Examination Mon. Oct. 24, 2016, 14:00–18:00

SSY121 – Introduction to Communication Engineering

- Contact persons: Mohammad Nazari (031 - 772 1771) and Fredrik Brännström (031 - 772 1787) will visit the exam after approximately 1 and 3 hours.
- Instructions:
  - Write in English.
  - Use a pencil and eraser.
  - There is no page limit. Extra sheets of paper are available.
  - Solve the problems in any order (they are not ordered by difficulty).
  - Before handing in, sort the pages in problem order. Label each page with problem number and running page number. Do not hand in drafts or unused paper.
  - If any data is missing, make reasonable assumptions.
  - Chalmers' examination rules apply, available at student.portal.chalmers.se /en/chalmersstudies/Examinations/Pages/Examinationroominstructions.aspx
  - MP3/Music players **are not** allowed during the exam
- Allowed aids:
  - Mathematics Handbook by Råde and Westergren (any edition, including Beta) or equivalent
  - Chalmers-approved calculator
- Grading principles:
  - Explain the line of reasoning clearly. A good solution with a minor error usually gives close to full points, even if the answer is incorrect.
  - An answer without a clear motivation usually gives 0 points, even if it is correct.
  - Whenever possible, check if your answer is reasonable. An obviously unreasonable answer usually gives 0 points, even if the solution is almost correct.
- Solutions and results:
  - Solutions will be posted on the course website no later than 7 days after the exam.
  - The grading of the exam can be reviewed on Monday November 7, 2016, at 12:00–13:00 in Room Landahlsrummet (7430), floor 7, Department of Signals and Systems, EDIT building.

1. **True or false questions:** Justify *ALL* your answers using short and concise explanations (maximum 30 words per item). (Total points: 10)

   (a) A digital communication system uses a phase-shift keying constellation with eight points (8-PSK) over the additive white Gaussian noise (AWGN) channel. The matched filter receiver implementation requires at least 8 filters matched to the signals $\{s_m(t), 1 \leq m \leq 8\}$. (1)

   (b) The Symbol error rate for an envelope detector in an AWGN channel with equiprobable M-PSK signaling is $\frac{M-1}{M}$. (The envelope detector decides only based on the amplitude/magnitude of the received signal.) (1)

   (c) In a binary pulse-amplitude modulation (PAM) modulation system using a rectangular pulse, the length of the pulse is reduced from 1 second to 0.25 seconds. To maintain the same probability of error, the amplitude of the pulse should be increased by a factor of four. (1)

   (d) One of the challenges for the frequency-shift keying (FSK) signals is phase discontinuities resulting in large spectral lobes. To avoid this, continuous phase modulation (CPM) schemes are preferred. (1)

   (e) In the class of orthogonal signal constellations, for a fixed average bit energy, E_b, the minimum distance in the constellation, d_min, decreases with increasing M. (1)

   (f) Minimum-shift keying (MSK) signaling is an orthogonal signaling scheme exploiting minimum frequency separation required for both orthogonality of transmitted signals, and providing minimum probability of error in the coherent receiver. (1)

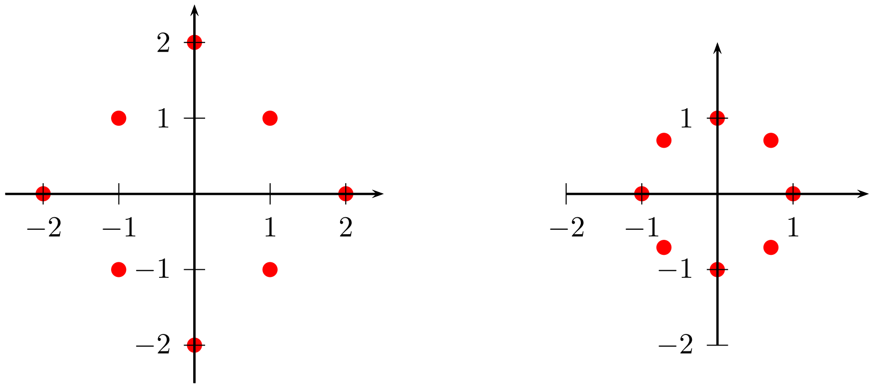
   (g) The nearest-neighbor (or minimum-distance) detector is the optimal detector provided that the signals are *both* equiprobable *and* have equal energy. (1)

   (h) In CDMA, different users are allotted small portions of the available bandwidth and each user transmits only in the allotted bandwidth without interfering in other user's bandwidth. (1)

   (i) For the one-sided bandwidth $B = 5$ MHz, ISI-free transmission with a symbol rate of $R_\text{s} = 1/T_\text{s} = 10$ Msymbol/s is *theoretically* possible using an RRC pulse with $\alpha > 0$, together with a matched filter receiver. (1)

   (j) In Shannon's communication model, the block modulator serves as the interface to the communication channel, and its primary purpose is to map the binary information sequence into signal waveforms. (1)

2. A transmitter and a receiver are communicating over the AWGN channel. The transmitter first transmits a header consisting of two symbols, equally likely, using BPSK whereafter the data is transmitted using either 8-QAM or 8-PSK, see Fig. **??**. Based on the header, the receiver decides what modulation scheme to use for ML-decoding. (Total points: 11)



(a) Un-normalized 8-QAM (b) 8-PSK

Figure 1: Constellations in Problem **??**.

   (a) Give an expression for the probability that both header symbols are received erroneously in terms of the signal-to-noise ratio, E_s/N_0. (2)

   (b) Assume now that the transmitter is using 8-QAM for transmission after the header and that the header is received correctly, i.e., the receiver decode using 8-QAM as well. Find the normalizing constant to make the average symbol energy equal to one for the 8-QAM constellation in Fig. **??**(a), give the high-SNR approximation for the SER and draw the decision regions for the normalized constellation. (3)

   (c) Now, assume the header is received erroneously and that the receiver is decoding with the 8-PSK constellation when the transmitter is transmitting using the (normalized) 8-QAM constellation. Find the high-SNR approximation for the SER. Compare and interpret the result with what you obtained in (b). (6)

3. Some questions regarding NFC and WiFi 802.11. (Total points: 4)

   (a) Bluetooth low energy (BLE) beacons are important because they address a number of challenges that marketers have been trying to solve for many years. Briefly describe two (and only two) of these challenges. (2)

   (b) Describe the difference between SU-MIMO and MU-MIMO in WiFi 802.11ac. (2)

4. In a binary antipodal signaling scheme, $s_1(t) = s(t)$ and $s_2(t) = -s(t)$, and the energy of $s(t)$ is E_{s}. The prior probabilities of messages 1 and 2 are p and $1-p$, respectively, and the variance of the noise is $\sigma^2 = \frac{N_0}{2}$.
(Total points: 6)

   (a) Find the decision boundary for the optimal receiver. (3)

   (b) Find the probability of error for the optimal receiver. (3)

5. Suppose a digital communication system employs Gaussian shaped pulses of the form
$$p(t) = e^{-\pi a^2 t^2}.$$
To reduce ISI, we impose $p(T_{\mathrm{p}}) = 0.01$ where T_{p} is the time between transmitted symbols. The one-sided bandwidth of $p(t)$ is defined as the value of W for which $\frac{P(W)}{P(0)} = 0.01$, where $P(f)$ is the Fourier transform of $p(t)$. Determine W and compare it to the one-sided bandwidth of the Root raised cosine-pulse with roll-off factor $\alpha = 1$, where the one-sided bandwidth is defined as the lowest frequency, f, for which $P_{\mathrm{RRC}}(f) = 0$.
(Hint: Use the fact that $e^{-j\omega t} = \cos(\omega t) - j\sin(\omega t)$ and the identity
$\int_{-\infty}^{\infty} e^{-cx^2}\cos(2\pi kx)dx = \sqrt{\frac{\pi}{c}}e^{-\frac{\pi^2k^2}{c}}$, $c \in (0,\infty)$.) (Total points: 6)

6. A communication system uses the four signals shown in Fig. **??** for transmission.

(Total points: 6)

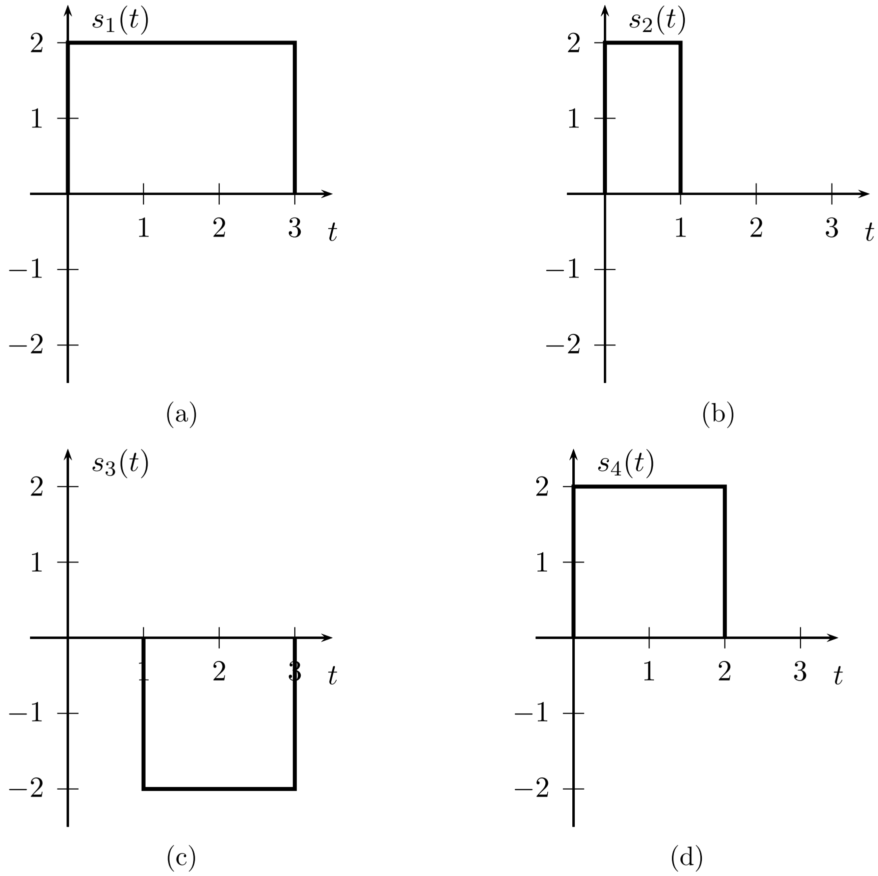


Figure 2: The signal alternatives in Problem **??**.

(a) Find a *minimal* set of orthonormal basis for the space spanned by these signals. (4)

(b) Express the signals as a superposition of the basis functions, and write their vector representation. (2)

7. A binary digital communication system transmits data over a point-to-point microwave link using BPSK modulation. The distance between the transmitter (TX) and the receiver (RX) is 100 km. To offset the effect of channel attenuation, repeaters (R) are used every 10 km. Each repeater, receives the signal, amplifies it by its gain G_i, and forwards it. The communication channel follows the free-space path loss model. Assume that $G_{\mathrm{T}} = G_{\mathrm{R}} = 0$ dB, $G_i = G = 80$ dB for all repeaters, and that the carrier frequency is chosen so that $\frac{\lambda}{4\pi} = 1$. In the receiver side, a minimum received power of 0.15 μW is required to guarantee the quality of service. (Total points: 3)

   (a) Find the transmission power required to meet the quality of service. (2)

   (b) If for some reason, a phase error $\phi = 45°$ occurs at the final receiver (destination), how much power is required in the transmitter side to still meet the quality of service? (1)

8. We want to transmit a data stream with bit rate $R_{\mathrm{b}} = 8$ kbit/s using a raised cosine pulse with roll-off factor $\alpha = 0.4$ and a 128-ary modulation scheme. How much one-sided channel bandwidth W is required to have ISI-free transmission assuming that a sampling receiver is used? (Total points: 2)