EE 5654 - Digital Communications Spring 2005

Instructor: R. Michael Buehrer

Lecture #1: Course Overview &

Review of Digital Communications

Today

- Overview of Course Mechanics
- Overview of Digital Communications
- Handouts:
  - Course Syllabus
- Available on Web Site
  - Homework #1
  - Lecture #1

Course Mechanics

- CRN 11753
  - Meeting Time: Tues/Thurs 2-3:15pm
  - Room: Durham 261
  - One meeting during the term on Sat.
    - April 16 - Digital Communications Mini-Conference
- Please check your calendars now!
  - If you have conflicts due to religious observances or other immovable, important events, please see me before the end of the second week of class. After that time, I will not consider making special arrangements except in the case of an emergency.

Instructor: R. Michael Buehrer

- Office: Durham 433
- Phone (during office hours): 231-1898
- e-mail: buehrer@vt.edu
- Office Hours:
  - T/Th 9:30am-12:00noon
- I work in the field of wireless communications with the MPRG laboratory
- To learn more about my work, see my website:
  - http://www.mprg.org/people/buehrer/

Web Site for Course Documents

- http://www.mprg.org/people/buehrer/5654/ecpe_5654.htm
- What will be available in “.pdf” format:
  - Lecture Notes
  - Handouts
  - Test and Homework Solutions
  - Useful resources for projects
  - Access to HW and Notes is password protected
    - Username: modulate
    - Password: dig_com
- In order to read .pdf files you will need Adobe Acrobat Reader (available free - instructions on website)

Instructor: R. Michael Buehrer

- Personal:
  - Married
  - Four children: Faith (9), JoHannah (7), Noah (4), Gabrielle (2)
  - Hobbies: hiking, running, photography, philosophy, Bible study and star-gazing
  - Also teach at Blacksburg Christian Fellowship
    - I would be more than happy to talk to anyone interested in learning more about Church history, Old Testament Studies, New Testament or Christianity

Required Course Materials

- **Textbook:**
  - John G. Proakis, Digital Communications, 4th edition, McGraw-Hill, 2001. ISBN# 0-07-232111-3
- **Access to Networked PC or Workstation**
- **Software:**
  - Student Edition of Matlab 5.3 or 6.0 for Windows
  - Other versions of Matlab are acceptable, but may not be completely compatible with *.m files which we distribute. (There will be very few of these.)

Prerequisites

- **Some prior background in communications**
  - A good test: Do you know the difference between ASK, FSK, and QPSK?
  - One course which provides this background:
    - ECE 4634 - Analog and Digital Communications
- **You should be comfortable with basic probability and random process theory**
  - A good test: How is the autocorrelation function of a random process related to the power spectral density?
  - One course which provides this background:
    - ECE 5605 - Stochastic Processes I

Grading - Homework (10%)

- Approximately 5-10 assignments
- Problems will focus on practicing the techniques and algorithms that we discuss in class.
- Grading will be on a simple scale with 2 points per part of a problem (0=did not attempt, 1=attempted, 2=correct)
- You may discuss the problems in groups but solutions should then be your own.
- Homework due in class. *Late homework will not be accepted.*

Grading - Exams (60%)

- In-class Mid-Term
  - Thursday, March 3
  - 30% of Final Grade
  - 1 Page of notes allowed
- Final Exam
  - Friday May 6, 10:05am-12:05pm
  - This classroom
  - 30% of Final Grade
  - 2 pages of notes allowed
  - Covers the entire course
- Make up exams will be given *only in the case of an emergency.*

Grading - Class Project (30%)

- You will propose and carry-out a semester-long project
  - 30% of Final Grade
- I will give a list of recommended topics
  - You can also propose your own
  - Note that at least two students have published conference papers based on previous class projects!
  - Will likely require computer simulation (preferably Matlab)
- Work as individual or in small groups (1-4 people)
- **Additional material on project assignment is posted on the course web page**

Important Project Info

- February 3: Project Proposals Due
- April 16: Oral Project Presentations
  - Digital Communications “Mini-Conference”
- April 28: Written Projects Due
- Project Grading
  - Communication skills (oral and written) 25%
    - 10% from presentation and 15% from report
  - Technical accuracy 25%
    - 5% from presentation and 20% from report
  - Completeness in results (based on proposal) 30%
    - 10% from presentation and 20% from report
  - Conclusion (what do your results show?) 20%
    - 5% from presentation and 15% from report

What's the Point?

- The course has five main components:
  - Lectures – these are meant to introduce the key concepts in the course and provide you with fundamental understanding
  - 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 provide you deeper understanding of the material and to provide you with practice of class concepts
  - Design project – This is meant to help you understand the "bigger picture" and provide you with simulation and research experience
  - Exams – These are meant to show me how well you have grasped the material

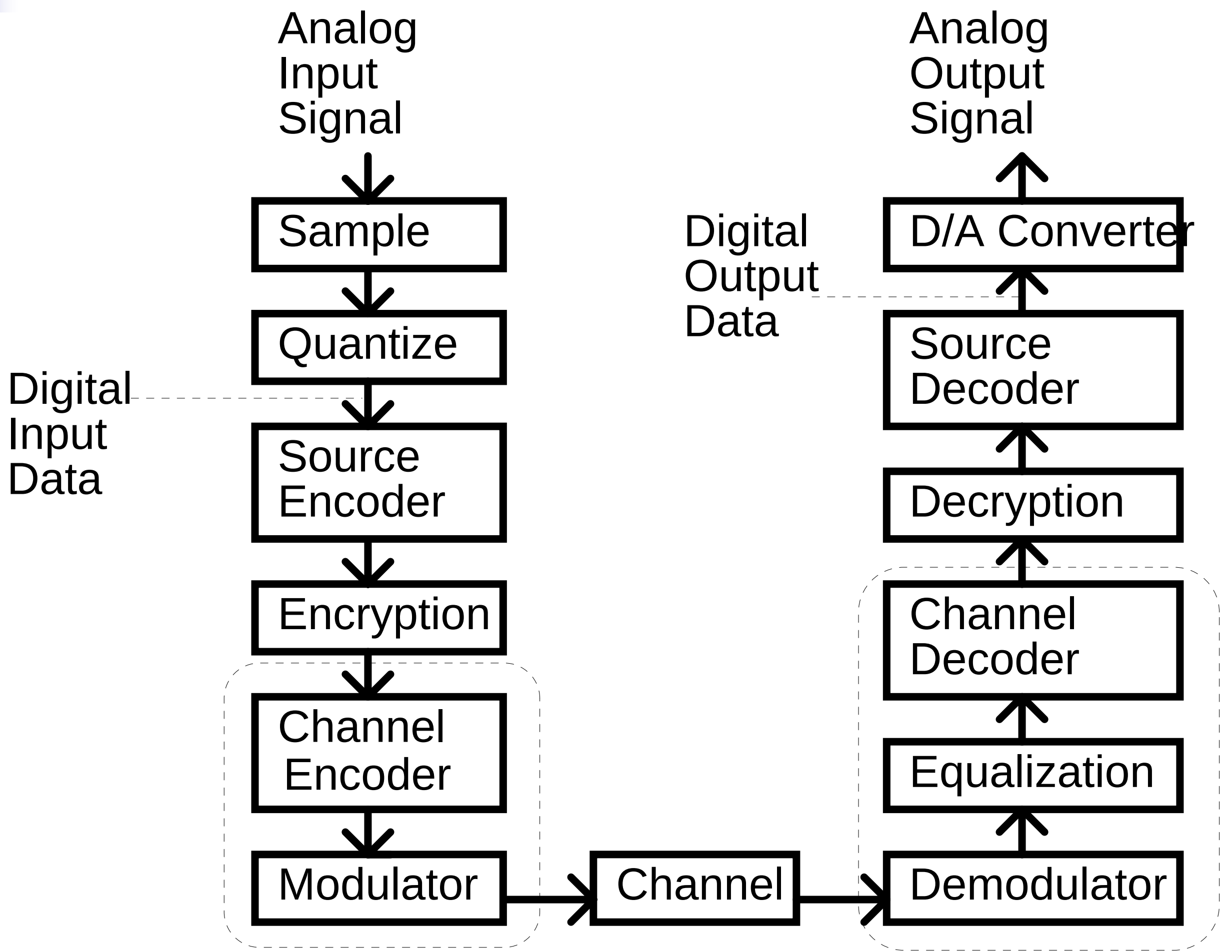
Homework Problems

- By definition the homework does not completely overlap with the lectures.
- We will have homework assignments that are a blend of book problems (intended for deeper understanding) and my own homework problems that will be more similar to the lectures.
- All homework problems are profitable and useful for learning!

Why digital communications?

- Any noise introduces distortion to an analog signal. Since a digital receiver need only distinguish between a finite number of waveforms it is possible to recover digital information without corruption a large percentage time.
- Many signal processing techniques are available to improve system performance: source coding, channel (error-correction) coding, equalization, encryption
- Digital ICs are inexpensive to manufacture. A single chip can be mass produced at low cost, no mater how complex
- Digital communications allows integration of voice, video, and data on a single system
- Digital communications systems provide a more flexible tradeoff between bandwidth efficiency and energy efficiency than analog communications

Block Diagram of Digital Communications System



Analog Input Signal

- Note that digital transmission can be used even for information that is inherently analog
- Analog information is continuous in time and amplitude
  - Examples: voice, video
- Need to convert analog information to binary signal for digital transmission
  - Make discrete in time – sampling
  - Make discrete in amplitude - quantization
- Goal is to minimize distortion of analog signal

Sampling

- Sampling makes a signal discrete in time
- Sampling Theorem says that a band-limited signal can be sampled without introducing distortion
- Baseband sampling theorem

  $$f_s \geq 2B$$

  - B - absolute bandwidth
- Bandpass sampling theorem
  - $f_s \geq 2B_T = 4B \quad (2B \text{ if complex baseband is purely real})$
    - B_T – transmission bandwidth

Note: Bandwidth is usually defined over a *positive* frequency range

Quantization

- Quantizer makes signal discrete in amplitude
- Unlike sampling, quantization introduces some distortion
- Data rate of a quantizer is dependent on sampling rate f_s and number of quantization levels $L=2^b$
- Good quantizers are able to use a small number of bits and while introducing a small amount of distortion

Digital Data

- After quantization, data is in digital (0,1) form
- Inherently digital information (e.g. computer files) does not require sampling or quantization
- However, source coding (e.g., compression) may still be used on inherently digital data to reduce redundancy and thus the required data rate
- We can also reduce the required data rate of the sampled analog sources through source coding techniques other than simple quantization
  - e.g., vocoders

Source Coding

- Source Coding removes redundancy in digital data to reduce the data rate requirements
  - Ex: 000000000000111110000000001111
  - Example Compression:

$$\underbrace{0}_{\text{bit}}\ \underbrace{1100}_{12}\ \underbrace{1}_{\text{bit}}\ \underbrace{0101}_{5}\ \underbrace{0}_{\text{bit}}\ \underbrace{1001}_{9}\ \underbrace{1}_{\text{bit}}\ \underbrace{0100}_{4}$$

    - only 20 bits instead of 30
- Can be done on digital information or combined with sampling/quantization for analog information

Encryption

- Encryption techniques can ensure data privacy
- Encryption is the ‘coding’ we envision when we think of spies and secret decoder rings - Communications engineers use the word "coding" for other ideas
- Very good "public key" encryption algorithms exist - this worries the folks at NSA
- We will not talk about encryption in detail, but encryption would make a good project

Channel Encoder

- Provides protection against transmission errors by selectively inserting redundant data
- Note that source encoding works to squeeze out redundant information. The channel encoder inserts redundant information in a very selective manner to protect against transmission errors
- Also called Forward Error Correction (FEC) coding
- We will study the role that error correction coding plays in system design, including block codes, convolutional codes, trellis coded modulation and turbo codes

Modulator

- Converts digital data to a continuous waveform suitable for transmission over channel - usually a modulated sinusoidal wave
  - Exception: Impulse Radio or UWB
- Information is transmitted by varying one or more parameters of the waveform such as
  - Amplitude
  - Phase
  - Frequency
- Although we modulate a high frequency sinusoid, we will study modulation in terms of the complex baseband (using a signal space approach)

Examples of Modulation

- Amplitude Shift Keying (ASK) or On/Off Keying (OOK):

$$1 \Rightarrow A\cos\left(2\pi f_c t\right)$$

$$0 \Rightarrow 0$$

- Frequency Shift Keying (FSK):

$$1 \Rightarrow A\cos\left(2\pi f_1 t\right)$$

$$0 \Rightarrow A\cos\left(2\pi f_0 t\right)$$

- Phase Shift Keying (PSK):

$$1 \Rightarrow A\cos(2\pi f_c t)$$

$$0 \Rightarrow A\cos(2\pi f_c t + \pi) = -A\cos(2\pi f_c t)$$

Notes on Modulation

- Choice of modulation greatly effects system performance
- Channel coding and modulation can be combined as a single operation. This results in "trellis coded modulation" which yields outstanding performance.
- We will study modulation extensively
  - Signal space representation
  - Spectral characteristics
  - Optimum receiver structures
  - Much more depth than ECE 4634

Channel

- Carries signal - could be a telephone wire, free space
- Presents distorted signal to demodulator. Possible effects include attenuation, noise, amplitude fading and temporal or spectral dispersion.
- Fading is very important concept - studied in depth in the Cellular and Personal Communications class
  - Rayleigh fading
  - Ricean fading
  - Log-normal “shadowing”
- We will *usually* assume a very simple channel model - additive white Gaussian noise (AWGN)
- Will also address Rayleigh. Ricean, and Nakagami fading channels

What Makes a Good Communication System?

- Large data rate (measured in bits/sec)
- Small bandwidth (measured in Hertz)
- Small signal power (measured in Watts or dBW)
- Low distortion (measured in S/N or bit error rate)
- Low cost - with digital communications, large complexity does not always result in large cost
- In practice, there must be tradeoffs made in achieving these goals

Tradeoffs in System Design: Data Rate vs. Bandwidth

- Increased data rate leads to shorter data pulses which leads to larger bandwidth.
- The tradeoff between pulse duration and bandwidth cannot be avoided, however, some systems use bandwidth more efficiently than others.
- We will define Bandwidth Efficiency as the ratio of data rate R_b to bandwidth W: $\eta_B = R_b / W$
- We want large bandwidth efficiency η_B

Tradeoffs in System Design: Fidelity vs. Signal Power

- One way to get an error free signal would be to use huge amounts of power to blast over the noise.
- Some types of modulation achieve relative error free transmission at lower powers than others.
- We define Energy Efficiency: $\eta_E = E_b / N_o \big|_{\text{target } P_b}$
- We desire small η_E

Tradeoffs in System Design: Bandwidth Efficiency vs. Energy Efficiency

- It is possible for a system design to trade between bandwidth efficiency and energy efficiency.
- Examples:
  - Binary modulation sends only one bit per use of the channel. *M*-ary modulation can send multiple bits, but is more vulnerable to errors.
  - Error correction coding: inserting redundant bits improves bit error rate, but increases bandwidth.
- This is a fundamental tradeoff in digital communications.

Conclusions

- This course will deal with many aspects of digital communications systems including
  - Digital modulation
    - Representation
    - Performance
  - Forward error correction coding
    - Block codes
    - Convolutional codes
    - Turbo Codes
    - Trellis Coded Modulation
  - Equalization
  - Fading and Diversity