ECE4634
Digital Communications
Fall 2007

Instructor: Dr. R. Michael Buehrer

Lecture #1: Course Overview

Announcements

- **Today's Handouts:**
  - Course Syllabus
  - Course Notes for Lecture #1
    - Course Notes for futures classes will be posted on the class web site.
- **First Homework**:
  - Fourier Transforms
  - Available on the website
  - Due Friday 8/31
- **Reading**
  - Chapter 1

Course Mechanics

- Meeting Times and Location:
  - CRN 91876 MWF 10:10 - 11:00 am
  - Room RAND 331
- Instructor:
  - Dr. R. Michael Buehrer, Associate Professor
- Contact Information:
  - Office: 433 Durham Hall
  - Phone: 231-1898
  - e-mail: buehrer@vt.edu
- Grader:
  - Jesse Reed jesser@vt.edu

Office Hours

- Instructor Office Hours:
  - MW 11:15 – 12:15 pm, Thurs 9:30-11am
- If you need to see me outside regular office hours, please make an appointment via e-mail
- I check my e-mail several times a day, so e-mail may be the best way to answer many *quick* questions

About Your Instructor

- Education:
  - Undergraduate: University of Toledo, 1991
  - Ph.D.: Virginia Tech, 1996
- Research Experience
  - Dissertation: *The application of Multiuser Detection to CDMA Cellular Systems* (1996)
  - Bell Labs – Lucent Technologies: Distinguished Member of Technical Staff in the Wireless Communications Lab (1996-2001)
  - Associate Prof. with MPRG Laboratory (since 2001)
- Personal
  - Five kids (11,9,7,5, & 2 yrs. old)
  - Hobbies: sports, hiking, star gazing, gardening
  - Practicing Christian
  - Deacon at Blacksburg Christian Fellowship
    - Teach Old Testament Survey, New Testament Survey, Church History, Christian Thought
    - Currently co-teaching a course on Church History
    - Occasionally preach

Research Interests

- Ultra-Wideband sensor and communication systems
- Position-Location Networks
- Advanced Signal Processing Techniques to improve communications
  - Space-Time Coding (MIMO systems)
  - Multiuser Detection
  - Adaptive Antennas
- Interaction between Physical Layer Algorithms and Radio Resource Control Algorithms
  - Multi-antenna scheduling
- Adaptive Modulation and Coding
- Simulation Techniques for Combined Physical Layer / RRC Layer Research
- Software Radio

DRS Graduate Fellowship

- DRS Signal Solutions Sponsors a Graduate Fellowship for US Citizens interested in obtaining a Master of Science in Electrical Engineering with a wireless communications specialty
- If you are interested in graduate school please feel free to stop by my office during office hours
- Current DRS Graduate Fellow will be giving a talk in September which will provide more info.
- DRS also currently hiring for intern and full-time positions

Course Web Site

- http://www.mprg.org/people/buehrer/4634/ecpe_4634.htm
- What will be available:
  - Lecture Notes (.pdf)
  - Homework Assignments & Solutions (.pdf)
  - Useful resources for projects (*Matlab files)*
  - Course Syllabus
- In order to read .pdf files you will need Adobe Acrobat Reader (available free - instructions on website)
- If you know of good links for inclusion in the course web site, e-mail me and I will add them

User: analog
Psswd: ana_com

Required Course Materials

- **Textbook:**
  - Haykin and Moher, Introduction to Analog & Digital Communications, Second Edition, Wiley, 2007.
- **Access to Networked PC or Workstation**
- **Software:**
  - *Matlab* for Windows
  - I have versions 6.0 (R12), 6.5 (R13) and 7.1. Other versions of *Matlab* are acceptable, but may not be 100% compatible with *.m files which we distribute. It is your decision whether you want to purchase a new version or use an old version. I can provide some (but not exhaustive) support.
  - Version 7.1 is available through student software (www.computing.vt.edu)

Course Components

- The course has six main components:
  - *Lectures* – These are meant to introduce the key concepts in the course and provide you with fundamental understanding. This is the primary source of information in the class. I will provide you with lecture notes on the website typically the weekend before class (no guarantees though).
  - *Book* –This is meant to supplement the lectures and provide more detail that cannot be covered in a 50 minute lecture. (section numbers given in the syllabus).
  - *Homework* – This is meant to (a) test your understanding of the class material and (b) provide a means for you to obtain a "deeper" understanding. Not every homework problem is a repetition of in-class examples. They are meant to help you learn, not to see if you can reproduce an in-class example.
  - Quizzes – These are meant to simply motivate you to keep up with the material. They will consist of one simple, fundamental question. We will also have extra-credit quizzes during class fairly often.
  - *Design projects* – These are meant to help you understand the "big picture" (how these topics fit into real-world applications).
  - *Exams* – These are meant to show me how well you have grasped the material .

Grading

- Homework 10%
- Quizzes 10%
- In-class midterm I 20%
- In-class midterm II 20%
- Design Projects 20%
- Final Exam 20%
- Final grade scale will be based on overall class performance.

Grading Scale

- "Minimum Guaranteed" grade scale
  - 94-100 A
  - 90-93 A-
  - 87-89 B+
  - 83-86 B
  - 80-82 B-
  - 77-79 C+
  - 73-76 C
  - 70-72 C-
  - 67-69 D+
  - 63-66 D
  - 60-62 D-
  - < 60 F

Grading "Curve": Typically, the actual grading scale is a little lower. For example, last year a ~5 point curve was applied.

Homework

- 8 homework assignments
  - Schedule is posted on the web
  - Assignments will be posted *at least* one week in advance of the due date
  - It is your responsibility to check the website!
- Will consist of short problems which let you practice basic concepts, as well as more complicated problems to help you learn the material.
- Problems will be graded on a simple scale to allow quick feedback. Each *part of a problem* will be worth 2 points:
  - 2/2 - correct answer (solutions will be posted)
  - 1/2 - wrong answer but meaningful attempt
  - 0/2 - no meaningful attempt of problem

Homework (cont.)

- **Late Assignments**: All assignments are due by the end of class on the due date.
  - If you will be out of town, you must make arrangements to get me the assignment before the due date.
  - Any assignment turned in within 24 hours of the end of class on the date due, will be accepted with a ½ credit penalty.
  - *After 24 hours homework will NOT be accepted.*
- Lowest homework grade will be dropped.
  - This allows you some margin for error in the above policy.
- We will have homework assignments that are a blend of book problems (intended for deeper understanding) and my own homework problems that will be similar to the lectures (intended to reinforce concepts from class).

Tests and Exams

- Two In-Class Midterm Exams - 20% each
- Final Exam - 20%
  - Wednesday, December 13 7:45am – 9:45am
    - Please double check time/date of final
- Closed book but notes are allowed
  - 1 page for midterm exams, 2 pages for final
- We will have a help session to work sample problems before the final exam
- **Missed Exams**: If you miss an exam, you must obtain a note from the Dean's Office excusing your absence in order to take a make-up exam.

Quizzes

- We will have weekly quizzes
  - Every Friday unless an exam is scheduled
- Quiz will consist of single, simple question (5-10 minutes)
- No studying necessary provided that you review your class notes for the week
- Purpose is to keep you engaged with the material on a regular basis
- Lowest quiz grade will be dropped
  - Allows you to miss one quiz without penalty

Design Projects

- We will have a series of design projects, designing a digital cellular telephone link.
- The projects will consist of:
  - Three open ended design problems, each asking you to design a portion of the system using *Matlab* modules to help you evaluate design choices.
  - Each project will require a *concise* written report detailing your design choices. Note that written reports provide you an opportunity to develop your communication skills. These skills are a necessity to any engineer. Your ideas (and your career) are limited by you ability to communicate.

Extra Credit

- Every year a few students come to me at the end of the semester asking for extra credit
- The time to think about extra credit is now.
- On days we don't have a quiz, there will typically be an in-class drill problem given. The first student to finish the problem and properly explain the solution to the rest of the class will be awarded 5 points extra credit on their quiz grade.
  - Quiz grade can exceed 100%
- Additional Note on Grading: I really am on your side! I want you to succeed in this class!
- Yet another additional Note on Grading: If you absolutely positively need a minimum grade to graduate or stay in school, plan NOW. Please don't tell me this at the end of the semester.

Travel

- An unfortunate part of my job is travel. Every semester I must travel a least a little. I do everything in my power to insure that it doesn't impact class. However, it is inevitable that I will miss some class.
- Guest lecturer will present class material
- Current travel
  - November 26-30 – *GlobeCom* communications conference. I will miss 1-2 lectures.
- At the moment I do not have any other travel scheduled

Course Objectives

- After completing this course you should be able to:
  - Design a scalar quantizer for a given source with a required fidelity and determine the resulting data rate;
  - Determine the auto-correlation function of a line code and determine its power spectral density;
  - Determine the power spectral density of bandpass digital modulation formats.
  - Design digital communication systems, given constraints on data rate, bandwidth, power, fidelity, and complexity;
  - Analyze the performance of a digital communication link when additive noise is present in terms of the signal-to-noise ratio and bit error rate;
  - Compute the power and bandwidth requirements of modern communication systems, including those employing ASK, PSK, FSK, and QAM modulation formats;

Prerequisites

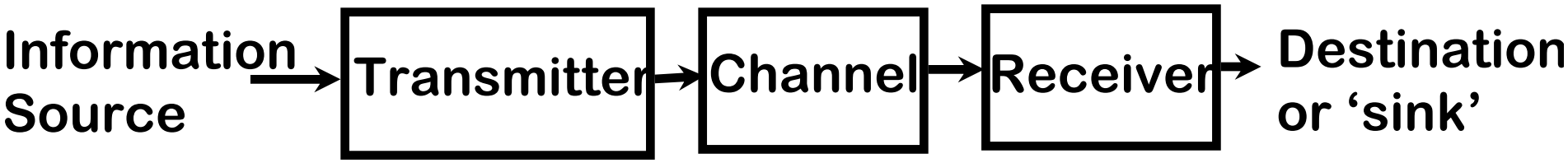
- Coming into this class you should already have a knowledge of
  - Signals and Linear Systems
  - Fourier Transforms
  - Input/Output relationships in a linear time invariant system
  - Basic Probability
    - probability density functions
    - random variables, mean, expectation
- May be satisfied by completion of ECE3614 AND STAT4714

Great Course to also Take

- 4664 – Analog and Digital Communications Laboratory
  - Will closely follow this course in terms of content
  - All lab work done *in class* – No lengthy report to write afterwards
  - Prep work minimal if you are taking 4634
  - Great hands-on experience to compliment this course

Communications

- **Definition:** Communications is the transfer of information at one time or location to another time or location



- Communication systems can be analyzed using standard signal and system theory

A Communications System

- Information Source
  - Information may take many forms: data, image, voice, video
  - Information can be either analog or digital
    - Analog information can also be ‘digitized’
  - Information is defined as the amount of “surprise” at the rx.
- Transmitter
  - Processes information and puts it into a form suitable for transmission
  - This typically means transforming into an electromagnetic signal
    - Can be either ‘baseband’ or ‘bandpass’
- Channel
  - Relays information between locations (without perfect fidelity)
- Receiver
  - Must reconstruct transmitted information from the corrupted received waveform as accurately as possible

Key Inventions in the History of Communications

- ~3000 B.C. Written Language
- 1440 Printed Type (Gutenberg)
- 1844 Telegraph (Morse)
- 1876 Telephone (Bell)
- 1897 Wireless Telegraph (Marconi)
- 1918 Practical AM receiver (Armstrong)
- 1920 First Radio Broadcasts
- 1928 Television (Farnsworth)
- 1933 FM Radio (Armstrong)
- 1936 BBC begins first TV broadcasts
- 1948 Information Theory (Shannon)
- 1950 Digital Long Distance Telephone Lines (Bell Labs)
- 1962 Telstar I communication satellite (Bell Labs)
- 1979 First commercial cellular telephone (Motorola/AT&T)
- 1990 Second Generation (Digital) cellular systems (TDMA)
- 1992 – The Internet takes off
- 1993 CDMA Cellular systems
- 2002 - Third Generation Cellular Systems

What Makes a Good Communication System?

- Good Received Signal Fidelity
  - Analog System: high Signal-to-Noise Ratio (*SNR*)
  - Digital System: low Bit Error Rate (*BER*)
- Low Transmit Signal Power
- A large amount of information is transmitted
- Signal occupies a small bandwidth
- System has a low cost (complexity?)
  - Complex digital operations have steadily grown cheaper
- Communications engineers must trade off all of these

Examples of Tradeoffs in Communications Designs

- Satellite and Deep Space Communications
  - Power is expensive to generate in space and transmission distances are enormous - Must be very energy efficient
- Microwave Relay Towers
  - Power is cheap, but available bandwidth is restricted by regulation - Must be very bandwidth efficient
- Cellular Phones
  - Power is costly (impacts battery life and size) but bandwidth is also limited - Must be both bandwidth and power efficient

Bandpass vs. Baseband

- The **information** signal or message signal *m(t)* is a *baseband* signal, that is it contains energy about D.C. ($f = 0$)
- The **transmitted** signal may be at baseband or may be a bandpass signal, that is it contains energy about $f = f_c$ where $f_c >> 0$.
- Wireless signals are (almost) always *bandpass* due to FCC regulations and physical antenna limitations whereas wireline signals could be either bandpass or baseband .
- Each wireless application is assigned a specific frequency band in which it can radiate energy. This is one reason why Fourier Transforms (spectral information) are so important in communications.

Digital vs. Analog Communications

- Digital Communications System
  - transmit a finite number of signals
  - text and data are naturally digital information sources
- Analog Communications
  - transmit a continuous (uncountably infinite) range of signals
  - voice and video are natural analog information sources
- An analog information source can be converted into a digital source by
  - Sampling the signal in time
  - Quantizing the signal amplitude to a finite number of levels
- This course will deal almost exclusively with digital communications, but much of analog system analysis applies directly to digital systems

Digital Communications is Nearly Ubiquitous

- Complex digital operations can now be implemented inexpensively on a single integrated circuit
- Many good processing techniques are available for digital signals:
  - encryption (not 'coding'), data compression (source coding), error correction (channel coding), channel equalization
  - Warning! The word 'coding' is *terribly* overused in communications
- Easy to mix different signals and data
- Digital receivers can be made tolerant to noise
  - Need only distinguish between a fixed number of symbols
- Even traditional analog systems such as broadcast radio and television are beginning the transformation to digital

Closing Thoughts ...

- Boston Newspaper Editorial, 1879
  - "All educated individuals must realize that the transmission of the human voice on a wire is impossible, and even if it were, would be of no practical value whatsoever."
  - Alexander Graham Bell invented the telephone in 1876
- Guglielmo Marconi - "It's dangerous to put limits on wireless." 1897 (invented the wireless telegraph)
- Today's Goal: Universal Ubiquitous High Speed Personal Communications
  - Today, we are confident of what we have not yet built.
  - The people in this room (**YOU**) will help make this possible!