# SSY121 – Introduction to Communication Engineering

## Course Memo

Version 1.0

August 30, 2021

## 1 Introduction

In this course students obtain a basic understanding of important concepts in communication engineering and an insight into modern communication standards, with some emphasis on commercial wireless systems. A theoretical framework for signal analysis and transmission is developed, and it is utilized to design a simple digital communication system in a project. It is a broad course that gives an overview of the communications field, paving the way for deeper studies in the field, and also serving as a stand-alone course that provides students from other fields with the theoretical and practical foundations of communications.

The course has been defined in collaboration with the communications industry, in order to prepare students as well as possible for the reality after graduation. Traditionally, a fresh M.Sc. employee is often quite qualified technically, but less aware of what the industry expects in terms of teamworking skills and project work. Therefore, the project in this course was defined to resemble an industry project, which in some senses is quite different from a regular academic project.

The course elements are lectures, exercises, and one project. Attendance at lectures and exercises is voluntary, whereas the project and the written exam are mandatory for passing the course. Some details of this memo may change during the course. The most updated version is always available on the course website (see below).

## 2 Learning outcomes

After completion of this course, the student should be able to:

- Explain the purpose of each of the main blocks (source encoder/decoder, channel encoder/decoder, modulator/demodulator) in the Shannon communication model
- Choose signal waveforms and receiver filters for digital transmission over linear channels with additive white noise but no intersymbol interference
- Synchronise the frame structure, symbol timing and phase of a received signal, and format signals on the transmitter side to facilitate such synchronization
- Describe and motivate the functions in some modern communication standards
- Derive and calculate the uncoded bit and symbol error rate, including bounds and approximations, for transmission over the additive white Gaussian noise channel (AWGN) for simple constellations (PAM, QAM, PSK)
- Convert continuous-time signals to a discrete constellation using orthonormal basis (Gram-Schmidt procedure)
- Solve a complex task as a member of a project team, by planning and organising subtasks, establishing roles and common values within the team, reporting and delivering results and self-evaluating the process
- Characterise a typical development project in industry and the process for defining, running and closing such projects
- Demonstrate ability, at design in communication engineering, to make assessments with regard to ethical aspects, by:
  - describe and analyse possible ethical consequences and propose countermeasures
  - apply ethical principles to presentation of results

## 3 Help and information

All information is found on the course website: https://www.canvas.chalmers.se/courses/15229

The staff is happy to answer any questions. Please contact them by email.

## 4 Course staff


- Fredrik Brännström (Examiner and Lecturer) fredrik.brannstrom@chalmers.se
- Mohammad Nazari (Teaching Assistant) mohammad.nazari@chalmers.se
- Yibo Wu (Teaching Assistant) yibo@chalmers.se
- Erik Svenske (Guest Lecturer) erik.svenske@prospero.se


All communication with the course staff will be in English. No other language should be used, even if you happen to have another language in common.

## 5 Course material

The *course book* is:

- J. B. Anderson, Digital Transmission Engineering, 2nd ed., Wiley, 2005. Sold at Cremona.

The supplementary literature will be posted on the course website:

- Course Memo, 2021 (this document)
- Project Memo: "Acoustic Messenger," 2021
- Request for Proposal (RFP), 2021
- Introduction to Matlab, 2021
- Exercises with solutions, 2021
- Homework assignments with solutions, 2021
- Formula Sheet
- P. Mattisson, Working in Projects, Rev. C 2015
- Comments/Errata on Digital Transmission Engineering, 2010
- E. Ström, Notes on Signals and Systems, rev. E, 2007
- Old exams
- A few selected articles

Additional documents, such as lecture slides, will be handed out and posted on the course website during the course.

As a *side reading* for those who want to go deeper into the topics of the course, we recommend:

- Proakis, Digital Communications, 5th ed., McGraw-Hill, 2008.
- Ziemer and Tranter, Principles of Communications, 6th ed., 2010.
- Viterbi and Omura, Principles of Digital Communication and Coding, 1979.

## 6 Lectures

The course schedule is included in Appendix A. Most of the lectures take place in the beginning of the course. The pace of lectures is reduced in the second half of the course, when the project work is more intensive.

The objective of the lectures is to highlight the most important parts of the course. However, all relevant parts are not covered in detail, and some parts are approached from a different angle in the lectures than in the book. It is therefore recommended to read the corresponding sections in the course book before the lecture. The recommended reading is listed in Appendix B.

## 7 Computer Exercises

In the computer sessions $C_1$, $C_2$, and $C_3$, you will be solving MATLAB exercises that are related to the course project. The TA will be present during these exercise session to clarify any doubts and concepts.

If you are new to MATLAB, it is recommended to familiarize with it before the course project begins. All the project members are required to contribute MATLAB code. Document "Introduction to MATLAB 2020" has been uploaded to help the beginners in MATLAB.

## 8 Exercises

The purpose of the exercises (tutorials) is not to solve a lot of standard problems at high speed. The purpose is to facilitate learning and understanding of the course material. The ability to solve standard problems does not imply understanding; however, understanding gives problem solving skills.

It is important that you are active during the exercises. Always try to understand what aspects of communications the problems are treating. If you cannot see the point with a certain problem, ask the TA! There is a meaning behind every problem in this course.

There will be nine exercise sessions in this course. Sessions $E_1$, $E_2$, $E_3$, and $E_4$ will be devoted to solving new problems. These sessions will be started with a short review of the theory and a motivation why the theory is useful for a communications engineer. After the

introduction, the TA will solve a number of problems. A pdf with the problems will be uploaded to the course web page one week before the exercise session. It is recommended that students take a look at problems to be solved before exercise sessions and try to solve them. The solutions to the problems will be uploaded to the course web page after the session. In the end of these exercise sessions, the students will receive a homework assignment, which will also be uploaded to the course web page. Each homework assignment consists of three problems and each problem gives 1 point for the final score. The homework assignments are not mandatory, but can give up to 12 points to the final score. The solutions need to be submitted through the Canvas course web page (paper solutions may be scanned) before the next exercise session. Solutions submitted after that will not be graded. The students are allowed to discuss the homework assignments, but individual solutions are required.

Exercise sessions $H_1$, $H_2$, $H_3$, and $H_4$ will be devoted to discussing the homework assignment handed out in the previous exercise session. In the beginning of the session the students fill in a sheet indicating which problems they have solved. Most difficult problems will be solved by the TA. The homework assignments (submitted on time) will be corrected before the next exercise session. Outside the exercise sessions, the students are welcome to ask questions to about homework by emailing the TA.

The last exercise session, $E_5$, will be a preparation session for the exam where exam problems from previous years will be discussed.

## 9 Project

One mandatory project is included in the course. It is examined continuously during the course. Not only the final result counts, but also the process in which the result was obtained.

The purpose of the project is to give hands-on experience about how to design a transmitter and receiver for a digital communication system complying to some specifications, while using a real physical channel. Another purpose is to give knowledge and experience about development projects and about working in teams. The course concludes with a wrap-up workshop, hosted by Ericsson (remotely), where this experience is commented on by Ericsson engineers and compared with real development projects in industry.

The project is defined in the Project Memo and the Request for Proposal (RFP). Each team will receive the channel hardware (headsets) in order to develop the system. The headsets must be returned at the demonstration of the project solution, please take good care of it. In case of equipment failure, contact the TAs.

The project assignment will be solved in teams of about four students. On the course website there is a group called "Project Sign-up". Each student enrolled in the course must join this group. The deadline for this sign up is shown in the project schedule in Appendix C. Based on the students registered in this list the course staff will compose the teams. The resulting teams will be informed by email. Each team will be assigned a name with the form "Group $N$", where $N$ is the team's number. Any problem forming the group (member missing, wrong email address, etc.) must be immediately reported to Yibo Wu.

The teams should develop their software in MATLAB. Any Windows computer may be used for the development. Students who have their own computers are encouraged to install MATLAB. Chalmers has a generous student license for MATLAB and it can be downloaded from the student portal (Contact and service - IT services - Software). All deliverables, including text, figures, tables, MATLAB code, etc., must be authored by the team itself. Copying any material (from other teams, the internet, or elsewhere) is considered cheating and will result in disciplinary action.

## 10 Examination and grading

The course ends with a written examination. The final grade is the sum of three parts $G = P + E + H$, where the project and the exam are mandatory parts.

- Project points $P$ at least 20 (out of maximum 40), see Project Memo for more information.
- Exam points $E$ at least 12 (out of maximum 48).
- Homework assignment points $H$ (maximum 12), see Section 8.

Note that since the project (and the distribution points on the different parts of the course) can change from year to year, project and exam points must be earned in the same year (defined

from September to August). For example, project points earned one year expire after the second reexam in August the year after.

The final course grade $G$ is

$$\begin{aligned} 0 \leq & G < 40 && \text{FAIL} \\ 40 \leq & G < 60 && \text{grade 3} \\ 60 \leq & G < 80 && \text{grade 4} \\ 80 \leq & G \leq 100 && \text{grade 5} \end{aligned}$$

On the written exam, the solutions are more important than the answers. Hence, a good solution that yields an incorrect (but reasonable) answer because of a minor mistake can give almost full score, whereas a correct answer without a correct solution may give 0 points. The exam must be answered in English. At the exam, the following aids are allowed:

- L. Råde and B. Westergren, Mathematics Handbook (any edition, including the old editions called Beta). Sold at DC and Cremona.
- Pencils, erasers, rulers and dictionaries are authorised aids at all examinations.
- Additional information regarding exams, see https://student.portal.chalmers.se/en/chalmersstudies/Examinations/Pages/default.aspx

# A Schedule of the course

| When | What | Where | Who | Contents |
|---|---|---|---|---|
| Wed. Sept. 1<br>10:00-11:45 | $L_1$ | zoom | FB | Course organization. Brief signals and systems review.<br>Dig. Comm. Systems: History, models, spectrum regulations,<br>and the designer's dilemma |
| Wed. Sept. 1<br>13:15-15:00 | $L_2$ | zoom | FB | Baseband transmission of pulses. Nyquist pulses,<br>ISI, and the sampling Rx. The linear receiver. |
| Wed. Sept. 1<br>15:15-17:00 | $E_1$ | zoom | MN | Fourier analysis, Nyquist pulse, sinc and RC pulses, sampling receiver. |
| Mon. Sept. 6<br>08:00-09:45 | $C_1$ | zoom | YW | Sampling and Reconstruction |
| Mon. Sept. 6<br>10:00-11:45 | $L_3$ | zoom | FB | Orthogonal pulses, correlator Rx, and matched filter Rx. Vector<br>representation of signals and signal space. Minimum distance detection. |
| Wed. Sept. 8<br>10:00-11:45 | $L_4$ | MS Teams | ES | Projects and teamwork in today's<br>communications industry. |
| Wed. Sept. 8<br>13:15-15:00 | $L_5$ | zoom | FB | Passband transmission. 1D modulations: OOK, BPSK, and PAM.<br>2D modulations: QPSK, PSK, and QAM. A very common $\mathcal{P}$. |
| Wed. Sept. 8<br>15:15-17:00 | $H_1$ | zoom | MN | Fourier analysis, Nyquist pulse, sinc and RC pulses, sampling receiver. |
| Mon. Sept. 13<br>08:00-09:45 | $C_2$ | zoom | YW | Signal Space, Constellation and Pulse trains |
| Mon. Sept. 13<br>10:00-11:45 | $L_6$ | zoom | FB | Eye diagrams and constellation plots. Constant envelope<br>modulation schemes: FSK and CPFSK. Signal spectra. |
| Wed. Sept. 15<br>10:00-11:45 | $L_7$ | zoom | FB | Phase, symbol, and frame synchronization. A random<br>model for communications and the AWGN channel. |
| Wed. Sept. 15<br>13:15-15:00 | $E_2$ | zoom | YW | Vector space, Gram-Schmidt algorithm, constellation, matched filter. |
| Mon. Sept. 20<br>08:00-09:45 | $C_3$ | zoom | YW | Matched filter, Eye Diagram, and synchronization. |
| Mon. Sept. 20<br>10:00-11:45 | $L_8$ | zoom | FB | ML and MAP detection in AWGN channels. |
| Wed. Sept. 22<br>10:00-11:45 | $L_9$ | zoom | FB | TBD. |
| Wed. Sept. 22<br>13:15-15:00 | $H_2$ | zoom | YW | Vector space, Gram-Schmidt algorithm, constellation, matched filter. |
| Mon. Sept. 27<br>10:00-11:45 | $L_{10}$ | zoom | FB | Pairwise error probability. Union bound. Error<br>probability of 1D and 2D constellations. Gray coding. |
| Wed. Sept. 29<br>10:00-11:45 | $L_{11}$ | zoom | FB | Wired, wireless, and optical link characteristics. Impairments: noise,<br>interference, channel filtering, synch. errors, nonlinearities, fading. |
| Wed. Sept. 29<br>13:15-15:00 | $E_3$ | zoom | MN | ML/MAP detection, symbol and bit error probability, Gray code. |
| Mon. Oct. 4<br>10:00-11:45 | $L_{12}$ | zoom | FB | TBD |
| Wed. Oct. 6<br>10:00-11:45 | $L_{13}$ | zoom | FB | Multiple Access Techniques: FDMA, TDMA, CDMA. Introduction to<br>"Advanced" (modern) Topics in Communications: OFDM, MIMO,<br>error control coding, coded modulation, data compression. |
| Wed. Oct. 6<br>13:15-15:00 | $H_3$ | zoom | MN | ML/MAP detection, symbol and bit error probability, Gray code. |
| Mon. Oct. 11<br>10:00-11:45 | $E_4$ | zoom | MN | MSK modulation, phase/time/frame synchronization, link budget. |
| Wed. Oct. 13<br>10:00-11:45 | $L_{14}$ | zoom | FB | Project Quiz and course review |
| Mon. Oct. 18<br>10:00-11:45 | $H_4$ | zoom | MN | MSK modulation, phase/time/frame synchronization, link budget. |
| Wed. Oct. 20<br>10:00-11:45 | $E_5$ | zoom | MN | Open question and answer session, exam examples. |
| Wed. Oct. 20<br>14:00-16:30 | - | zoom? | FB | Ericsson workshop. |
| Wed. Oct. 27<br>08:30-12:30 | Exam | ? | | Written examination |

$L_n$: Lecture $n$, $C_n$: Computer exercise $n$, $E_n$: Exercise $n$, $H_n$: Homework $n$,
FB: Fredrik Brännström, MN: Mohammad Nazari, YW: Yibo Wu, and ES: Erik Svenske.
The schedule is tentative. Any updates will be announced on the course website.

## B Lecture Plan

The lectures are based on the following literature. The page and chapter numbers refer to Anderson, Digital Transmission Engineering, except where otherwise stated.

- $L_1$:
  - Chapter 1
- $L_2$:
  - pp. 13–25 (until eq. (2.2-7)).
  - From p. 63 until top of p. 69.
- $L_3$:
  - pp. 25–29 (Sec. 2.2.3).
  - p. 43 (Sec. 2.5).
  - pp. 45–50 (Sec. 2.5.2, except eq. (2.5-9) and eq. (2.5-10)).
  - pp. 53–56 (Sec. 2.5.4).
  - pp. 47–50 of Viterbi's book.
- $L_4$:
  - Working in Projects.
- $L_5$:
  - pp. 79–98, except Sec. 3.2.2.
  - pp. 105–107 (Sec. 3.5).
- $L_6$:
  - pp. 36–38 (Sec. 2.4.2).
  - pp. 119–121.
  - pp. 100–102 (Sec. 3.4.2).
  - pp. 142–144 (Sec. 3.8.2).
  - pp. 29–35, except Sec. 2.3.1.
  - pp. 85–87 (Sec. 3.2.2).
- $L_7 + L_8$:
  - pp. 214-231.
  - pp. 43-45 (Sec. 2.5 and Sec. 2.5.1).
  - pp. 50-53 (Sec. 2.5.3).
- $L_9$:
  - TBD
- $L_{10}$:
  - pp. 57–63.
  - p. 92.
  - pp. 99–100.
- $L_{11}$:
  - pp. 39–43 (Sec. 2.4.3).
  - pp. 285–287 (Sec. 5.4 and Sec. 5.4.1).
  - pp. 135–137 (Sec. 3.8).
  - pp. 247–262.
- $L_{12}$:
  - TBD.
- $L_{13}$:
  - Selected articles.
- $L_{14}$:
  - Review of all above.

## C Schedule of the Project

| When | Contents | Type |
|---|---|---|
| Mon. Sept. 6 11:59 am | Deadline for project registration. | – |
| Mon. Sept. 6 18:00 | Teams are formed. Information is sent by email. | – |
| Tue. Sept. 7 | First project team meeting (Unsupervised). | – |
| Thu. Sept. 9 11:59 am | Deadline for Common Values. | Deliverable 1 |
| Thu. Sept. 9 11:59 am | RFP, and the required files are handed out. | – |
| Fri. Sept. 10 11:59 am | Time Report 1 | Deliverable 9.1 |
| Tue. Sept. 14 18:00 | Deadline for proposal. | Deliverable 2 |
| Wed. Sept. 15 15:30–18:30 | Hearings in room TBD. | – |
| Fri. Sept. 17 11:59 | Time Report 2 | Deliverable 9.2 |
| Fri. Sept. 24 11:59 am | Deadline for Status Report 1. | Deliverable 3 |
| Fri. Sept. 24 11:59 am | Time Report 3 | Deliverable 9.3 |
| Fri. Oct. 1 11:59 am | Deadline for Status Report 2. | Deliverable 4 |
| Fri. Oct. 1 11:59 am | Time Report 4 | Deliverable 9.4 |
| Fri. Oct. 8 11:59 am | Deadline for Status Report 3. | Deliverable 5 |
| Fri. Oct. 8 11:59 am | Time Report 5 | Deliverable 9.5 |
| Wed. Oct. 13 10:00–10:20 | Project Quiz via zoom. | – |
| Wed. Oct. 13 12:00–17:00 | Sign up for demonstration. | – |
| Fri. Oct. 15 11:59 am | Deadline for Test Report and Software. | Deliverable 6, 7 |
| Fri. Oct. 15 11:59 am | Time Report 6 | Deliverable 9.6 |
| Fri. Oct. 15 17:00–20:00 | Allocated for demonstration (room 5225). | – |
| Mon. Oct. 18 11:59 am | Deadline for experience report. | Deliverable 8 |
| Mon. Oct. 18 17:00–20:00 | Allocated for demonstration (room 5225). | – |
| Tue. Oct. 19 17:00–20:00 | Allocated for demonstration (room 5225). | – |
| Wed. Oct. 20 14:00–16:30 | Project wrap-up workshop by Ericsson (zoom?) | – |

The schedule is tentative. Any updates will be announced on the course website.