Optics Technology Advances

North American Network Operators’ Group Meeting
New Orleans, Louisiana
3-5 June 2013
Chris Cole
Outline

- 10G
- Optics Specifications
- Pluggable Modules
- 40G
- Multi-link Modules
- 100G
- Board Mounted Optical Engines
- 400G
- Summary
Mainstream 10G MMF: SR NRZ XFP/SFP+

Electric I/O | Optical I/O
---|---
pin pair | fiber pair | \( \lambda \) | Gb /s
1 | 10 | 1 | 1 | 10
10 | 10
Optics Specifications

- Engineering View: Link Budget in dB
  - Link Budget = Penalties + Loss
    - Penalties: Fiber Chromatic Dispersion, PMD, others
    - Loss: Fiber attenuation, connector loss, others

- Operator View: Reach in meters or kilometers
- Reach as only spec is fine for MMF optics
  - Link budget is mainly Penalties over specified reach
  - Reach is synonymous with Penalties
- Reach as only spec is not OK for SMF datacenter optics
  - Link budget is mainly Loss over max. reach
  - SMF optics are rarely used over max. reach
  - Loss is what operators really care about
  - Reach is often not synonymous with Loss
## Optics Specification Example

<table>
<thead>
<tr>
<th>Client optics specification</th>
<th>High density data center duplex or parallel MMF</th>
<th>Structured data center duplex or parallel SMF</th>
<th>Data center &amp; central office duplex SMF</th>
<th>General data center duplex SMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>reach (determines min. penalty)</td>
<td>300m</td>
<td>500m</td>
<td>2km</td>
<td>10km</td>
</tr>
<tr>
<td>minimum loss budget</td>
<td>2dB</td>
<td>3dB</td>
<td>4dB</td>
<td>6dB</td>
</tr>
<tr>
<td>10G standard</td>
<td>10GbE-SR</td>
<td>none</td>
<td>OC-192 SR-1 G.693 10G</td>
<td>10GbE-LR</td>
</tr>
</tbody>
</table>

- 300m (or 100m) for MMF interface is sufficient
- 500m, or 2km or 10km for SMF optics is insufficient
- Ask for 500m/3dB, or 2km/4dB, or 10km/6dB min. for SMF
- Sufficient loss gives plug and play: no link engineering!
Pluggable Module Characteristics

- the good (il buono)
  - multiple applications supported
  - pay as you go
  - confined, replaceable failures
  - common market
  - specialized R&D & production

- the bad (il cattivo)
  - increased component count
  - SI complicated by I/O connector
  - power increased by I/O SerDes
  - density limited by SFP+ size

- & the ugly (il brutto)
  - poor thermal interface
  - heat localized at host front
Mainstream 40G MMF: SR4 Parallel QSFP+

1x12 MPO parallel connector & MMF cable differs from 10GE-SR

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</tr>
<tr>
<td>Gb/s</td>
<td>λ</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

MPO connector
Mainstream 40G SMF: LR4 WDM QSFP+

duplex LC connector & SMF cable is same as 10GE-LR
High Density 10G SMF: LR Parallel QSFP+

Octopus break-out cable connects

QSF+ ↔ 4x SFP+ 
(same for high density 10G MMF: SR parallel QSFP+)

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<td>λ</td>
</tr>
<tr>
<td>Gb /s</td>
<td></td>
</tr>
<tr>
<td>pin</td>
<td>10</td>
</tr>
<tr>
<td>fiber</td>
<td>1</td>
</tr>
<tr>
<td>Gb /s</td>
<td>10</td>
</tr>
<tr>
<td>4x10 pin</td>
<td>4x10 fiber</td>
</tr>
<tr>
<td>4x10 fiber</td>
<td>4x10 Gb /s</td>
</tr>
</tbody>
</table>
# Multi-Link Example: 1UI Line Card Density

<table>
<thead>
<tr>
<th>Form Factor</th>
<th>Electrical I/O</th>
<th>Rows</th>
<th>10GE Ports</th>
<th>40GE Ports</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFP+</td>
<td>1x10G</td>
<td>Double</td>
<td>48</td>
<td>N.A.</td>
<td>~40W</td>
</tr>
<tr>
<td>QSFP+</td>
<td>4x10G</td>
<td>Double</td>
<td>176</td>
<td>44</td>
<td>~80W</td>
</tr>
<tr>
<td>CFP4 MLG</td>
<td>4x25G</td>
<td>Double</td>
<td>360</td>
<td>72</td>
<td>~120W</td>
</tr>
</tbody>
</table>

- Integer multiple density increase
- Thermal load increase
- Single channel failure requires bringing down multiple links to replace

3-5 June 2013
100G Modules: CFP / CFP2 / CFP4
CFP / CFP2 / CFP4 Module 1UI Card Density

- 4x CFP (or 5x)
- 8x CFP2 (or 10x)
- 16x CFP4 (or 20x)
- 32x CFP4 (belly-to-belly) (or 36x)
Gen1 100G MMF: SR10 CFP / CFP2 / CXP

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<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>100GBASE-SR10</th>
<th>100</th>
</tr>
</thead>
</table>

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Gen1 100G SMF: LR4 CFP

Electric I/O | Optical I/O
---|---
pin pair | Gb/s | fiber pair | λ | Gb/s
10 | 1 | 100GBASE-LR4 | 4 | 25
100 | 100
Gen2 MMF: SR4 CFP2 / CFP4 / QSFP28

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<tr>
<td>Gb/s</td>
<td>λ</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>25GBASE-SR4</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>100</td>
</tr>
</tbody>
</table>
### Gen2 SMF: LR4 CFP2 / CFP4 / QSFP28

![Diagram of Gen2 SMF](image)

#### Electric I/O vs. Optical I/O

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<tr>
<td><strong>pin pair</strong></td>
<td>Gb /s</td>
</tr>
<tr>
<td>CAUI-4</td>
<td>4</td>
</tr>
<tr>
<td>100GBASE-LR4</td>
<td>100</td>
</tr>
</tbody>
</table>

**Note:**
- CDR: Clock and Data Recovery
- LD: Laser Driver
- DML: Distributed Mode Laser
- TEC: Thermoelectric Cooler
- TIA: Transimpedance Amplifier
- PIN: Photodiode Infrared
- SMF: Single Mode Fiber

**Specifications:**
- Data rate: 25 Gb/s per pin
- Wavelength: 1550 nm
- Distance: 10 km
- Power: 0 dBm
- Operating temperature: -40°C to +85°C
Future 40G & 100G Technologies

- 40Gb/s per lane (Serial)
  - 1x40G architecture
  - Candidate to replace Copper wires for servers
- 50Gb/s per lanes
  - 2x50G architecture
  - 2x density improvement
- Parallel SMF
  - Similar to SR4 but for SMF instead of MMF
  - Ongoing industry debate about broad market potential for longer reach datacenter links
- Board Mounted Optical Engines
- Higher Order Modulation
Board Mounted Optical Engine
Board Mounted Optical Engine Card Example

12 x 100G MXP

1x100G / 3x40G / 12x10G
to each port
Higher Order Modulation

- Four basic parameters determine link rate:
  - Symbol rate (Baud)
  - Number of fibers (Parallel)
  - Number of wavelengths (WDM)
  - Number of bits/symbol (modulation order)

- Higher Order Modulation (>1bit/symbol) example
  - PAM-4 instead of NRZ (PAM-2) reduces by 2x the Baud, or number of fibers, or number of wavelengths
Gen 1 400G MMF: SR16

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</tr>
<tr>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>400</td>
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</table>

- **Electric I/O**
  - Pin pair
  - Gb/s 25

- **Optical I/O**
  - Fiber pair
  - λ 1
  - Gb/s 25

**2 x 16 MMF MT ferrule**
Gen 1 400G MMF: SR16

400GE over MMF by using the 100GBASE-SR4 PMD

100G Ethernet up to 100 m on OM4

Multi-Mode Fiber Infrastructure

400G Ethernet up to 100 m on OM4

Parallel Multi-Mode Fiber Infrastructure

32 Fibers Used
Gen1 400G SMF: LR4x4 4x CFP4

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Gen1 400G SMF: LR4x4  4x CFP4

100G Ethernet up to 10 km
Duplex Single-Mode Fiber Infrastructure

400G Ethernet up to 10 km
Parallel Single-Mode Fiber Infrastructure
(Actual distance limited by market adoption)

Only 8 Fibers Used

Juniper Networks

2 400 Gb/s Ethernet Study Group
Victoria BC, Canada, May 2013
Gen2 400G SMF: LR8 CFP2

LR4 Alternative: 4:1 WDM with Higher Order Modulation

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</tr>
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What’s After 400G?

- 1Tb/s Ethernet
  - Has been extensively discussed
  - Vestige of 10x historical Ethernet speed jumps
  - Will require huge R&D investment
  - 2.5x speed increase from 400G is not compelling

- 1.6Tb/s Ethernet
  - 4x speed increase reasonable return on R&D $
  - More likely future speed jumps
  - Similar to historical Transport speed jumps
  - Gen1 can use 4x 400G architecture
Summary

- **10G**
  - Duplex LC NRZ MMF and SMF
  - Pluggable Transceivers

- **40G and 100G**
  - Parallel MPO MMF
  - Duplex LC WDM SMF
  - Multi-link modules with break-out cables
  - Board Mounted Optics

- **Future 40G, 100G, 400G and 1.6T**
  - Faster lane rates
  - Parallel MPO SMF
  - Higher Order Modulation (w/ WDM)