Program for EQ2310 Digital Communications

August 2012

1 About This Course

This is an introductory course on aspects of modern digital communication systems. Its main purpose is to serve as a first course in Digital Communications in the basic curricula of the Communications System Engineering program and the Wireless Systems Engineering program at KTH. The course gives a broad introduction to the principles of digital communications, introducing the fundamental principles and methods used in current communications systems. Problem-solving and design based on mathematical modelling are integral parts of digital communication systems engineering. The emphasis of the course is therefore on mathematical modelling in communication system design and analysis.

The course is a prerequisite for the course EQ2410 Advanced Digital Communications.

2 Syllabus

Modulation techniques

- Complex baseband representation, spectral description of random processes, linear modulation (ASK, PSK, FSK), digital modulation techniques (BPSK, QPSK, QAM), differential modulation

Demodulation and signal detection

- Gaussian basics, hypothesis testing, vector representation of signals and noise, optimal detection in additive white Gaussian noise (AWGN), receiver structures, performance analysis and error probability.

Synchronization and non-coherent communication

- Design requirements, parameter estimation, non-coherent communication, differential detection, performance analysis.

Fundamental limits of performance

- Introduction to information theory, entropy and mutual information, channel capacity.

Channel coding

- Block and convolutional codes, maximum likelihood decoding, coding gain, coded modulation.

3 Learning Objectives

To successfully pass the course, you should be able to:

- Characterize and apply basic techniques in modern digital communications, such as digital modulation for transmission, optimal receivers for detection, and binary block codes and convolutional codes for channel coding;
- Perform simple experiments with a purpose-build hardware platform, obtain and analyse results relevant for system performance, and report findings in writing;
- Develop and use simple software modules (e.g., using Matlab) implementing basic techniques in modern digital communications to numerically evaluate and analyse small-scale modules communications systems, and report the development and results;

- Describe and demonstrate that the implementation and development of modern communication technology requires mathematical modelling and problem solving;
- Apply mathematical modelling to basic problems in digital communications systems, and explain how this is used to analyse and synthesize methods and algorithms within the field.

To acquire a higher grade, you should in addition be able to:

- Compare different techniques in modern digital communications, and judge the applicability of different techniques in different situations;
- Formulate and apply advanced mathematical models which are applicable and relevant in the case of a given problem, and when explicit assumptions are missing, evaluate and compare different possibilities and make own relevant assumptions.

Besides from the aims related to your knowledge and skills in digital communications, the course also aims at improving your ability to

- Learn with and from other students;
- Approach and solve a complex engineering task;
- Communicate your results and conclusions effectively;
- Review and give feedback on work performed by other students.

4 Prerequisite

You must have basic knowledge in calculus, linear algebra, and probability theory. In addition you must have successfully achieved the learning outcomes required to pass EQ1100 Signal and Systems. It is furthermore important that the learning outcomes of the course EQ1220/EQ1240 Signal Theory (or equivalent knowledge) are achieved as soon as possible.

5 Course Structure and Credits

Structure

Lectures	28h
Tutorials	26h
Ticking Sessions	6h
Laboratory Exercise	4h
Examination	5h

In addition a take-home (computer-based) project assignment will be distributed.

Credits

One written examination	7.5 ECTS cu
Lab and project exercises	1.5 ETCS cu
Grades	ETCS (A, B, C, D, E, FX, F)

6 Instructors

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7 Course Material

- Main textbook: Upamanyu Madhow, "Fundamentals of Digital Communications" Cambridge University Press 2008. Sold at Kårbokhandeln.
- Course website:

  https://www.kth.se/social/course/EQ2310/

  - Lecture notes
  - Homework problems
  - Laboratory exercise notes
  - Project assignment notes and software
  - Lecture, tutorial, and ticking session schedules
  - Old exams and exam solutions
  - Collections of problems in communications theory.

Additional material will be handed out during the duration of the course.

- SIGNE – Pulse amplitude modulation (memo for hardware-based lab exercise);
- QPSK – Analysis of a phase shift keying system (memo for software-based project assignment).

8 Teaching and Learning

Lectures (Period 1)

Two lectures will be given each week in period 1. As preparation for each lecture, you are required to complete a reading assignment. Each lecture will emphasise the most important parts of the corresponding reading assignment, and put new concepts and techniques into context of previously learned material.

Before some lectures a 10 minutes quiz may be conducted based on the material of previous lectures. The quiz will be peer-reviewed, which means that your quiz will be marked by one of your fellow students. The intention of the peer-review process is to provide you with timely feedback of how well you have learned previous material. The results of the review process will not be considered towards your final grade.

Tutorials (Period 1)

Two tutorials will be given each week in period 1. A problem set is given in advance for each tutorial session. As preparation before a tutorial session, you are asked to prepare your own solution to the

particular problem set in order to maximise your learning outcome. During tutorial sessions, a course instructor will go through the respective problem set on the board, asking questions to you and your fellow students to get your input to the solution.

"Ticking" Sessions (Period 1)

Three "ticking" sessions will be held during this course. The class will be divided into three groups (Group A-C). In a ticking session a set of three problems are handed out a week before the session. You are then expected to attempt to solve these problems such that you are able to go to the board and explain your solution approach. You do not have to get the correct results; however, you must be able to explain and justify your approach to solve the problem and to lead a discussion with the other students as to how the problem is to be solved. You can work together with other students in order to prepare for the sessions; however, at the board you present your solution approach as an individual.

Before a session you tick off the problems that you are willing to explain at the board. By the end of the three ticking sessions you will have collected at most nine ticks. Based on your ticks, you will be credited with bonus points on the exam and re-exams as follows:

Number of ticks	Bonus points on the exam
0…5	0
6	0.5
7	1
8	1.5
9	2

If it is clear to the instructor that you have not prepared for the session, your ticks for that session will be erased. Note that in this case you will not be able to collect more than 6 ticks, which correspond to 0.5 bonus points on the exam. You are allowed to use any bonus you have been awarded on all exams in this course attempted during the academic year 2012/13.

Laboratory Exercise (Period 2)

The laboratory exercise will be held in the Department's course lab, and you will be guided by a lab instructor. The exercise is performed in groups of two students. You will need to sign up for the exercise via a web-based registration service available from the course website. The schedule for the lab sessions will be announced soon. **The deadline for registration is Monday October 1, 2012**.

In the lab exercise a simple digital communications system is investigated. The error performance is tested using an additive white Gaussian noise channel in the lab. Initially the system is optimized and tested, and these results are compared with theory. Then, the parameters of the matched filter and synchronization are offset reflecting probable real world imperfections. Finally the "de-tuned" performance is measured.

You must come prepared to the lab exercise. That is, you must have completed the preparatory assignments prior to attaining the lab exercise. You will not be allowed to participate if you come unprepared. The lab memo for the exercise can be downloaded from the course website.

Project Assignment (Period 2)

The project assignment is a mandatory part of the course. You can complete the assignment either by yourself, or in a team of at most two students. The project assignment is a take-home project per-

formed with the aid of a computer. Your work will be assessed based on a written report that you are required to hand in. Details can be found in the project memo. The memo and some initial matlab code for the project assignment can be downloaded from the course website.

The purpose of the exercise, which can be considered being a "hybrid" between a traditional laboratory experiment and a homework problem, is to illustrate some important aspects on analysis and simulations, both baseband and passband, of communication systems. As part of the project exercise, you will make some design choices for your communications system based on a series of specifications of target performance of the system. Aspects such as bit error probability, synchronization, carrier phase estimation, eye diagram, spectral properties, and practical imperfections due to filtering will be studied in a QPSK system operating over an AWGN channel. The problems addressed during regular tutorial sessions will provide you with sufficient background to make educated design choices. Preparing problem solutions in advance for the tutorial sessions will therefore give you an advantage when completing your project assignment.

The outcome of the exercise, in addition to increasing your knowledge of communication theory, is a short written technical report were you discuss your findings and comment on various aspects you find interesting. No list of questions is provided, but instead some general areas to be discussed in the report are provided. Thus, there are great opportunities to concentrate on those areas that you consider of most importance.

If you have worked in a team of two students you may choose to write one report each or one common report, with two authors. If you write separate reports, but have cooperated, then state who you have worked with. The report should be neatly structured, easy to follow and is not allowed to exceed six pages (excluding the cover page and the Matlab code). Unreadable reports will be failed immediately. Use a word-processor of your choice to write the report. Hand-written reports will not be approved. The language of the report can be either Swedish or English. A listing of the Matlab code written by the student(s) as part of the assignment must be enclosed as a separate appendix to the report.

9 Course Program (Tentative, changes may occur)

Lectures (Period 1)

No	Day	Time	Place	Topics	Material
1	Wed 29 Aug	13-15	E51	Introduction, preliminaries, complex baseband representation	1.1, 2.1, 2.2
2	Thu 30 Aug	10-12	E52	Random processes, linear modulation, differential modulation	2.3, 2.4, 2.5, 2.6, 2.7
3	Fri 31 Aug	10-12	D34	Gaussian basics, hypothesis testing	3.1, 3.2
4	Fri 7 Sept	8-10	V22	Signal space concepts	3.3
5	Mon 10 Sept	13-15	V3	Optimal detection, performance analysis	3.4, 3.5.1
6	Wed 12 Sept	13-15	E35	Performance analysis, link budget analysis	3.5.2, 3.6, 3.7
7	Mon 17 Sept	15-17	E52	Receiver requirements, parameter estimation	4.1, 4.2, 4.3

8	Thu 20 Sept	13-15	D34	Non-coherent communication, performance analysis	4.4, 4.5
9	Mon 24 Sept	15-17	E52	Channel capacity, Shannon theory	6.1, 6.2
10	Thu 27 Sep	10-12	Q36	Channel capacity, optimization	6.3, 6.4
11	Mon 1 Oct	15-17	E31	Introduction to coding, block codes, convolutional codes	7.1.1, 7.1.2, 7.5
12	Thu 4 Oct	10-12	Q36	Viterbi decoding, performance analysis	7.1.3, 7.1.4, 7.1.5
13	Mon 8 Oct	15-17	E52	Industry lecture, TBA	Handouts
14	Wed 10 Oct	13-15	E52	Course summary and recap.	1, 2, 3, 4, 6, 7.1, 7.2

Note: "*x.y*" in the table above refers to chapter *x* and section *y* in the textbook.

Tutorials (Period 1)

No	Day	Time	Place	Topics	Problems
1	Mon 3 Sept	15-17	E52	Complex baseband representation, random processes, linear modulation	TB2.8, 2-37a, 2-46
2	Tue 4 Sept	10-12	E52	Gaussian basics, hypothesis testing, probabilities	TB3.3, TB3.4, 2-14, 2-21
3	Fri 7 Sept	10-12	V22	Signal space concepts	2-1, 2-15, 2-37
4	Tue 11 Sept	8-10	V21	Optimal detection, performance analysis	2-3, 2-9, 2-20
5	Thu 13 Sept	8-10	E52	Performance analysis, bit error probability	2-44, 2-63, 2-68
6	Tue 18 Sept	8-10	D34	Parameter estimation	TB4.3abc, TB4.4, TB4.5
7	Fri 21 Sept	8-10	D34	Non-coherent communication, performance analysis	TB4.7, TB4.10, TB4.11
8	Tue 25 Sept	8-10	D34	Channel capacity, Shannon theory	1-3, 3-1, 3-2, 3-3
9	Thu 27 Sept	15-17	Q21	Channel capacity calculations	3-6, 3-8, 3-9
10	Tue 2 Oct	10-12	E52	Block codes, convolutional codes	3-11, 3-25, TB7.4
11	Fri 5 Oct	13-15	Q21	Viterbi algorithm, performance analysis	3-32, 3-41, 3-43
12	Tue 9 Oct	10-12	E52	Coded modulation	3-34, TB7.24, TB7.8ab

13	Thu 11 Oct	13-15	L21	Exam paper problems	TBA

Note: "*x*-*y*" in the table above refers to chapter *x* and problem *y* in the "Collection of Problems", while "TB*x.y*" refers to chapter *x* and problem *y* in the course textbook.

Ticking Sessions (Period 1)

No	Day	Time	Place	Topics
1	Fri 14 Sept	13-15	Group A: B22 Group B: B23 Group C: M21	Lectures 1-4
2	Fri 28 Sept	8-10	Group A: Q15 Group B: Q17 Group C: Q22	Lectures 5-8
3	Fri 12 Oct	10-12	Group A: L31 Group B: L41 Group C: L42	All lectures

Note: "*x*-*y*" in the table above refers to chapter *x* and problem *y* in the "Collection of Problems.

The Laboratory Exercise (Period 2)

The registration deadline for the lab exercise will be **Monday October 1, 2012.** You can then get detailed information about possible time-slots for the laboratory exercise on the course website.

The Project Assignment (Period 2)

A tutorial providing guidance regarding the project assignment will be held to kick off the project assignment work.

No	Day	Time	Place	Topics
1	Wednesday 24 Oct	15-17	To be announced	Matlab project tutorial

The deadline for handing in your project assignment report is **Friday November 23rd, 2012** (hand in at STEX).

10 Requirements

Final Exam

You are required to pre-register for the final exam through the course website. The examination schedule is as follows.

Exam	Day	Time	Place
1	Saturday 20th October 2012	8.00-13.00	V11, V12, V21
2	To be announced		

The final exam is a traditional written exam of duration five hours. The exam will have two parts. Part I will contain three problems, each of which can give a maximum of five marks. You must have 67% or

more correct on Part I to be approved at the course (grade E). If you do not reach sufficient marks to be approved on Part I, your Part II solution will not be marked. Part II will contain two problems, each of which can give a maximum of five marks. The optional homework assignments give extra credit on Part I of the exam (see Section 8 for more details).

Allowed aids on exam:

- Handbooks (mathematical handbooks, e.g. Beta);
- Collection of signal processing formulas (downloaded from website);
- The course textbook;
- Lecture slides (downloaded from website).

The grade for the final exam will be determined as detailed below.

Score Part I	Score Part I+II+Bonus points	Grade
Score < 9		F
9 <= Score < 10		Fx
	10 <= Score < 14	E
	14 <= Score < 17	D
	17 <= Score < 20	C
	20 <= Score < 23	B
	23 <= Score	A

Laboratory Exercise and Report

You are required to complete laboratory exercise report by the end of the laboratory session. The report will be graded pass/fail, based on how well you have reached the corresponding learning objectives. You need to demonstrate that you are able to perform simple experiments with a purpose-build communications hardware platform. You further need to demonstrate that you can obtain and analyse results from the experiment relevant for system performance. To do this, it is required that you prepare a series of analytical exercises prior to the experiment in order to have relevant theoretical data for comparison. The report is completed and handed in by the end of the lab exercise based on the report template format provided.

Project Assignment Report

The deadline for handing in your project assignment report is **Friday November 23rd, 2012** (hand in at STEX). Reports handed in too late will not be corrected. The report will be graded pass/fail, based on how well you have reached the corresponding learning objectives. You need to demonstrate you can develop and use simple software modules, implementing basic techniques used in digital communications systems. You further need to demonstrate you can make relevant and sound choices when faced with an incompletely defined communications systems design problem, as well as provide numerical and analytical evidence that your design meets the system performance targets and specifications.

The result of your project work is to be reported in a technical report, with any plots and/or tables you find necessary. A length of four or five pages should suffice, and the report is not to exceed six pages (excluding the cover page and the enclosed Matlab code). The text should be clearly structured and easy to read. A good structure of the presentation, adhering to what is common for technical and scientific publications, is therefore necessary. A good text by Ashby [1] providing guidance for report writing can be downloaded from the course website.

Your results should also be possible to reproduce with reasonable effort based on your report. When grading the report, the technical content, as well as presentation and language qualities, are considered. At most two authors are allowed. Either Swedish or English is allowed as the language of choice. All Matlab code that has been written as part of the assignment must be enclosed as a separate enclosure (this is not considered to be part of the max-six-pages main report). The template provided with the project description will be used to grade the report. Use this template as cover page when you hand in the report.

Following the completion of the grading process, you can check out your report at STEX. There will be a second deadline for revising failed reports. This deadline will be announced when all reports have been checked and made available for potential revision. The second deadline, as well as any further information on this topic, will be posted on the course homepage. Note that reports that are failed a second time will not be considered for a new revision until the next time the course is given (fall of 2013).

11 References

[1] Ashby, M., "How to write a paper", Engineering Department, University of Cambridge, Cambridge, 6th Edition, April 2005.