LUND UNIVERSITY
Electrical and Information Technology

Exam in
Digital Communications, EITG05

May 4, 2019

Name: ______________________________

Id Number: ______________________________

Programme: ____________

Nbr of sheets: ____________

Mark with a cross the problems you solved.				
1	2	3	4	5

Signature: ______________________________

Control protocol						
1	2	3	4	5	$\sum$	Grade

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- During this exam you are allowed to use a calculator, the compendium, a printout of the lecture slides, and Tefyma (or equivalent).
- Please use a new sheet of paper for each solution. Write your anonymized assessment code + a personal identifier on each paper.
- Solutions should clearly show the line of reasoning and follow the methods presented in the course. If you use results from the compendium or lecture slides, please add a reference in your solution.
- If any data is lacking, make reasonable assumptions.

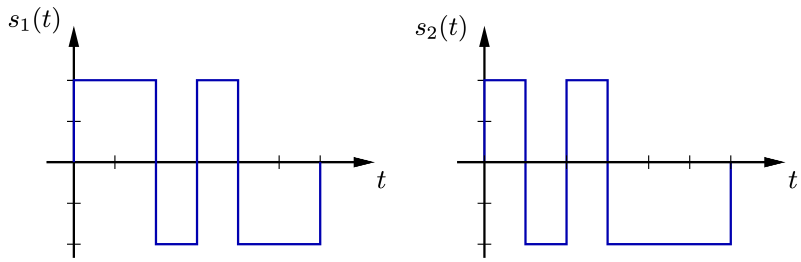
Good luck!

Problem 1

Determine for each of the five statements below if it is true or false.
Give a motivation for each of your answers.

(a) *"For 4-PAM signaling the energy of the signal $s(t)$ depends on the transmitted data."*

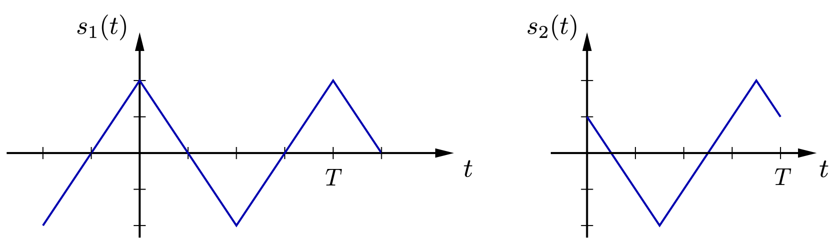
(b) *"The signals $s_1(t)$ and $s_2(t)$ in the figure below are orthogonal to each other."*



(c) Consider M-ary QAM signaling with a triangular pulse shape $g(t) = g_{tri}(t)$ of amplitude A and duration $T = T_s = 1\,\text{ms}$.

"If M is increased, then the bandwidth decreases."

(d) *"The signals in the figure below satisfiy the equation: $s_2(t) = g_{rec}(t) \cdot s_1(t + T/8)$"*

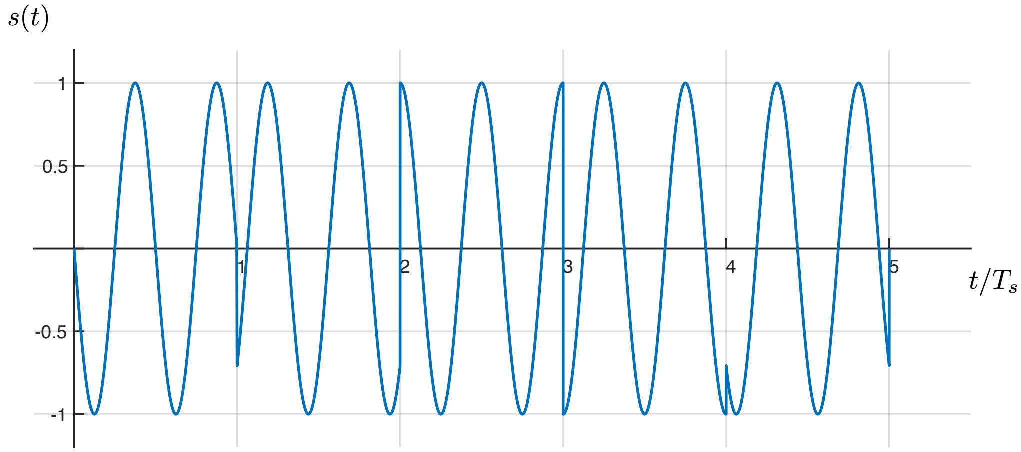


(e) *"QAM signaling allows for efficient power amplifiers because the variation of the squared envelope $e^2(t)$ is small."*

(10p)

Problem 2

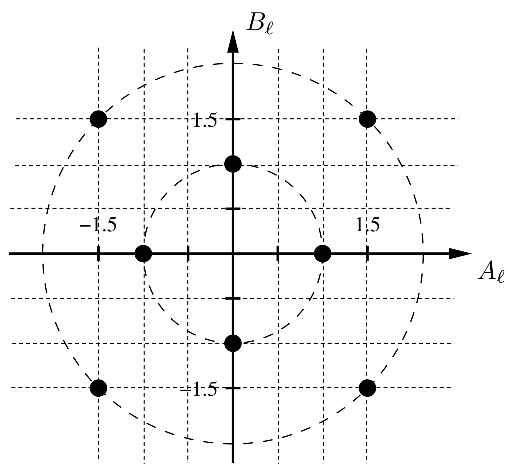
Consider the following transmitted signal $s(t)$, where $T_s = 2\,\mu s$:



(a) Determine the message sequence $\mathbf{m}$, the carrier frequency f_c, and the bit rate R_b.

(b) Draw a constellation diagram for this signaling method, and use some Gray mapping to assign bits to the signal alternatives.
Determine the corresponding sequence of transmitted bits $\mathbf{b}$.

Consider now the following 8-QAM signal constellation, which can be constructed as superposition of two 4-PSK constellations with different radius R_1 and $R_2 > R_1$:



(c) Determine the average energy per symbol $\bar{E}_s$ and the minimum Euclidean distance D^2_{min} for this constellation. All signal alternatives are transmitted with equal probability.

(d) For comparison, determine the value $\bar{E}_s$ for an 8-PSK constellation with the same D^2_{min} as obtained in (c). Which of the two constellations requires less energy?

Remark: Parts (c) and (d) can be solved independently from (a) or (b).

(10p)

Problem 3

Consider a 2-ray multi-path channel with impulse response

$$h(t) = \sum_{i=1}^{2} \alpha_i \, \delta(t - \tau_i) \ , \quad \text{where } \alpha_1 = 1, \alpha_2 = 0.5, \tau_1 = 0 \, \mu\text{s}, \tau_2 = 2 \, \mu\text{s} \ .$$

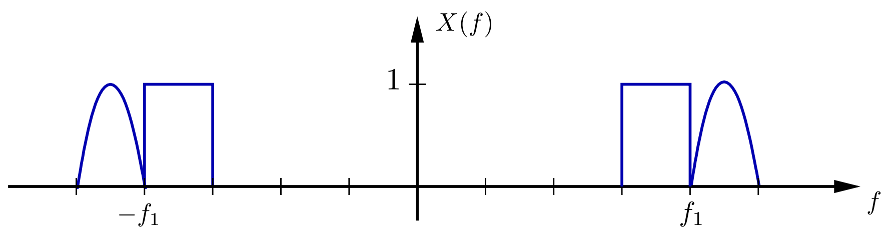
Binary antipodal signaling with rectangular pulse $g_{rec}(t)$ of amplitude A and duration $T = 3 \, \mu\text{s}$ is used for transmission over this channel.

(a) Draw the signal $z(t)$ at the output of the channel if $s_1(t) = +g_{rec}(t)$ is transmitted.

(b) What is the largest symbol rate R_s for which no overlap of signal alternatives will occur after the channel?

(c) Assume now a minimum Euclidean distance receiver that operates at the rate R_s from (b). Determine the decision variables ξ_0 and ξ_1 computed by the receiver if no noise is present, i.e., $r(t) = z(t)$.

The frequency spectrum $X(f)$ of a bandpass signal $x(t)$ is given as in the figure below:



(d) Before the signal is digitized at the receiver it is converted to an intermediate frequency as follows:

$$y(t) = x(t) \cdot \cos\left(2\pi \left(f_1 + f_2\right) t\right) \ , \quad \text{where } f_1 = 4 \, \text{MHz} \ , \ f_2 = 1 \, \text{MHz} \ .$$

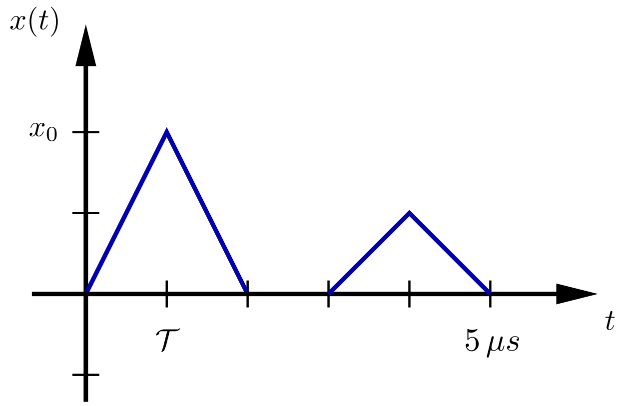
Draw the spectrum $Y(f)$ of the signal.

Remark: Part (d) can be solved independently from (a), (b), or (c).

(10p)

Problem 4

Consider a communication system employing 2-PAM modulation with equally likely signal alternatives. The combination of the transmit pulse $g(t)$, channel filter $h(t)$, and receiver filter $v(t)$ can be written as $x(t) = g(t) * h(t) * v(t)$. The signal is sampled in the receiver at time instants $\mathcal{T} + i\,T_s$, $i = 0, 1, 2, \ldots$.



(a) Assume that $T_s = 2\,\mu s$ and that we want to transmit the amplitude sequence $A[0] = 1$, $A[1] = -1$, $A[2] = -1$, $A[3] = 1$.
Draw the signal $y(t)$ at the output of the receiver filter in the interval $0 < t < 11\,\mu s$ in the absence of noise, i.e., $w(t) = 0$. Does ISI occur?

(b) Assume now that $T_s = 1\,\mu s$ and draw the discrete impulse response $x[i]$. Does ISI occur in this case?

(c) For the case $T_s = 1\,\mu s$, give an example of an amplitude sequence $A[i]$ for which the worst case ISI occurs. Is there a risk for erroneous decisions if $w(t) = 0$?

(d) Determine the largest symbol rate R_s that can be achieved without ISI.

(10p)

Problem 5

Consider a communication system with M-ary QAM signaling and a triangular pulse shape $g(t) = g_{tri}(t)$ with amplitude A and duration $T = T_s$. All signal alternatives are transmitted with equal probability and the system bandwidth W is measured by the main-lobe. The parameter of the additive white Gaussian noise is equal to $N_0 = 4 \cdot 10^{-20}\,\mathrm{W/Hz}$ and the propagation attenuation is $\alpha = 0.01 \cdot d[\mathrm{m}]^{-1}$, where $d = 200\,\mathrm{m}$.

A requirement is that the symbol error probability P_s satisfies $P_s \leqslant 10^{-9}$.

(a) For $M = 4$, determine the bandwidth efficiency ρ and the smallest amplitude A that fulfills these requirements.

(b) How does the required pulse amplitude A change if the modulation order is increased to $M = 16$? Explain this result.

(c) Assume now that the distance to the transmitter is reduced to $d = 150\mathrm{m}$. How much can the average transmitted energy $\bar{E}_s$ be reduced if $M = 16$?

(d) Repeat part (a) if a rectangular pulse $g(t) = g_{rec}(t)$ is used instead.

(10p)