Fiber Optics Evolution & Trends

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Evolution of Ethernet Baseband Data Rates

- 10x increases from 1986 to 2006
Ethernet Data Rate Call-for-Interest (CFI) 2006

IEEE 802.3 Study Group
10 lanes x 10Gbps Module Interface
Ethernet Data Rate IEEE – four and ten 10Gb/s Lanes

Shift in Paradigm
- Multiple increases in data rate
- Multiple lanes / Parallel Optics

Standard Ratified
June 2010

100 Gbps
40 Gbps
10 Gbps
1 Gbps

10GBASE-SR

10 GbE Breakout to 4 SFP+ Transceivers
- Enables High port density

100GBASE-SR10 CFP
40GBASE-SR4 QSFP

Block diagram for 40GbE **Parallel Optics** transmit/receive paths

*For clarity, only one direction of transmission is shown*

4 fibres x 10 Gb/s (parallel optics)

Supports Breakout Functionality
Ethernet Data Rate Increases – 25 Gb/s Lanes

**Task Force P802.3bs**
- 400 GbE
- 16 x 25G MMF (32f)

**IEEE 802.3bm**
- 100 GbE over MMF
- 25G Electrical lanes
- 4 x 25G parallel optics
  → Replaces 10 x 10G

To be Ratified Dec 2018

100BASE-SR4 QSFP28
Task Forces 802.3by
Single lane 25GbE
Getting to Higher Speed Ethernet, 50 Gb/s +

- On-Off Keying (OOK)
  - Binary Data
  - Two Digital Levels – “0” or “1”
  - Non-Return to Zero (NRZ)
  - Bit Rate = Baud rate
Getting to 50G Duplex Ethernet (cont’d)

- Signal quality is described by an eye diagram
  - Uses a Pseudo-Random Binary Sequence (PRBS $2^{31}-1$)
  - Used to qualify transceiver performance (can calculate BER)
Getting to 50G Duplex Ethernet (cont’d)

- New Signaling Technology
  - Pulse Amplitude Modulation
  - 4 Levels (PAM-4)
  - 25 Gbaud, 50 Gb/s
P802.3cd Task Force for Next Gen Ethernet Data Rates

PAM-4 Modulation

New Data Rates

400 Gbps
200 Gbps
100 Gbps
50 Gbps
10 Gbps
1 Gbps
100 Mbps


4 x 50 GbE
200GBASE-SR4 QSFP56
50GBASE-SR4 SFP56

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**NEW NETWORK ARCHITECTURE - SPINE/LEAF**

Spine/Leaf Data Center Network Architecture

- **N9500**
  - All Leaf Switches connected to all Spine Switches

- **40G uplinks from Leaf and Spine Switches**

- **WAN/Core Router**

- **Spine switches**
  - Multiple uplinks between Leaf and Spine Switches

- **Leaf switches**

- **Servers**
  - 10G links from Server to Leaf Switches
Proliferation of Breakout

- **Cost, Power and Space = efficiency per G/bit**
  - Wide adoption of breakouts/aggregation solution
    - 40G to 4x10G
    - 100G to 4x25G
    - 200G to 4x50G (future)
    - 400G to 4x100G (future)

- Circa 30% cost saving
- >60% less power
- >Space saving 2:1 – 3:1 typical
  - More space for revenue generating equipment
  - Where space is a premium/limited
  - Multiple generations of switch refreshes
# Ethernet Data Rates

<table>
<thead>
<tr>
<th>Data Rate Gb/s</th>
<th>Lane Rate Gb/s</th>
<th>Number of fibres</th>
<th>Number of Wavelengths</th>
<th>Year Standardized</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 40</td>
<td>10</td>
<td>2 8</td>
<td>1</td>
<td>2002 2015</td>
</tr>
<tr>
<td>25 100</td>
<td>25</td>
<td>2 8</td>
<td>1</td>
<td>2016 2015</td>
</tr>
<tr>
<td>50 100 200</td>
<td>50</td>
<td>2 4 8</td>
<td>1</td>
<td>2018</td>
</tr>
<tr>
<td>100 (TBD) 200</td>
<td>50</td>
<td>2 4 or 2 (TBD) 8 or 4 (TBD)</td>
<td>2 2 or 4 (TBD) 2 or 4 (TBD)</td>
<td>~2021</td>
</tr>
</tbody>
</table>
# 50G, 100G, & 200G PAM-4 Ethernet Standardization

## 50Gbe Interfaces Standardized in IEEE P802.3cd

<table>
<thead>
<tr>
<th>Interface</th>
<th>Channel Distance</th>
<th>Media Type</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>50GBASE-SR</td>
<td>100 m</td>
<td>Duplex MMF</td>
<td>50G PAM4 850nm</td>
</tr>
<tr>
<td>50GBASE-FR</td>
<td>2 km</td>
<td>Duplex SMF</td>
<td>50G PAM4 1300nm window</td>
</tr>
<tr>
<td>50GBASE-LR</td>
<td>10 km</td>
<td>Duplex SMF</td>
<td>50G PAM4 1300nm window</td>
</tr>
</tbody>
</table>

## 100Gbe Interfaces Standardized in IEEE P802.3cd

<table>
<thead>
<tr>
<th>Interface</th>
<th>Channel Distance</th>
<th>Media Type</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>100GBASE-SR4</td>
<td>100 m</td>
<td>4f Parallel MMF</td>
<td>4x50G PAM4 850nm</td>
</tr>
<tr>
<td>100GBASE-DR4</td>
<td>500 m</td>
<td>Duplex SMF</td>
<td>100G PAM4 1300nm window</td>
</tr>
</tbody>
</table>
# 400G PAM-4 Ethernet Standardization

## 200GbE Interfaces Standardized in IEEE P802.3cd/bs

<table>
<thead>
<tr>
<th>Interface</th>
<th>Channel Distance</th>
<th>Media Type</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>200GBASE-SR4</td>
<td>100 m</td>
<td>8f Parallel MMF</td>
<td>4x50G PAM4 850nm</td>
</tr>
<tr>
<td>200GBASE-DR4</td>
<td>500 m</td>
<td>8f Parallel SMF</td>
<td>4x50G PAM4 1300nm window</td>
</tr>
<tr>
<td>200GBASE-FR4</td>
<td>2 km</td>
<td>Duplex SMF</td>
<td>4x50G PAM4 CWDM</td>
</tr>
<tr>
<td>200GBASE-LR4</td>
<td>10 km</td>
<td>Duplex SMF</td>
<td>4x50G PAM4 LAN-WDM</td>
</tr>
</tbody>
</table>

## 400GbE Interfaces Standardized in IEEE P802.3bs

<table>
<thead>
<tr>
<th>Interface</th>
<th>Channel Distance</th>
<th>Media Type</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>400GBASE-SR16</td>
<td>100 m</td>
<td>32f Parallel MMF</td>
<td>16x25G NRZ 850nm Parallel</td>
</tr>
<tr>
<td>400GBASE-DR4</td>
<td>500 m</td>
<td>8f Parallel SMF</td>
<td>4x 100G PAM4 1300nm window</td>
</tr>
<tr>
<td>400GBASE-FR8</td>
<td>2 km</td>
<td>Duplex SMF</td>
<td>8x 50G PAM4 LAN-WDM</td>
</tr>
<tr>
<td>400GBASE-LR8</td>
<td>10 km</td>
<td>Duplex SMF</td>
<td>8x 50G PAM4 LAN-WDM</td>
</tr>
</tbody>
</table>

IEEE 802.3 CFI for 400GBASE-SR4.2 (or 400GBASE-SR2.4)
**Ethernet Module Form Factors**

- Two MMF Transceiver Form Factors – Duplex and Quad fibre pairs:
- 50G duplex is replacing 40G parallel (electronics no longer made)

<table>
<thead>
<tr>
<th>Per lane rate Gb/s</th>
<th>Single lane rate Form factor</th>
<th>IEEE Standard</th>
<th>Quad lane rate Gb/s</th>
<th>Quad lane rate Form Factor</th>
<th>IEEE Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SFP</td>
<td>1000BASE-SR</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>10</td>
<td>SFP+</td>
<td>10GBASE-SR</td>
<td>40</td>
<td>QSFP+</td>
<td>40GBASE-SR4</td>
</tr>
<tr>
<td>25</td>
<td>SFP28</td>
<td>25GBASE-SR</td>
<td>100</td>
<td>QSFP28</td>
<td>100GBASE-SR4</td>
</tr>
<tr>
<td>50</td>
<td>SFP56</td>
<td>50GBASE-SR</td>
<td>200</td>
<td>QSFP56</td>
<td>200GBASE-SR4</td>
</tr>
</tbody>
</table>

SFP – Small Form factor Pluggable  
QSFP – Quad SFP
Future Higher Speed Ethernet
Block diagram for **SWDM** (shortwave wavelength division multiplexing) transmit/receive paths

For clarity, only one direction of transmission is shown
SWDM Transmission

- SWDM requires a filter for each $\lambda$, each filter adds an insertion loss of 1.5 dB dB.
- End-to-end (TX & RX) has a reduction in signal power of 3 dB.
- Has a 3 dB reduction in SNR compared to parallel optics.
- SWDM/OM5 Channels will have reduced reach compared to parallel optics.

![Diagram of SWDM Transmission](image-url)
Two migration paths to higher data rates

1) Standards compliant & 2) Non-standard

1. IEEE 802.3 Standard
   - Parallel fibres
   - Ethernet Roadmap
   - LANE 1: 10G 1x10G
   - LANE 2: 40G 4x10G
   - LANE 3: 100G 4x25G
   - LANE 4: 25G 1x25G
   - 200G 4x50G
   - 100G 2x50G
   - 50G 1x50G
   - 400G (4x 2λ’s, 50G PAM4)

2. Non-Standard
   - Duplex fibres
   - SWDM over OM5
   - 40G BiDi 2λ’s @20G
   - 50G 2x25G
   - No breakout capability
   - 4λ’s @25G
   - 100G 2λ’s @50G
   - 200G 4λ’s @50G
   - Parallel fibres required for higher data rates >200 Gb/s

Technology & Timeline of Standards:
- Duplex NRZ
- PAM4
- Parallel Fibres + SWDM
- Higher Speed Lasers

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Multimode fibre Performance
Panduit Signature Core V OM5
Panduit’s Optical Research Laboratory
Fibre Modes in Multimode Fibre

A pulse of light splits and travels along different optical paths called “modes”

Three possible modes (optical paths)
• Laser optimized multimode fiber corrects for this distortion
  – Speeds up the modes traveling the longer paths
  – Keeps the individual modes (pulses) aligned

• Predominate multimode fiber sold today
Images of visible modes in MMF

Near-field Images - Ti: Al₂O₃ Laser SM launch into 3m fibre (850μm)

2 μm Offset

4 μm Offset

24 μm Offset
Laser Optimized Multimode fibres (OM3, OM4, and OM5 (Wideband), are designed so that all radial mode groups have the same delays –

Effective Modal Bandwidth (EMB) is calculated from the DMD waveforms.
Chromatic Dispersion

Different wavelengths propagate at different velocities

\[ n^2(\lambda) = 1 + \sum_i \frac{B_i \lambda^2}{\lambda^2 - C_i} \]

\[ v = \frac{c}{n} \]

Output Data

Input Data

Chromatic Dispersion

C = speed of light in vacuum

Measured time of flight

More delay

Shorter Wavelength

Pulse Distortion
Panduit’s fibre Research Discovery
VCSEL spatial-spectral coupling into MMF

Radial Spectral Dependency

- Short wavelengths couple to high-order modes
- Long wavelengths couple to low-order modes

Peak shift (P-shift) Delay between 5 & 19μm

Resultant DMD due to Modal Chromatic Dispersion

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Traditional DMD Core Index Profile Design

Requires All Radial Peaks Aligned
Signature Core™ DMD Core Index Profile

Compensates for Modal Chromatic Dispersion
Laser Optimized Multimode fiber Types

Fiber is Sorted and classified based on quality of Modal Dispersion

<table>
<thead>
<tr>
<th>Fibre Type</th>
<th>EMB at 850 nm (MHz·km)</th>
<th>EMB at 953 nm (MHz·km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OM3</td>
<td>2000</td>
<td>NA</td>
</tr>
<tr>
<td>OM4</td>
<td>4700</td>
<td>NA</td>
</tr>
<tr>
<td>Signature Core</td>
<td>5500</td>
<td>TBD</td>
</tr>
<tr>
<td>WBMMF (OM5)</td>
<td>4700</td>
<td>2470</td>
</tr>
</tbody>
</table>

- OM3 and OM4 are designed for high bandwidth at 850 nm
- MMF is sorted as OM3 & OM4 based on Effective Modal Bandwidth (EMB)
  - EMB is calculated from DMD measurement
- WBMMF is designed for high bandwidth at longer wavelengths (953 nm)
- Signature Core is the highest performance MMF available for single wavelength and BiDi systems
- WBMMF required for future generation SWDM 800 Gb/s with breakout to 400 Gb/s and 200 Gb/s
  - 4 wavelength transmission per fibre
400G Light Speed Event Demo – 7th March

100G SWDM1.4 - λ4, Duplex – Beta Modules

- Signature Core™ 300 meters - ZERO bit errors!
Consider ease of migration and scale

- PanMPO™ – always have the right cord
  - 8F PanMPO and 24F MPO added FY17

- Chassis to accepts multiple width cassettes
  - 4 Port Cassettes – 32 port switch map
  - 6 Port Cassettes – large install base
  - 12 Port Cassettes – cost effective & faster to deploy

- Field convertible – no tools required

- Mix & match cassette widths
Questions?

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