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!

<table>
<thead>
<tr>
<th>Problem</th>
<th>Score</th>
<th>Max Score</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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Name: ____________________________

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<tbody>
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<td>$1 \times 10^{-14}$</td>
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<td>15.882</td>
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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 (R1+R2) of 500Ω. Sketch the Bode plot and label the pole and zero frequencies.

\[ H(s) = \frac{R_2}{R_1 + R_2} \cdot \frac{1 + R_1 C_1 s}{1 + \frac{R_1 R_2}{R_1 + R_2} (C_1 + C_2) s} \]

HF gain = \( \frac{C_1}{C_1 + C_2} = 0.9\ \text{V/V} = -0.915\ \text{dB} \)

LF gain = \( \frac{R_2}{R_1 + R_2} = 0.226\ \text{V/V} = -12.92\ \text{dB} \)

Peaking = \( \frac{\text{HF gain}}{\text{LF gain}} = 12\ \text{dB} = 3.98 \)

\( \text{Peaking} = (0.9)(\frac{\text{freq}}{R_2}) = 3.98 \)

\( R_2 = 113\ \Omega \)

\( R_1 = 387\ \Omega \)

\( W_2 = 2\pi (2\ \text{GHz}) = \frac{1}{R_1 C_1} \)

\( \frac{1}{\text{freq}} = \frac{R_1 R_2}{R_1 + R_2} (C_1 + C_2) = 7.96\ \text{GHz} \)

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

\( C_2 = \frac{0.1 C_1}{0.9} = \frac{206\ \text{fF}}{9} = 22.9\ \text{fF} \)

\( R_1 = 387\ \Omega \)

\( R_2 = 113\ \Omega \)

\( C_1 = 206\ \text{fF} \)

\( C_2 = 22.9\ \text{fF} \)
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.

\[
\text{Attenuation} = 1 - \text{3 taps} \left( \frac{1}{2} \right) = 0.8
\]

\[
\sigma_{n,\text{amp}} = 1\text{mV} \quad \sigma_{n,\text{ADC}} = 1\text{mV}
\]

\[
\sigma_n = \sqrt{1 + \left( \frac{1}{2} \right)^2} = 1.12\text{mV}
\]

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. (20 points)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>K_n</th>
<th>RMS</th>
<th>Value (BER=10^{-12})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Differential Swing, V_{swing}</td>
<td></td>
<td>1V</td>
<td></td>
</tr>
<tr>
<td>RX Offset + Sensitivity</td>
<td></td>
<td>10mV</td>
<td></td>
</tr>
<tr>
<td>Power Supply Noise</td>
<td></td>
<td>10mV</td>
<td></td>
</tr>
<tr>
<td>Residual ISI (compute from max. transition)</td>
<td>0.05</td>
<td>= 50mV</td>
<td></td>
</tr>
<tr>
<td>Crosstalk (compute from max. transition)</td>
<td>0.05</td>
<td>= 50mV</td>
<td></td>
</tr>
<tr>
<td>Random Noise</td>
<td></td>
<td>= 1.12mV</td>
<td>= 15.76mV</td>
</tr>
<tr>
<td>Attenuation (from TX FIR &amp; modulation)</td>
<td>0.8</td>
<td>= 900mV</td>
<td></td>
</tr>
<tr>
<td>Total Noise</td>
<td></td>
<td>= 935.76mV</td>
<td></td>
</tr>
<tr>
<td>Differential Eye Height Margin</td>
<td></td>
<td>= 64.24mV</td>
<td></td>
</tr>
</tbody>
</table>

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)

\[
V_{\text{swing}} \left( 1 - 4K_n \right) \geq \text{Fixed Noise}
\]

\[
V_{\text{swing}} \geq \frac{\text{Fixed Noise}}{1 - 4K_n} = \frac{35.76\text{mV}}{1 - 0.9} = \frac{35.76\text{mV}}{0.1}
\]

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 $\kappa = 10^{-8} \sqrt{5}$, and that the jitter $\sigma$ 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?

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

$$0.5 \sigma_{\text{J},+\text{to}} + Q \sigma_{\text{J},-\text{to}} = \frac{1}{DR}$$

$$\sigma_{\text{J},+\text{to}} = \frac{1}{DR} - 0.5 \sigma_{\text{J},-\text{to}} = \frac{4 \text{ps} - 12 \text{ps}}{14.069} = 1.99 \text{ps}$$

$$\sigma_{\text{J},-\text{to}} = \sqrt{\sigma_{\text{TX}}^2 + \sigma_{\text{RX}}^2} \implies \sigma_{\text{TX}} = \sqrt{\sigma_{\text{J},+\text{to}}^2 - \sigma_{\text{RX}}^2} = \sqrt{(1.99)^2 - (1)^2} = 1.72 \text{ps}$$

For closed-loop PLL referenced to an ideal clock

$$\sqrt{2} \sigma_{\text{X}} = \kappa \sqrt{\frac{1}{2f_{\text{PLL}}}}$$

$$f_{\text{PLL}} = \frac{K^2}{4\pi \sigma_{\text{X}}^2} = \frac{(10^{-8} \sqrt{5})^2}{4\pi (1.72 \text{ps})^2} = 2.69 \text{ MHz}$$

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

PLL Loop Bandwidth (Hz) = 2.69 MHz
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 $\Delta T$. Assuming a common sinusoidal jitter component with amplitude, $J_p$, and frequency, $\omega$, on the forwarded clock and the data, the magnitude of the peak differential jitter at the receiver sampler is equal to

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

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 $J_{\text{diff}}$ if $\Delta T = 0$?

ii) If the jitter frequency is $\omega = 2\pi(150\text{MHz})$, what is the allowable skew, $\Delta T$, for the Peak $J_{\text{diff}} = \frac{J_p}{2}$?

\[ \Delta T = \frac{\cos^{-1} \left( \frac{7}{8} \right)}{2\pi(150\text{MHz})} = 5.36\text{ps} \]

\[ \text{Peak } J_{\text{diff}} (w/ \Delta T = 0) = 0 \]

\[ \Delta T (w/ J_{\text{diff}} = J_p/2 \text{ for } \omega = 2\pi(150\text{MHz})) = 5.36\text{ps} \]
Scratch Paper