The University of Texas at Austin
Dept. of Electrical and Computer Engineering
Midterm #2 **Take-Home Exam**

Prof. Brian L. Evans

Date: May 5, 2021 Course: EE 445S

Name: ____
Last, First

Please sign your name below to certify that you did not receive any help, directly or indirectly, on this test from another human other your instructor, Prof. Brian L. Evans, and to certify that you did not provide help, directly or indirectly, to another student taking this exam.

(please sign here) ____

- **Take-home exam** is scheduled for Wednesday, May 5, 2021, 10:30am to 11:59pm.
  - The exam will be available on the course Canvas page at 10:30am on May 5, 2021.
  - Your solutions can be on notebook paper, or on the test and your own paper, or whatever. This means that you won't have to print the test to complete the test.
  - ***Please include this cover page*** signed by you with your solution and upload your solution as a single PDF file to the course Canvas page by 11:59pm on May 5, 2021.
- **Fully justify your answers**. When justifying your answers, reference your source and page number as well as quote the particular content in the source for your justification. Sources can include course lecture slides, handouts, homework solutions, books, Web pages, etc.
- **Matlab**. No question on the test requires you to write or interpret Matlab code. If you base an answer on Matlab code, then please provide the code as part of the justification.
- **Internet access.** Yes, you may fully access the Internet when answering exam questions provided that you comply with the other instructions on this page.
- **Academic integrity.** You shall not receive help directly or indirectly on this test from another human except your instructor, Prof. Evans. You shall not provide help, directly or indirectly, to another student taking this exam.
- **Send questions to Prof. Evans.** You may send questions or concerns about this midterm exam during the test to Prof. Evans via Canvas or by e-mail at bevans@ece.utexas.edu.
- **Contact by Prof. Evans.** Prof. Evans might contact all students in the class during the exam through Canvas announcements. Please periodically monitor those announcements.

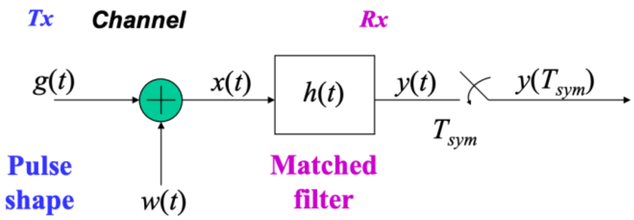
Problem	Point Value	Your score	Topic
1	24		Baseband PAM System
2	27		QAM Communication Performance
3	28		QAM Receiver Architecture Tradeoffs
4	21		Potpourri
Total	100		

Problem 2.1. *Baseband PAM System. 24 points.*

Consider a baseband pulse amplitude modulation (PAM) system with the parameters on the right.

The PAM system does not have A/D or D/A converters.

The problem focuses on the following part of the baseband PAM system:



where $w(t)$ is a Gaussian random signal with zero mean and variance σ^2.

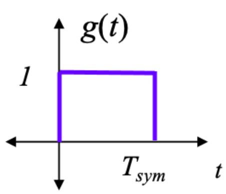
PAM System Parameters

- $2d$ constellation spacing
- f_{sym} symbol rate
- $g(t)$ pulse shape
- $h(t)$ matched filter impulse response
- J bits/symbol
- k constant
- M levels, i.e. $M = 2^J$
- n symbol index
- N_g symbol periods in $g(t)$
- T_{sym} symbol time

Assume the receiver is synchronized with the transmitter in parts (a), (b) and (c).

(a) Using the PAM System Parameters, give a formula for $h(t)$ that maximizes the SNR at the estimated symbol amplitude $y(T_{sym})$? *4 points.*

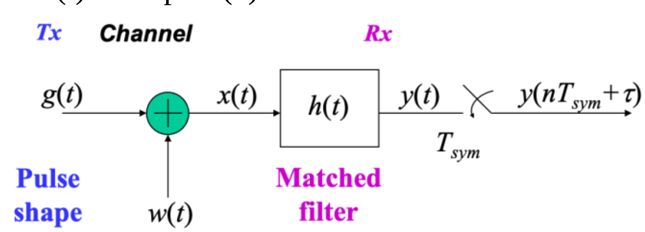
(b) Using your answer in part (a), plot $h(t)$ when $g(t)$ is the rectangular pulse shown below. *4 points.*



(c) Using your answer in part (b), plot $y(t)$ assuming there is no noise, i.e. $w(t) = 0$. *4 points.*

(d) Assume the receiver has an accurate T_{sym} but needs to find a symbol timing offset τ to synchronize with the transmitter as shown below. Develop an adaptive method to update τ in the nth symbol period using analog continuous-time signal processing; e.g., a differentiator circuit will compute a derivative of an analog continuous-time signal. Use $g(t)$ and $h(t)$ from part (b).

i. Give an objective function. *6 points.*

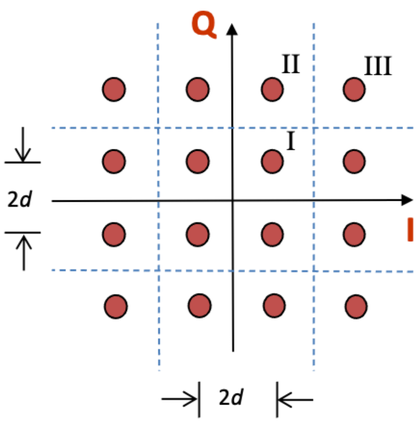


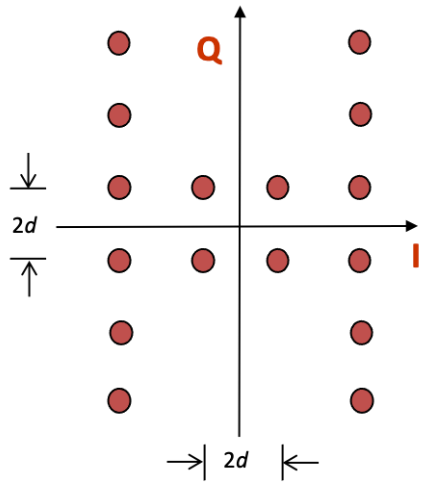
ii. Give the update for $\tau[n+1]$ given $\tau[n]$. *3 points.*

iii. How would you determine the value of the step size μ? *3 points.*

Problem 2.2 *QAM Communication Performance. 27 points.*

Consider the two 16-QAM constellations below. Constellation spacing is $2d$.





Energy in the pulse shape is 1. Symbol time T_{sym} is 1s. The constellation on the left includes the decision regions with boundaries shown by the in-phase (I) axis, quadrature (Q) axis and dashed lines.

Each part below is worth 3 points. **Please fully justify your answers.**

	Left Constellation	**Right Constellation**
(a) Peak transmit power	$18d^2$	
(b) Average transmit power	$10d^2$	
(c) Draw the type I, II and/or III decision regions for the right constellation on top of the right constellation ***that will minimize the probability of symbol error using such decision regions.***		
(d) Number of type I regions	4	
(e) Number of type II regions	8	
(f) Number of type III regions	4	
(g) Probability of symbol error for additive Gaussian noise with zero mean & variance σ^2	$3Q\left(\frac{d}{\sigma}\right)-\frac{9}{4}Q^2\left(\frac{d}{\sigma}\right)$	
(h) Express d/σ as a function of the Signal-to-Noise Ratio (SNR) in linear units	$\text{SNR} = \frac{10d^2}{\sigma^2}$ $\frac{d}{\sigma} = \sqrt{\frac{\text{SNR}}{10}}$	

(i) For the right constellation, will using the type I, II, and III rectangular decision regions lead to Gray coding for symbols? Either give a Gray coding for the right constellation, or show that it is not possible. *3 points.*

Problem 2.3. *QAM Receiver Architecture Tradeoffs*. *28 points*.

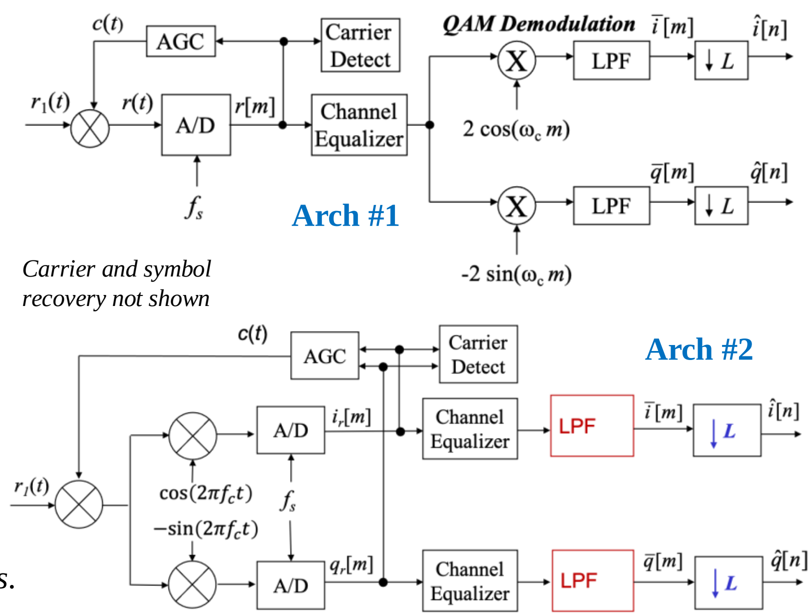
In this problem, you evaluate tradeoffs in the two QAM receiver architectures on the right:

(1) Single analog-to-digital (A/D) converter

(2) Two A/D converters, one for the in-phase channel and one for the quadrature channel

In both architectures,

$r_1(t)$ is the baseband QAM signal
i is the in-phase component
q is the quadrature component
J bits per symbol (assume J is even)
M constellation points where $M = 2^J$



Please evaluate the following tradeoffs.

(a) Which architecture consumes less power in its A/D converters? How much less? *9 points*.

(b) Describe an automatic gain control (AGC) algorithm for architecture #2 including equations. The algorithm has access to both A/D converter outputs. Give the computational complexity. *6 points*.

(c) Describe a carrier detection algorithm for architecture #2 including equations. The algorithm has access to both A/D converter outputs. Give the computational complexity. *6 points*.

(d) Which architecture would you advocate using? Why? Describe the tradeoffs considered. *7 points*.

Problem 2.4. *Potpourri*. *21 points.*

Please determine whether the following claims are true or false and **support each answer with a brief justification**. A true or false answer without any justification will not earn any points.

(a) PAM and QAM transmission using the same constellation size and symbol rate will always have the same symbol error rate when both receivers are operating at the same received SNR. *3 points*.

(b) Pulse shaping filters are designed to contain the spectrum of a transmitted signal in a communication system. In a communication system, the pulse shape should be zero at non-zero integer multiples of the symbol duration and have its maximum value at the origin. *3 points*.

(c) The LTI components of wired and wireless channels have impulse responses of infinite duration, and each can be modeled as an FIR filter. Wired channel impulse responses do not change over time, whereas wireless channel impulse responses change over time. *3 points*.

(d) A receiver in a digital communication system employs a variety of adaptive subsystems, including automatic gain control, carrier recovery, and symbol timing recovery. A transmitter in a digital communication system does not employ any adaptive systems. *3 points*.

(e) When designing an FIR channel equalizer for a communication system using same amount of training data and the same filter length, an adaptive least mean-squares method should always be used over a least-squares method. *3 points.*

(f) In a communications system using a rectangular QAM constellation, the fastest and most accurate way for the receiver to find the constellation point closest to the received symbol amplitude is to use Euclidean distance. *3 points*.

(g) When the received SNR is $-\infty$ dB, the symbol error rate is 100%. That is, there is no chance that any symbol will be decoded correctly. *3 points*