td>
</tr>
<tr>
<td>ENGN 811</td>
<td>Methodologies for Advanced Engineering Projects</td>
<td>3</td>
</tr>
<tr>
<td>ENGN 812</td>
<td>Engineering Leadership</td>
<td>3</td>
</tr>
<tr>
<td>ENGN 813</td>
<td>Engineering Ethics</td>
<td>3</td>
</tr>
</tbody>
</table>

Concentration Courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
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</tr>
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<tbody>
<tr>
<td>ECE 516</td>
<td>Cyber Defense Fundamentals</td>
<td>3</td>
</tr>
<tr>
<td>ECE 519</td>
<td>Cyber Physical System Security</td>
<td>3</td>
</tr>
<tr>
<td>ECE 607</td>
<td>Machine Learning I</td>
<td>3</td>
</tr>
<tr>
<td>ECE 642</td>
<td>Computer Networking</td>
<td>3</td>
</tr>
<tr>
<td>ECE 651</td>
<td>Statistical Analysis and Simulation</td>
<td>3</td>
</tr>
<tr>
<td>ECE 842</td>
<td>Computer Communication Networks</td>
<td>3</td>
</tr>
<tr>
<td>ECE 887</td>
<td>Digital Communications</td>
<td>3</td>
</tr>
<tr>
<td>ECE 880</td>
<td>Machine Learning II</td>
<td>3</td>
</tr>
<tr>
<td>ECE 895</td>
<td>Topics in Electrical and Computer Engineering</td>
<td>3</td>
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<td>ECE 896</td>
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</tr>
<tr>
<td>ECE 897</td>
<td>Independent Study</td>
<td>3</td>
</tr>
<tr>
<td>ENMA 670</td>
<td>Cyber Systems Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ENMA 854</td>
<td>Big Data Fundamentals</td>
<td>3</td>
</tr>
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<td>ENMA 871</td>
<td>Risk and Vulnerability Management of Complex Interdependent Systems</td>
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<td>ENMA 895</td>
<td>Topics in Engineering Management</td>
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<tr>
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Cybersecurity Engineering Program

Hongyi Wu, Graduate Program Director, Doctor of Engineering, Cybersecurity
231 Kaufman Hall
757-683-4586
www.odu.edu/eng/

Doctor of Engineering, Cybersecurity

The Department offers a Doctor of Engineering (D.Eng.) degree with concentration in Cybersecurity in accordance with the admission criteria and degree requirements specified in the Frank Batten College of Engineering and Technology section in this catalog.

A minimum of 48 hours of graduate work beyond the master's degree is required including:

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<td>ECE 880</td>
<td>Machine Learning II</td>
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<td>ECE 895</td>
<td>Topics in Electrical and Computer Engineering</td>
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<td>Independent Study in Engineering Management</td>
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</tr>
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</table>

Biomedical Engineering Program

Christian Zemlin, Graduate Program Director
Innovation Research Building, 4211 Monarch Way, Suite 355
757-683-3745
www.odu.edu/eng/programs/biomedical/

The Biomedical Engineering graduate degree programs are available to full-time and part-time students seeking to improve their research and professional skills in biomedical engineering. The programs strive to provide the highest quality engineering education at the graduate level, to engage in scholarly research at the forefront of biomedical engineering, and to serve the profession of biomedical engineering. While the biomedical engineering program is administered by the Department of Electrical & Computer Engineering, the program is highly interdisciplinary and students are admitted from broad areas of engineering, science, and healthcare. Cutting-edge research opportunities and instruction are offered in:

- Bioelectrics and Pulsed Power
- Cellular & Molecular Bioengineering
- Cardiovascular Engineering
- Medical Image Analysis and Simulation
- Musculoskeletal Biomechanics
- Plasma Medicine
- Systems Biology & Computational Bioengineering

Facilities: The Biomachina Laboratory; the Biomechanics Laboratory; the Cardiac Electrophysiology Laboratory; the Cellular Mechanobiology Laboratory; the Medical Imaging, Diagnosis and Analysis (MIDA) Laboratory; the Medical Simulations Laboratory; the Plasma Engineering and Medicine Institute (PEMI); the Systems Analysis of Metabolic Physiology and Exercise (SAMPE) Laboratory; and the Virginia Institute for Imaging and Vision Analysis (VIIVA).

The program also has strong ties to several other on- and off-campus laboratories including the Applied Research Center at the Jefferson National Laboratory, the Center for Brain Research and Rehabilitation, the Frank Reidy Research Center for Bioelectrics, and the Virginia Modeling, Analysis and Simulation Center (VMASC). The program is supported by regional, national, and international clinical collaborators. These unique resources position the biomedical engineering program to be a leader in education and research in the Southeast and nationally.

Master of Engineering - Biomedical Engineering

Master of Engineering Admission Requirements

Admission to the Master of Engineering program in biomedical engineering is in accordance with Old Dominion University and Frank Batten College of Engineering and Technology requirements for master's programs as specified in this catalog. Specific additional requirements include the following:
1. Completion of a bachelor’s degree in Engineering, Science or Mathematics from an accredited institution, although students from other educational backgrounds may apply with appropriate leveling courses.
2. A minimum GPA of 3.00 (out of 4.0) is required of most students. A student with a lower GPA meeting ODU’s graduate admission requirements and with evidence of a high level of professional capability may be eligible for admission to the program upon submission of a petition to the graduate program director.
3. Recent scores, typically, not more than five years old, on the Graduate Record Examination’s (GRE) verbal, quantitative, and analytical writing sections must be submitted by all applicants.
4. Two letters of recommendation (typically from faculty in the highest degree program completed when the application is within five years of graduation from that degree program) are encouraged but not required.
5. The applicant must submit a resume and a statement of purpose and goals.
6. Foundation knowledge in physics, basic chemistry, physiology, computer programming, and mathematics (including differential equations and statistics) is expected.

**Master of Engineering Degree Requirements**

The Master of Engineering in Biomedical Engineering requires either the completion of a comprehensive exam or a master's project near the end of the student's program. Students should discuss this requirement with the Graduate Program Director. In addition, the following coursework is required.

**Common Core (Choose Three)**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>BME 720</td>
<td>Modern Biomedical Instrumentation</td>
</tr>
<tr>
<td>BME 721</td>
<td>Mathematical Modeling in Physiology</td>
</tr>
<tr>
<td>BME 726</td>
<td>Biomaterials</td>
</tr>
<tr>
<td>BME 727</td>
<td>Advanced Transport Phenomena in Biomedical Systems</td>
</tr>
</tbody>
</table>

**BME Technical Electives (Choose Four)**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>BME 554</td>
<td>Introduction to Bioelectronics</td>
</tr>
<tr>
<td>BME 562</td>
<td>Introduction to Medical Image Analysis</td>
</tr>
<tr>
<td>BME 564</td>
<td>Biomedical Applications of Low Temperature Plasmas</td>
</tr>
<tr>
<td>BME 612</td>
<td>Digital Signal Processing I</td>
</tr>
<tr>
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</tr>
<tr>
<td>BME 724</td>
<td>Neural Engineering</td>
</tr>
<tr>
<td>BME 751</td>
<td>Computational and Statistical Methods in Biomedical Engineering</td>
</tr>
<tr>
<td>BME 762</td>
<td>Applied Medical Image Analysis</td>
</tr>
<tr>
<td>BME 795</td>
<td>Special Topics in Biomedical Engineering</td>
</tr>
</tbody>
</table>

**Total Hours**

30

* The technical elective courses can be selected from the biomedical engineering technical electives or a wide variety of appropriate graduate courses in engineering, biology, chemistry, psychology, computer science, modeling and simulation, mathematics, statistics, or other programs. Technical electives without the BME prefix must be approved by the graduate program director.

**Master of Science, Engineering - Biomedical Engineering**

**Master of Science Admission Requirements**

Admission to the Master of Science, Engineering - Biomedical Engineering program is in accordance with Old Dominion University and Frank Batten College of Engineering and Technology requirements for master’s programs as specified in this catalog. Specific additional requirements include the following:

1. Completion of a bachelor’s degree in Engineering, Science or Mathematics from an accredited institution, although students from other educational backgrounds may apply with appropriate leveling courses.
2. A minimum GPA of 3.00 (out of 4.0) is required of most students. A student with a lower GPA meeting ODU’s graduate admission requirements and with evidence of a high level of professional capability may be eligible for admission to the program upon submission of a petition to the graduate program director.
3. Recent scores, typically, not more than five years old, on the Graduate Record Examination’s (GRE) verbal, quantitative, and analytical writing sections must be submitted by all applicants.
4. Two letters of recommendation (typically from faculty in the highest degree program completed when the application is within five years of graduation from that degree program) are encouraged but not required.
5. The applicant must submit a resume and a statement of purpose and goals.
6. Foundation knowledge in physics, basic chemistry, physiology, computer programming, and mathematics (including differential equations and statistics) is expected.

**Master of Science Degree Requirements**

The Master of Science program requires completion of 8 three-credit courses and 6 thesis research credits. The five technical electives should be chosen to meet the student’s research and career objectives.

**BME Fundamentals (Choose Three)**

<table>
<thead>
<tr>
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</tr>
<tr>
<td>BME 727</td>
<td>Advanced Transport Phenomena in Biomedical Systems</td>
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**BME Technical Electives (Choose Three)**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
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<tbody>
<tr>
<td>BME 554</td>
<td>Introduction to Bioelectronics</td>
</tr>
<tr>
<td>BME 562</td>
<td>Introduction to Medical Image Analysis</td>
</tr>
<tr>
<td>BME 564</td>
<td>Biomedical Applications of Low Temperature Plasmas</td>
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<tr>
<td>BME 612</td>
<td>Digital Signal Processing I</td>
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<tr>
<td>BME 720</td>
<td>Modern Biomedical Instrumentation</td>
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<tr>
<td>BME 721</td>
<td>Mathematical Modeling in Physiology</td>
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<tr>
<td>BME 724</td>
<td>Neural Engineering</td>
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<tr>
<td>BME 751</td>
<td>Computational and Statistical Methods in Biomedical Engineering</td>
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<tr>
<td>BME 762</td>
<td>Applied Medical Image Analysis</td>
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<tr>
<td>BME 795</td>
<td>Special Topics in Biomedical Engineering</td>
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</tbody>
</table>

**Total Hours**

30

* The technical elective courses can be selected from the biomedical engineering technical electives or a wide variety of appropriate graduate courses in engineering, biology, chemistry, psychology, computer science, modeling and simulation, mathematics, statistics, or other programs. Technical electives without the BME prefix must be approved by the graduate program director.

**Doctor of Philosophy, Engineering - Biomedical Engineering**

**Doctor of Philosophy Admission Requirements**

Admission to the Ph.D. program in biomedical engineering is in accordance with Old Dominion University and Frank Batten College of Engineering and Technology requirements.
Technology requirements for doctoral programs as specified in this catalog. Specific additional requirements include the following:

1. Completion of a master’s degree in a closely related field is expected. However, students who have completed 24 credits of graduate courses in an appropriate field from an accredited institution or have demonstrated an exceptionally high level of academic capability may petition for direct admission into the program.
2. A minimum GPA of 3.50 (out of 4.0) is required of most students. A student with a lower GPA meeting ODU’s graduate admission requirements and with evidence of a high level of professional capability may be eligible for admission to the program upon submission of a petition to the graduate program director.
3. Recent scores, typically, not more than five years old, on the Graduate Record Examination’s (GRE) verbal, quantitative, and analytical writing sections must be submitted by all applicants.
4. Three letters of recommendation (typically at least two of which are from faculty in the highest degree program completed when the application is within five years of graduation from that degree program) are encouraged but not required.
5. The applicant must submit a resume and a statement of purpose and goals.
6. Foundation knowledge in physics, basic chemistry, physiology, computer programming, and mathematics (including differential equations and statistics) is expected.

**Doctor of Philosophy Degree Requirements**

The Ph.D. in biomedical engineering is offered in accordance with the general requirements for doctoral degrees as specified in the Requirements for Graduate Degree Section of this catalog. Specific program of study requirements include the following:

1. Completion of a minimum of 48 hours of graduate credits to include: a minimum of 24 credits of course work beyond the master’s degree and a minimum of 24 credits of dissertation research. At least 15 credits of non-dissertation course work must be at the 800-level.
2. Successful completion of a written diagnostic examination before the end of the first academic year.
3. Successful completion of a written and oral qualifying examination near the completion of the coursework.
4. Successful presentation of a dissertation research proposal at the beginning of the dissertation research.
5. The successful completion and public defense of a dissertation representing independent, original research worthy of publication in a peer-reviewed scholarly journal. At least one published and one submitted manuscript as first author in peer-reviewed, indexed journals are expected.

The program of study will be developed with the approval of the graduate program director and the student’s advisor. The program shall include a common core of 14 credits and 10 credits of technical electives.

<table>
<thead>
<tr>
<th>Common Core *</th>
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<tr>
<td>BME 820 Modern Biomedical Instrumentation</td>
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<tr>
<td>BME 821 Mathematical Modeling in Physiology</td>
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<tr>
<td>BME 826 Biomaterials</td>
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<tr>
<td>BME 827 Advanced Transport Phenomena in Biomedical Systems</td>
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<tr>
<td>BIOL 747/847 Responsible Conduct of Research</td>
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<tr>
<th>Technical Electives **</th>
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<tr>
<td>BME 554 Introduction to Bioelectrics</td>
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<td>BME 862 Applied Medical Image Analysis</td>
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**Advanced Engineering Certificate - Biomedical Engineering**

The Graduate Certificate in Biomedical Engineering Program offers students and professionals the opportunity to further their knowledge with advanced study in the growing area of Biomedical Engineering. The program is designed to provide well-rounded instruction in several key facets of Biomedical Engineering. Those who complete the Program receive the Advanced Engineering Certificate in Biomedical Engineering from Old Dominion University and a letter of recognition from the Batten College of Engineering and Technology. Courses taken for the certificate program may later be applied to the M.E. or Ph.D. degree in Biomedical Engineering. For complete information on the admission and certificate requirements, please refer to the Batten College of Engineering and Technology’s section on graduate certificate programs: [catalog.odu.edu/graduate/frankbattencollegeofengineeringandtechnology/interdisciplinarygraduatecertificateprograms](http://catalog.odu.edu/graduate/frankbattencollegeofengineeringandtechnology/interdisciplinarygraduatecertificateprograms)

**BIOMEDICAL ENGINEERING Courses**

**BME 554. Introduction to Bioelectronics. 3 Credits.** This course covers the electrical properties of cells and tissues as well as the use of electrical and magnetic signals and stimuli in the diagnosis and treatment of disease. Typical topics to be covered include basic cell physiology, endogenous electric fields in the body, electrocardiography, cardiac pacing defibrillation, electrotherapy, electroproporation, electrotherapy in wound healing. In addition ultra-short electrical pulses for intracellular manipulation and the application of plasmas to biological systems will be covered.

**BME 562. Introduction to Medical Image Analysis. 3 Credits.** Introduction to basic concepts in medical image analysis. Medical image registration, segmentation, feature extraction, and classification are discussed. Basic psychophysics, fundamental ROC analysis and FROC methodologies are covered. Cross-listed with ECE 562/MSIM 562.
BME 564. Biomedical Applications of Low Temperature Plasmas. 3 Credits.
This course is cross listed between ECE and Biology. It is designed to be taken by senior undergraduate students and first year graduate students. The course contents are multidisciplinary, combining materials from engineering and the biological sciences. The course covers an introduction to the fundamentals of non-equilibrium plasmas, low temperature plasma sources, and cell biology. This is followed by a detailed discussion of the interaction of low temperature plasma with biological cells, both prokaryotes and eukaryotes. Potential applications in medicine such as wound healing, blood coagulation, sterilization, and the killing of various types of cancer cells will be covered. Prerequisites: Senior standing.

BME 612. Digital Signal Processing I. 3 Credits.
This course will present the fundamentals of digital signal processing. Topics will include frequency domain analysis of discrete-time linear systems, sampling and reconstruction of signals, the Discrete Fourier Transform (DFT) and Fast Fourier Transform (FFT), and digital filter design and implementations. Practical applications and examples will be discussed. Problem solving using MATLAB is required. Cross-listed with ECE 612. Prerequisite: ECE 381 or equivalent.

BME 630. Advanced Bioelectrics. 3 Credits.
A one-semester course covering advanced topics in bioelectrics. The course will cover advanced applications of pulsed power and plasma in the medical, biological and environmental fields. (Cross listed with ENGN 630.).

BME 695. Topics in Biomedical Engineering. 3 Credits.
This course will be offered as needed, depending upon the need to introduce special subjects to target specific areas of master's-level specializations in biomedical engineering.

BME 699. Master's Thesis. 1-9 Credits.
Directed research for the master's thesis. Prerequisite: departmental approval.

BME 720. Modern Biomedical Instrumentation. 3 Credits.
This course covers the design of modern biomedical instruments including select diagnostic, assistive, therapeutic, prosthetic, imaging, and virtual devices and systems. Techniques for mechanical, electrical, and chemical sensor and transducer design; stimulation and measurement; data acquisition; digital signal processing; and data visualization will be examined.

BME 721. Mathematical Modeling in Physiology. 3 Credits.
This course on mathematical modeling in human physiology emphasizes the development of mathematical models, their implementation, and the interpretation of simulation data. The course focuses on cellular physiology, including membrane channels, excitability, and calcium dynamics; it also covers intercellular communication and spatially distributed systems.

BME 724. Neural Engineering. 3 Credits.
This course presents engineering techniques for the restoration and augmentation of human function via direct interactions between the nervous system and artificial devices, with particular emphasis on brain-computer interfaces. Novel interfaces, hardware and computational issues, and practical and ethical considerations will also be covered.

BME 726. Biomaterials. 3 Credits.
This course cover fundamental principles and properties of biomedical materials used as implants, prostheses, orthosis, and tissue-engineered materials as medical devices in contact with tissues and organs. Advanced concepts of biocompatibility and material characterization will be discussed. Physiological response factors associated with materials and implanted devices used in the human body will be presented, including immunological responses, wound healing, clotting cascade and surface compatibility. Other topics such as ethical considerations and medical device regulatory mechanisms will be discussed.

BME 727. Advanced Transport Phenomena in Biomedical Systems. 3 Credits.
The course focuses on fundamental principles of mass transport and biochemical reactions applied to the study of metabolic and physiological systems, drug delivery, hemodialysis, blood oxygenators, immobilized enzyme reactors and bioartificial organs.

BME 751. Computational and Statistical Methods in Biomedical Engineering. 3 Credits.
This course covers the theoretical foundation and application of commonly used techniques in biomedical engineering. Topics include linear algebra, partial differential equations, regression analysis, applied probabilities, multivariate distributions, Bayesian statistics, hypothesis tests, multiple comparisons, ANOVA, solution of non-linear equations, numerical methods and optimization. Programming software will be used to perform simulations and analyze biomedical data. Prerequisites: Graduate status.

BME 755. Biomembranes and Ion Channels. 3 Credits.
This course will give an overview of the structure and dynamics of biomembranes, the ion channels that are embedded in them, and the electrical properties of biomembranes. Topics include molecular dynamics modeling of biomembranes, membrane damage and repair, ion channel dynamics and their experimental assessment using patch clamping, and excitability in neurons and cardiomyocytes. Prerequisite: ECE 454 or ECE 554 or BIOL 523.

BME 762. Applied Medical Image Analysis. 3 Credits.
Course explores hands-on exposure to state-of-the-art algorithms in medical image analysis, which builds on open-source software (Insight Segmentation and Registration Toolkit - ITK), as well as the principles of medical image acquisition in the modalities of clinical interest. Medical imaging modalities - X-rays, CT, and MRI/ITK image pipeline; image enhancement, feature detection; segmentation - basic techniques, feature-based classification and clustering, graph cuts, active contour and surface models; surface and volume meshing; registration - transformations, similarity criteria; shape and appearance models are all explored and discussed in this course. Prerequisites: Knowledge of C++ and object-oriented programming.

BME 783. Digital Image Processing. 3 Credits.
Principles and techniques of two-dimensional processing of images. Concepts of scale and spatial frequency. Image filtering in spatial and transform domains. Applications include image enhancement and restoration, image compressing, biomedical imaging for diagnosis of disease, and image segmentation for computer vision. Prerequisites: ECE 782 or ECE 882.

BME 795. Special Topics in Biomedical Engineering. 1-3 Credits.
Special courses covering selected graduate-level topics in biomedical engineering.

BME 797. Independent Study. 1-3 Credits.
This course allows students to develop specialized expertise by independent study (supervised by a faculty member). Prerequisites: departmental approval.

BME 820. Modern Biomedical Instrumentation. 3 Credits.
This course covers the design of modern biomedical instruments including select diagnostic, assistive, therapeutic, prosthetic, imaging, and virtual devices and systems. Techniques for mechanical, electrical, and chemical sensor and transducer design; stimulation and measurement; data acquisition; digital signal processing; and data visualization will be examined.

BME 821. Mathematical Modeling in Physiology. 3 Credits.
This course on mathematical modeling in human physiology emphasizes the development of mathematical models, their implementation, and the interpretation of simulation data. The course focuses on cellular physiology, including membrane channels, excitability, and calcium dynamics; it also covers intercellular communication and spatially distributed systems.

BME 824. Neural Engineering. 3 Credits.
This course presents engineering techniques for the restoration and augmentation of human function via direct interactions between the nervous system and artificial devices, with particular emphasis on brain-computer interfaces. Novel interfaces, hardware and computational issues, and practical and ethical considerations will also be covered.
BME 826. Biomaterials. 3 Credits.
This course covers fundamental principles and properties of biomedical materials used as implants, prostheses, orthosis, and tissue-engineered materials as medical devices in contact with tissues and organs. Advanced concepts of biocompatibility and material characterization will be discussed. Physiological response factors associated with materials and implanted devices used in the human body will be presented, including immunological responses, wound healing, clotting cascade and surface compatibility. Other topics such as ethical considerations and medical device regulatory mechanisms will be discussed.

BME 827. Advanced Transport Phenomena in Biomedical Systems. 3 Credits.
The course focuses on fundamental principles of mass transport and biochemical reactions applied to the study metabolic and physiological systems, drug delivery, hemodialysis, blood oxygenators, immobilized enzyme reactors and bioartificial organs.

BME 851. Computational and Statistical Methods in Biomedical Engineering. 3 Credits.
This course covers the theoretical foundation and application of commonly used techniques in biomedical engineering. Topics include linear algebra, partial differential equations, regression analysis, applied probabilities, multivariate distributions, Bayesian statistics, hypothesis tests, multiple comparisons, ANOVA, solution of non-linear equations, numerical methods and optimization. Programming software will be used to perform simulations and analyze biomedical data. Prerequisites: Graduate status.

BME 855. Biomembranes and Ion Channels. 3 Credits.
This course will give an overview of the structure and dynamics of biomembranes, the ion channels that are embedded in them, and the electrical properties of biomembranes. Topics include molecular dynamics modeling of biomembranes, membrane damage and repair, ion channel dynamics and their experimental assessment using patch clamping, and excitability in neurons and cardiomyocytes. Prerequisite: ECE 454 or ECE 554 or BIOL 523.

BME 862. Applied Medical Image Analysis. 3 Credits.
Course explores hands-on exposure to state-of-the-art algorithms in medical image analysis, which builds on open-source software (Insight Segmentation and Registration Toolkit - ITK), as well as the principles of medical image acquisition in the modalities of clinical interest. Medical imaging modalities - X-rays, CT, and MR/ITK image processing, image enhancement, feature detection; segmentation - basic techniques, feature-based classification and clustering, graph cuts, active contour and surface models; surface and volume meshing; registration - transformations, similarity criteria; shape and appearance models are all explored and discussed in this course. Prerequisites: Knowledge of C++ and object-oriented programming.

BME 883. Digital Image Processing. 3 Credits.
Principles and techniques of two-dimensional processing of images. Concepts of scale and spatial frequency. Image filtering in spatial and transform domains. Applications include image enhancement and restoration, image compressing, biomedical imaging for diagnosis of disease, and image segmentation for computer vision. Prerequisites: ECE 783 and ECE 883.

BME 895. Special Topics in Biomedical Engineering. 1-3 Credits.
Special courses covering selected graduate-level topics in biomedical engineering.

BME 897. Independent Study. 1-3 Credits.
This course allows students to develop specialized expertise by independent study (supervised by a faculty member). Prerequisites: departmental approval.

BME 899. PHD Dissertation Research. 1-9 Credits.
Directed research for the doctoral dissertation.

BME 999. Doctoral Graduate Credit. 1 Credit.
This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.

ELECTRICAL AND COMPUTER ENGINEERING Courses

ECE 503. Power Electronics. 3 Credits.
Power electronics provides the needed interface between an electrical source and an electrical load and facilitates the transfer of power from a source to a load by converting voltages and currents from one form to another. Topics include: alternating voltage rectification, Pulse Width Modulation (PWM), DC converters (Buck, Boost, Buck-Boost, Cuk and SEPIC converters), negative feedback control in power electronics, isolated switching mode power supply, flyback and forward power supply, solid state power switches, AC inverter. (offered spring) Prerequisites: ECE 303 and a grade of C or better in ECE 202 and ECE 287.

ECE 504. Electric Drives. 3 Credits.
Electric drives efficiently control the torque, speed and position of electric motors. This course has a multi-disciplinary nature and includes fields such as electric machine theory, power electronics, and control theory. Topics include: switch-mode power electronics, magnetic circuit, DC motor, AC motor, Brushless DC motor, induction motor, speed control of induction motor, vector control of induction motor, stepper-motor. (offered fall) Prerequisites: ECE 303 and grades of C or better in ECE 202 and ECE 287.

ECE 505. Power System Design & Analysis. 3 Credits.
This course covers basic power circuit analysis and introductory power system engineering and focuses on the transmission line design, power flow study, short circuit protection, and power distribution in electric power systems, followed by a survey of several applications and case studies. Prerequisite: ECE 303 or equivalent knowledge in electric machines and circuits.

ECE 506. Introduction to Visualization. 3 Credits.
The course provides a practical treatment of computer graphics and visualization with emphasis on the usage of industry standard application programming interface (API) libraries for modeling and simulation applications. It introduces covers computer graphics fundamentals, including mathematical foundations, rendering pipeline, geometrical transformations, 3D viewing visualization principles, and projections, lighting software architecture for visualization in modeling and shading, texture mapping, etc. simulation. It teaches OpenGL programming for developing interactive visualization for modeling and simulation applications. Unity game engine is utilized to illustrate advanced concepts and techniques. Interactive visualization software architecture for modeling and simulation and visualization principles based on perception is covered in depth with case studies. (cross listed with MSIM 541) Prerequisites: a grade of C or better in CS 250.

ECE 507. Introduction to Game Development. 3 Credits.
An exciting introductory course focused on game development theory and modern practices using Unity game engine with emphasis on educational game development. Topics covered in this course include game architecture, 3D computer graphics theory, content generation, user interaction, graphical user interface, audio, game physics, high level shading language, animation, physics, C# language scripting, physics, and artificial intelligence. Students will develop games related to science, technology, engineering, and mathematics (STEM) education. The developed games can run on a variety of platforms, including personal computers, smart phones, computer, mobile, and game consoles. (cross listed with MSIM 408/MSIM 508) Prerequisites: CS 361 or equivalent.

ECE 508. Fundamentals of Electric Vehicles. 3 Credits.
This course covers the fundamentals of electric vehicles and focuses on the components, power control, energy management, power train dynamics and other related topics in purely electric and hybrid electric vehicle systems, including a survey of several applications and case studies. Prerequisites: ECE 303 and ECE 403, or instructor approval.
ECE 510. Model Engineering. 3 Credits.
The goal of this course is to develop understanding of the various modeling paradigms appropriate for capturing system behavior and conducting digital computer simulation of many types of systems. The techniques and concepts discussed typically include UML, concept graphs, Bayesian nets, Markov models, Petri nets, system dynamics, Bond graphs, etc. Students will report on a particular technique and team to implement a chosen system model. (cross-listed with MSIM 510) Prerequisites: MSIM 205 or equivalent. Pre- or corequisite: MSIM 320 or equivalent.

ECE 511. Networked System Security. 3 Credits.
Course presents an overview of theory, techniques and protocols that are used to ensure that networks are able to defend themselves and the end-systems that use networks for data and information communication. Course will also discuss industry-standard network security protocols at application, socket, transport, network, VPN, and link layers, popular network security tools, security, performance modeling and quantification and network penetration testing. Discussion will be based on development of system level models and simulations of networked systems. Cross-listed with MSIM 511. Prerequisites: CS 150 or ENGN 150, and junior standing or permission of the instructor.

ECE 516. Cyber Defense Fundamentals. 3 Credits.
This course focuses on cybersecurity technology, information protection and assurance, and computer systems and networks security. The objectives are to understand the basic security models and concepts, learn fundamental knowledge and tools for building, analyzing, and attacking modern security systems, and gain hands-on experience in cryptographic algorithms, security fundamental principles, and Internet security protocol and standards. Prerequisites: ECE 355 or permission of the instructor.

ECE 517. Secure and Trusted Operating Systems. 3 Credits.
Course will review typical operating systems developing system models and identifying potential vulnerabilities. Course will discuss policies and their implementation required to fix such vulnerabilities to arrive at a secure and trusted Computing Base. Course examines the security architecture Security Enhanced Linux (SELinux) Windows and Android OS. Cross-listed with MSIM 517.

ECE 519. Cyber Physical System Security. 3 Credits.
Cyber Physical Systems (CPS) integrate computing, networking, and physical processes. The objectives of this course are to learn the basic concepts, technologies and applications of CPS, understand the fundamental security challenges and national security impact, and gain hands-on experience in CPS infrastructures, critical vulnerabilities, and practical countermeasures. Prerequisites: ECE 355 or permission of the instructor.

ECE 541. Advanced Digital Design and Field Programmable Gate Arrays. 3 Credits.
Course will provide a description of FPGA technologies and the methods using CAD design tools for implementation of digital systems using FPGAs. It provides advanced methods of digital circuit design, specification, synthesis, implementation and prototyping. It introduces practical system design examples. (Offered spring) Prerequisites: ECE 341.

ECE 543. Computer Architecture. 3 Credits.
An introduction to computer architectures. Analysis and design of computer subsystems including central processing units, memories and input/output subsystems. Important concepts include datapaths, computer arithmetic, instruction cycles, pipelining, virtual and cache memories, direct memory access and controller design. (offered fall) Prerequisites: ECE 341 and ECE 346.

ECE 551. Communication Systems. 3 Credits.
Fundamentals of communication systems engineering. Modulation methods including continuous waveform modulation (amplitude, angle). Design of modulation systems and the performance in the presence of noise. Communication simulation exercises through computer experiments. Prerequisites: ECE 304 and ECE 302.

ECE 552. Introduction to Wireless Communication Networks. 3 Credits.

ECE 554. Introduction to Bioelectrics. 3 Credits.
Covers the electrical properties of cells and tissues as well as the use of electromagnetic signals and stimuli in the diagnosis and treatment of disease. Typical topics to be covered include basic cell physiology, endogenous electric fields in the body, electrocardiography, cardiac pacing, defibrillation, electrotherapy, electroporation, electrotherapy in wound healing. In addition, ultrashort electrical pulses for intracellular manipulation and the application of plasmas to biological systems will be covered. Prerequisites: PHYS 111N or higher; MATH 200 or higher.

ECE 555. Network Engineering and Design. 3 Credits.
Emphasis is on gaining an understanding of networking design principles that entails all aspects of the network development life cycle. Topics include campus LAN models and design, VLANs, internetworking principles and design, WAN design, design of hybrid IP networks, differentiated vs. integrated services, traffic flow measurement and management. (offered spring) Prerequisites: ECE 355 or permission of the instructor.

ECE 558. Instrumentation. 3 Credits.
Computer interfacing using a graphical programming language with applications involving digital-to-analog conversion (DAC), analog-to-digital conversion (ADC), digital input output (DIO), Virtual Instrument System Architecture (VISA) and universal Service Bus (USB). Analysis of sampled data involving use of probability density function, mean and standard derivations, correlations, and the power spectrum. (offered spring, summer) Prerequisite: ECE 302 or permission of the instructor.

ECE 561. Automatic Control Systems. 3 Credits.

ECE 562. Introduction to Medical Image Analysis (MIA). 3 Credits.
Introduction to basic concepts in medical image analysis. Medical image registration, segmentation, feature extraction, and classification are discussed. Basic psychophysics, fundamental ROC analysis and FROC methodologies are covered. Prerequisites: a grade of C or better in MATH 212.

ECE 564. Biomedical Applications of Low Temperature Plasmas. 3 Credits.
This course is cross listed between ECE and Biology. It is designed to be taken by senior undergraduate students and first year graduate students. The course contents are multidisciplinary, combining materials from engineering and the biological sciences. The course covers an introduction to the fundamentals of non-equilibrium plasmas, low temperature plasma sources, and cell biology. This is followed by a detailed discussion of the interaction of low temperature plasma with biological cells, both prokaryotes and eukaryotes. Potential applications in medicine such as wound healing, blood coagulation, sterilization, and the killing of various types of cancer cells will be covered. Prerequisites: Senior standing.

ECE 570. Foundations of Cyber Security. 3 Credits.
Course provides an overview of theory, tools and practice of cyber security and information assurance through prevention, detection and modeling of cyber attacks and recovery from such attacks. Techniques for security modeling, attack modeling, risk analysis and cost-benefit analysis are described to manage the security of cyber systems. Fundamental principles of cyber security and their applications for protecting software and information assets of individual computers and large networked systems are explored. Anatomy of some sample attacks designed to compromise confidentiality, integrity and availability of cyber systems are discussed. Cross-listed with MSIM 570. Pre- or corequisite: MSIM 510 or permission of the instructor.
ECE 571. Introduction to Solar Cells. 3 Credits.
This course is designed to provide the fundamental physics and characteristics of photovoltaic materials and devices. A focus is placed on i) optical interaction, absorption, and design for photovoltaic materials and systems, ii) subsequent energy conversion processes in inorganic/organic semiconductor such as generation, recombination, and charge transport, and iii) photovoltaic testing and measurement techniques to characterize solar cells including contact and series resistance, open circuit voltage, short circuit current density, fill factor, and energy conversion efficiency of photovoltaic devices. (Offered fall) Prerequisites: ECE 332.

ECE 572. Plasma Processing at the Nanoscale. 3 Credits.
The science and design of partially ionized plasma and plasma processing devices used in applications such as etching and deposition at the nanoscale. Gas phase collisions, transport parameters, DC and RF glow discharges, the plasma sheath, sputtering, etching, and plasma deposition. Prerequisites: ECE 323.

ECE 573. Solid State Electronics. 3 Credits.
The objective of this course is to understand basic semiconductor devices by understanding semiconductor physics (energy bands, carrier statistics, recombination and carrier drift and diffusion) and to gain an advanced understanding of the physics and fundamental operation of advanced semiconductor devices. Following the initial introductory chapters on semiconductor physics, this course will focus on p-n junctions, metal-semiconductor devices, MOS capacitors, MOS field effect transistors (MOSFET) and bipolar junction transistors. Prerequisites: ECE 313, ECE 323 and ECE 332.

ECE 574. Optical Fiber Communications. 3 Credits.
This course introduces seniors and first year graduates to the physics and design of optical fiber communication systems. The topics covered are: electromagnetic waves; optical sources including laser diodes; optical amplifiers; modulators; optical fibers; attenuation and dispersion in optical fibers; photodetectors; optical receivers; noise considerations in optical receivers; optical communication systems. Prerequisite: ECE 323.

ECE 583. Embedded Systems. 3 Credits.
This course covers fundamentals of embedded systems: basic architecture, programming, and design. Topics include processors and hardware for embedded systems, embedded programming and real time operating systems. Pre- or corequisite: ECE 346.

ECE 595. Topics in Electrical and Computer Engineering. 1-3 Credits.
Study of topics in electrical and computer engineering. Prerequisites: departmental approval.

ECE 596. Topics in Electrical and Computer Engineering. 1-3 Credits.
Study of topics in electrical and computer engineering. Prerequisites: departmental approval.

ECE 601. Linear Systems. 3 Credits.
A comprehensive introduction to the analysis of linear dynamical systems from an input-output and state space point of view. Concepts from linear algebra, numerical linear algebra and linear operator theory are used throughout. Some elements of state feedback design and state estimation are also covered. Prerequisites: MATH 307.

ECE 607. Machine Learning I. 3 Credits.
Course provides a practical treatment of design, analysis, implementation and applications of algorithms. Topics include multiple machine learning models: linear models, neural networks, support vector machines, instance-based learning, Bayesian learning, genetic algorithms, ensemble learning, reinforcement learning, unsupervised learning, etc. Prerequisites: Graduate standing.

ECE 611. Numerical Methods in Engineering Analysis. 3 Credits.
Course intended to provide graduate students in Electrical and Computer Engineering with a basic knowledge of numerical methods applied to engineering problem-solving process. The course includes the following topics: Introduction to computing (Matlab), Truncation errors and Taylor series, Numerical integration, Solution of non-linear equations, Least-Square regression, Interpolations, Ordinary and partial differential equations, and Finite difference methods. Applications to the area of electrical engineering. Prerequisites: Graduate standing or advisor's permission (for BS/MS students).

ECE 612. Digital Signal Processing I. 3 Credits.
This course will present the fundamentals of digital signal processing. Topics will include frequency domain analysis of discrete-time linear systems, sampling and reconstruction of signals, the Discrete Fourier Transform (DFT) and Fast Fourier Transform (FFT), and digital filter design and implementations. Practical applications and examples will be discussed. Problem solving using MATLAB is required. Prerequisites: ECE 381 or equivalent.

ECE 623. Electromagnetism. 3 Credits.
Review of electrostatic and magnetostatic concepts, time varying field, Maxwell's equations, plane wave propagation in various media, transmission lines, optical wave guides, resonant cavities, simple radiation systems, and their engineering applications. Prerequisites: ECE 323 or equivalent.

ECE 642. Computer Networking. 3 Credits.
The course is based on the ISO (International Standard Organization) OSI (Open Systems Interconnection) reference model for computer networks. A focus is placed on the analysis of protocols at different layers, network architectures, and networking systems performance analysis. Current topic areas include LANs, MANs, TCP/IP networks, mobile communications, and ATM. Prerequisites: ECE 455 or ECE 555 or permission of the instructor.

ECE 643. Computer Architecture Design. 3 Credits.
Digital computer design principles. The course focuses on design of state-of-the-art computing systems. An emphasis is placed on superscalar architectures focusing on the pipelining and out-of-order instruction execution operations. Prerequisites: ECE 443 or ECE 543.

ECE 648. Advanced Digital Design. 3 Credits.
This course introduces methods for using high level hardware description language such as VHDL and/or Verilog for the design of digital architecture. Topics include top-down design approaches, virtual prototyping, design abstractions, hardware modeling techniques, algorithmic and register level design, synthesis methods, and application decomposition issues. Final design project is required. Prerequisites: ECE 341.

ECE 651. Statistical Analysis and Simulation. 3 Credits.
An introduction to probabilistic and statistical techniques for analysis of signals and systems. This includes a review of probability spaces, random variables, and random processes. Analysis and simulation of systems with random parameters and stochastic inputs are considered. Prerequisites: MATH 312 and one undergraduate course in probability or statistics or permission of instructor.

ECE 652. Wireless Communications Networks. 3 Credits.
Fundamental concepts in wireless communication systems and networks: radio waveform propagation modeling (free-space, reflections and multipath, fading, diffraction and Doppler effects); physical and statistical models for wireless channels; modulation schemes for wireless communications and bandwidth considerations; diversity techniques; MIMO systems and space-time coding; multiuser systems and multiple access techniques (TDMA, FDMA, CDMA); spread spectrum and multiuser detection; introduction to wireless networking and wireless standards; current and emerging wireless technologies. Prerequisites: ECE 451 or ECE 551 or permission of instructor.

ECE 667. Cooperative Education. 1-3 Credits.
Student participation for credit based on academic relevance of the work experience, criteria, and evaluative procedures as formally determined by the department and the Cooperative Education/Career Development Services program prior to the semester in which the work experience is to take place.
ECE 668. Internship. 1-3 Credits.
Academic requirements will be established by the department and will vary with the amount of credit desired. Allows students an opportunity to gain short duration career related experience. Meant to be used for one-time experience. Work may or may not be paid. Project is completed during the term. Prerequisites: approval by department and Career Development Services.

ECE 669. Practicum. 1-3 Credits.
Academic requirements will be established by the department and will vary with the amount of credit desired. Allows students an opportunity to gain short duration career related experience. Student is usually already employed - this is an additional project in the organization. Prerequisites: approval by department and Career Development Services.

ECE 695. Topics in Electrical or Computer Engineering. 3 Credits.
This course will be offered as needed, depending upon the need to introduce special subjects to target specific areas of master's-level specializations in electrical or computer engineering.

ECE 698. Master's Project. 1-3 Credits.
Individual project directed by the student’s professor in major area of study.

ECE 699. Thesis. 1-9 Credits.
Directed research for the master’s thesis. Prerequisites: departmental approval.

ECE 731. Graduate Seminar. 1 Credit.
Graduate seminar presentations concerning technical topics of current interest given by faculty and invited speakers. Prerequisites: graduate standing.

ECE 742. Computer Communication Networks. 3 Credits.
This is an advanced level course in data communications. A focus is placed on the analysis, modeling, and control of computer communication systems. Topics include packet switched networks, circuit switched networks, ATM networks, network programming, network control and performance analysis, network security, and wireless sensor networks. Prerequisites: ECE 642 or permission of instructor.

ECE 751. Computational and Statistical Methods in Biomedical Engineering. 3 Credits.
This course covers the theoretical foundation and application of commonly used techniques in biomedical engineering. Topics include linear algebra, partial differential equations, regression analysis, applied probabilities, multivariate distributions, Bayesian statistics, hypothesis tests, multiple comparisons, ANOVA, solution of non-linear equations, numerical methods and optimization. Programming software will be used to perform simulations and analyze biomedical data.

ECE 754. Advanced Bioelectronics. 3 Credits.
Bioelectronics is a new field encompassing both the science and technology of applying electrical stimuli to biological systems. This course covers the pulsed power technology that is required to generate electrical stimuli as well as the biological responses they evoke in cells and tissues. Particular emphasis is placed on the medical applications of bioelectronics, including tumor ablation, gene electrotransfer, wound healing, decontamination with cold plasma, and treatment of cardiac arrhythmias. Prerequisite: ECE 454 or ECE 554 or BIQE 454 or BIQE 554.

ECE 755. Biomembranes and Ion Channels. 3 Credits.
This course will give an overview of the structure and dynamics of biomembranes, the ion channels that are embedded in them, and the electrical properties of biomembranes. Topics include molecular dynamics modeling of biomembranes, membrane damage and repair, ion channel dynamics and their experimental assessment using patch clamping, and excitability in neurons and cardiomyocytes. Prerequisites: ECE 454 or ECE 554 or BIOL 523.

ECE 762. Digital Control Systems. 3 Credits.
Mathematical representation, analysis, and design of discrete-time and sampled-data control systems. Topics include transfer function and state space representations, stability, the root locus method, frequency response methods, and state feedback. Prerequisites: ECE 381, ECE 461 or ECE 561, and ECE 601 or permission of instructor.

ECE 763. Multivariable Control Systems. 3 Credits.
A comprehensive introduction to techniques applicable in control of complex systems with multiple inputs and outputs. Both the frequency domain and state variable approaches are utilized. Special topics include robust and optimal control. Prerequisites: ECE 461 or ECE 561 and ECE 601 or permission of instructor.

ECE 766. Nonlinear Control Systems. 3 Credits.
An introduction to mathematical representation, analysis, and design of nonlinear control systems. Topics include phase-plane analysis, Lyapunov stability theory for autonomous and nonautonomous systems, formal power series methods and differential geometric design techniques. Prerequisites: ECE 461 or ECE 561 and ECE 601 or permission of instructor.

ECE 772. Fundamentals of Solar Cells. 3 Credits.
The course provides an overview of the fundamentals of solar cell technologies, design, and operation. The course is designed for graduate students in Engineering and Science interested in the field of alternative energy. The course objectives are to make sure each student: understands the various forms of alternative energies, understands solar cell design, understands solar cell operation, and acquires knowledge of the various solar cells technologies. The topics to be covered include: Alternative energies; Worldwide status of Photovoltaics; Solar irradiance; Review of semiconductor properties; Generation, recombination; Basic equations of device physics; p-n junction diodes; Ideal solar cells; Efficiency limits; Efficiency losses and measurements; Module fabrication; c-Si technology; classical; Photovoltaic systems; Design of stand-alone system; Residential PV systems. Prerequisites: Graduate standing in Engineering and Science.

ECE 773. Introduction to Nanotechnologies. 3 Credits.
This course will introduce the rapidly emerging field of nanotechnology with special focus on underlying principles and applications relevant to the nanoscale dimensions. Specifically, this course will cover (1) the basic principles related to synthesis and fabrication of nanomaterials and nanostructures, (2) zero-, one-, two- and three-dimensional nanostructures, (3) characterization and properties of nanomaterials, and (4) application of nanoscale devices. Prerequisites: Graduate standing in Engineering and Science.

ECE 774. Semiconductor Characterization. 3 Credits.
Introduction of basic methods for semiconductor material and device characterization. Topics include resistivity, carrier doping concentration, contact resistance, Schottky barrier height, series resistance, channel length, threshold voltage, mobility, oxide and interface trapped charge, deep level impurities, carrier lifetime, and optical, chemical and physical characterization. Prerequisites: ECE 473 or ECE 573 or equivalent.

ECE 775. Non-thermal Plasma Engineering. 3 Credits.
This course covers the fundamental principals governing low temperature plasma discharges and their applications. First the fundamental properties of plasmas are introduced. These include the kinetic theory of gases, collisional processes, and plasma sheaths. Then in-depth coverage of the physical mechanisms underlying the operation of non-equilibrium plasma discharges is presented, including important characteristics such as their ignition, evolution, and eventual quenching. Finally, practical applications of non-thermal plasmas, including applications in biology and medicine, are presented. Prerequisites: graduate standing.

ECE 777. Semiconductor Process Technology. 3 Credits.
Theory, design and fabrication of modern integrated circuits that consist of nano scale devices and materials. Topics include crystal growth and wafer preparation process including epitaxy, thin film deposition, oxidation, diffusion, ion implantation, lithography, dry etching, VLSI process integration, diagnostic assembly and packaging, yield and reliability. Prerequisites: ECE 473 or ECE 573.

ECE 780. Machine Learning II. 3 Credits.
Advanced topics in machine learning and pattern recognition systems. Data reduction techniques including principle component analysis, independent component analysis and manifold learning. Introduction to sparse coding and deep learning for data representation and feature extraction. Prerequisite: ECE 607 or equivalent.
ECE 782. Digital Signal Processing II. 3 Credits.
Review of time domain and frequency domain analysis of discrete time signals and systems. Fast Fourier Transforms, recursive and non-recursive digital filter analysis and design, multirate signal processing, optimal linear filters, and power spectral estimation. Prerequisites: ECE 412 or equivalent.

ECE 783. Digital Image Processing. 3 Credits.
Principles and techniques of two-dimensional processing of images. Concepts of scale and spatial frequency. Image filtering in spatial and transform domains. Applications include image enhancement and restoration, image compressing, and image segmentation for computer vision. Prerequisites: ECE 381 or ECE 612 or ECE 782 or ECE 882.

ECE 784. Computer Vision. 3 Credits.
Principles and applications of computer vision, advanced image processing techniques as applied to computer vision problems, shape analysis and object recognition. Prerequisite: graduate standing.

ECE 787. Digital Communications. 3 Credits.
Fundamental concepts of digital communication and information transmission: information sources and source coding; orthonormal expansions of signals, basis functions, and signal space concepts; digital modulation techniques including PAM, QAM, PSK and FSK; matched filters, demodulation and optimal detection of symbols and sequences; bandwidth; mathematical modeling of communication channels; channel capacity. Prerequisites: ECE 451/ECE 551 or equivalent or permission of the instructor.

ECE 795. Topics in Electrical and Computer Engineering. 3 Credits.
Topics in Electrical and Computer Engineering Prerequisites: departmental approval.

ECE 796. Topics in Electrical and Computer Engineering. 3 Credits.
Study of selected topics in Electrical and Computer Engineering. Prerequisites: departmental approval.

ECE 797. Independent Study. 1-3 Credits.
This course allows students to develop specialized expertise by independent study (supervised by a faculty member). Prerequisites: departmental approval.

ECE 831. Graduate Seminar. 1 Credit.
Graduate seminar presentations concerning technical topics of current interest given by faculty and invited speakers.

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ECE 877. Semiconductor Process Technology. 3 Credits.
Theory, design and fabrication of modern integrated circuits that consist of nano scale devices and materials. Topics include crystal growth and wafer preparation process including epitaxy, thin film deposition, oxidation, diffusion, ion implantation, lithography, dry etching, VLSI process integration, diagnostic assembly and packaging, yield and reliability. Prerequisites: ECE 473 or ECE 573.

ECE 880. Machine Learning II. 3 Credits.
Advanced topics in machine learning and pattern recognition systems. Data reduction techniques including principle component analysis, independent component analysis and manifold learning. Introduction to sparse coding and deep learning for data representation and feature extraction. Prerequisites: ECE 607 or equivalent.

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ECE 892. Doctor of Engineering Project. 1-12 Credits.
Directed individual study applying advanced level technical knowledge to identify, formulate, and solve a complex, novel problem in electrical and computer engineering.

ECE 895. Topics in Electrical and Computer Engineering. 3 Credits.
Topics in Electrical and Computer Engineering. Prerequisites: departmental approval.

ECE 896. Topics in Electrical and Computer Engineering. 3 Credits.
Topics in Electrical and Computer Engineering.

ECE 897. Independent Study. 1-3 Credits.
This course allows students to develop specialized expertise by independent study (supervised by a faculty member) Prerequisites: departmental approval.

ECE 899. Dissertation Research. 1-9 Credits.
Directed research for the doctoral dissertation. Prerequisites: departmental approval.

ECE 998. Master's Graduate Credit. 1 Credit.
This course is a pass/fail course for master's students in their final semester. It may be taken to fulfill the registration requirement necessary for graduation. All master's students are required to be registered for at least one graduate credit hour in the semester of their graduation.

ECE 999. Doctoral Graduate Credit. 1 Credit.
This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.