STUDY GUIDE FOR

DIGITAL COMMUNICATIONS
ETD 732

Compiled by
Prof. L.P. LINDE

2009

1. Lecturers and Secretary

Course Coordinator and Lecturer #1:	Prof L.P. Linde
Office:	15-25 Eng. Tower Main Campus University of Pretoria
Mail address:	Dept. of Electrical, Electronic and Computer Engineering University of Pretoria Pretoria 0002
Telephone:	+27 12 420-2168
Fax number:	+27 12 362 5000
E-mail address:	llinde@postino.up.ac.za louis.linde@up.ac.za
Consulting hours:	By appointment

Lecturer #2:	Dr J.P. de Villiers
Office:	15-23 Eng1 Tower Main Campus University of Pretoria
Mail address:	Dept. of Electrical, Electronic and Computer Engineering University of Pretoria Pretoria 0002
Telephone:	
Fax number:	
E-mail address:	pieter.de.villiers@up.ac.za
Consulting hours:	By appointment

Secretary:	Me Mari Ferreira
Office:	15-06 Eng. Tower Main Campus University of Pretoria
Mail address:	Dept. of Electrical, Electronic and Computer Engineering University of Pretoria Pretoria 0002
Telephone:	+27 12 420-3736
Fax number:	+27 12 362 5000
E-mail address:	mari.ferreira@up.ac.za

2. References

2.1 Prescribed text

[1] J.G. Proakis, *Digital Communications*, Fourth or Fifth Edition, New York: McGraw-Hill, 2001/2008. ISBN: 0-07-232111-3.

[2] L.P. Linde and D.J. van Wyk, "*Forward Error Control Strategies – An Introduction"*, V1.2, 2002.

2.2 Recommended text

[3] Wozencraft and I. Jacobs, *Principles of Communications Engineering*, McGraw-Hill, 1965.

[4] R.E. Ziemer and R.L. Peterson, *Introduction to Digital Communication*, Second Edition, Prentice-Hall, 2001. ISBN: 0-13-896481-5.

[5] A.J. Viterbi and J.K. Omura, *Principles of Digital Communication and Coding*, McGraw-Hill, New-York, 2nd edition, 1985. ISBN: 0-07-067516-3

[6] A. Papoulis: *Probability, Random Variables and Stochastic Processes* – 3rd Edition, McGraw-Hill, 1991. ISBN: 0-07-048468-6

[7] W.H. Tranter, K.S. Shanmugan, T.S. Rappaport and K.L. Kosbar, Principles of Communication Systems Simulation with Wireless Applications, Prentice-Hall, 2004. ISBN: 0-13-494790-8

IEEE Magazines

Reference will occasionally be made to papers from the following IEEE magazines:

IEEE Transactions on Information Theory (IT)
IEEE Transactions on Communications (COM)
IEEE Transactions on Vehicular Technology (VT)
IEEE Transactions on Wireless Communications (WC)
IEEE Journal on Selected Areas in Communications (JSAC)

3. Course Objectives and Study Themes

DIGITAL COMMUNICATIONS ETD732 is presented as an introductory or preparatory post-graduate course in the SIGNALS and TELECOMMUNICATIONS GROUP. This course covers very important fundamental principles and theory required to properly master the more advanced and specialised second semester courses, such as MOBILE COMMUNICATION ETR732, CODING THEORY ETK732, ADAPTIVE SYSTEMS ETA732 and SOFTWARE RADIO TECHNIQUES ETS732. Consult the post-graduate brochure or the Signals and Telecommunications Group Head for information on other specialist subjects to be presented in the second semester. It is particularly important to carefully consider your choice of modules and ensure that the best combination is chosen that will provide maximum support for the possible completion of a subsequent Master’s dissertation and possibly a follow-up PhD thesis.

From Figure 1 the three primary components of any communication system may be identified:

- (i) The (information) source or ‘transmitter';
- (ii) The communication medium or ‘channel';
- (iii) The (information) sink or ‘receiver'.

The optimal utilisation and integration of these three communication subsystems are embodied by Shannon's three communication theorems, namely:

- (i) The Source Encoding Theorem;
- (ii) The Channel Coding theorem;
- (iii) The Channel Capacity Theorem.

The first theorem is concerned with the optimal digitisation and compression of the information source, so that maximum information may be conveyed (transmitted) with the minimum number of symbols. The focus here is therefore on the elimination of redundancy in the original source output. The second theorem addresses the protection of the information (bits) against the detrimental effects of the channel by introducing, in a controlled manner, redundancy in the form of extra bits. The channel effects and restrictions may consist of noise and distortion (the latter as a result of limited transmission bandwidth, transmitter power etc). The last theorem forms the basis of classical communication, and in fact integrates the first two theorems to simultaneously ensure maximum information transfer in the presence of Additive White Gaussian Noise (AWGN), bandwidth and power constraints, to achieve optimum (error-free) performance as long as a defined maximum transmission rate, called the channel capacity, is not exceeded.

DIGITAL COMMUNICATIONS ETD732 addresses the basic aspects of the said three communication theorems/laws, namely source coding, channel coding and lastly optimum detection with a view of optimising information transfer (channel capacity) in the presence of AWGN and fading. Some emphasis will also be placed on digital (carrier) modulation techniques (such as found in the existing cellular standards, and more), optimum filtering for minimum ISI, synchronisation aspects such as carrier and symbol recovery methods, forward error correction coding and adaptive equalisation techniques, although these topics will be covered in more detail in second semester specialist courses such as CODING THEORY ETK732 AND ADAPTIVE SYSTEMS ETA732.

Various adaptive communication techniques are required to achieve the specified quality of service in practical communication systems. These systems include, amongst others, carrier recovery and Doppler (frequency-offset) tracking, temporal synchronisation (e.g., bit/symbol/frame/word/zero time reference recovery and tracking methods) adaptive equalisers, noise cancellers, power control and AGC, etc.

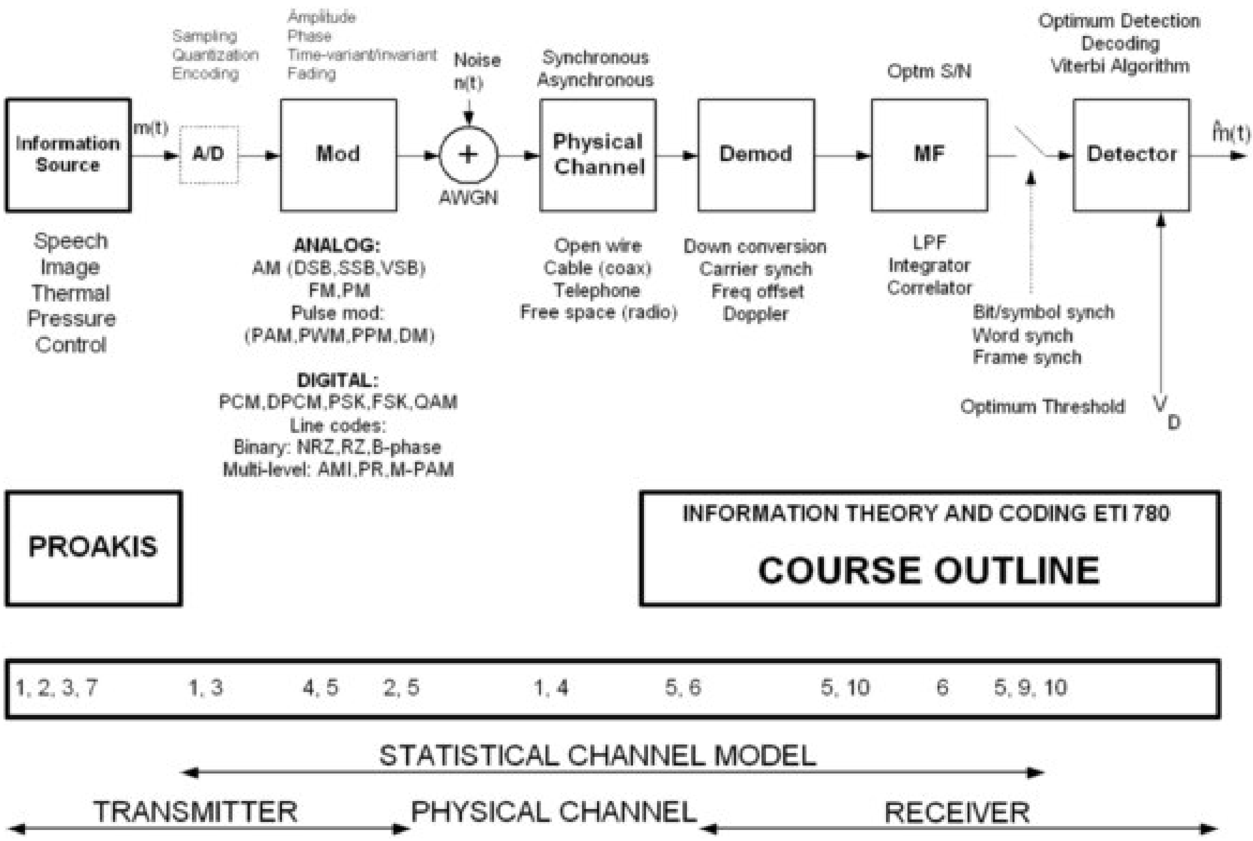

Figure 1 Schematic course outline: Digital Communications ETD732

4.0 Study Themes

References: [1] Chapter 2 and [6].

Theme 1: Probability, Random Variables and Stochastic Processes

This part of the course is a revision of undergraduate work. Students are required to have a sound working knowledge in the basic definitions and axioms of probability theory, random variables and stochastic processes, such as

- ► Statistical Averages of Random Variables (RVs)
- ► Functions of RVs
- ► Probability Density Functions (PDFs) or Distributions
- ► Transformation of RVs and PDFs
- ► Sums of RVs and the Central Limit Theorem
- ► Power Spectral Density (PSD)
- ► Response of a Linear Time-Invariant (LTI) System to a random input signal
- ► Sampling Theorem for Band-limited Stochastic Processes
- ► Discrete-Time Stochastic Signals and Systems
- ► Cyclo-Stationary processes.

Theme 2: Characterisation of Communication Signals and Systems

References: [1] Chapters 1 & 3.

Study Theme 3 is considered to be revision of undergraduate work. Students will be expected to acquire a sound knowledge of Signal Processing techniques, including a sound knowledge of signal types (signal classification), time-frequency relationships (transform theory, e.g., Fourier, Laplace and Z-transforms), and elementary network analysis and circuit theory. This section is started with the characterisation of band-pass signals and systems, including the mathematical representation of band-pass stationary stochastic processes. This is followed with a vector representation of signals (Gram-Schmidt). The complex representation of bandpass and RF-signals leads to a method to derive a baseband equivalent model of band-pass and RF type signals, which is extremely important in the simulation and efficient DSP-realisation of all carrier-modulated signals. The theme is concluded with an extensively illustrated presentation of digitally modulated signals and the derivation of their PSDs.

- ► Representation of Band-Pass Signals and Systems
- ► Signal Space Representations.
- ► Representation of Digitally Modulated Signals

- ► Equivalent baseband representation of carrier-modulated signals for simulation and DSP-realisation purposes

- ► Spectral Characteristics of Digitally Modulated Signals

Theme 3-1: Optimum Receivers for the AWGN Channel

References: [1] Chapter 4 and [3], [4].

In Study Theme 3 (Part 1), we described various types of modulation methods that may be used to transmit digital information through a communication channel. It was shown that the modulator at the transmitter performs the function of mapping the digital sequence into signal waveforms which are required to be matched to the communication channel.

This Study Theme deals with the design and performance characteristics of optimum receivers for the various modulation methods, when the channel corrupts the transmitted signal the addition of Gaussian noise. The study of this theme covers the following communication issues and principles:

- ► Optimum receiver design principles in the presence of AWGN

- ► Performance measures for optimum receivers for memoryless operation

Theme 3-2: Carrier and Symbol Synchronization (if time permits)

References: [1] Chapter 5 and [4],[7].

This study theme (3 Part II) is also covered in Mobile Communication ETR732, and will therefore only be done when time permits. The focus is on optimum synchronisation principles and techniques. It is known that the output of the demodulator in a digital communication system must be periodically sampled, once per symbol interval, in order to recover the transmitted information. Since the propagation delay from the transmitter to the receiver is generally unknown at the receiver, symbol timing must be derived from the received signal in order to synchronously sample the output of the demodulator.

The propagation delay in the transmitted signal also results in a carrier offset, which must be estimated at the receiver to ensure phase-coherent demodulation. This study theme we consider methods for deriving carrier and symbol synchronisation at the receiver.

The following concepts are covered in this Study Theme:

- ► Signal Parameter Estimation
- ► Carrier Phase Estimation
- ► Symbol Timing Estimation
- ► PLL theory with applications

Theme 4: Signal Design and Communication through Bandlimited Linear Filter Channels and Equalisation Principles

Lecturer(s): Mr J.P. de Villiers / Prof L.P. Linde

References: [1] Chapters 4, 9, 10 and [4],[7].

In this study theme the problem of signal design when the channel is band-limited to some specified bandwidth *W* Hz is considered. Under this condition, the channel may be modelled as a linear filter having an equivalent low-pass frequency response *C(f)* that is zero for $|f|>W$. It is shown that when the channel is ideal for $|f|\leq W$, a signal pulse can be designed that will enable symbol rates comparable or exceeding the channel bandwidth *W.* On the other hand, when the channel is not ideal, signal transmission at the symbol rate equal to or exceeding *W* will result in inter-symbol-interference (ISI) among a number of adjacent symbols. The second topic treated here is the use of coding to shape the spectrum of the transmitted signal, and thus, to avoid the problem of ISI.

The study of narrowband transmission is extended to the case where the channel response characteristic *C(f)* is not known a-priori. An example of this case is the dial-up telephone network, where the channel may be different every time a new number is dialled and a new channel is established between the sender and the receiver. For such channels, it is not possible to design optimum fixed demodulation filters. In stead, an adaptive mechanism (filter) is required at the receiver as a means for compensating or reducing the ISI in the received signal. This particular device is called an equaliser. Several types of equalisation methods are treated in this Study Theme 4.

Theme 5: Revision of Information Theory and Source Coding

References: [1] Chapters 6, 16 and [5].

This study theme can be considered to be the hart of Information Theory. Students will be introduced to the following Information-Theoretic concepts and theorems:

- ► Mathematical Models for Information Sources
- ► A Logarithmic Measure of Information
- ► Coding for Discrete Sources: Shannon-Fano, Huffman and Lempel-Ziv coding techniques
- ► Coding for Analogue Sources: Optimum Quantisation
- ► Coding techniques for Analogue Sources: Temporal versus Spectral Waveform Coding; Model-Based Source Coding Techniques
- ► Shannon's Channel Capacity Theorem

Theme 6: Introduction to Algebraic Coding Theory and Channel (Error Control) Coding

Lecturer(s): Mr L. Staphorst / Prof L.P. Linde

References: [1] Chapter 7 & 8, as well as [2], [4] and [5].

Since this study theme is now extensively covered in a separate second semester module, viz Coding Theory ETK732, only a rudimentary introduction to the underlying basic mathematic foundation (algebraic coding theory) and a short introduction to error correction concepts (as applied to block coding) will be given, if time permits.

Here channel coding and decoding is initially treated from a general viewpoint. It is shown that even randomly selected codes on average yield performances close to the capacity of a channel. In the case of orthogonal signals, it is demonstrated that the channel capacity limit may be achieved as the number of signals approaches infinity.

In this section, an introduction to Algebraic Coding Theory (Linear Algebra) is given. It is then applied to block codes and their performance are evaluated for the AWGN channel. The code performance is evaluated for both hard-decision and soft-decision decoding.

On conclusion of this study theme student should have a basic knowledge and insight in block and convolutional codes, as well as the necessary algebraic and mathematical skills to analyse, design and simulate any of the available error correction codes for AWGN communication channel applications.

The following concepts and coding principles are covered in Study Theme 6:

- ► An introduction to linear algebra and finite field theory
- ► Linear Block Codes: Generator and Parity Check Matrix derivation and design, performance evaluation in AWGN channels.
- ► Convolutional Codes: Transfer function, The Viterbi algorithm, Code distance properties, Concatenated coding techniques, Performance evaluation

5. Assessment

Grading policy

The final mark for ETD732 will consist of a *semester mark* (50%) and an *examination mark* (50%). The semester mark is based on evaluation during the semester, and the examination mark is based on a substantial final assignment.

The semester mark and final mark are made up as follows:

	% of semester mark	% of final mark
Before Block 1:		
Assignment 1	10%	5%
Assignment 2	5%	2.5%
Assignment 3	5%	2.5%
During Block 1:		
Special Assignment 1[1]	20%	10%
Semester Test 1	10%	5%
After Block 1:		
Assignment 4	10%	5%
Assignment 5	5%	2.5%
Assignment 6	5%	2.5%
During Block 2:		
Special Assignment 2[1]	20%	10%
Semester Test 2	10%	5%
Examination assignment	-	50%
TOTAL:	100%	100%

[1] The Special Assignments 1 & 2 are considered to be part of the Semester Tests 1 & 2

Class attendance

Class attendance during mini-block weeks is mandatory.

Semester tests

An open-book semester test of two hours will be written during each mini-block, covering the work completed since the previous assessment opportunity up and until that point in time.

Examination refusal

Students with semester marks below 40% will not be allowed to attempt the final examination assignment.

Final examination

A take-away examination assignment will be handed out during Block 2A (Tuesday 21 April 2009) to be completed within three to four weeks. The final hand-in date/time will be strictly Monday 8 June 2009 before 14:00.

Ethics

Students are encouraged to discuss course work with one another, especially during mini-block weeks. *However, each student should hand in his/her own work for assignments. Plagiarism, including copying the work of another student and copying from the Internet, is absolutely unacceptable. Dishonesty such as plagiarism during tests and the final exam can be punished by expulsion from the University.*

6. Course Outline

BLOCK 1A DAY 1:		**Monday 2 March 2009**	
LECTURER: Prof LP Linde			
Period	**Time**	**Subject**	**Reference(s)**
1	09:00 – 10:00	**Registration** **Introduction: Digital Communications** Overview **Introduction:** **Probability, Random Variables and Stochastic Processes**	Study Guide [1] Chapter 1 [1] Chapter 2
Tea	10:00 – 10:30		
2	10:30 – 12:30	Discussion: Assignment 1 **Prob., RV's & SP**	[1] Chapter 2
Lunch	12:30 – 13:30		
3	13:30 – 15:00	**Characterisation of Communication Signals and Systems:** (Revision)	[1] Chapter 3
Coffee	15:00 – 15:30		
4	15:30 – 16:30	Problems for **BLOCK 1A DAY 2** **Conclusion, Day 1**	[1] Chapters 2 & 3

BLOCK 1A DAY 2:		**Tuesday 3 March 2009**	
LECTURER: Prof LP Linde			
Period	**Time**	**Subject**	**Reference(s)**
1	09:00 – 10:00	**Characterisation of Communication Signals and Systems: Problems (Assignment 2)**	[1] Ch's 1, 2 & 3
Tea	10:00 – 10:30		
2	10:30 – 11:30	**Optimum Receivers for the AWGN Channel:** (Revision)	[1] Chapter 4
3	11:30 – 12:30	**Optimum Receivers for the AWGN Channel: Non-coherent detection (Assignment 3)**	[1] Chapter 4
Lunch	12:30 – 13:30		
4	13:30 – 14:30	Discussion, Assignment 3 – Part I	[1] Chapter 4
5	14:30 – 15:30	**Introduction to Synchronisation Systems** Assignment 3 – Part II Scope of Block 1 Test: [1] Ch's 2,3,4 & 5	[1] Chapter 5 Class Notes
6	15:30 – 16:30	**Evaluation Test 1** **Hand in Special Assignments 1A & 1B** Assignments for **BLOCK 2A** **Conclusion: Block 1A Day 2**	[1] Ch's 1, 2 , 3 & 4 + Tutorials Assignments

BLOCK 2A DAY 1: **LECTURER: Prof L.P. Linde**			**Monday 20 April 2009**
Period	**Time**	**Subject**	**Reference(s)**
1	08:30 – 10:00	**Signal Design for Bandlimited Channels:** ISI and Nyquist's criteria **Communication Systems through Band-Limited Channels** **Discuss Assignment 4 – Part I**	[1] Ch 9 Study Guide [1] Ch 9 Course notes
Tea	10:00 – 10:30		
2	10:30 – 12:30	**Introduction to Equalisation:** Linear Equalisation	[1] Ch 10 [1] Ch 10
Lunch	12:30 – 13:30		
3	13:30 – 14:30	**Introduction to Adaptive Equalisation:** Decision-Feedback equalisation **Discuss Assignment 4 - Part II** Hand in Special Assignment 2	[1] Ch 10
Coffee	14:30 – 15:00		
4	15:00 – 16:30	* Introduction to linear algebra and elementary (finite) field theory	[1] Ch 7 Study Guide Course notes

BLOCK 2A DAY 2: **LECTURER: Mr L. Staphorst / Prof L.P. Linde**			**Tuesday 21 April 2009**
Period	**Time**	**Subject**	**Reference(s)**
1	09:00 – 10:00	**Revision of Information Theory** **Discuss Assignment 5**	[1] Ch 6 Course Notes
Tea	10:00 – 10:30		
2	10:30 – 11:30	**Introduction to Algebraic Coding Theory** Block Error Control Coding Examples and problems	[1] Ch 7 Course notes
3	11:30 – 12:30	**Introduction to Block Coding**	[1] Ch 7 Course notes
Lunch	12:30 – 13:30		
4	13:30 – 14:30	**Discuss Assignment 6**	
5	14:30 –16:00	**EVALUATION TEST 2 (BLOCK 2A): 90 min**	[1] Ch's 6 & 7 + Course notes
6	16:00 – 16:30	Handing out of exam assignments, to be handed in on 8 June 2009 before 14:00. Conclusion: Block 2A Day 2 **END OF FORMAL COURSE**	Hand in: 08/06/09

NOTE: This year, Monday 27 April is a holiday (freedom Day)!!

7. Assignments

Six short assignments as well as two Special Assignments are due for this course. Note that the latter will count towards the semester mark and will be marked as part of the two Semester Tests.

Tutorials and Assignments for BLOCK 1:

The first three Assignments need to be completed before the first Block Course, whereas the First Special Assignment has to be handed in during Block 1**.**

NOTE!! The latest hand in date for the first three Assignments is Monday 23 February 2009 before 14:00. This is to allow the course instructor and research assistants sufficient time to evaluate the work before the first block course (1-8 March), when these assignments will be discussed in classed. Of course no marks can be given to assignments when they have already been covered in class.

Assignment 1: Probability (Revision of Probabilistic Concepts and Stochastic processes)

Please study Chapters 1 and 2 in Proakis [1], then complete Assignment 1 (attached) and hand in on **Monday 9 February 2009** before 14:00.

Assignment 2: Characterisation of Communication Signals and Systems

Study Proakis [1] Chapter 3 (revision of undergraduate work!), then complete Assignment 2 (attached) and hand in by **Monday 16 February 2009** before 14:00.

Assignment 3: Optimum Receivers in AWGN, and an Introduction to Synchronisation Systems

Study Proakis [1] Chapters 4 and 5.
Complete Assignment 3 (attached) and hand in on **Monday 23 February 2009** before 14:00.

Special Assignment 1: Simulation of a Random Number Generator

To be handed in during Block 1 on **Wednesday 4 March 2009**.

Tutorials and Assignments for BLOCK 2:

During Block 1 you have been introduced to the basic concepts of Stochastic Processes, Characteristics of Communication Signals and Systems, Optimum Receiver Principles and an introduction to Synchronisation Systems. During Block 2 the following topics will be covered:

1. Study [1] Chapters 9 & 10 (Bandlimited communications, signal distortion, ISI, equalisers, coding for spectral shaping).
2. Study [1] Chapter 6 and 16: Revision of Information theory and Shannon's Channel Capacity.
3. Study [1] Chapter 7 Introduction to Algebraic Coding Theory and Block Coding for the AWGN Channel), as well as the additional notes on this subject ([2], to be submitted during Block 1).

The next three Assignments, 4, 5 and 6, have to be completed after Block 1 (before Block 2, with latest hand-in date on **Tuesday 14 April 2009**, before 14:00), whereas Special Assignment 2 has to be handed in on **Wednesday 22 April 2009**.

Assignment 4: Bandlimited Communications in AWGN

Complete Assignment 4 Part I (Chapter 9) and Part II (Chapter 10 problems) and hand in on **Monday 16 March 2009**, before 14h00.

Assignment 5: Revision of Information Theory and Channel Capacity

[1] Chapters 6 and 16 – Assignment 5 to be announced / handed out. To be completed and handed in before or on Tuesday 14 April 2009, before 14:00. Note that these assignments may form part of the individual exam assignments for each student (i.e., will contribute towards the exam mark).

Assignment 6: Introduction to Algebraic Coding Theory and Block Coding for the AWGN Channel

Complete Assignment 6 (Block codes, [1] Chapter 7) and hand in on **Monday 6 April 2009**, before 14h00.

Special Assignment 2: To be announced

To be handed in during Block 2 on **Tuesday 21 April 2009**.

A brief description of each Assignment, as well as due dates, are given below. More detail will be provided in due course on the course homepage.

EXAM Assignment

To be handed out during day 2 of Block 2, and to be handed in on 8 June 2009 before 14:00.

DIGITAL COMMUNICATIONS ETD732

ASSIGNMENT 1

PROBABILITY, RANDOM VARIABLES (RVs) AND STOCHASTIC PROCESSES (SP) (REVISION)

[100]

Study Proakis [1] Chapters 1 and 2 (problem numbers from 5th edition in brackets) and then complete the following problems **to be handed in on Monday 9 February 2009, before 14:00:**

1.	Problem	# 2.2	(2.15)	Chapter 2
3.	"	# 2.3 & 2.4	(2.17 & 2.18)	"
4.	"	# 2.6	(2.24)	
5.	"	# 2.7	(2.27)	
6.	“	# 2.11 & 2.12	(2.37 & 2.38)	
6.	"	# 2.10 to 2.16	(2.33, 2.37, 2.38, 2.40 to 2.42)	“
7.	"	# 2.19 & 2.20	(2.46 & 2.47)	
8.	"	# 2.23	(2.51)	
9.	"	# 2.24	(2.52)	
10.	“	# 4.3 & 4.4	(2.53 & 2.54)	"

DIGITAL COMMUNICATIONS ETD732

ASSIGNMENT 2

CHARACTERISATION OF COMMUNICATION SIGNALS AND SYSTEMS [100]

Study Proakis [1] Chapter 3 and then do the following problems (numbers in brackets are taken from the fifth edition) **to be handed in on Monday 16 February 2009, before 14:00:**

1.	# 4.3, 4.4 & 4.16	(2.53, 2.54 & 2.49)	
2.	# 4.18	(3.2)	
3.	# 5.16 & 5.17	(3.4 & 3.5)	
4.	# 5.20 & 5.22	(3.6 & 3.7)	
5.	# 4.30	(3.12)	
6.	# 4.15	(3.13)	PSD of data signals
7.	# 4.20 & 4.25	(3.14 & 3.18)	“
8.	# 4.14	(3.26 & 3.29)	“

DIGITAL COMMUNICATIONS ETD732

ASSIGNMENT 3

OPTIMUM RECEIVERS IN AWGN **[100]**

Study Proakis [1] Chapter 4 and then do the following problems (problem numbers from 5th edition shown in brackets), **to be handed in on Monday 16 February 2009, before 14:00**.

1. # 5.1 & 5.2	(4.11 & 4.12)
2. # 5.3	(4.37)
3. # 5.7 & 5.5	(4.1 & 4.2)
4. # 5.4	(4.4)
5. # 5.8 (Classify the signalling scheme!)	(4.13)
6. # 5.14	(4.15)
7.	(4.18)
8. # 5.21	(4.20)
9. # 5.24	(4.24)
10. # 5.26	(4.23)
11. # 5.27	(4.28)
12. # 5.42	(4.36)
13. # 5.43	(4.38)

DIGITAL COMMUNICATIONS ETD732

SPECIAL ASSIGNMENT 1-A

SUBJECT: RANDOM NUMBER GENERATOR; PROBABILITY DENSITY FUNCTIONS, STATISTICAL AVERAGES

HAND IN BY <u>Wednesday 4 March 2009</u>

INTRODUCTION

Study the attached papers by Wichmann and Hill [1], as well as the one by Coates, Janacek and Lever [2] and then simulate a generator of your own in the programming language of your choice. The advantage of the Wichmann-Hill algorithm is that it is not computer (wordlength)-dependant, and can therefore be easily ported to any platform. The algorithm implements a uniform (unipolar) number generator, which outputs numbers with random amplitudes in the range 0 to 1. From this output random numbers with virtually any conceivable amplitude distribution can be generated by applying the appropriate transformation (mapping). An example of an application of this procedure can be found in the Information Theory course notes, where zero mean Gaussian distributed random numbers is obtained from the uniform number generator by firstly transforming the latter two bipolar uniform numbers with zero mean, and thereafter mapping these numbers to Gaussian random variables with unit variance by using the so-called Marsaglia-Bray algorithm [3].

ASSIGNMENT

You are required to implement the Wichmann-Hill algorithm in the programming language of your choice and then generate and store random numbers of any specified number N (typically as many as $N = 10^5$, but typically 10^6 samples to facilitate accurate statistical measurements). The following tests must subsequently be performed on the stored data samples:

(i) First determine theoretical expressions for the uniform and Gaussian distributions and then find expressions for all statistics (up to the second order, i.e., mean, mean-square and variance) of both the Uniform and Gaussian distributions;

(ii) Validate your Uniform and Gaussian random number generator distributions by measuring and plotting the probability density functions (pdfs);

(iii) Measure and verify the mean and standard deviations of both the Uniform and Gaussian generator outputs by comparing the measurement results with the theoretical values derived in (i);

(iv) Repeat (i) to (iii) above for any other amplitude distribution of your own choice - verify by comparing theory with simulation results;

(v) Measure and plot the Power Spectral Densities (PSDs) of the Uniform, Gaussian and chosen pdf distributed generators by applying your own FFT program and the definition of the PSD for a stationary random process:

$$S_X(f) = \lim_{T\to\infty} \frac{E\{|X_T(f)|^2\}}{T} \qquad \text{[W/Hz]} \tag{1}$$

where $X_T(f)$ denotes the Fourier-Transform (F-T) of a block of T seconds of the Stochastic Process X(t) in the interval [-1/2T,1/2T]. E is the expectation operator.

For a sampled SP, the above expressions have to be adapted to reflect the sampling process. In this case:

$$\mathscr{F}\{X(t)\}\big|_{f=\frac{n}{NT_s}} \simeq T_s X\left(\frac{n}{NT_s}\right) \tag{2}$$

for X(t) in the interval t [0, $T=NT_s$], with:

$$X\left(\frac{n}{NT_s}\right) = \sum_{k=0}^{N-1} X(kT_s)e^{-j2\pi nk/N} \tag{3}$$

the DFT of the SP X(t) in the interval [0, $T=NT_s$]. T_s denotes the sampling period.

Comment on your PSD-findings for each distribution.

FULL MARKS: [100]

REFERENCES

[1] B. Wichmann and D. Hill, "Building a random number generator", *Byte,* pp 127-128, March 1987.

[2] R.F.W. Coates, G.J. Janacek and K.V. Lever, "Monte Carlo simulation and random number generation", IEEE JSAC, Vol. 6, No. 1, pp 58-66, January 1988.

[3] G. Marsaglia and T.A. Bray, "A convenient method for generating normal variables", *SIAM Rev.,* Vol. 6, pp 260-264, 1964.

DIGITAL COMMUNICATIONS ETD732

SPECIAL ASSIGNMENT 1-B

Hand in on Monday 9 March 2009, before 14:00

1 Develop a random number generator capable of generating unipolar (a_k ε {*0,A*}) and bipolar (a_k ε {*-A,A*}) random data, where *A* denotes the maximum signal amplitude, using the Uniform as well as Gaussian distributed random numbers (variables) (rv's), u_k and g_k, developed in Special Assignment 1A. Such algorithms form part of many software packages, such as DaDisp, MathCad and Matlab, but may also be written in C-code by using the results presented by Wichmann and Hill [1] and by applying mappings such as the Marsaglia-Bray mapping (Uniform → Gauss) [2][2].

2 The channel below has to be simulated with a view of evaluating the performance of digital modulation schemes in the presence of various channel impairments (Gauss, Rayleigh, Rice, Poisson, impulsive etc).

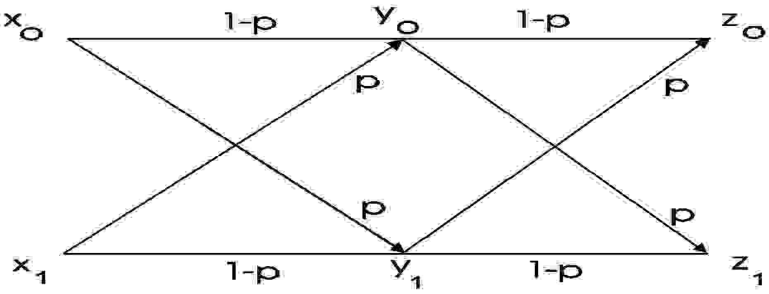

Figure 1 Binary symmetric channel (Consider only one section)

Simulate a binary communication system incorporating the binary channel depicted in Figure 1, producing:

2.1 Gaussian distributed errors at an average rate of one error in 10^{-3};
2.2 Poisson-distributed errors. Define and describe your own Poisson channel statistics (error rate occurrence, average burst length, etc) and verify your measured results with theory.
2.3 How would you go about to realize an unsymmetrical as opposed to a Binary Symmetrical Channel (BSC) in 2.1?

FULL MARKS : [100]

REFERENCES

[1] B. Wichmann and D. Hill, "Building a random number generator", *Byte,* pp 127-128, March 1987.
[2] G. Marsaglia and T.A. Bray, "A convenient method for generating normal variables", *SIAM Rev.,* Vol. 6, pp 260-264, 1964.

[2] References available on request

DIGITAL COMMUNICATIONS
ETD732

SPECIAL ASSIGNMENT 1A MARKING SCHEME

FULL MARKS: [100]

STUDENT: ______________________ **No:** _________________________

1	Theoretical derivations: (10 + 10)	_________	[20]
2	Probability Density Functions (Graphical displays): (10+10)	_________	[20]
3	Measured results (Ave and st deviations, C++ vs Matlab) (5+5)	_________	[10]
4	Repeat 1 – 3 with own distribution: (5 + 5 + 5)	_________	[15]
5	Power Spectral Density Measurements wit FFT-program: (5+5+5)	_________	[15]
5.	Program listings:	_________	[10]
6	Report form:	_________	[10]
	TOTAL:	_________	**[100]**

DIGITAL COMMUNICATIONS
ETD732

SPECIAL ASSIGNMENT 1B MARKING SCHEME

FULL MARKS: [100]

STUDENT: ______________________ **No:** _________________________

1	Generation of unipolar and bipolar random data, using uniform and Gauss distributed random number generators simulated in SA1. Is there any difference between the two data generators?	_________	[20]
2	Simulation of BSC:		
2.1	Theoretical approach/analysis	_________	[10]
2.2	Simulation of channel inducing Gaussian-distributed errors	_________	[15]
2.2	Simulation of channel with Poisson-distributed errors (in time)	_________	[15]
2.3	Extension of 2.1 and 2.2 to a binary unsymmetrical channel	_________	[15]
3	Discussion of results	_________	[10]
4.	Program listings:	_________	[10]
5	Report form:	_________	[10]

FULL MARKS: _________ **[100]**

DIGITAL COMMUNICATIONS ETD732

ASSIGNMENT 4

Revision of Digital Communications through Bandlimited Channels: [1] Ch 9
Introduction to Adaptive Equalisation: [1] Ch 10 [150]

Study Proakis [1] Chapters 9 and 10 and then complete the following problems **to be handed in on Monday 16 March 2009, before 14:00:**

1. Problems to be anounced, based on Proakis' 5th edition.

DIGITAL COMMUNICATIONS ETD732

ASSIGNMENT 5

Revision of Information theory and Channel Capacity Marks: [100]

Study the notes on "*Error control coding:* [3], as well as Proakis [1] Chapter 7 and then complete the following problems, **to be handed in on Monday 6 April 2009 before 14:00:**

PROBLEM

1. # 7.4 & 7.8
2. # 7.13
3. # 7.14 & 7.15
4. # 7.16
5. # 7.17

DIGITAL COMMUNICATIONS ETD732

ASSIGNMENT 6

Introduction to Algebraic Coding Theory and Block Coding for the AWGN Channel

[100]+20

Study the notes on "Forward Error Correction Strategies – An Introduction" [2], as well as Proakis [1] Chapter 7 and then complete the following problems, **to be handed in on Tuesday 14 April 2009, before 14:00:**

1. Do Tutorials FEC-1 [50], FEC-2 [75] and FEC-3 [75] in [2] (available from secretary, Me Mari Ferreira, Eng I room 15-06). Note that Assignment FEC-3 contains some software development, for which (20) bonus marks can be earned.

2. Additional problems from Proakis (5th edition), to be announced

DIGITAL COMMUNICATIONS ETD732

SPECIAL ASSIGNMENT 2

To be handed in on Wednesday 22 April 2009, before 14:00

Problem to be announced during Block 1.