EEE 5544 Noise in Linear Systems

[Stochastic Methods in Engineering I]

and

EEL 4516 Noise in Devices and Communication Systems

Syllabus

1. **Catalog Description (EEE 5544):** (3 credits) Passage of electrical noise and signals through linear systems. Statistical representation of random signals, electrical noise, and spectra.

   Catalog Description (EEE 4516): (3 credits) Origin, characterization and measurement of random noise. Calculation of signal-to-noise ratios and probability of errors in communication systems.

   Instructor's clarification: This course starts from the fundamentals of probability and covers probability, random variables, random vectors, and random processes, with applications to control, signal processing, and communications.

   

   The focus is on the mathematical tools required to model and quantify random phenomena.

2. **Pre-requisites:** EEL 3135 (Introduction to Signals and Systems) or equivalent, MAS 3114 (Computational Linear Algebra) or equivalent.

   Pre-requisite knowledge for success in this course: Very strong mathematical skills, including multidimensional calculus. Solid understanding of systems theory, including convolution, Fourier transforms, and impulse functions. Knowledge of basic linear algebra, including matrix properties and eigen-decomposition.

3. **Meeting Times:** 11:45 – 12:35 AM, Monday/Wednesday/Friday
   Meeting Location: NEB 102
   Class/laboratory schedule: 3 classes/week, 50 minutes each

4. **Course Objectives:** Upon completion of this course, the student should be able to

   - Recite the axioms of probability; use the axioms and their corrolaries to give reasonable answers
   - Determine probabilities based on counting (lottery tickets, etc.)
   - Calculate probabilities of events from the density or distribution functions for random variables
   - Classify random variables based on their density or distribution functions
   - Simulate random variables and random processes

- Know the density and distribution functions for common random variables
- Determine random variables from definitions based on the underlying probability space
- Use conditional probability, total probability, and Bayes' law
- Find maximum likelihood and maximum a posteriori decision rules
- Determine the density and distribution functions for functions of random variables using several different techniques presented in class
- Calculate expected values for random variables
- Find MMSE estimators for random variables
- Determine whether events, random variables, or random processes are statistically independent
- Use inequalities to find bounds for probabilities that might otherwise be difficult to evaluate
- Use transform methods to simplify solving some problems that would otherwise be difficult
- Evaluate probabilities involving multiple random variables or functions of multiple random variables
- Use the Karhunen-Loève transform to decorrelate random variables and use PCA for dimensionality reduction
- Classify random processes based on their time support and value support
- Classify random processes based on stationarity
- Evaluate the mean, autocovariance, and autocorrelation functions for random processes at the output of a linear filter
- Evaluate the power spectral density for wide-sense stationary random processes
- Give the matched filter solution for a simple signal transmitted in additive white Gaussian noise
- Determine the steady state probabilities for a Markov chain

5. **Contribution of course to meeting the professional component:** *Does not apply*
6. **Relationship of course to program outcomes:** *Does not apply*
7. **Instructor:** Dr. Sean Meyn
   (a) Office: 455 NEB
   (b) Email: meyn@ece.ufl.edu
   (c) Web site (personal): http://www.meyn.ece.ufl.edu/
   (d) Twitter (personal account): @spmeyn
   (e) Office hours: Monday 12:35–1:30 PM, Wednesday 10:30–11:30 AM, or by appointment

8. **Teaching Assistant:** Islam S. Badreldin

   (a) Office: NEB 484

   (b) Email: ibadreldin @ufl.edu

   (c) Office hours: Monday 10:40–11:30 AM and Wednesday 12:50–1:40 PM

9. **Teaching Assistant:** Ali Sadeghian

   (a) Office: TBD

   (b) Email: asadeghian@ufl.edu

   (c) Office hours: Thursdays 4:00–5:30 PM

10. **Class Response System:** Both on-campus and off-campus students will need to use Learning Catalytics to complete interactive activities during the class. However, off-campus students must enroll in the off-campus section of Learning Catalytics. The cost is $12 per semester. Sign up here:

    `https://learningcatalytics.com/`

11. **Material and Supply Fees:** Students pay a fee for taking a course that is offered on EDGE. Students are required to have an account with the selected classroom response system provider.

12. **Recommended Textbook:** Alberto Leon-Garcia, *Probability, Statistics, and Random Processes for Electrical Engineering*, Pearson Prentice Hall, 3rd ed., 2008 (ISBN 0131471228).

13. **Alternative Textbook:** Henry Stark and John W. Woods, *Probability, Statistics, and Random Processes for Engineers*, Prentice Hall, 4th ed., 2011 (ISBN 0132311232).

14. **Course Notes:** Course notes developed by the instructor will be provided in PDF for download.

15. **E-Learning:** All students must use the class web site, which is on E-Learning in Canvas: https://elearning.ufl.edu/.

16. **Computational Tools:** Python or MATLAB will be required in some exercises. The former is preferred because it is free, and is also an industry-standard (e.g., Python is used at Google research). Details on recommended distributions of Python will be posted to the course website.

    MATLAB is available on the ECEL cluster. As departmental computer resources are limited, students may want to purchase the student version of MATLAB or install GNU Octave, which is a free MATLAB replacement.

17. **Recommended Reading:**

    - If you feel like you are having a hard time with basic probability, I suggest:
      - D. P. Bertsekas and J. N. Tsitsiklis, *Introduction to Probability*, 2nd ed., 2008 (ISBN 978-1-886529-23-6).

  - Sheldon Ross, *A First Course in Probability*, Prentice Hall, 8th ed., 2009 (ISBN 978-0136033134).
- For more depth on filtering of random processes:
  - Bruce Hajek, *Random Processes for Engineers*, Cambridge University Press, 2015 (ISBN 1107100127) (early versions available online)
  - Michael B. Pursley, *Random Processes in Linear Systems*, Prentice Hall, 2002 (ISBN 0-13-067391-9)
  - Ramon van Handel, *Lecture Notes on Hidden Markov Models.* (available online – beautiful notes, but most suitable for S.M. II)
- Additional Reference:
  - Athanasios Papoulis and S. Unnikrishna Pillai, *Probability, Random Variables and Stochastic Processes*, McGraw Hill, 4th ed., 2002 (ISBN 0-07-112256-7)

18. **Course Outline: (as time allows)**

- **Week 1**
  - Introduction to probability models & philosophies
  - Random experiments
  - Samples spaces and set operations
  - Combinatorial (counting) analysis
- **Week 2**
  - Probability spaces and axioms of probability
  - Statistical independence
  - Mutually exclusive events
  - Conditional probability
  - Chain rule
  - *Assignments:* Homework 1 Preparation Assessment, Homework 1
- **Week 3**
  - Total probability
  - Bayes' rule
  - Maximum likelihood and maximum *a posteriori* decision rules
  - Sequential experiments
  - The Poisson law
  - Single random variables and types of random variables
  - *Assignments:* Homework 2 Preparation Assessments, Homework 2

- **Week 4**
  - Distribution and density functions
  - Important random variables
  - Computing probabilities for Gaussian random variables
  - Point conditioning, total probability, Bayes' rule for continuous random variables
  - *Assignments:* Homework 3 Preparation Assessment, Homework 3
- **Week 5**
  - Multiple random variables
  - Joint and marginal distribution and density functions
  - *Assignment:* Homework 4 Preparation Assessment, Homework 4
- **Week 6**
  - Computing probabilities using joint distributions and densities
  - Conditioning with multiple random variables
  - *Assignment:* Homework 5
- **Week 7**
  - Functions of one random variable
  - One function of multiple random variables
  - Order statistics
  - *Exam 1*
- **Week 8**
  - Functions of several random variables
  - Generating random variables
  - Expected value of a random variable
  - Expected value of a function of a random variable
  - Moments of a single random variable: mean, variance, standard deviation, Nth moment, Nth central moment
  - *Assignment:* Homework 6
- **Week 9**
  - Poisson points

  - Expected value of function of multiple RVs: sum or RVs, product of RVs
  - Joint moments
  - Covariance and correlation coefficient
  - Bivariate jointly Gaussian random variables
  - Cauchy-Schwartz Inequality
  - Conditional expected value
  - Minimum mean-square error estimation

  - *Assignment:* Homework 7

- **Week 10**
  - Complex random variables
  - Transform methods: Characteristic and moment-generating functions, Laplace transform and probability generating functions
  - Applications of transform methods: determining moments, characterizing functions of random variables, sums of independent random variables
  - Markov and Chebyshev inequalities, Chernoff bound

  - *Assignment:* Homework 8

- **Week 11**
  - Laws of Large Numbers
  - The Central Limit Theorem
  - Random Vectors
  - Jointly Gaussian random vectors
  - Covariance matrices and properties
  - Decorrelating/whitening random variables and application to principal components analysis
- **Week 12**
  - Random processes
  - Moving average and autoregressive processes
  - Mean, autocorrelation, and autocovariance functions
  - Power at the output of a filtered random process

  - *Exam 2*

- **Week 13**
  - Properties of autocorrelation and autocovariance functions
  - Stationarity

  - Gaussian random processes
  - Multiple random processes

  - *Assignment:* Homework 9

- **Week 14**
  - Time-invariant filtering of random processes
  - Important classes of random processes
  - Power spectral density

  - *Assignment:* Homework 10

- **Week 15:**
  - Matched filters
  - Sampling random processes
  - Markov chains

  - *Exam 3*

19. **Attendance and Expectations:** Attendance will not be taken. However, the classroom response system will be used to ask questions in almost every class. Students can respond using their smart phone, tablet, or laptop. The responses will affect on-campus students' grades. In addition, students are expected to know all material covered in class, even if it is not in the book.

20. **Homework:** *Homework must be uploaded to Canvas on its due-date Friday prior to lecture.* Extensions cannot be granted.

    No formal project is required, but, as mentioned above, students will be required to use Python or MATLAB in solving some homework problems.

    Homework sets will be graded on a spot-check basis: if I give ten problems, we may only grade two of them.

    When students request that a submission (test or homework) be regraded, I reserve the right to regrade the entire submission rather than just a single problem.

21. **Grading:**

    - Grading for on-campus students will be based on three exams (25% each), classroom responses and quizzes (15%), and selected homework problems (10%).
    - Grading for EDGE students will be based on three exams (25% each), homework (15%), and class participation and quizzes (10%).

- The participation score for EDGE students will take into account in-class participation, e-mail or instant messaging exchanges, discussions outside of class, etc.
- *EEL 4516 students will have reduced problem set on some homeworks and exams.*

22. **Grading Scale:** Grades (and the corresponding grade points) will be assigned according to the Registrar's official policies. Grades will be curved. However, an A grade of $> 90\%$ is guaranteed an A, $> 80\%$ is guaranteed a B, etc.

    Undergraduate students, in order to graduate, must have an overall GPA and an upper-division GPA of 2.0 or better (C or better). Note: a C- average is equivalent to a GPA of 1.67, and therefore, it does not satisfy this graduation requirement.

    Graduate students, in order to graduate, must have an overall GPA of 3.0 or better (B or better). Note: a B- average is equivalent to a GPA of 2.67, and therefore, it does not satisfy this graduation requirement.

    For more information on grades and grading policies, please visit: https://catalog.ufl.edu/ugrad/current/regulations/info/grades.aspx

23. **Make-up Exam Policy:** If an exam must be missed, the student must see the instructor and make arrangements **in advance** unless an emergency makes this impossible. Approval for make-up exams is much more likely if the student is willing to take the exam early. Any other exam absence will result in the student receiving a zero for that grade. Students who miss pop quizzes or online quizzes will receive zeros for that grade.

24. **Honesty Policy:** All students admitted to the University of Florida have signed a statement of academic honesty committing themselves to be honest in all academic work and understanding that failure to comply with this commitment will result in disciplinary action.

    This statement is a reminder to uphold your obligation as a student at the University of Florida and to be honest in all work submitted and exams taken in this class and all others.

    Additional requirements and information:

    Honor statements on tests must be signed in order to receive any credit for that test.

    I understand that many of you will have access to at least some of the homework solutions. Time constraints prohibit me from developing completely new sets of homework problems each semester. Therefore, I can only tell you that homework problems exist for your benefit. It is dishonest to turn in work that is not your own. In creating your homework solution, you should not use the homework solution that I created in a previous year or someone else's homework solution. *If I suspect that too many people are turning in work that is not their own, then I will completely remove homework from the course grade.*

Collaboration on homework is permitted **and encouraged** unless explicitly prohibited, provided that:

(a) Collaboration is restricted to students currently in this course.

(b) Collaboration must be a shared effort.

(c) Each student must write up his/her homework independently.

(d) On problems involving MATLAB programs, each student should write their own program. Students may discuss the implementations of the program, but students should not work as a group in writing the programs.

We have a zero-tolerance policy for cheating in this class.

If you talk to anyone other than me during an exam, I will give you a zero. If you plagiarize (copy someone else's words) or otherwise copy someone else's work, I will give you a failing grade for the class. Furthermore, I will be forced to bring academic dishonesty charges against anyone who violates the Honor Code.

25. **Accommodation for Students with Disabilities:** Students requesting classroom accommodation must first register with the Dean of Students Office. That office will provide the student with documentation that he/she must provide to the course instructor when requesting accommodation.

26. **UF Counseling Services:** Resources are available on-campus for students having personal problems or lacking clear career and academic goals. The resources include:

    - U Matter, We Care: http://www.umatter.ufl.edu, 294-CARE (2273), umatter@ufl.edu, @UMATTERWECARE
    - UF Counseling & Wellness Center, 3190 Radio Rd, 392-1575, psychological and psychiatric services.
    - Career Resource Center, Reitz Union, 392-1601, career and job search services.

27. **Software Use:** All faculty, staff and student of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.