Texas A&M University
Department of Electrical and Computer Engineering

ECEN 720 – High-Speed Links

Spring 2015

Exam #2

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are **7** pages in your exam
- You may use one 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

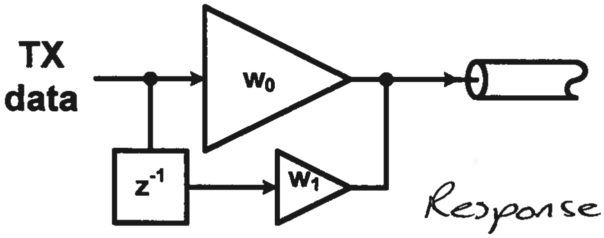
UIN:

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)
TX FIR Equalization

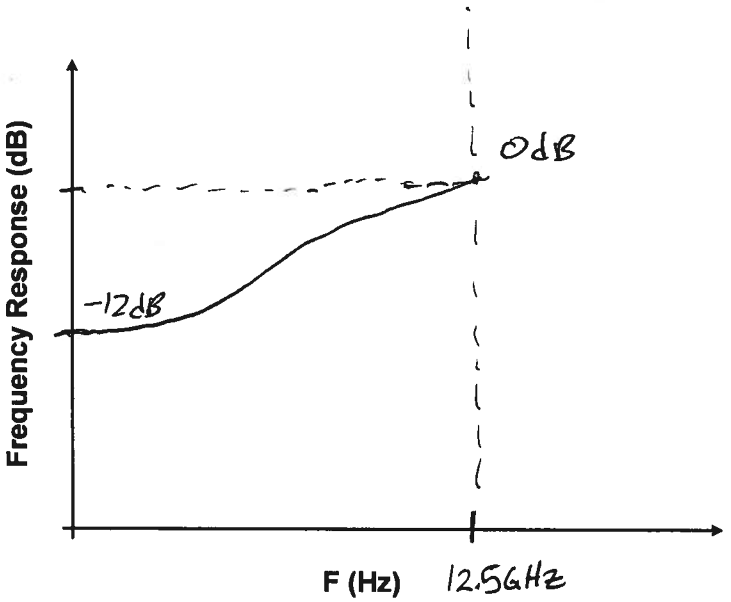
a) Give the equalizer coefficients to realize 12dB of frequency peaking at the Nyquist frequency (relative to the DC response) for 50Gb/s PAM4 modulation. Assume that $|W_0| + |W_1| = 1$.
b) Sketch the equalizer magnitude response out to the Nyquist frequency. Label the magnitude value in dB at low frequencies and at the Nyquist frequency.



Response at Nyquist Frequency is $W_0 - W_1$

Response at DC is $W_0 + W_1$

$W_0 = 5/8$
$W_1 = -3/8$



For 12dB of peaking relative to DC : $\frac{W_0 - W_1}{W_0 + W_1} = 4$

Peak Power Constraint : $|W_0| + |W_1| = 1$, this should occur w/ Nyquist frequency data. Thus

$$\frac{W_0 - W_1}{W_0 + W_1} = \frac{1}{W_0 + W_1} = 4, \quad \begin{matrix} W_0 + W_1 = \frac{1}{4} \\ W_0 - W_1 = 1 \end{matrix} \Rightarrow \begin{matrix} W_0 = \frac{5}{8} \\ W_1 = -\frac{3}{8} \end{matrix}$$

Problem 2 (35 points)

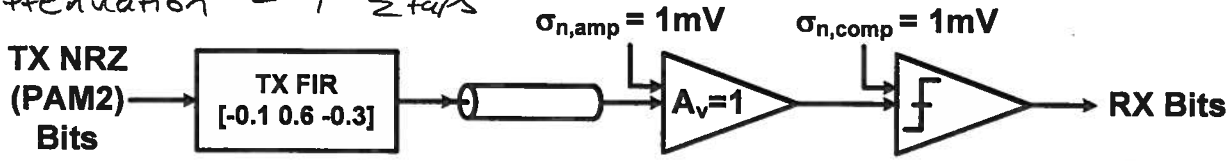
This problem compares the voltage noise budgeting of a serial link system with PAM2 and PAM4 modulation. Here we will conservatively assume that all distributions combine in a worst-case manner.

PAM2 System

The system consists of a transmitter with a 3-tap FIR filter which sends NRZ (PAM2) 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 $= 1 - \sum \text{taps} = 1 - 0.2 = 0.8$

$\sigma_{Rx} = \sqrt{1^2+1^2} = 1.41$m



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. (10 points)

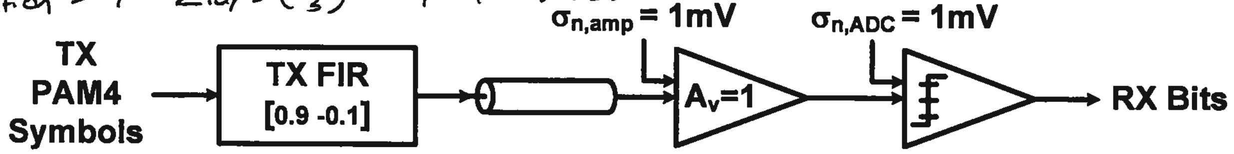
Parameter	K_n	RMS	Value (BER=10^{-12})
Peak Differential Swing, V_{swing}			1V
RX Offset + Sensitivity			5mV
Power Supply Noise			5mV
Residual ISI	0.05		= 50mV
Crosstalk	0.05		= 50mV
Random Noise		= 1.41mV	= 19.9mV
Attenuation (TX FIR)	= 0.8		= 800mV
Total Noise			= 929.9mV
Differential Eye Height Margin			= 70.1mV

PAM4 System

The system consists of a transmitter with a 2-tap FIR filter which sends PAM4 symbols over a channel to a receiver modeled as a simple amplifier followed by a 2-bit ADC. Each receiver block has a noise component which should be referred to the receiver input.

Attenuation = $1 - \Sigma_{taps}\left(\frac{1}{3}\right) = 1 - (0.8)\left(\frac{1}{3}\right) = 0.733$

$\sigma_{Rx} = \sqrt{1^2+1^2} = 1.41mV$



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. (10 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 (compute from max. transition)	0.05		= 50mV
Crosstalk (compute from max. transition)	0.05		= 50mV
Random Noise		= 1.41mV	= 19.9mV
Attenuation (from modulation)	= 0.733		= 733mV
Total Noise			= 862.9mV
Differential Eye Height Margin			= 137.1mV

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 for both the PAM2 and PAM4 systems? (10 points)

$$V_{swing}\left(1 - \Sigma K_N\right) \geq \text{Fixed Noise}$$

$$V_{swing} \geq \frac{\text{Fixed Noise}}{1 - \Sigma K_N}$$

$$\text{PAM2}: V_{swing} \geq \frac{29.9mV}{1-0.9} = 299mV$$

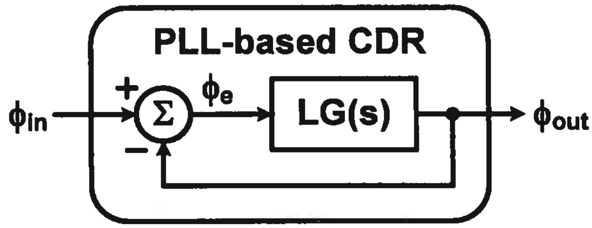
$$\text{PAM4}: V_{swing} \geq \frac{29.9mV}{1-0.833} = 179mV$$

Min. V_{swing} (PAM2) = 299mV

Min. V_{swing} (PAM4) = 179mV

Problem 3 (35 points)

This problem investigates a simple PLL-based CDR which can be modeled by the simplified transfer function below. Assume that the only source of random noise in the PLL-based CDR below is from the VCO, which has $\kappa = 5\times10^{-9}\sqrt{s}$ and the PLL has a loop bandwidth f_L=10MHz. What is the **self-referenced accumulated rms jitter,** $\sigma_T = \sqrt{2}\sigma_x$?



$$\frac{\phi_{out}(s)}{\phi_{in}(s)} = \frac{LG(s)}{1+LG(s)} \approx \frac{1}{1+\frac{s}{2\pi f_L}}$$

$$\sigma_T = \sqrt{2}\,\sigma_x = K\sqrt{\Delta T} = K\sqrt{\frac{1}{2\pi f_{PLL}}}$$

$$= 5\times10^{-9}\sqrt{s}\sqrt{\frac{1}{2\pi(10MHz)}} = 631fs$$

σ_T = 631fs

Assume that the PLL is used in a 25Gb/s NRZ half-rate system and the 12.5GHz VCO has a duty cycle error of ±1ps which you can model as a deterministic jitter component, DJ=2ps. Including this DJ and the **transmit-clock referenced σ**

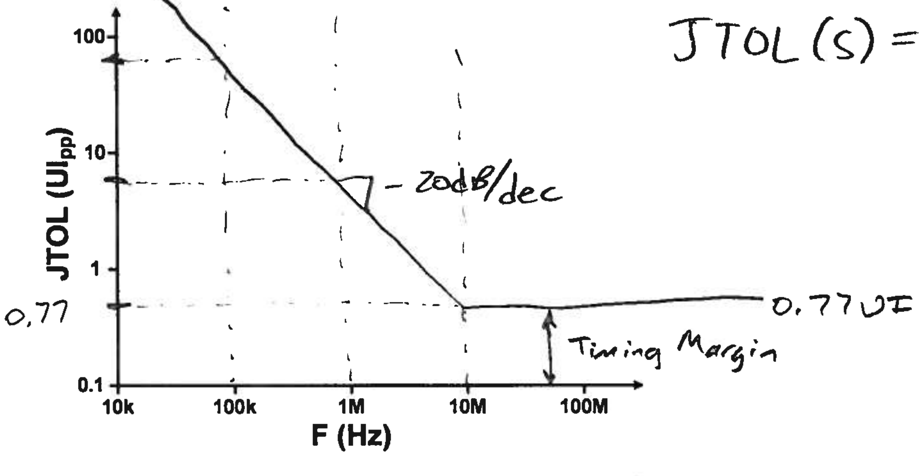
Total jitter $(BER=10^{-15}) = DJ + Q\sigma_x = 2ps + 15,882\left(\frac{631fs}{\sqrt{2}}\right) = 9.09ps$

Timing Margin = 40ps − 9.09ps = 30.91ps = 0.77UI

25Gb/s timing margin (BER=10^{-15}) = 30.91p

Using this timing margin value and assuming that the input data has ONLY a sinusoidal jitter component, sketch the jitter tolerance plot versus frequency. Label the high frequency timing margin and the key frequencies and slopes in the plot.

$$JTOL(s) = \frac{TM}{1 - \frac{\phi_{out}(s)}{\phi_{in}(s)}}$$



Scratch Paper