Texas A&M University
Department of Electrical and Computer Engineering

ECEN 720 – High-Speed Links

Spring 2019

Exam #2

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are **6** pages in your exam
- You may use <u>one</u> double-sided page of notes and equations for the exam
- Good Luck!

Problem	Score	Max Score
1		30
2		35
3		35
Total		**100**

Name: SAM PALERMO

UIN:

TABLE 13-1. Q_{BER} as a Function of the Bit Error Rate

BER	Q_{BER}	BER	Q_{BER}	BER	Q_{BER}
1×10^{-3}	6.180	1×10^{-10}	12.723	1×10^{-17}	16.987
1×10^{-4}	7.438	1×10^{-11}	13.412	1×10^{-18}	17.514
1×10^{-5}	8.530	1×10^{-12}	14.069	1×10^{-19}	18.026
1×10^{-6}	9.507	1×10^{-13}	14.698	1×10^{-20}	18.524
1×10^{-7}	10.399	1×10^{-14}	15.301	1×10^{-21}	19.010
1×10^{-8}	11.224	1×10^{-15}	15.882	1×10^{-22}	19.484
1×10^{-9}	11.996	1×10^{-16}	16.444	7.7×10^{-24}	20.000

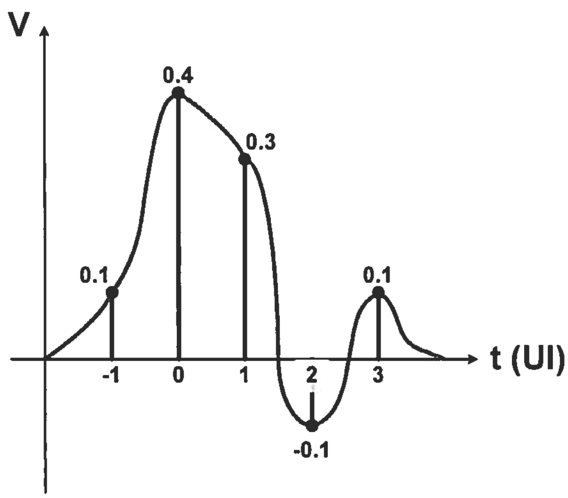
Problem 1 (30 points)

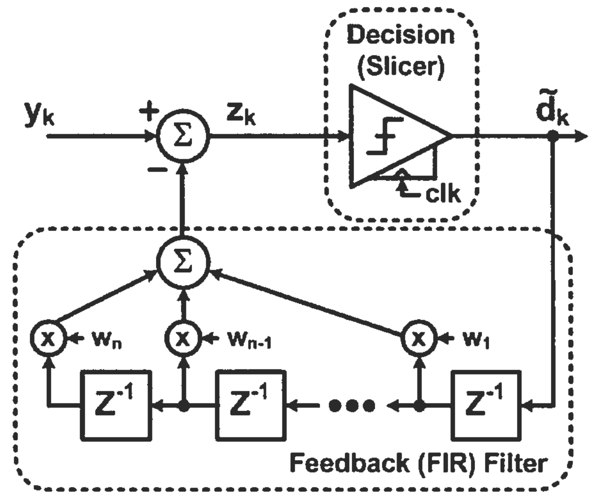
A channel has the pulse response, $y^{(1)}$, below for a "1" bit. A DFE with FIR feedback filter is used for equalization. Assume ideal delay cells.

a) What is the minimum number of DFE taps required for a worst-case eye height of 0.4V? What are the tap values?

b) Assume that you can have as many FIR feedback taps in the DFE as you would like. What is the best (worst-case) eye height that you can achieve with only this DFE equalization?

$y^{(1)} = [0.1\ \ 0.4\ \ 0.3\ \ -0.1\ \ 0.1]$





Worst-Case Eye Height = 2[Cursor − Σ|ISI|]

* DFE only cancels post-cursor ISI!!!

Best eye height w/DFE only is w/ W = [0.3 −0.1 0.1]

Eye height = 2(0.4 − 0.1) = 0.6

* To achieve eye height of 0.4

2(0.4 − 0.6 + Σ|taps|) = 0.4 ⇒ Σ|taps| = 0.4

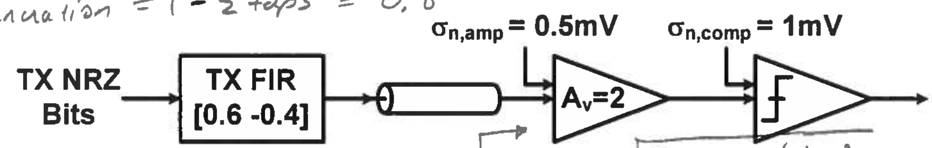
This can be achieved w/ 2-taps W = [0.3 −0.1]

Minimum DFE taps required for worst-case eye height of 0.4V = [0.3 −0.1]

Best (worst-case) eye height achievable with many DFE taps = 0.6V

Problem 2 (35 points)
This problem involves the voltage noise budgeting of a serial link system. Here we will conservatively assume that all distributions combine in a worst-case manner. The system consists of a transmitter with a 2-tap FIR filter which sends NRZ bits over a channel to a receiver modeled as a simple amplifier followed by a comparator. Each receiver block has a noise component which should be referred to the receiver input.

Attenuation = 1 − Σ taps = 0.8



$\sigma_{in} = \sqrt{(0.5)^2 + \left(\frac{1}{2}\right)^2} = 0.707mV$

Complete the following noise budget table assuming a TX peak differential swing of 1V_{ppd} and a target BER=10^{-12}. You can refer to the Q_{BER} table on page 2 if needed. (15 points)

Parameter	**K_n**	**RMS**	**Value (BER=10^{-12})**
Peak Differential Swing, V_{swing}			1V
RX Offset + Sensitivity			5mV
Power Supply Noise			5mV
Residual ISI	0.05		= 50mV
Crosstalk	0.05		= 50mV
Random Noise		= 0.707mV	= 9.95mV
Attenuation (TX FIR)	= 0.8		= 800mV
Total Noise			= 919.95mV
Differential Eye Height Margin			= 80.05mV

What is the minimum peak differential swing, V_{swing}, for a **BER=10^{-12}**, i.e. as the differential eye height margin goes to zero? (15 points)

$V_{swing}(1 - \Sigma K_n) - \text{Fixed Noise} \geq 0$

$V_{swing} \geq \frac{\text{Fixed Noise}}{1 - \Sigma K_n} = \frac{19.95mV}{1 - 0.9} = 199.5mV$

What is the minimum peak differential swing, V_{swing}, for a **BER=10^{-15}**, i.e. as the differential eye height margin goes to zero? (5 points)

For BER = 10^{-15} ⟹ Random Noise = 15.882(0.707) = 11.23mV

$V_{swing} \geq \frac{21.23mV}{1-0.9} = 212.3mV$

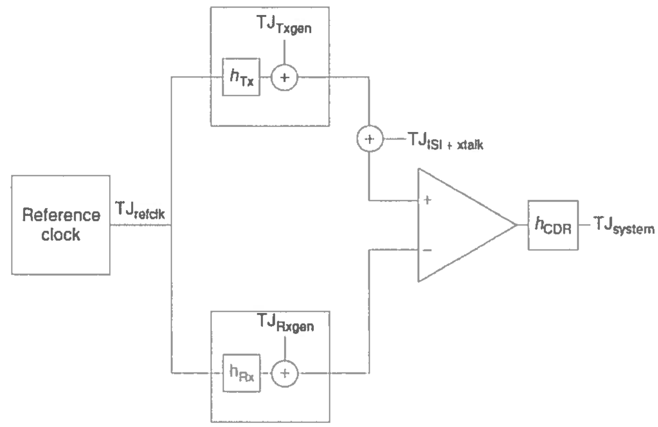
Problem 3 (35 points)

This problem involves computing a jitter budget for the system below, which should operate at a **10^{-15} BER.**

a) Complete the system jitter budget table below.

b) What is the maximum possible data rate?

10^{-15} BER ⇒ Q = 15.882



Parameter	**Term**	**σ_{RJ} (ps)**	**$DJ_{\delta\delta}$ (ps)**	**TJ (BER=10^{-15})**
Reference Clock	TJ_{refclk}	2.1	27.9	61.25
Transmitter	TJ_{TXgen}	1.3	30.1	50.75
Channel	$TJ_{ISI+xtalk}$	0	43	43
Receiver	TJ_{RXgen}	1.5	65.7	89.52
TOTAL (BER=10^{-15})		2.89	166.7	212.60

Max Data Rate $= \frac{1}{212.6ps} = 4.70 Gb/s$

Max Data Rate (**BER = 10^{-15}**) = 4.70Gb/s

Scratch Paper