

# ELECTRICAL ENGINEERING PROGRAM

## ***Aims and Scope of the Graduate Program***

The Electrical Engineering (EE) program offers students a training program and facilities that will equip them to have successful and productive careers in modern-day electrical engineering. The EE degree program has three major tracks: (1) solid-state electronics; (2) electromagnetics and photonics; and (3) communications and signal processing

## ***Master's Degree***

The Master of Science (M.S.) program in EE requires a minimum of three semesters of residence at KAUST (two fall and one spring semesters, including one summer). Under exceptional circumstances with the approval of the academic advisor and the EE program chair, a student may take extra academic load to complete the M.S. requirements in two semesters of residence at KAUST (one fall and one spring semesters, including one summer).

The EE M.S. degree requires a minimum of 36 credits of academic work. Of these credits, 24 must be in coursework. Students may elect to earn an M.S. degree without a thesis or an M.S. degree with a thesis.

All students (with or without a thesis) must complete 24 credits of coursework, including core requirements in a track area and electives, as detailed below:

1. Core Curriculum (12 credits): Three courses (nine credits) from the list of courses in one selected track area.
  - Solid-State Electronics: EE 202, EE 203, EE 205, EE 208
  - Electromagnetics and Photonics: EE 221, EE 223, EE 231, EE 233
  - Communications and Signal Processing: EE 241, EE 242, EE 243, EE 251

Plus, one course (three credits) from Applied Mathematics. EE courses cross-listed under AMCS degree program can be used to fulfill this requirement (unless they are used to satisfy the EE course requirements).

2. Elective Curriculum (12 credits): Two additional elective courses (six credits) in EE. Courses from any EE track can be used to fulfill this requirement. Two additional courses (six credits) from any 200- or 300-level course in any degree program at KAUST.

The student must also register for EE 298 (non-credit seminar course) for at least one semester of the degree program

## **Thesis Option**

A minimum of 12 credits of M.S. Thesis Research (EE 297) is required. Students are permitted to register more than 12 credits of EE 297 as necessary and with the permission of the thesis advisor. Under exceptional circumstances and with the permission of the thesis advisor and the EE program chair, an M.S. thesis student may extend his/her residence to four semesters. With the permission of the M.S. thesis

advisor, six credits of EE 297 may be replaced with broadening experience coursework (see Non-Thesis Option).

Evaluation of satisfactory completion of M.S. thesis work is performed by a committee comprising the M.S. thesis advisor and two other faculty members. The chair of the committee must be a faculty member within the EE program. The evaluation of M.S. thesis credits is through a pass or a fail grade. The requirement of a public EE seminar based on the student's work is left to the discretion of the M.S. thesis advisor. For additional details on thesis requirements and committee formation, see General Degree Program Guidelines.

The student is responsible for scheduling the thesis defense date with his/her supervisor and committee members. It is advisable that the student submits a written copy of the thesis to the thesis committee members at least two weeks prior the defense date.

### **Non-Thesis Option**

A minimum of 12 credits of academic work embodying research and broadening experienced is required.

1. **Research Experience (six credits):** Students must complete six credits through one or a combination of the options listed below:
  - **Directed Research (EE 299):** Master's-level supervised research.
  - **Research Tools Courses:** Courses offered by Core Labs that teach students how to use tools and techniques required at labs to carry out research.
2. **Broadening Experience (six credits):** Students must complete six credits through one or a combination of the options listed below:
  - **Non-technical Broadening Experience Courses:** Six credits of courses that broaden a student's M.S. experience.
  - **Ph.D.-Level Courses:** Six credits of EE courses numbered 300 or greater. Any course in the Ph.D. core requirements that is passed with a minimum grade of B- may be used towards meeting the core Ph.D. requirements of the EE program if the student chooses to continue for a Ph.D. degree in EE at KAUST.
  - **Internship:** Six credits of research-based summer internship (administered as Directed Research, EE 299). Summer internships are subject to approval by the student's academic advisor and the EE program chair. A student may not enroll in two summer internships.

## ***Degree of Doctor of Philosophy***

### **Credit Requirements**

- Minimum six credits course work in the EE degree program (300 level or above)
- Minimum 60 credits of Dissertation Research (EE 397)
- A Ph.D. student who enters with an M.S. degree can take EE 397 immediately starting from the first semester of his/her residence (up to 12 credits)
- A Ph.D. student who enters with a B.S. degree is not allowed to take EE 297/EE 397 or EE 299/EE 297 in the first two semesters of his/her residence
- The standard credit load for a Ph.D. student is 12 credits in a given semester. This includes remedial (non-degree) English or Mathematics courses required based on pre-semester evaluation/placement tests
- The minimum credit load for a Ph.D. student is nine credits in a given semester. Students need to petition to carry the minimum credit load and gain approval of the academic advisor
- The maximum credit load for a Ph.D. student is 15 credits in a given semester. This is allowed with the approval of the academic advisor

### **GPA Requirement**

- The cumulative GPA must be B for a student to remain in good standing and to be able to graduate
- The passing grade in any course is B-

### **Seminar Requirement**

- The student must register for EE 398 (no credit) in at least one semester of his/her residence

### **Credit Transfer**

- Ph.D. students are not allowed to transfer any credits of course work from the previous institutions they attended

### **Requirements for Students in the B.S. to Ph.D. Track**

B.S. students who are accepted directly to the EE Ph.D. program must complete the 24-credit M.S. degree course requirement within the first two semesters of their enrollment at KAUST. Starting from the end of their second semester of residence, they are enrolled in the EE Ph.D. program and are subject to the Ph.D. degree requirements. If a B.S.-to-Ph.D. track student wants to leave KAUST with an M.S. degree, he/she has to satisfy the M.S. degree requirements, which depend on the option chosen, in addition to the 24-credit course requirement. In this case, credits taken under EE 397 or EE 399 can be counted towards EE 297 or EE 299 with the approval of the thesis advisor and

the EE program chair. Two 300-level courses, which are taken to satisfy the Ph.D. requirements, can be counted towards the M.S. degree requirement.

### **Exam Requirements**

- Subject-Comprehensive Exam
- Research Proposal Examination
- Final Examination

### **Ph.D. Exams**

#### 1) Subject-Comprehensive Exam

The subject-comprehensive exam is offered in the first week of the semester (fall and spring; and in summer on demand). The examination is administrated (separately) by two faculty members from the course track the student is following (excluding the student's research/thesis advisor) and one faculty member external to that track (including degree programs external to the EE degree program).

#### Requirements

- The student must have a research advisor
- Students entering with Bachelor's degrees must pass the exam no later than the *fourth semester* in residence
- Students entering with Master's degrees must pass the exam no later than the *second semester* in residence
- The student must indicate in writing his/her intention to take the exam at least *eight weeks* prior to the exam
- The student must submit the names of the examiners at least *eight weeks* prior to the exam. The names must be approved by the Graduate Degree Coordinator.

The purpose of the examination is to evaluate the student's

- understanding in fundamental topics of the course track he/she is following
- ability to analyze problems and construct solutions

The evaluation is performed by

- asking quantitative and qualitative questions related to the topics covered in the courses taken by the student in the form of a written and/or an oral exam.

The recommended length of the examination is 30-45 minutes.

#### Decision Process

Each examiner grades the student based on the above two criteria and reports the outcome to the Graduate Program Coordinator. The Graduate Program Coordinator includes the reports in the student's data sheet together with the student's doctoral qualification coursework, GRE scores, and the overall academic record as measured by the student's GPA. The Degree Coordinator will then call an EE faculty meeting.

## Results

One of the following outcomes is possible

- Pass: The student is qualified for the doctoral program. The “Pass” decision is achieved by majority vote.
- Failure with retake permitted: The student is not qualified for the doctoral program but allowed to retake the examination one more time.
- Failure: The student is not qualified for the doctoral program and is not allowed to retake the examination exam (See the note below).

The Graduate Degree and Program Coordinators are responsible for informing the students about the outcome of the faculty meeting.

## Notes

- Under exceptional conditions, if a student fails the exam twice, he/she might still be qualified for the doctoral program. But for this to be possible:
  - The research advisor of the student must provide solid evidence of the student’s progress in research (such as published/submitted papers).
  - The qualification decision should be accepted by all of the EE faculty members.

## 2) Research Proposal Examination

The research proposal examination is an oral exam administered by the student’s research proposal examination committee.

### Requirements

- The student must have passed the subject-comprehensive exam.
- Students entering with Bachelor’s degrees must pass the exam no later than the sixth semester in residence
- Students entering with Master’s degrees must pass the exam no later than the fourth semester in residence
- Student must contact each committee member and arrange for a suitable time and place for the exam. The student must submit the information regarding the time and place for the examination to the Graduate Program Coordinator at least six weeks prior to the date chosen for the exam.

The student must submit the research proposal to the committee at least one week prior to the examination. The examination begins with the presentation by the student. Then the committee questions the student regarding the problem, the preliminary results, and the proposed work. The committee may suggest alternative methods of attacking the problem or suggest different aspects of the problem as suitable areas for exploration. The committee also may ask questions of a more general nature in order to test the adequacy of the student’s preparation for the proposed research.

## Result

One of following outcomes is possible:

- Pass: The student passed the exam and may proceed to independent study and research for the doctoral degree. The “pass” decision is achieved by the consensus of the committee with a maximum of one negative vote.
- Failure with retake permitted: If more than one member casts a negative vote, one retake of the examination is permitted if the entire committee agrees. The student must prepare a new research proposal and be examined again within the next six months.
- Failure: If more than one member casts a negative vote and retake of the examination is not permitted, the student has failed the exam and will be dismissed from the program.

## 3) Final Examination

The final examination for the doctoral degree is an oral examination on the student’s written dissertation administered by the student’s final examination committee.

### Requirements

- The student must have passed the research proposal examination
- The student must have completed 60 dissertation credits
- The final examination must take place at least one year (but no later than three years) after the research proposal examination.
- The student must contact each committee member and arrange for a suitable time and place for the examination. The student must submit the information regarding time and place for the examination to the Graduate Program Coordinator at least eight weeks prior to the date chosen for the exam.

The student must submit the dissertation to the committee at least two weeks prior to the final exam. The examination begins with a presentation by the student outlining the problem chosen, the procedures and methods used, and the results obtained. The committee then questions the student regarding the thesis work. The student may be asked to clarify matters in the dissertation and to defend various aspects of the work. Errors and ambiguities in the dissertation may be brought to the student’s attention.

## Result

One of the following outcomes is possible:

- Pass: The student passed the exam and the dissertation is accepted as submitted. The “pass” decision is achieved by the consensus of the committee with a maximum of one negative vote.
- Pass with revisions: The student passed the exam but the dissertation will be accepted after specified corrections and revisions are made. The “pass with revisions” decision is achieved by the consensus of the committee with a maximum of one negative vote.

- *Failure with retake permitted:* If more than one member casts a negative vote, one retake of the examination is permitted if the entire committee agrees. The student must revise the thesis and be examined again within the next six months.
- *Failure:* If more than one member casts a negative vote and retake of the examination is not permitted, the student has failed and the dissertation will not be accepted. The student will leave the program without a degree.

### Research Proposal and Final Examination Committees

Before the research proposal examination, the student should consult with the research advisor regarding the members of the research proposal and final examination committees. These committees must satisfy the following conditions:

- Both committees must include at least three KAUST faculty members, one of whom should be external to EE degree program.
- In both committees, one of the members must have primary research interests in an area different from that of the student.
- The student must submit the names of the research proposal examination committee members to the Graduate Program Coordinator at least six weeks prior the research proposal examination.
- It is expected that all members of the research proposal examination committee will carry forward to the final examination committee.
- Additionally, the final examination committee should include a member external to KAUST. This member should hold a faculty (or equivalent) position at another institution.
- The student must submit the names of the final examination committee members to the Graduate Program Coordinator at least eight weeks prior the final examination.
- The names of the committee members must be approved by the Graduate Degree Coordinator and the Division Dean. Once constituted, the composition of the committees can only be changed upon approval of both the Graduate Degree Coordinator and the Division Dean.
- In the final examination, a non-voting KAUST faculty member, appointed by the Division Dean, serves as a monitor to ensure that the established protocol is followed, and the required forms are completed.

It is the student's responsibility to contact each potential committee member and ask him/her to serve on the committees in a timely manner.

## ***Electrical Engineering Program Course Catalog***

### **Solid-State Electronics**

Core Courses: EE 202, EE 205, EE 203, EE 208

Elective Courses: EE 201, EE 203, EE 204, EE 223, EE 302, EE 303, EE 304, EE305, EE 307, EE 391, EE 204, EE 206, EE 306, EE 307, EE 308, EE 392

### **Electromagnetics and Photonics**

Core Courses: EE 221, EE 223, EE 231, EE 233

Elective Courses: EE 222, EE 321, EE 322, EE 323, EE 393, EE 208, EE 232, EE 331, EE 332, EE 333, EE 334, EE 394

### **Communications and Signal Processing**

Core Courses: EE 242, EE 243, EE 241, EE 251

Elective Courses: EE 241, EE 244, EE 341, EE 342, EE 343, EE 395, EE 252, EE 253, EE 351, EE 352, EE 353, EE 396

### **200 Level Courses**

**EE 201. VLSI Design (3-0-3)** Design techniques for rapid implementations of very large-scale integrated (VLSI) circuits, MOS technology and logic. Structured design. Design rules, layout procedures. Design aids: layout, design rule checking, logic and circuit simulation. Timing. Testability. Architectures for VLSI. Projects to develop and lay out circuits.

**EE 202. Monolithic Amplifier Circuits (3-0-3)** Analysis and design of BJT and MOS multi-transistor amplifiers. Feedback theory and application to feedback amplifiers. Stability considerations, pole-zero cancellation, root locus techniques in feedback amplifiers. Detailed analysis and design of BJT and MOS integrated operational amplifiers. Lectures and laboratory.

**EE 203. Solid-State Device Laboratory (2-1-3)** Semiconductor material and device fabrication and evaluation: diodes, bipolar and field-effect transistors, passive components. Semiconductor processing techniques: oxidation, diffusion, deposition, etching, photolithography. Lecture and laboratory. Projects to design and simulate device fabrication sequence.

**EE 204. Integrated Microsystems Laboratory (1-2-3)** Development of a complete integrated microsystem, from functional definition to final test. MEMS-based transducer design and electrical, mechanical and thermal limits. Design of MOS interface circuits. MEMS and MOS chip fabrication. Mask making, pattern transfer, oxidation, ion implantation and metallization. Packaging and testing challenges. Students work in interdisciplinary teams.

**EE 205. Introduction to MEMS(1-2-3) (Same as ME 323)** Micro electro mechanical systems (MEMS), devices and technologies. Micro-machining and microfabrication techniques, including planar thin-film processing, silicon etching, wafer bonding, photolithography, deposition and etching. Transduction mechanisms and modeling in

different energy domains. Analysis of micromachined capacitive, piezoresistive and thermal sensors/actuators and applications. Computer-aided design for MEMS layout, fabrication and analysis.

**EE 206. Physical Principles Underlying Smart Devices (3-0-3)** Structural properties of materials. Basic quantum mechanics of electrons in solids. Band theory and trap states. Charge transport, band conduction and hopping conduction. Optical properties of materials. Piezoelectric and ferro-electric phenomena. Magnetic effects in materials. Physical phenomena will be related transistors, light emitters, sensor and memory devices.

**EE 208. Semiconductor Optoelectronic Devices (3-0-3)** Materials for optoelectronics, optical processes in semiconductors, absorption and radiation, transition rates and carrier lifetime. Principles of LEDs, lasers, photo detectors, modulators and solar cells. Optoelectronic integrated circuits. Designs, demonstrations and projects related to optoelectronic device phenomena.

**EE 221. Electromagnetic Theory (3-0-3)** Review of vector algebra and calculus, coordinate transformations. Fundamental electromagnetic concepts: Maxwell's equations, Lorentz force relation, electric and magnetic polarizations, constitutive relations, boundary conditions, Poynting theorem in real and complex forms, energy relations. Solution of the Helmholtz equation: plane, cylindrical, and spherical waves, potentials. Electromagnetic theorems: uniqueness, duality, reciprocity, equivalence and induction theorems, Huygen's and Babinet's principles. Guided fields: waveguides, dispersion, phase and group velocities, attenuation, inhomogeneous waveguides, resonant cavities. Antennas: elementary antennas, radiation patterns.

**EE 222. Antenna Theory and Design (3-0-3)** Fundamental antenna system parameters: gain, directivity, efficiency, input impedance. Theory of transmitting and receiving antennas: reciprocity, equivalence, and induction theorems, Huygen's principle. Elementary antennas: dipoles, loops, traveling-wave antennas. Antenna arrays: analysis and synthesis of linear arrays, mutual impedance, phased arrays. Aperture antennas: Fourier transform, Babinet's principle. Antenna noise temperature. Special topics: log-periodic antennas, microstrip antennas, corrugated waveguides and horns, reflector and lens antennas.

**EE 223. Microwave Circuits (3-0-3)** Fundamental microwave concepts: Transmission-line theory, guided wave propagation, S-parameters, ABCD matrix, signal-flow graphs, impedance and admittance transformation, matching networks, Smith chart. Microwave components: microstrip and coplanar lines, directional couplers, power dividers, low-pass and band-pass filters, diode detectors, microwave integrated circuits.

**EE 231. Principles of Optics (3-0-3)** Basic principles of optics: light sources and propagation of light; geometrical optics, lenses and imaging; ray tracing and lens aberrations; interference of light waves, coherent and incoherent light beams; Fresnel and Fraunhofer diffraction. Overview of modern optics with laboratory demonstrations.

**EE 232. Applied Quantum Mechanics (3-0-3) (Same as MSE 232)** Introduction to nonrelativistic quantum mechanics. Summary of classical mechanics, postulates of quantum mechanics and operator formalism, stationary state problems (including

quantum wells, harmonic oscillator, angular momentum theory and spin, atoms and molecules, band theory in solids), time evolution, approximation methods for time independent and time-dependent interactions including electromagnetic interactions, scattering.

**EE 233. Photonics (3-0-3)** Introduction to photonics, lasers and fiber optics. Topics include mirrors, interferometers, modulators and propagation in waveguides and fibers; photons in semiconductors, including semiconductor laser, detectors and noise effects, with applications to fiber light wave systems, high-power lasers and display technologies.

**EE 241. Probability and Random Processes (3-0-3) (Same as AMCS 241 and CS241)** Introduction to probability and random processes. Topics include probability axioms, sigma algebras, random vectors, expectation, probability distributions and densities, Poisson and Wiener processes, stationary processes, autocorrelation, spectral density, effects of filtering, linear least-squares estimation and convergence of random sequences.

**EE 242. Digital Communication and Coding (3-0-3)** Digital transmission of information across discrete and analog channels. Sampling; quantization; noiseless source codes for data compression: Huffman's algorithm and entropy; block and convolutional channel codes for error correction; channel capacity; digital modulation methods: PSK, MSK, FSK, QAM; matched filter receivers. Performance analysis: power, bandwidth, data rate and error probability.

**EE 243. Communication Networks (3-0-3)** *Prerequisite: preceded or accompanied by EE 241.* System architectures. Data link control: error correction, protocol analysis, framing. Message delay: Markov processes, queuing, delays in statistical multiplexing, multiple users with reservations, limited service, priorities. Network delay: Kleinrock independence, reversibility, traffic flows, throughput analysis, Jackson networks, Multiple access networks: ALOHA and splitting protocols, carrier sensing, multi-access reservations.

**EE 244. Wireless Communications (3-0-3)** *Prerequisite: preceded or accompanied by EE 241, EE 242.* This course introduces fundamental technologies for wireless communications. It addresses the following topics: review of modulation techniques, wireless channel modeling, multiple access schemes, cellular communications, diversity techniques, equalization, channel coding, selected advanced topics such as CDMA, OFDM, Multiuser detection, space time coding, smart antenna, software radio.

**EE 251. Digital Signal Processing and Analysis (3-0-3)** Introduction to digital signal processing of continuous and discrete signals. The family of Fourier transforms including the discrete Fourier transform (DFT). Development of the fast Fourier transform (FFT). Signal sampling and reconstruction. Design and analysis of digital filters. Correlation and spectral estimation.

**EE 252. Estimation, Filtering and Detection (3-0-3)** *Prerequisite: EE 241.* Principles of estimation, linear filtering and detection. Estimation: linear and nonlinear minimum mean squared error estimation and other strategies. Linear filtering: Wiener and Kalman

filtering. Detection: simple, composite, binary and multiple hypotheses. Neyman-Pearson and Bayesian approaches.

**EE 253. Wavelets and Time-Frequency Distribution (3-0-3)** *Prerequisite: EE 251.* Review of DTFT and digital filtering. Multirate filtering. Filter banks and subband decomposition of signals. Multiresolution subspaces. Wavelet scaling and basis functions and their design: Haar, Littlewood-Paley, Daubechies, Battle-Lemarie. Denoising and compression applications. Spectrogram, Wigner-Ville, Cohen's class of time-frequency distributions and their applications.

**EE 297. Thesis Research (variable credit)** Master-level supervised thesis research.

**EE 298. Graduate Seminar (non-credit)** Master-level seminar focusing on special topics within the field.

**EE 299. Directed Research (variable credit)** Master-level supervised research.

### **300 Level Courses**

**EE 302. Integrated Analog/Digital Interface Circuits (3-0-3)** *Prerequisite: EE 202.* This course covers most of the well-known analog-to-digital conversion schemes. These include the flash, folding, multi-step and pipeline Nyquist rate, architectures. Oversampling converters are also discussed. Practical design work is a significant part of this course. Students design and model complete converters.

**EE 303. Integrated Circuits (3-0-3)** *Prerequisite: EE 202.* Integrated circuit fabrication overview, relationships between processing choices and device performance characteristics. Long-channel device I-V review, short-channel MOSFET I-V characteristics including velocity saturation, mobility degradation, hot carriers, gate depletion. MOS device scaling strategies, silicon-on-insulator, lightly doped drain structures, on-chip interconnect parasitics and performance. Major CMOS scaling challenges. Process and circuit simulation.

**EE 304. Integrated Microsystems (3-0-3)** *Prerequisites: EE 204, EE 205.* Review of interface electronics for sense and drive and their influence on device performance, interface standards, MEMS and circuit noise sources, packaging and assembly techniques, testing and calibration approaches and communication in integrated microsystems. Applications, including RF MEMS, optical MEMS, bioMEMS and microfluidics. Design project using CAD and report preparation.

**EE 305. Advanced MEMS Devices and Technologies (3-0-3)** *Prerequisite: EE 205.* Advanced micro electro mechanical systems (MEMS) devices and technologies. Transduction techniques, including piezoelectric, electrothermal and resonant techniques. Chemical, gas and biological sensors; microfluidic and biomedical devices. Micromachining technologies such as laser machining and microdrilling, EDM, materials such as SiC and diamond. Sensor and actuator analysis and design through CAD.

**EE 306. Electronic and Optical Properties of Semiconductors (3-0-3)** *Prerequisite: EE 206.* The course discusses in detail the theory behind important semiconductor based experiments such as Hall effect and Hall mobility measurement, velocity-field measurement, photoluminescence, gain, pump-probe studies, pressure and strain dependent studies. Theory will cover: Band structure in quantum wells; effect of strain

on band structure; transport theory; Monte Carlo methods for high field transport; excitons, optical absorption, luminescence and gain.

**EE 307. High-Speed Transistors (3-0-3)** Detailed theory of high-speed digital and high-frequency analog transistors. Carrier injection and control mechanisms. Limits to miniaturization of conventional transistor concepts. Novel submicron transistors including MESFET, heterojunction and quasi-ballistic transistor concepts.

**EE 308. Semiconductor Lasers and LEDs (3-0-3)** *Prerequisite: EE 208.* Optical processes in semiconductors, spontaneous emission, absorption gain, stimulated emission. Principles of light-emitting diodes, including transient effects, spectral and spatial radiation fields. Principles of semiconducting lasers, gain-current relationships, radiation fields, optical confinement and transient effects.

**EE 321. Numerical Methods in Electromagnetics (3-0-3)** Review of vector algebra, calculus, and electromagnetic theory. Introduction to computational electromagnetics. Finite difference time domain method (FDTD): fundamentals, absorbing boundary conditions, perfectly matched layers. Integral equations: fundamentals, method of moments (MOM), Galerkin's technique, conjugate gradient FFT. Finite element method (FEM): fundamentals, vector and higher-order elements. Hybridization of FEM and boundary integral methods. Application of the above methods to the solution of practical problems in electromagnetics involving wave propagation on transmission lines, interference of antennas, scattering, and characterization of cavity resonances.

**EE 322. Active Remote Sensing (3-0-3)** *Prerequisites: EE 221, EE 222.* Radar equation, noise statistics, resolution techniques, calibration. Space and ground propagation, synthetic aperture radar, scatterometers, scattering models, surface and volume scattering. Land and oceanographic applications.

**EE 323. Microwave Measurements Laboratory (1-2-3)** *Prerequisites: EE 221, EE 223.* Advanced topics in microwave measurements: power spectrum and noise measurement, introduction to state-of-the-art microwave test equipment, methods for measuring the dielectric constant of materials, polarimetric radar cross section measurements, near-field antenna pattern measurements, electromagnetic emission measurement (EM compatibility). Followed by a project that will include design, analysis, and construction of a microwave subsystem.

**EE 331. Classical Optics (3-0-3)** *Prerequisite: EE 231.* Theory of electromagnetic, physical and geometrical optics. Classical theory of dispersion. Linear response, Kramers-Kronig relations and pulse propagation. Light scattering. Geometrical optics and propagation in inhomogeneous media. Dielectric waveguides. Interferometry and theory of coherence. Diffraction, Fresnel and Fraunhofer. Gaussian beams and the ABCD law.

**EE 332. Lasers (3-0-3)** *Prerequisites: EE 331, EE 333.* Complete study of laser operation: the atom-field interaction; homogeneous and inhomogeneous broadening mechanisms; atomic rate equations; gain and saturation; laser oscillation; laser resonators, modes and cavity equations; cavity modes; laser dynamics, Q-switching and mode-locking. Special topics such as femto-seconds lasers and ultra-high-power lasers.

**EE 333. Optical Waves in Crystals (3-0-3) Prerequisite: EE 233.** Propagation of laser beams: Gaussian wave optics and the ABCD law. Manipulation of light by electrical, acoustical waves; crystal properties and the dielectric tensor; electrooptic, acoustooptic effects and devices. Introduction to nonlinear optics; harmonic generation, optical rectification, four-wave mixing, self-focusing and self-phase modulation.

**EE 334. Nonlinear Optics (3-0-3) Prerequisites: EE 331, EE 333.** Formalism of wave propagation in nonlinear media, susceptibility tensor, second harmonic generation and three-wave mixing, phase matching, third-order nonlinearities and fourwave mixing processes, stimulated Raman and Brillouin scattering. Special topics: nonlinear optics in fibers, including solitons and self-phase modulation.

**EE 341. Information Theory (3-0-3) Prerequisite: EE 241.** The concepts of source, channel, rate of transmission of information. Entropy and mutual information. The noiseless coding theorem. Noisy channels, the coding theorem for finite state zero memory channels. Channel capacity. Error bounds. Parity check codes. Source encoding.

**EE 342. Channel Coding Theory (3-0-3) Prerequisite: EE 241.** The theory of channel coding for reliable communication and computer memories. Error correcting codes; linear, cyclic and convolutional codes; encoding and decoding algorithms; performance evaluation of codes on a variety of channels.

**EE 343. Digital Communication Theory (3-0-3) Prerequisite: EE 241, EE 242.** Theory of digital modulation and coding. Optimum receivers in Gaussian noise. Signal space and decision theory. Signal design. Bandwidth and dimensionality. Fundamental limits in coding and modulation. Capacity and cutoff rate. Block, convolutional and trellis coding. Continuous phase modulation. Filtered channels and intersymbol interference. Equalization. Spread-spectrum. Fading channels. Current topics.

**EE 351. Advanced Signal Processing (3-0-3) Prerequisites: EE 241, EE 251.** Estimators of second-order properties of random processes: nonparametric and model-based techniques of spectral estimation, characterization of output statistics for nonlinear systems, time-frequency representations. Performance evaluation using asymptotic techniques and Monte Carlo simulation. Applications include speech processing, signal extrapolation, multidimensional spectral estimation and beam forming.

**EE 352. Image Processing (3-0-3) Prerequisites: EE 241, EE 251.** Theory and application of digital image processing. Random field models of images. Sampling, quantization, image compression, enhancement, restoration, segmentation, shape description, reconstruction of pictures from their projections, pattern recognition. Applications include biomedical images, time-varying imagery, robotics and optics.

**EE 353. Adaptive Signal Processing (3-0-3) Prerequisites: EE 241, EE 251.** Theory and applications of adaptive filtering in systems and signal processing. Iterative methods of optimization and their convergence properties: transversal filters; LMS (gradient) algorithms. Adaptive Kalman filtering and least-squares algorithms. Specialized structures for implementation (e.g., least-squares lattice filters, systolic

arrays). Applications to detection, noise canceling, speech processing and beam forming.

**EE 391. Advanced Topics in Circuits and Microsystems (3-0-3)** Doctoral-level lectures focusing on state of the art within the field.

**EE 392. Advanced Topics in Solid State Devices (3-0-3)** Doctoral-level lectures focusing on state of the art within the field.

**EE 393. Advanced Topics in Electromagnetics (3-0-3)** Doctoral-level lectures focusing on state of the art within the field.

**EE 394. Advanced Topics in Photonics (3-0-3)** Doctoral-level lectures focusing on state of the art within the field.

**EE 395. Advanced Topics in Communications (3-0-3)** Doctoral-level lectures focusing on state of the art within the field.

**EE 396. Advanced Topics in Signal Processing (3-0-3)** Doctoral-level lectures focusing on state of the art within the field.

**EE 397. Dissertation Research (variable credit)** Doctoral-level supervised dissertation research.

**EE 398. Graduate Seminar (non-credit)** Doctoral-level seminar focusing on special topics within the field.

**EE 399. Directed Research (variable credit)** Doctoral-level supervised research.