ECE 767: Error-Control Coding
Department of Electrical and Computer Engineering
North Carolina State University
Spring 2008

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Office Hours: Tues. 3:00-5:00pm and by appointment
Course Webpage: http://courses.ncsu.edu/ece767/lec/001/www

Description: An introduction to the theory and practice of codes to detect and correct errors in digital data communication and storage systems. Topics include linear block codes, cyclic codes, cyclic redundancy checksums, BCH and Reed-Solomon codes, convolutional codes, trellis-coded modulation, LDPC and turbo codes, Viterbi and sequential decoding, and encoder and decoder architecture. Applications will be discussed in the design of computer memories, local-area networks, compact disc digital audio, NASA's deep space network, high-speed modems, communications satellites, and cellular telephony.

General: Prereq: ECE 714 (Random Processes) or equivalent. Prior exposure to digital communications and linear algebra is helpful. Lectures are MW 9:35-10:50am in EB2 1230. The latest course information is available on the course webpage along with lecture notes, homework assignments, readings, practice exams and homeworks.

Text: S. Lin and D. Costello, Jr., *Error Control Coding,* 2^{nd} e. Upper Saddle River, NJ: Pearson Prentice Hall, 2004. A set of course notes is also available on the course webpage.

Homework: There will be six homeworks, each worth 20 pts. The lowest homework grade will be dropped. Solutions will be posted on the webpage. Homeworks are expected to be entirely the student's own work. Late homeworks will not be accepted.

Projects: Each homework contains one or more “mini-projects.” These projects enable you to demonstrate your understanding of course concepts by solving real-world design problems using MATLAB. Further information on the projects will be given later in class.

Exams: There will be two exams, each worth 200pts.

- Exam I: Wednesday, February 27
- Exam II: Monday, May 5, 8:00-11:00am

Each student may bring one 8.5 x 11” reference sheet to each exam. Otherwise, exams are closed book and closed notes. Calculators may be used but usually are not needed.

Grading Policy: The final score for the course is computed as follows:

- Homework: 100 pts (20 pts each, best five out of six)
- Exams: 400 pts (200 pts each)

A perfect score in this course is 600

Academic Integrity: I expect that your signature on any test or assignment means that you neither gave nor received unauthorized aid. All provisions of the university *Code of Student Conduct* apply to this course, cf. http://www.ncsu.edu/policies/student_services/student_discipline/POL11.35.1.php

Disabilities: Reasonable accommodations will be made for students with verifiable disabilities. To qualify for these accommodations, students must register with Disability Services at 1900 Student Health Center, Campus Box 7509, 515-7653 (http://www.ncsu.edu/provost/offices/affirm_action/dss/) For more information, see http://www.ncsu.edu/provost/hat/current/appendix/appen_k.html

References: The following books have been placed on reserve at the library:

1. R. E. Blahut, *Theory and Practice of Data Transmission Codes*. New York: Wiley, 1994.
2. S. B. Wicker, *Error-Control Systems for Digital Communication and Storage.* Englewood Cliffs, NJ: Prentice-Hall, 1995.
3. R. J. McEliece, *Finite Fields for Computer Scientists and Engineers*. Boston: Kluwer Academic Publishers, 1987. (A good reference for the algebra of finite fields.)
4. E. Berlekamp, ed., *Key Papers in the Development of Coding Theory*. New York: IEEE Press, 1974. (A collection of important papers in coding theory, including the original papers that introduced block codes, convolutional codes, Reed-Solomon codes, etc.)

Course Organization and Scope:

I. Course Overview (1 lecture)

II. Preliminaries (2 lectures)
   a. Communication Channel Models and Error Probability
   b. Discrete Channels
   c. Block Codes for Discrete Channels

III. Introduction to Abstract Algebra (2 lectures)
   a. Groups and Finite Fields
   b. Linear Algebra over Finite Fields

IV. Linear Block Codes (3 lectures)
   a. Generator and Parity-Check Matrices
   b. Distance Properties of Group Codes
   c. Decoding: The Standard Array
   d. Examples: Hamming, Hadamard, and Simplex Codes

V. Algebra II: Extension Fields (3 lectures)
   a. Polynomials over GF(p), Factorization and Euclid's Algorithm
   b. Constructing Extensions of GF(p)
   c. Primitive Elements and the Table of Logarithms
   d. Conjugates and Minimal Polynomials
   e. Implementing Field Arithmetic in Digital Logic

VI. Cyclic Codes (3 lectures)
   a. Generator and Parity-Check Polynomials
   b. Systematic Cyclic Codes
   c. Connections to Linear Block Codes
   d. Encoding Cyclic Codes via Linear Shift-Register Circuits
   e. Examples: Cyclic Hamming, Simplex and Golay Codes
   f. Decoding: The Meggitt Decoder
   g. Decoding: Error Trapping
   h. Cyclic Redundancy Checksums (CRCs) for error detection
   i. Examples: CCITT Standards for 16- and 32-bit CRCs

VII. Reed-Solomon and BCH Codes (3 lectures)
   a. The Vandermonde Matrix in GF(q)
   b. Reed-Solomon Codes
   c. Bose-Chaudhuri-Hochquengham Codes
   d. The Peterson-Gorenstein-Zierler Decoder
   e. The Berlekamp-Massey Algorithm
   f. Forney's Algorithm
   g. Applications: Burst-Error Correction
   h. Applications: Concatenated Coding
   i. Examples: The Compact Disc Digital Audio Standard

VIII. Convolutional Codes (4 lectures)
   a. Generator Polynomials and Encoding Circuits
   b. Connections to Block Codes

c. Tree, Trellis and State Diagrams
d. Catastrophic Codes
e. Distance Properties of Convolutional Codes
f. Decoding: The Viterbi Algorithm and Sequential Decoding
g. Example: The NASA/ESA Planetary Standard

IX. Trellis-Coding Modulation (3 lectures)
   a. Bandwidth-efficient Modulation
   b. Code Design Criterion
   c. Ungerboeck Codes
   d. Set-Partitioning Labels
   e. Asymptotic Coding Gain
   f. Systematic Feedback Encoders
   g. Examples: Ungerboeck PSK and QAM Codes
   h. Multiple TCM
   i. Example: MSAT-X (NASA's Land Mobile Satellite Experiment)

X. Turbo Codes (2 lectures)
   a. The Turbo Principle
   b. Soft-input, Soft-output (SISO) Decoding
   c. The Bahl-Cocke-Jelinek-Rajiv Algorithm
   d. Recursive Systematic Convolutional (RSC) codes
   e. Parallel and Serial Concatenation of Codes
   f. Example: Turbo Codes for the Wideband CDMA Cellular Telephony Standard
   g. Interleavers for Turbo Coding
   h. Iterative (Turbo) Decoding
   i. Advantages of Turbo Codes
   j. Examples: Best Known Turbo Codes for PSK and QAM

XI. Advanced Topics (2 lectures)
   a. Low-Density Parity Check (LDPC) Codes
   b. Coding for Fading Multipath Channels
   c. Example: Digital Subscriber Line Modems
   d. Space-Time Coding and Modulation