Texas A&M University
Department of Electrical and Computer Engineering

ECEN 720 – High-Speed Links

Spring 2025

Exam #2

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- Please write your name in the space provided below
- Please verify that there are **7** pages in your exam
- Good Luck!

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

Name: SAM PALERMO

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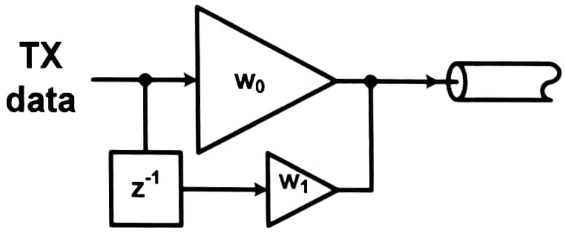
TABLE 13-1. Q_{BER} as a Function of the Bit Error Rate

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 (35 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 $W_0 + W_1$

$W_0 = 5/8$

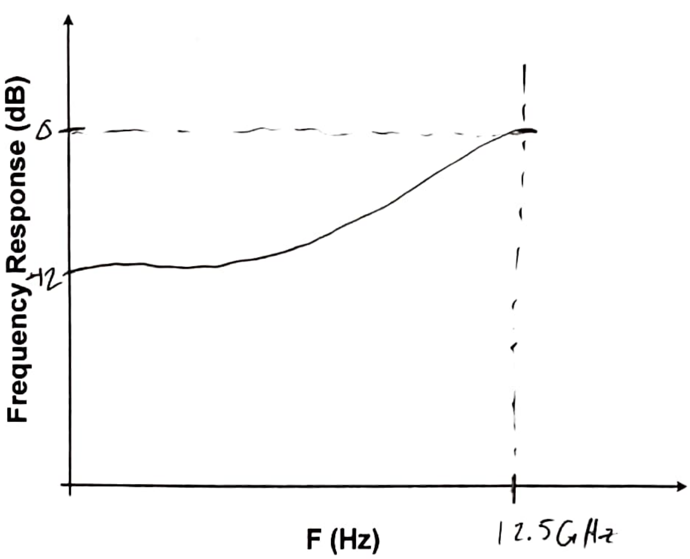
$W_1 = -3/8$

For 12dB 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.

$W_0 - W_1 = 1 \qquad W_0 + W_1 = \frac{1}{4}$

$\Rightarrow W_0 = \frac{5}{8}, \; W_1 = -\frac{3}{8}$

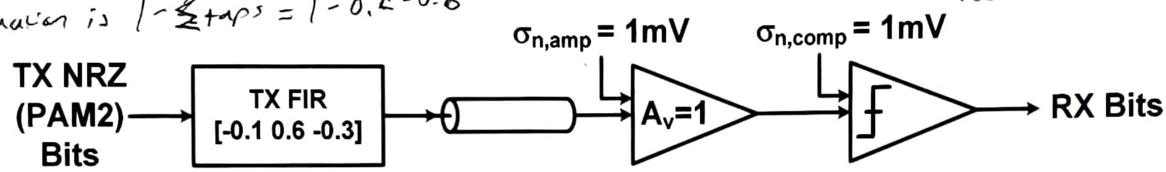


Problem 2 (35 points)
This problem compares the voltage noise budgeting of a serial link system with PAM2 and PAM4 modulation. Here we will conservatively assume that all distributions combine in a worst-case manner.

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.

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

Attenuation is $1 - \sum taps = 1 - 0.2 = 0.8$



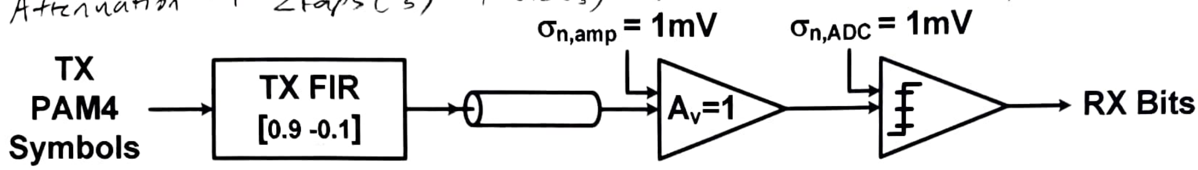
Complete the following noise budget table assuming a TX peak differential swing of $1V_{ppd}$ and a target BER=10^{-12}. You can refer to the Q_{BER} table on page 2 if needed. (10 points)

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 $= 1 - \Sigma \text{taps}(\frac{1}{3}) = 1 - 0.8(\frac{1}{3}) = 0.733$ $\sigma_{Rx} = \sqrt{1^2+1^2} = 1.41\text{mV}$



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 (TX FIR and 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)

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

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

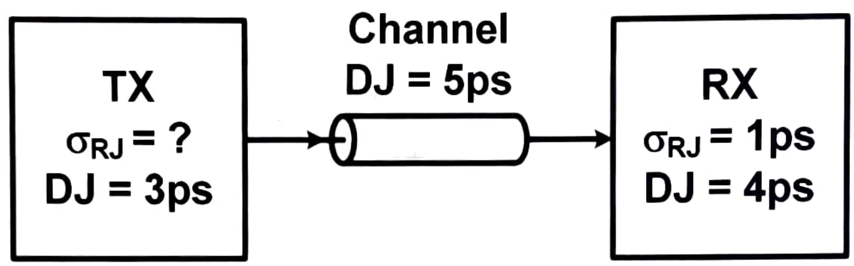
PAM2: $V_{swing} \geq \frac{29.9\text{mV}}{1-0.9} = 299\text{mV}$ PAM4: $V_{swing} \geq \frac{29.9\text{mV}}{1-0.833} = 179\text{mV}$

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

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

Problem 3 (30 points)

This problem involves designing a TX PLL loop bandwidth to satisfy a system jitter budget, given the following jitter components from the TX, channel, and RX. What is the maximum TX random rms jitter, $\sigma_{RJ,TX}$, for a BER=10^{-12} at a 25Gb/s data rate? Assume that the only source of random noise in the TX PLL below is from the VCO, which has $\kappa = 10^{-8}\sqrt{s}$, and that the jitter σ of interest is closed-loop and referenced to an ideal clock. What is the necessary TX PLL loop bandwidth to satisfy the system jitter budget?



$$DJ_{,tot} + Q\sigma_{j,tot} = \frac{1}{DR}$$

$$\sigma_{j,tot} = \frac{\frac{1}{DR} - DJ_{,tot}}{Q} = \frac{40ps - 12ps}{14.069} = 1.99ps$$

$$\sigma_{j,tot} = \sqrt{\sigma_{TX}^2 + \sigma_{Rx}^2} \Rightarrow \sigma_{TX} = \sqrt{\sigma_{j,tot}^2 - \sigma_{Rx}^2} = \sqrt{1.99_{ps}^2 - 1_{ps}^2} = 1.72ps$$

$$\sigma_x = K\sqrt{\frac{1}{2\pi f_{PLL}}}$$

$$f_{PLL} = \frac{K^2}{2\pi\sigma^2} = \frac{(10^{-8}\sqrt{s})^2}{2\pi(1.72ps)^2} = 5.38MHz$$

Max $\sigma_{RJ,TX}$ (w/ DR=25Gb/s) = 1.72ps

PLL Loop Bandwidth (Hz) = 5.38MHz