Texas A&M University
Department of Electrical and Computer Engineering

ECEN 720 – High-Speed Links

Spring 2021

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		25
2		25
3		25
4		25
Total		**100**

Name: SAM PALERMO

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

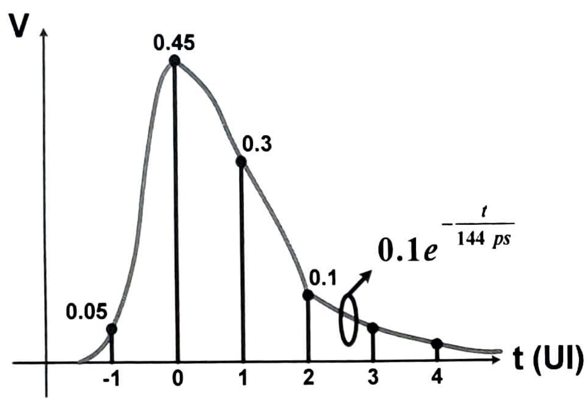
BER	Q_{BER}	BER	Q_{BER}	BER	Q_{BER}
1×10^{-3}	6.180	1×10^{-10}	12.723	1×10^{-17}	16.987
1×10^{-4}	7.438	1×10^{-11}	13.412	1×10^{-18}	17.514
1×10^{-5}	8.530	1×10^{-12}	14.069	1×10^{-19}	18.026
1×10^{-6}	9.507	1×10^{-13}	14.698	1×10^{-20}	18.524
1×10^{-7}	10.399	1×10^{-14}	15.301	1×10^{-21}	19.010
1×10^{-8}	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

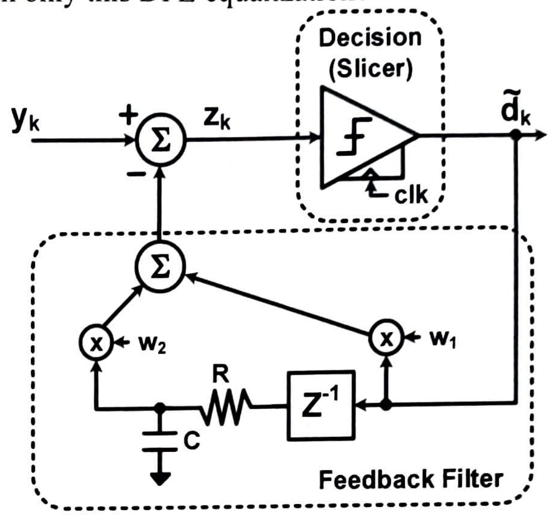
Problem 1 (25 points)
A channel has a 10Gb/s pulse response, $y^{(1)}$, below for a "1" bit. Assume that the ISI beginning at the second post-cursor position is equal to

$$0.1e^{-\frac{t}{144ps}}$$

The DFE shown below is used for equalization.

a) Given the DFE feedback filter design parameters to provide the maximum eye opening. Assume ideal delay cells.
b) What is the eye height that you can achieve with only this DFE equalization?





For maximum eye opening: W_1 = 1st post-cursor ISI = 0.3
The RC filter weighted by W_2 should cancel all ISI terms starting with the 2nd post cursor.
The τ of the RC filter should equal the τ of the ISI

$$\tau = RC = 144ps \Rightarrow C = 100fF, \ R = 1.44k\Omega$$

The weighting coefficient W_2 should yield peak amplitude 0.1.
The peak response of the LPF is

$$W_2\left(1 - e^{-\frac{T_b}{\tau}}\right) = 0.1$$

$$W_2 = \frac{0.1}{1 - e^{-\frac{100p}{144p}}} = 0.2$$

The DFE should cancel all but the pre-cursor ISI
$\Rightarrow$ Eye height = 2(Cursor − Σ|pre-cursor|)
= 2(0.45 − 0.05) = 0.8

W_1 = 0.3

W_2 = 0.2

R = 1.44kΩ

C = 100fF

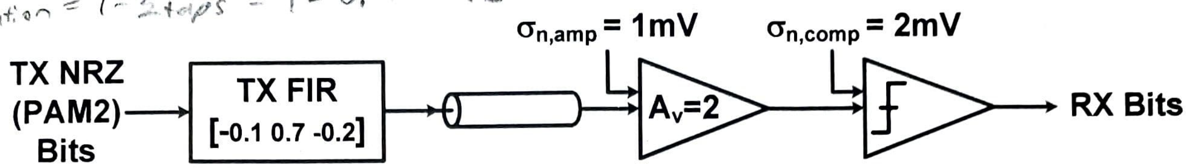
Eye height achievable with DFE = 0.8V

Problem 2 (25 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 3-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.

$\sigma_{Rx} = \sqrt{1^2 + \left(\frac{2}{2}\right)^2} = 1.41mV$

Attenuation $= 1 - \Sigma taps = 1 - 0.4 = 0.6$



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			10mV
Power Supply Noise			10mV
Residual ISI	0.1		= 100mV
Crosstalk	0.1		= 100mV
Random Noise		= 1.41mV	= 19.84mV
Attenuation (TX FIR)	= 0.6		= 600mV
Total Noise			= 839.84mV
Differential Eye Height Margin			= 160.16mV

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?

$$V_{swing} \geq \frac{\text{Fixed Noise}}{1 - \Sigma K_N} = \frac{39.84mV}{1 - 0.8} = 199.2mV$$

What is the minimum peak differential swing, V_{swing}, for a **BER=10^{-18}**, i.e. as the differential eye height margin goes to zero?

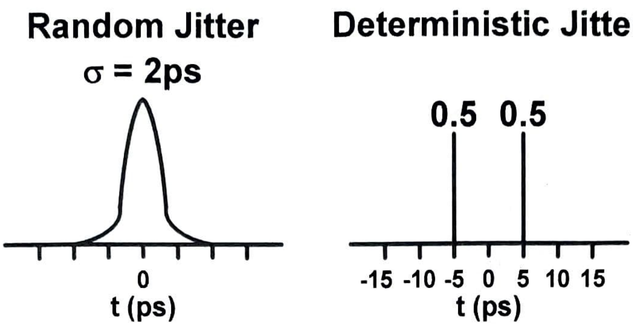
For BER $= 10^{-18}$ Random Noise $\Rightarrow 1.41mV(17.514) = 24.7mV$

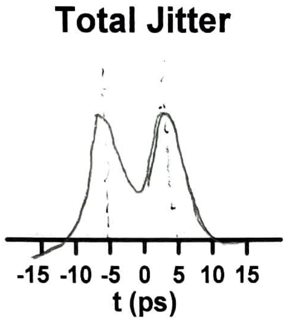
$$V_{swing} \geq \frac{44.7mV}{1 - 0.8} = 223.5mV$$

Problem 3 (25 points)

This problem involves the timing noise budgeting of serial link systems.

i. System jitter can be decomposed into the following random and deterministic jitter PDFs. Qualitatively sketch the total jitter PDF and give the total jitter at a 10^{-15} **BER.**



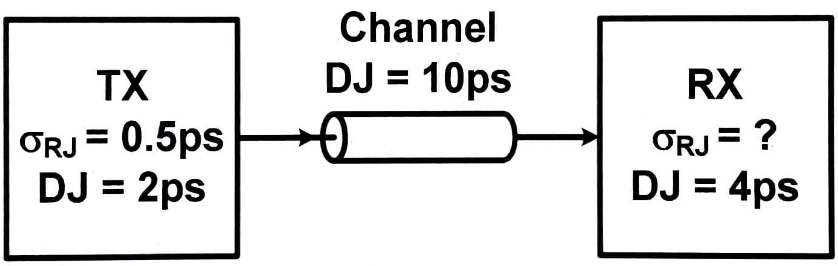


$TJ = DJ_{\delta\delta} + Q_{BER}\sigma_{RJ}$

$= 10ps + 15.882(2ps) = 41.8ps$

TJ (**BER** = 10^{-15}) = 41.8 ps

ii. Given the following jitter components from the TX, channel, and RX. What is the maximum RX random rms jitter, $\sigma_{RJ,RX}$, for a **BER=10^{-12}** at a 25Gb/s data rate?



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

$\sigma_{j,tot} = \frac{\frac{1}{DR} - DJ_{,tot}}{Q_{BER}} = \frac{40ps - 16ps}{14.069} = 1.71ps$

$\sigma_{j,tot} = \sqrt{\sigma_{TX}^2 + \sigma_{RX}^2} \Rightarrow \sigma_{RX} = \sqrt{\sigma_{j,tot}^2 - \sigma_{TX}^2} = \sqrt{(1.71ps)^2 - (0.5ps)^2}$

Max $\sigma_{RJ,RX}$ (w/ DR=25Gb/s) = 1.64 ps

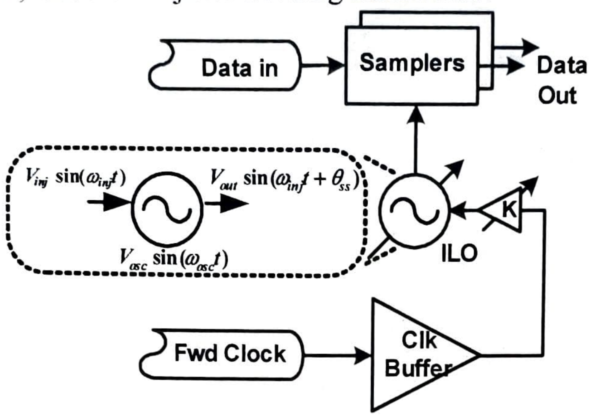
Problem 4 (25 points)

The figure below models a forwarded-clock system with a receiver de-skew circuit that consists of an injection locked LC oscillator (ILO).

a) If the ILO has a 5GHz center frequency and a $Q = 6$, what is the injection strength required for a maximum jitter tracking bandwidth of 200MHz?

b) Using the injection strength from part (a), what frequency offset should the injection signal have to generate a 45° phase shift?

c) With a 45° phase shift, what is the jitter tracking bandwidth?



KEY EQUATIONS

$$\omega_p = \sqrt{\frac{K^2}{A^2} - \Delta\omega^2}$$

$$\theta_{ss} = sin^{-1}\left(\frac{A}{K}\Delta\omega\right)$$

$$A = \frac{2Q}{\omega_o} = \frac{12}{2\pi(5GHz)} = 382ps$$

a. For max JTB $\Rightarrow \omega_p = \frac{K}{A}$

$$K = A\omega_p = \frac{2Q}{\omega_o}\omega_p = \frac{2(6)}{2\pi(5GHz)}(2\pi\ 200MHz)$$

$K = 0.48$

b. $$\Delta\omega = \frac{K}{A}\sin\theta_{ss} = \frac{0.48(2\pi)(5GHz)}{2(6)}\sin 45° = 888Mrad/s = 141MHz$$

c. $$\omega_p = \sqrt{\frac{K^2}{A^2} - \Delta\omega^2} = \sqrt{\frac{(0.48)^2}{(382ps)^2} - (888Mrad/s)^2} = 889Mrad/s = 142MHz$$

K (max JTB = 200MHz) = 0.48

Δf (θ_{ss} = 45°) = 141MHz

JTB (θ_{ss} = 45°) = 142MHz