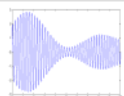
ECE3614
Introduction to Communications Systems
Fall 2007

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:
  - Available on the website
  - Due Thursday, Aug. 30

Lecture Overview

- The objectives of today's lecture are
  - Explain the course mechanics
  - Provide an overview of the course
  - Describe the major components of the course
  - List the prerequisite knowledge required
- Reading
  - Chapter 1

Course Mechanics

- Meeting Times and Location:
  - CRN 91852 TR 8:00-9:15 am
  - Room Durham 261
- Instructor:
  - Dr. R. Michael Buehrer
    Associate Professor
- Contact Information:
  - Office: 433 Durham Hall
  - Phone: 231-1898
  - e-mail: buehrer@vt.edu
- Grader:
  - Justin Kelly jk1311@vt.edu

Office Hours

- Instructor Office Hours:
  - MW 11:15am-12:15pm
  - 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 most *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

Course Web Site

- http://www.mprg.org/people/buehrer/3614/ece_3614.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: comm_sys
Psswd: Modulate1

Required Course Materials

- **Textbook:**
  - Haykin and Moher, Introduction to Analog and Digital Communications, 2nd Ed., Wiley and Sons, 2007.
- **Access to Networked PC or Workstation**
- **Software:**
  - *Matlab* for Windows
  - I have versions 6.0 (R12), 6.5 (R13) and 7.0. 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 7.0 is available through student software (www.computing.vt.edu) and the bookstore

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). As part of the lectures we will have in-class drill problems which allow you to interact with the material and keep you involved. *Attending the lectures is absolutely crucial to successfully completing this course!*
  - *Book* –This is meant to supplement the lectures and provide more detail that cannot be covered in a 75 minute lecture. (section numbers given in the syllabus).
  - *Homework* – This is meant to (a) provide you an opportunity to interact with 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 and provide an opportunity of in-class interaction. They will consist of one simple, fundamental question.
  - *Design project* – This is 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	15%
Design Project	10%
Quizzes	10%
In-class midterm I	20%
In-class midterm II	20%
Final Exam	25%

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 7-9 point curve was applied.

Homework

- 11 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.)

- Note: 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 time the assignment is due, will be accepted with a ½ credit penalty. After 24 hours homework will NOT be accepted.
- I will drop your lowest (in terms of # of points) homework grade.
- 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).
- Solutions will be posted on the website

Design Project

- This course will also involve a semester long design project
- Final report (no more than 4-6 pages of text) should describe results from each stage of the design
- Group project
  - 2-3 person groups
- Assigned Sept. 6, due Nov. 29
- Project will involve Matlab
  - More details to come

Tests and Exams

- Two In-Class Midterm Exams - 20% each
- Final Exam - 25%
  - Monday, December 10   3:25-5:25pm
    - Please double check time/date of final
- Closed book but sheet of notes is allowed
  - 1 page for midterm exams, 2 pages for final
- We will have a help session to work sample problems before the final exam
  - We may also have help sessions for the midterms.

Quizzes

- We will have (nearly) weekly quizzes
- Quiz will consist of single, simple question (5 minutes)
- No studying necessary provided that you keep up with the material
- Solution will be discussed in-class immediately following the quiz
- Purpose is to keep you engaged with the material on a regular basis and provide additional in-class interaction
- Lowest quiz grade will be dropped
  - Allows you to miss one quiz without penalty
  - No make-up quizzes unless requested ahead of time

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 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 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 successfully completing this course the student should be able to
  - Compute the Fourier transform and the energy/power spectral density of communications signals.
  - Calculate the bandwidth and signal-to-noise ratio of a signal at the output of a linear time-invariant system given the signal and the power spectral density of the noise at the input of the system.
  - Explain the operation of amplitude and angle modulation systems in both the time and frequency domains including plotting the magnitude spectra and computing the power and bandwidth requirements of each type of signal.

Course Objectives (cont.)

- After successfully completing this course the student should be able to
  - Design a basic analog or digital communications system including: (1) the selection of a digital or analog modulation format, (2) the block-diagram design of a transmitter for the system, (3) the block-diagram design of a superheterodyne receiver for the system, (4) the design of a time or frequency division multiplexing scheme, as appropriate, and (5) the choice of an appropriate pulse shape and analog to digital converter (if needed) to meet performance requirements.
  - Evaluate a given analog or digital communications system in terms of the complexity of the required transmitters and receivers and the power and bandwidth requirements of the system.

Prerequisites

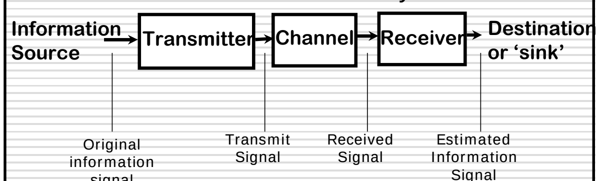
- Coming into this class you should already have a knowledge of
  - Signals and Linear Systems
  - Fourier Transforms
  - Input/Output relationships in a linear time invariant system
- May be satisfied by completion of ECE 2704

Overview of the Course

- The course can be broken down into three basic segments:
  - Section I – Signals and System Theory applied to communications (8 lectures, four weeks)
  - Section II – Analog Communication Systems (12 lectures, seven weeks)
  - Section III – Digital Communication Systems (6 lectures, three weeks)

What is Communications?

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



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

Examples

- Broadcast Radio
  - Music and voice are transmitted from a broadcast station to large number of receivers (i.e., radios) over the air
- Broadcast Television
  - Images are transmitted from a broadcast station to a large number of receivers (i.e., TVs) over the air
- Telephone system
  - Voice (digital data also possible) transmitted from one point to another point (i.e., one phone to another) through wires (both copper and optical fiber)
- Cellular telephone
  - Voice (digital data also possible) transmitted from one point to another point through both wires and over the air
- Internet (computer networks)
  - Digital data transmitted from one point to another point through wires
- Satellite communication systems
  - Digital data or voice transmitted from one point to another point using satellite as an intermediate transmitter/receiver

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)
- 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

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

Digital vs. Analog

- In this course we will spend much of out time investigating analog modulation techniques despite the fact that all new communication systems are digital
- However, digital modulation is simply analog modulation where the message signal is binary (or *M*-ary)
  - We will show how analog modulation techniques apply to digital modulation
- We will also spend some of the class discussing baseband digital communications
- 4634 Digital Communications studies bandpass digital techniques in detail

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.

To Study Communication Systems you must understand….

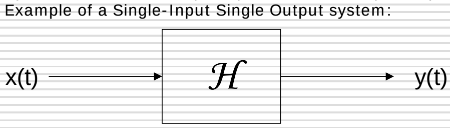
- Signals and Systems
  - We will briefly review
- Modulation Theory
  - We will study this in detail
- Fourier Analysis
  - We will review this in detail and use it throughout the course
- Detection Theory
  - Given that this signal is corrupt at the receiver, how do we determine the original signal?
  - We will examine this through a measure termed *signal-to-noise ratio*
- Probability Theory
  - Since the transmit signal and noise are both unknown to the receiver, we can use probability theory to study communications systems
  - We will touch on this aspect for analog systems but will defer detailed discussion for 4634

Signals and Systems

- In this class we will rely on mathematical representations of signals and systems to describe communications
  - Relies on background obtained from 2704
- A system is characterized by inputs and outputs which are mathematically modeled as signals
- We will also mathematically represent the signals at various points within a communications system
- Mathematical representations of the various components of the system can be viewed as subsystems with input-output relationships defined by
  - Impulse response in the time domain
  - Transfer function in the frequency domain

System Representation

- $\mathcal{H}$ typically used to represent the system
- *x(t)* typically used to represent the excitation or input to the system
- *y(t)* typically used to represent the response or output of the system
- Systems can have multiple inputs and/or mulitple outputs
- Example of a Single-Input Single Output system:



- For Linear Systems: $\underbrace{y(t)}_{\text{output}} = \underbrace{x(t)}_{\text{input}} \otimes \underbrace{h(t)}_{\text{impulse response}}$ $\quad \underbrace{Y(f)}_{\text{output}} = \underbrace{X(f)}_{\text{input}} \underbrace{H(f)}_{\text{Transfer Function}}$

System Properties

- There are several properties of systems that are important to understand
- Many properties allow us to make simplifications in our analysis
- Specific properties
  - Homogeneity
  - Time Invariance
  - Additivity
  - Linearity
  - Stability
  - Causality
  - Memory
  - Invertibility

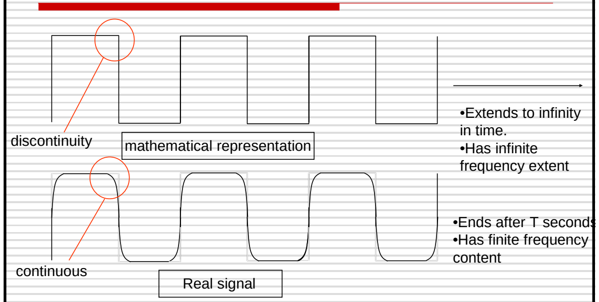
Mathematical Descriptions

- Many systems which are encountered in engineering process signals which represent physical processes that are measured, controlled, or recorded.
- We design and analyze systems by representing these signals using mathematical descriptions which are typically functions of time or space.
- Our representations will not exactly match the real-world signals, but they are sufficiently close to allow extremely accurate prediction of the system behavior.

Physically Realizable Functions

- Have finite time duration (finite energy!)
- Occupy finite frequency spectrum
- Are continuous
- Have finite peak value
- Are real-valued
- All real-world signals will have these properties, although sometimes we use mathematical models which violate these conditions.

Mathematical Representations



Classification of Signals

- Although functions can operate on any type of variable, we will be most concerned with functions of *time*
- Signals (or more specifically their mathematical representations) can be categorized according to a few major features
  - Continuous Time vs. Discrete Time
  - Deterministic vs. Random
  - Power vs. Energy
  - Periodic vs. Aperiodic

Conclusions

- Today we have
  - Described the basic components of the course and the class mechanics
  - Provided an overview of the course content
- Next lecture we will
  - Begin our discussion of the Fourier Analysis for communication systems by examining the Fourier Series