Texas A&M University
Department of Electrical and Computer Engineering

ECEN 720 – High-Speed Links

Spring 2017

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		30
3		30
4		10
Total		**100**

Name: SAM PALERMO

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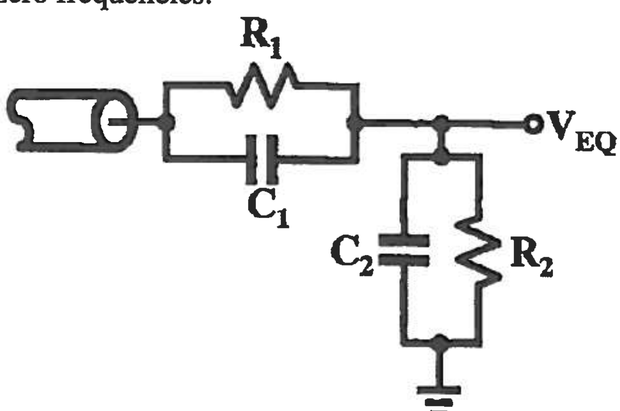
TABLE 13-1. Q_{BER} as a Function of the Bit Error Rate

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 (30 points)
RX Passive CTLE Equalization
Design the passive CTLE below to achieve 12dB peaking, HF Gain = 0.9V/V, and a 2GHz zero frequency. Use a total resistance (R_1+R_2) of 500Ω. Sketch the Bode plot and label the pole and zero frequencies.



$$H(s) = \frac{R_2}{R_1+R_2} \frac{1 + R_1C_1s}{1 + \frac{R_1R_2}{R_1+R_2}(C_1+C_2)s}$$

$$HF\ gain = \frac{C_1}{C_1+C_2} = 0.9\ V/V = -0.915d$$

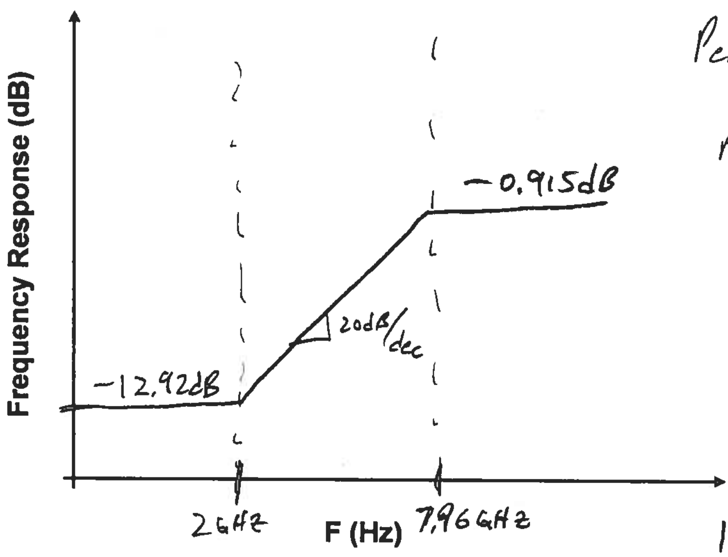
$$LF\ gain = \frac{R_2}{R_1+R_2} = 0.226\ V/V = -12.92d$$

$$Peaking = \frac{HFgain}{LFgain} = 12dB = 3.98$$

$$Peaking = (0.9)\left(\frac{500\Omega}{R_2}\right) = 3.98$$

$$R_2 = 113\Omega$$

$$R_1 = 387\Omega$$



$$W_z = 2\pi(2GHz) = \frac{1}{R_1C_1} \qquad W_p = \frac{1}{\frac{R_1R_2}{R_1+R_2}(C_1+C_2)} = 50G\ rad/s = 7.96GHz$$

$$C_1 = \frac{1}{2\pi(2GHz)(387\Omega)} = 206fF$$

$$C_2 = \frac{0.1}{0.9}C_1 = \frac{206fF}{9} = 22.9fF$$

R_1 = 387Ω

R_2 = 113Ω

C_1 = 206fF

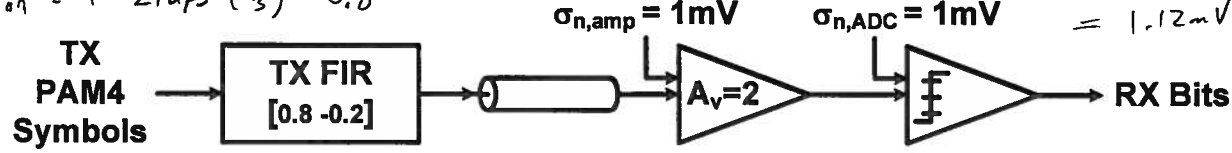
C_2 = 22.9fF

Problem 2 (30 points)

This problem involves the voltage noise budgeting of a serial link system with PAM4 modulation. 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 PAM4 symbols over a channel to a receiver modeled as a simple buffer followed by a 2-bit ADC. Each receiver block has a noise component which should be referred to the receiver input.

$\sigma_{in} = \sqrt{1 + \left(\frac{1}{2}\right)^2} = 1.12mV$

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



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. (20 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 (compute from max. transition)	0.05		= 50mV
Crosstalk (compute from max. transition)	0.05		= 50mV
Random Noise		= 1.12mV	= 15.76mV
Attenuation (from TX FIR & modulation)	= 0.8		= 800mV
Total Noise			= 935.76mV
Differential Eye Height Margin			= 64.24mV

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 the PAM4 system? (10 points)

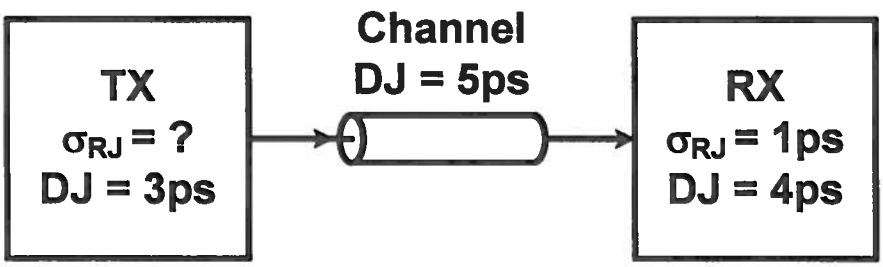
$$V_{swing}\left(1 - \sum K_N\right) \geq \text{Fixed Noise}$$

$$V_{swing} \geq \frac{\text{Fixed Noise}}{1 - \sum K_N} = \frac{35.76mV}{1 - 0.9}$$

Min. V_{swing} (PAM4) = 358mV

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?



$$BER = 10^{-12} \Rightarrow Q = 14.069$$

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

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

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

For closed-loop PLL referenced to an ideal clock

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

$$f_{PLL} = \frac{\kappa^2}{4\pi\sigma_x^2} = \frac{(10^{-8}\sqrt{s})^2}{4\pi(1.72ps)^2} = 2.69MHz$$

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

PLL Loop Bandwidth (Hz) = 2.69MHz

Problem 4 (10 points)

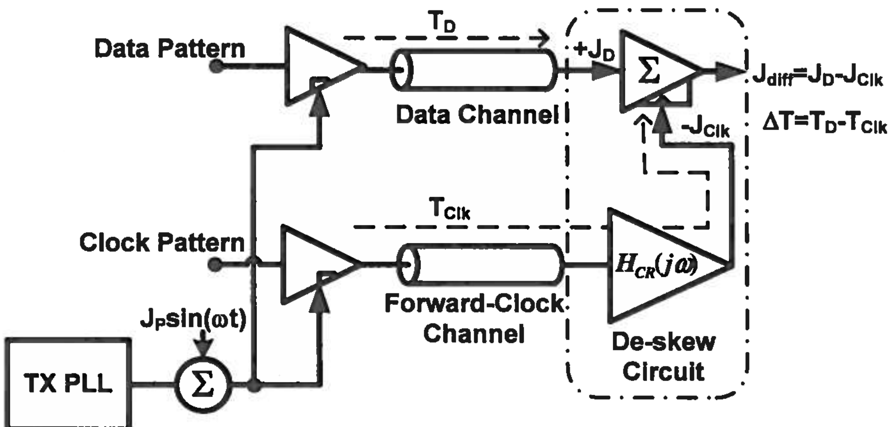
The figure below models a forwarded-clock system with a receiver de-skew circuit with a jitter transfer function of $H_{CR}(j\omega)$ and a skew between the data channel and clock channel of ΔT. Assuming a common sinusoidal jitter component with amplitude, J_p, and frequency, ω, on the forwarded clock and the data, the magnitude of the peak differential jitter at the receiver sampler is equal to

$$\text{Peak } J_{diff} = J_p \left|1 - e^{-j\omega\Delta T}\left|H_{CR}(j\omega)\right|\right|$$

Assuming that the de-skew circuit displays an all-pass jitter transfer characteristic, i.e. $|H_{CR}(j\omega)| = 1$, calculate the following:

i) What is the Peak J_{diff} if $\Delta T = 0$?

ii) If the jitter frequency is ω=2π(150MHz), what is the allowable skew, ΔT, for the Peak $J_{diff} = \frac{J_p}{2}$?



i) $w/\Delta T = 0 \Rightarrow$ Peak $J_{diff} = J_p|1-e^0| = 0$

ii) Peak $J_{diff} = J_p\left|1-e^{-j\omega\Delta T}\right| = J_p/2$

$$\left|1 - e^{-j\omega\Delta T}\right| = \frac{1}{2}$$

$$\left|1 - \cos\omega\Delta T + j\sin\omega\Delta T\right| = \frac{1}{2}$$

$$\sqrt{1 - 2\cos\omega\Delta T + \cos^2\omega\Delta T + \sin^2\omega\Delta T} = \frac{1}{2}$$

$$1 - \cos\omega\Delta T = \frac{1}{8}$$

$$\cos\omega\Delta T = \frac{7}{8}$$

$$\Delta T = \frac{\cos^{-1}\left(\frac{7}{8}\right)}{\omega} = \frac{\cos^{-1}(7/8)}{2\pi(150MHz)}$$

$$= 536ps$$

Peak J_{diff} (w/ $\Delta T = 0$) = ∅

ΔT (w/ $J_{diff} = J_P/2$ for ω = 2π(150MHz)) = 536ps

Scratch Paper