The challenges for a 10km PMD @ 800G

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Overview

• Ethernet 10km SMF PMDs have been adopted across the industry for a broad set of applications:
  • Campus, Mobile, Access deployments.
  • Service Provider applications where 100G-LR4 was widely adopted as the initial 100G SMF (and needs an upgrade path). Inter-building applications, peering points etc.
  • Intra-DC or Intra-building environments when infrastructure requires.
Ethernet 10km PMDs

• From a product roadmap perspective, they are the:
  • Shortest of the longer reach products
  • Longest of the shorter reach products
• Development ROI of 10km modules benefits strongly from high leverage of one of these groups
• Alignment Option 1: 10km and high volume 2km solutions have 100% design consistency which can then use binning & tuning in a production environment to produce the necessary 10km units.
• Alignment Option 2: 10km and 40km solutions have common architecture and design that can yield the necessary 40km or 10km units.
Duplex fiber solutions: As bit rate increases, longer reaches become more difficult. Creates a transition of technologies to keep up.
10km standards alignment

Observation on IEEE and industry history around 10 km reaches

<table>
<thead>
<tr>
<th></th>
<th>2km</th>
<th>10km</th>
<th>40km</th>
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</thead>
<tbody>
<tr>
<td>25Gbe</td>
<td>Single λ</td>
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<td>Single λ</td>
</tr>
<tr>
<td>50 Gbe</td>
<td>Single λ</td>
<td>Single λ</td>
<td>Single λ</td>
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<tr>
<td>100Gbe</td>
<td>Single λ</td>
<td>Single λ</td>
<td>LAN WDM</td>
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<tr>
<td></td>
<td>4 λ</td>
<td>CWDM</td>
<td>CWDM</td>
</tr>
<tr>
<td>200Gbe</td>
<td>4 λ</td>
<td>CWDM</td>
<td>LAN WDM</td>
</tr>
<tr>
<td>400Gbe</td>
<td>4 λ</td>
<td>CWDM</td>
<td>CWDM</td>
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<tr>
<td></td>
<td>8 λ</td>
<td>LAN WDM</td>
<td>LAN WDM</td>
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Notes:
1. tighter wavelength range
2. tighter spectral width

Observations:
- IEEE 802.3 has history of grouping technical solutions between reaches for leverage and economy of scale
- Lowest cost solution always used for highest volume reach (2km)
  - That solution generally extended to max reach possible
- History of grouping 10km & 40km when 2km solution not practical for those reaches (100G and 200G)
- No history of separate solutions for each reach

800G Projections:
- 2 km based on CWDM IMDD
- 40km based on coherent
- 10 km is TBD

*Table replicated from williams_3df_01_220222.pdf
Ethernet PMD market success factors

Cost and interop are very important considerations

- Costs are strongly affected by volume
  - IMDD: Adjacency to high volume 2km helps if significant leverage
  - Coherent: Traditionally lower volume, IEEE adoption changes that, reduces costs (see: williams_3df_01a_220329.pdf)
- Costs are affected by margin/yield
  - Greater product design margin and yield drives cost efficiencies
- Costs are impacted by development costs
  - Greater leverage or minimized additional development lowers cost
- Interop → link budget margin is the #1 contributor to ensure interop
Achieving Technical feasibility

10km SMF impairments create new challenges for an 800G PMD than at lower data rates previously defined.

• Chromatic dispersion (CD) introduces ISI with penalty increasing by a factor of four with every doubling of baud rate
• Four-wave mixing (FWM) – interactions between closely spaced wavelengths – introduces a power penalty depending on fiber zero dispersion wavelength
• Polarization mode dispersion (PMD) – introduces ISI with penalty increasing with baud rate

These are all additional challenges for IMDD @ 10km on top of the challenges with achieving 200Gb/s per λ

Coherent detection can compensate for CD and PMD. As a single wavelength solution, coherent does not suffer any FWM penalty
Fiber Impairments

• Fiber impairments drive technology changes
  • Transition from IMDD to coherent occurs when fiber impairment penalties force increasingly complex implementations

• 802.3cu reduced reach from 10km to 6km for 400GBASE-LR4

• Jan 2020 Joint ITU/IEEE workshop discussed tightening fiber specifications (zero CD wavelength). See:
  • Data presented indicated the specs for existing classes of G.652 would not be changed.
  • Creating a new tighter specification is an option

• 800G specifications in 802.3dj will need to address existing fiber
  • Requiring characterization of existing fiber plant would bring additional cost
Addressing these 10km technical challenges

<table>
<thead>
<tr>
<th></th>
<th>IMDD</th>
<th>Coherent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chromatic Dispersion</strong></td>
<td>• CD impact on FWM and ISI not fully characterized.</td>
<td>Built in compensation in DSP</td>
</tr>
<tr>
<td></td>
<td>• Redefining fiber specs may be needed to limit penalties.</td>
<td>• Supports existing fiber specs up to 40km or more.</td>
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<tr>
<td></td>
<td></td>
<td>• CD @ 10km is a relaxation of 40km requirement.</td>
</tr>
<tr>
<td><strong>Four Wave Mixing</strong></td>
<td>New polarization interleaving schemes and/or channel gapping are required to mitigate ISI. (untested in volume production)</td>
<td>No issue</td>
</tr>
<tr>
<td><strong>Polarization Mode dispersion</strong></td>
<td>Presentations to date suggest a modification of fiber specs is need to gain relief.</td>
<td>• PMD compensation is well known DSP function. DGD + SoPMD @ 10km is a relaxation of 40km requirement.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Tested in volume production.</td>
</tr>
<tr>
<td><strong>MPI</strong></td>
<td>Needs analysis – penalty needs to be considered in link budget</td>
<td>DSP compensation techniques well known.</td>
</tr>
<tr>
<td><strong>Interop/link budget margin</strong></td>
<td>Unknown at this time.</td>
<td>Significant link margin. Predictable performance lowers risk of interop issues.</td>
</tr>
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*Note: Analysis for PMD + CD for worst case ISI is needed to evaluate MLSE capability & complexity*
IMDD Development Impact: FR4 vs LR4

• How does the LR4 design diverge from the FR4?
  • New wavelength grid requiring cooled lasers
  • Polarization interleaving (or unequal wavelength spacings)
  • Chirp management
  • MLSE – potentially increases complexity of FR4 DSP

• Even with these modifications, new fiber specs may still be required to mitigate impairments

• Proposed LR4 implementations require significant technical changes and will not interop with an FR4
Summary

4x200G IMDD for 10km 800GbE presents technical challenges that are not present for 2km

The LR application needs to address **CD, PMD, and FWM** with a **high yielding** implementation

→ These are not aligned with **DR/FR reaches**
→ Addressing these will place a burden on IMDD DSP design

Coherent implementations address these impairments with significant margin.

A 10km 800GbE coherent implementation can be designed to align with the 40km application