PCI-SIG ENGINEERING CHANGE NOTICE

<table>
<thead>
<tr>
<th>TITLE:</th>
<th>OCuLink Cable Spec ECN</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATE:</td>
<td>March 23, 2018</td>
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<tr>
<td>AFFECTED DOCUMENT:</td>
<td>OCuLink 1.0</td>
</tr>
<tr>
<td>SPONSOR:</td>
<td>Alex Haser (Molex), Jay Neer (Molex)</td>
</tr>
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</table>

**Part I:**

1. **Summary of the Functional Changes**
   
The IL/ fitted IL requirements have been clarified. The language of this portion of the spec has been reworked to eliminate confusion and provide uniformity in the subsections included in the following document.

2. **Benefits as a Result of the Changes**
   
The signal integrity requirements necessary for OCuLink compliance have been clarified. The method for calculating fitted IL has been simplified. The equations for limit lines have been redefined to report values as losses (positive values).

3. **Assessment of the Impact**
   
This section of the spec has been made easier to follow and is therefore less likely to misinterpret.

4. **Analysis of the Hardware Implications**
   
Connectors and cables must adhere to the fully specified signal integrity requirements described in the following text.

5. **Analysis of the Software Implications**
   
None, this change does not affect software.

**Part II:** Changes are reflected in Sections 7.3 through 7.3.6 (begins on the next page).
7.3 **Mated Cable Assembly** Electrical Specifications

The OCuLink cable assembly contains insulated conductors terminated in a connector at each end for use as a link segment between host boards. This cable assembly is primarily intended as a point-to-point interface between host boards using controlled impedance cables. All mated cable assembly measurements are to be made between TP1 and TP4 with CCB test fixtures, which includes a connector mated to either end of the cable assembly. CCB test fixtures are to be removed before comparing measured performance against the specifications listed in this section. It is recommended measurements be de-embedded using a TRL calibration (see Section 7.4 for more information on de-embedding). All requirements are to be met when analyzed in an 85 Ω reference frame.

- These mated cable assembly specifications are based upon twin axial cable characteristics. Table 7-1 provides a summary of the cable assembly characteristics and references addressing each parameter. Reported values are at 4 GHz. Limits apply to 2.5 GT/s, 5.0 GT/s, and 8.0 GT/s data rates and are written in terms of baud frequency. Baud frequencies are 2.5 GHz, 5 GHz, and 8 GHz for the 2.5 GT/s, 5.0 GT/s, and 8.0 GT/s data rates, respectively. Note that plots show loss (positive values).

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<th>Value</th>
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<td>7.3.2</td>
<td>dB</td>
</tr>
<tr>
<td>Minimum insertion loss</td>
<td>7.3.2</td>
<td>0</td>
<td>dB</td>
</tr>
<tr>
<td>Minimum differential return loss</td>
<td>7.3.3</td>
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<td>OCuLink Maximum Total Cable Assembly Lane-to-Lane skew (Sc)</td>
<td>7.3.8</td>
<td>0.96</td>
<td>ns MAX</td>
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### 7.3.1. Characteristic Impedance and Reference Impedance

The nominal differential characteristic impedance of the cable assembly is 85 Ω. The differential reference impedance for cable assembly **Specifications** must be 85 Ω.
7.3.2. **Pinout for x4 Fixed Internal Connector**

**Mated Cable Assembly Differential Insertion Loss**

The differential insertion loss of each pair of a mated OCuLink cable assembly, in dB, must be less than the maximum limit defined in Equation 7-1, as illustrated in Figure 7-5.

### 2.5 GT/s, 5.0 GT/s, and 8.0 GT/s:

**Equation 7-1**  
\[ ILC_{\text{cable}}(f) = 2 + 5.5\sqrt{f} + 0.5 f \]  
for \( 0.05 \text{ GHz} \leq f \leq f_b \text{ GHz} \)

Where:
- \( f \) is the frequency, in GHz
- \( f_b \) is the baud frequency, in GHz
- \( ILC_{\text{cable}}(f) \) is the maximum mated cable assembly insertion loss, in dB

The fitted cable assembly insertion loss, \( ILC_{\text{cable fitted}}(f) \), as a function of frequency \( f \), is defined in Equation (7-1).

**Equation (7-1)**

\[ ILC_{\text{cable fitted}}(f) = a_1\sqrt{f} + a_2f + a_4f^2 \]

Where:
- \( f \) is the frequency in GHz
- \( ILC_{\text{cable}}(f) \) is the fitted cable assembly insertion loss, in dB

Given the cable assembly insertion loss measured between TP1 and TP4 is at \( N \) uniformly spaced frequencies \( f_i \) spanning the frequency range 50 MHz to 12000 MHz with a maximum frequency spacing of 10 MHz, the coefficients of the fitted insertion loss are determined using Equation (7-2) and Equation (7-3).

**Equation (7-2)**

\[
F = \begin{bmatrix}
\sqrt{f_1} & f_1 & f_1^2 \\
\sqrt{f_2} & f_2 & f_2^2 \\
\vdots & \vdots & \vdots \\
\sqrt{f_N} & f_N & f_N^2 
\end{bmatrix}
\]

**Note:** The polynomial coefficients \( a_1, a_2 \), and \( a_4 \) are determined using Equation (7-3). In Equation (7-3), \( T \) denotes the matrix transpose operator and \( IL \) is a column vector of the measured insertion loss value, \( I_{IL,n} \) at each frequency, \( f_n \).

**Equation (7-3)**
Examples of maximum and minimum fitted insertion loss are illustrated in Figure 7-5. The coefficients for the maximum loss curve are: $a_1 = 6.9$, $a_2 = 0.6$, and $a_4 = 0.05$.

The coefficients for the minimum loss curve are: $a_1 = 0.5$, $a_2 = 0.18$, and $a_4 = 0$.

\[
\begin{bmatrix}
  a_1 \\
  a_2 \\
  a_4
\end{bmatrix} = (F^T F)^{-1} F^T J L
\]
Figure 7-55: Example Maximum Mated Cable Assembly Insertion Loss
This insertion loss limit is intended to accommodate cables up to 2 m long (using 34 awg).
7.3.3. **Mated** Cable Assembly Differential Return Loss

The differential return loss of each pair of the mated OCuLink cable assembly, in dB, must be greater than the minimum limit defined in meet the values determined using Equation (7-24), as illustrated in Figure 7-6.

**2.5 GT/s, 5.0 GT/s, and 8.0 GT/s:**

\[
\text{Equation 7-2:} \quad \text{RLCable}(f) = \begin{cases} 
10 \text{ dB} & \text{for } 0.05 \text{ GHz} \leq f \leq 2 \text{ GHz} \\
(12 - f) \text{ dB} & \text{for } 2 \text{ GHz} < f \leq f_b \text{ GHz}
\end{cases}
\]

Where:

- \(f\) is the frequency, in GHz
- \(f_b\) is the baud frequency, in GHz
- \(\text{RLCable}(f)\) is the maximum mated cable assembly return loss, in dB

\[
\text{Equation (7-4)}: \\
\text{RLCable}(f) = \begin{cases} 
-10 \text{ dB} & \text{for } 0.05 \leq f \leq 2 \text{ GHz} \\
(12-f) \text{ dB} & \text{for } 2 < f \leq 8 \text{ GHz}
\end{cases}
\]

\[-4 \text{ dB} \text{ for } 8 < f \leq 12 \text{ GHz}\]
Figure 7: Minimum Mated Cable Assembly Return Loss
7.3.4. **Mated Cable Assembly** Differential to **Common-mode Return Loss**

The differential to common-mode return loss of the mated OCuLink cable assembly, in dB, of the cable assembly must be greater than the minimum defined in Equation (7-35), as which is illustrated in Figure 7-7.

**2.5 GT/s, 5.0 GT/s, and 8.0 GT/s:**

\[
DCMCCable(f) = 20 - \left(\frac{2}{3}\right)f \\
\text{for } 0.05 \text{ GHz} \leq f \leq f_b \text{ GHz}
\]

Where:
- \(f\) is the frequency, in GHz
- \(f_b\) is the baud frequency, in GHz
- \(DCMCR(f)\) is the minimum mated cable assembly differential to common-mode return loss, in dB

\[
\text{DiffCMRLCable}(f) = 20 \left(\frac{2}{3}\right)f - 20 \text{ dB for } 0.05 \text{ GHz} \leq f \leq 12 \text{ GHz}
\]
Figure Error! No text of specified style in document.7-27: Minimum Mated Cable Assembly Differential to Common-mode Cable Assembly Return Loss
7.3.5. **Mated Cable Assembly** Differential to Common-mode Conversion Loss minus Insertion Loss

The difference between the mated OCuLink cable assembly differential to common-mode conversion loss and the cable assembly insertion loss, in dB, must meet be greater than the minimum limit defined in Equation (7-4).

**2.5 GT/s, 5.0 GT/s, and 8.0 GT/s:**

\[
\text{Equation 7-4} \quad \text{DCMC-ILCable}(f) = 10 \text{ dB} \quad \text{for } 0.05 \text{ GHz} \leq f \leq f_b \text{ GHz}
\]

Where:

- \(f\) is the frequency, in GHz
- \(f_b\) is the baud frequency, in GHz
- DCMC(f) is the mated cable assembly differential to common-mode insertion loss, in dB
- ILCable(f) is the mated cable assembly differential insertion loss, in dB

**Equation (7-5)**

\[
\text{DiffToCMConv-ILCable}(f) = 10 \text{ dB for } 0.05 \leq f \leq 12 \text{ GHz}
\]

7.3.6. **Mated Common-mode to Cable Assembly** Common-mode Return Loss

The common-mode to common-mode return loss of the mated OCuLink cable assembly, in dB, of the cable assembly must meet be greater than the minimum limit defined in Equation (7-5).

**2.5 GT/s, 5.0 GT/s, and 8.0 GT/s:**

\[
\text{Equation 7-5} \quad \text{CMRLCable}(f) = 2 \text{ dB} \quad \text{for } 0.05 \text{ GHz} \leq f \leq f_b \text{ GHz}
\]

Where:

- \(f\) is the frequency, in GHz
- \(f_b\) is the baud frequency, in GHz
- CMRLCable(f) is the minimum mated cable assembly common-mode return loss, in dB
Crosstalk between differential pairs influences the data signals and any subsequent loss and jitter budgets. All system board and cable assembly designs must properly account for any crosstalk that may exist among the various pairs of differential signals. Crosstalk is due to coupling through a channel, may be either at the near-end (NEXT) or at the far-end (FEXT). The total contribution from all aggressors on a particular victim is captured by the multi-disturber or powersum crosstalk.

The NEXT loss that couples within a channel is from Lanes that transmit data in the opposite direction as the victim Lane. Therefore, MDNEXT loss on a receive Lane must be summed across contributions from the four transmit Lanes at the near end of the mated cable assembly, yielding four aggressors total for a four-Lane interface. Similarly, the FEXT loss that couples within a channel is from the Lanes that transmit data in the same direction as the victim Lane. Therefore, MDFEXT loss on a receive Lane must be summed across contributions from the three remaining receive Lanes at the far end of the mated cable assembly, yielding three aggressors total for a four-Lane interface.

Equation 7.6 provides the calculation for MDNEXT loss; Equation 7.7 provides the calculation for MDFEXT loss. Each component potentially has impact on a design and must be planned for accordingly. The equation for NEXT is shown in Equation 7.8; the equation for FEXT is shown in Equation 7.9.

Crosstalk between differential pairs influences and impacts the data signals and any subsequent loss and jitter budgets. Note that all eye diagrams must account for any and all crosstalk present, in order to limit crosstalk impacts and implications. All system boards interfacing with a cable assembly must also properly account for crosstalk. The system board must also account for potential crosstalk that occurs on the printed circuit board, as well as within the connector itself.

Equation 7.6

\[
\text{MDNEXT}(f) = -10 \log_{10} \sum_{i=3}^{i=0} 10^{-\text{NLi}(f)/10} \quad \text{for } 0.05 \text{ GHz} \leq f \leq f_b \text{ GHz}
\]

Where:
- \( f \) is the frequency, in GHz
- \( f_b \) is the baud frequency, in GHz
- MDNEXT\( (f) \) is the multi-disturber near-end crosstalk loss at frequency \( f \)
- NL\( i(f) \) is the NEXT loss at frequency \( f \) of victim-aggressor combination \( i \), in dB
- \( i \) is the victim-aggressor pair (0 to 3)
\[ \text{MDNEXT loss}(f) = -10 \log_{10} \sum_{i=3}^{i=0} 10^{-\text{NL}_i(f)/10} \text{ for } 0.05 \text{ GHz} \leq f \leq 12 \text{ GHz} \]

Where:

- \( \text{MDNEXT loss}(f) \) is the MDNEXT loss at frequency \( f \)
- \( \text{NL}_i(f) \) is the NEXT loss at frequency \( f \) of pair combination \( i \) in dB
- \( f \) is the frequency, in GHz
- \( i \) is the 0 to 3 (pair-to-pair combination)

The MDNEXT loss between a receive Lane and all transmit Lanes (e.g., closest in proximity) must meet the limits specified by Equation (7-9).

\[ \text{MDFEXT}(f) = -10 \log_{10} \sum_{i=0}^{i=2} 10^{-\text{FL}_i(f)/10} \text{ for } 0.05 \text{ GHz} \leq f \leq f_b \text{ GHz} \]

Where:

- \( f \) is the frequency, in GHz
- \( f_b \) is the baud frequency, in GHz
- \( \text{MDFEXT}(f) \) is the multi-disturber far-end crosstalk loss at frequency \( f \)
- \( \text{FL}_i(f) \) is the FEXT loss at frequency \( f \) of victim-aggressor combination \( i \), in dB
- \( i \) is the victim-aggressor pair (0 to 2)
The MDNEXT loss and MDFEXT loss summed on each receive Lane of a mated OCuLink cable must be greater than the limits defined in Equations 7-8 and 7-9 respectively. These limits are illustrated in Figure 7-8.

2.5 GT/s, 5.0 GT/s, and 8.0 GT/s:

Equation 7-8

\[ \text{MDNEXT\_Cable}(f) = 31.5 - 12.5 \log_{10} \left( \frac{f}{4} \right) \text{ dB} \quad \text{for } 0.05 \text{ GHz} \leq f \leq f_b \text{ GHz} \]

Where:

- \( f \) is the frequency, in GHz
- \( f_b \) is the baud frequency, in GHz
- MDNEXT\_Cable is the minimum mated cable assembly MDNEXT loss, in dB

Equation (7-9)

\[ \text{MDFEXT\_loss}(f) \geq 31.5 - 15 \log_{10} \frac{f}{4} \text{ dB} \quad \text{for } 0.05 \text{ GHz} \leq f \leq f_b \text{ GHz} \]

Where:

- \( f \) is the frequency, in GHz
- \( f_b \) is the baud frequency, in GHz
- MDFEXT\_loss is the minimum mated cable assembly MDFEXT loss, in dB
- \( f_b \) is the baud frequency, in GHz

Equation (7-10)

\[ \text{MDFEXT\_loss}(f) = -10 \log_{10} \sum_{i=0}^{2} \frac{10^{-\text{NL}(f)/10}}{10} \text{ for } 0.05 \text{ GHz} \leq f \leq 12 \text{ GHz} \]

Where:

- \( f \) is the frequency, in GHz
- \( f_b \) is the baud frequency, in GHz
- MDFEXT\_loss is the Multi-Disturber Far End Cross Talk loss at frequency \( f \)
- \( \text{NL}(f) \) is the FEXT loss at frequency \( f \) of pair combination \( i \), in dB
- \( i \) is the 0 to 2 (pair-to-pair combination)

The MDFEXT loss between a receive Lane at the far end and with the noise source (Transmitters) at the near end must meet the limits specified by Equation (7-11).

Equation 7-9

\[ \text{MDFEXT\_Cable}(f) = 31 - 15 \log_{10} \left( \frac{f}{4} \right) \text{ dB} \quad \text{for } 0.05 \text{ GHz} \leq f \leq f_b \text{ GHz} \]

Where:

- \( f \) is the frequency, in GHz
- \( f_b \) is the baud frequency, in GHz
- MDFEXT\_Cable is the minimum mated cable assembly MDFEXT loss, in dB
Figure 7-8: Minimum Mated Cable Assembly MDNEXT Loss and MDFEXT Loss

Equation (7-11)

\[ \text{MDFEXT\_loss}(f) \geq 31 - 15 \times \log\left(\frac{f}{4}\right) \text{ dB} \quad 0.05 \text{ GHz} \leq f \leq 12 \text{ GHz} \]

Where:

\( f \) is the frequency, in GHz
7.3.8. **Connector/Cable** Lane-to-Lane Skew

The **skew** time delay across a cable assembly at any point is measured using zero crossings of differential voltage of the compliance pattern, while simultaneously transmitting on all physical lanes. The compliance pattern is defined in the *PCI Express Base Specification*. The skew for a mated cable assembly is quantified as the difference between the longest and shortest time delays measured for a given assembly. The maximum skew permitted for 2.5 GT/s, 5.0 GT/s, and 8.0 GT/s OCuLink cable assemblies is 0.9ns.

7.3.9. **Within-Lane Skew**

Maximum within-Lane skew is not specified in this specification in the time domain. Within-Lane skew is instead controlled in the frequency domain by means of the restrictions on differential-to-common mode return loss and differential-to-common mode conversion loss minus insertion loss.