100 Gigabit Ethernet - Technology and Test & Measurement

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Agenda – the now, the next, and the future

- IEEE Standardization
- Client Interface CFP
- Test Solution for Lab&Production (ONT-600)
- Test Solution for Field Application (MTS-8000)
- Future Outlook
100 GE / 40 GE ...

... is an evolution ...

In terms of ethernet standard

... and a revolution

Because of
- Parallel electrics & optics
- Gearboxes
- Data skew
- OTN clients
- optical transmission

Climbing the Rate Ladder

- Multiplicity of technologies at 10 & 40G
- Convergence at 100G
- No SONET/SDH at 100G
IEEE 802.3ba Objectives

- Support full-duplex operation only
- Preserve the 802.3 / Ethernet frame format utilizing the 802.3 MAC
- Preserve minimum and maximum FrameSize of current 802.3 standard
- Support a BER better than or equal to 10^-12 at the MAC/PLS service interface
- Provide appropriate support for OTN
- Support a MAC data rate of 40 Gb/s
  - Provide Physical Layer specifications which support 40 Gb/s operation over:
    - at least 10km on SMF
    - at least 100m on OM3 MMF
    - at least 10m over a copper cable assembly
    - at least 1m over a backplane
- Support a MAC data rate of 100 Gb/s
  - Provide Physical Layer specifications which support 100 Gb/s operation over:
    - at least 40km on SMF
    - at least 10km on SMF
    - at least 100m on OM3 MMF
    - at least 10m over a copper cable assembly

IEEE 802.3ba Objectives

<table>
<thead>
<tr>
<th>PMD</th>
<th>40GE</th>
<th>100GE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMF</td>
<td>40GBASE-SR4</td>
<td>100GBASE-SR10</td>
</tr>
<tr>
<td>SMF &lt;10km</td>
<td>40GBASE-LR4</td>
<td>100GBASE-LR4</td>
</tr>
<tr>
<td>SMF &gt;10km</td>
<td>40GBASE-LR4</td>
<td>100GBASE-LR4</td>
</tr>
<tr>
<td>SMF non-standard</td>
<td>100GBASE-EA4</td>
<td></td>
</tr>
</tbody>
</table>

Bild 1: Standardisierung für 100 GbE und 40 GbE
40/100 GbE Optics

Adaptation of parallel 64B/66B encoded clients

Adaptation of OTU3 and OTU4 over Multichannel Parallel Interfaces

100 GbE / OTN Interworking

Client Application
MAC

Adaptation
OPU4
ODU4
OTU4

Adaptation

Adaptation

20 Virtual Lanes
20 Logical Lanes

G.709 Appendix VII: Adaptation of parallel 64B/66B encoded clients

G.709 Annex C: Adaptation of OPU4 and OTU4 over Multichannel Parallel Interfaces

10*11.2G CAUI

10*10G CAUI

100 GbE / OTN Interworking
CFP module – Block diagram for Gearbox CFP

For 100G M=10 & N=4
10 electrical lanes running at 10G
4 optical lanes running at 25G
REFCLK is electrical lane speed/16 ~ 644 MHz

100G LR4 CFP block diagram

Micro-controller – runs MDIO I/O and controls key functions
Clock multiplier
Converts 644 MHz => 10.3G Hz
RX Gearbox
Includes demux and 25G CDR
TOSA
4 x 25G Laser, 5nm spacing => cooled
Evolving to serial FR CFP
For 40G SONET/SDH

100G & OTU4
100G LR4 (OpNext or Finisar)
100G 10λ (NeoPhotonics)
100G SR10 (Reflex)

1310 nm

40G & OTU3
40G LR4 QSFP+ (JDSU)
40G LR4 CFP (OpNext)

850 nm

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Client-/Line interface

Windrose diagram showing:
- CFP, QSFP
- Multi Lane Distribution
- LAN 41.25 Gbps (40GE)
- 4 λ with 10.3125 Gbps
- OTL 3.4
- OTU3, OTU3e1, OTU3e2
- Enhanced FEC
- Higher Modulation formats, as ODB, DPSK, DQPSK and PM-QPSK
- Adaptive PMD compensation
- CD compensation with FBG
- Coherent Detection
- CFP
- Multi Lane Distribution, MLD
- 100GE, OML4.4, OML4.10
- 4 λ with 25/28 Gbps
- OTU4
- Enhanced FEC
- Higher Modulation formats, e.g. PM-QPSK
- Adaptive PMD compensation
- CD compensation with FBG
- Coherent Detection
Description of CFP functional blocks

- **Gearbox**
  - Currently chip set (likely to become single CMOS chip)
  - Acts as 10 x 10G <> 4 x 25G MUX/DEMUX
  - Complex high-speed chip

- **TOSA (TX Laser)**
  - 4 matched cooled lasers (1295nm, 1300nm, 1305nm, 1310nm)
    - Currently EML but will migrate to DML and then PIC

- **ROSA (RX photodiode)**
  - 4 matched 25/28G PIN with optical demux assembly
    - Early PIC candidate

- **Clock multiplier (CMU)**
  - Converts clk/16 from 644 MHz to 10.3125 GHz (low jitter)

- **Clock recovery (CDR)**
  - Recovers 25G (and generates 10.3125 GHz) clock from 25G line side signal

- **Microcontroller**
  - Controls the above functional blocks via MDIO

CFP Optics – Status

- Vendors have publically announced products
  - First series parts – some performance caveats
- Gearbox very challenging technology
  - Other vendors announced gearbox ICs (CMOS)
- Longer term gearbox will be integrated in line card ASIC to make simpler 4x25G electrical i/o
- CFP is not the end game for 100GE optics
  - CFP2 (native 25G I/O) then CFP4/QSFP2?
- 2nd generation CFP vendors will release CMOS gearbox based 100G LR4 parts through 2012
- 1st generation CFP2 parts demonstrated in H1 2012
  - But likely productized in 2013
System OEMs have expressed reservations about jitter budget, reach, and thermal limitations of the 25G QSFP+ module

CFP MSA will study CFP4 as alternative to QSFP+

Source: cfp-msa.org
40/43 Gigabit Transponder

43Gbps Coherent PM-(D)QPSK 300pin Transponder

MI 5000XM

Features:
- Tunable transmit laser for C-Band with coverage of 50 GHz ITU grid and integral wavelength locker
- Data precoder and decoder for PM-(D)QPSK modulation
- Coherent transmission technology with Digital Signal Processing (DSP)
- Chromatic Dispersion (CD) compensation of up to 50000 ps/nm
- Polarization Mode Dispersion (PMD) tolerance of up to 55 ps
- Optical Receiver Tuning for non fully demultiplexed WDM applications

The MI 5000XM is a coherent PM-(D)QPSK full C-band tunable 40Gbps transponder module for Dense Wavelength Division Multiplexing (DWDM) network applications. The excellent transmission performance makes the MI 5000XM an ideal solution for regional, long haul and ultra-long haul 40Gbps transmission in today's networks with 50GHz channel spacing.

Source: www.oclaro.com

Test and Measurement
What need to be tested?
- Lab and Production
- Service Validation Tests (SVT)
JDSU - Addressing the High-Speed Product Life Cycle

“Vision: Deliver Next Generation technologies across the entire product life cycle”

R&D and Validation
Feature depth & completeness

Manufacturing
Simple, cost-effective solution for fast test cycle

Deployment
Small-sized solution for service activation and troubleshooting

ONT
100G shipping for 2 years
40G shipping for 10 years

ONT
Cost-optimized for mfg

T-BERD/MTS
Service Activation
Troubleshooting
Ethernet, OTN, SONET/SDH

Lab & Production: ONT-600 with 40G & 100G Solutions

40G V2 Module
(300-pin MSA)
- OTU3/OTU3e1/3e2
- OC-768/STM-256
- Full ODU Muxing
- Jitter/Wander/Electrical
- NRZ/DPSK versions

100/40G CFP Module
- 40GE & 100GE
- OTL/OTU4/OTU3
- Full ODU Muxing
- CFP/QSFP+ Tests
- 256 Streams QoS
- STL/OC-768/STM-256

Complete lab & production package
The leader in OTN testing
Coverage of layer 1-2-3 for 40GE/100GE

Key Differentiators
- Single-button CFP transponder deep test
- Unique Dynamic skew feature
- The deepest ODU multiplexing feature set
- 256 Ethernet/IP streams with QoS SyncE testing
Simple Structure on ONT

Simple Menu structure helps ‘peel the onion’ without tears!

First get the physical layer up and running. Applications help the critical photonics integration phase.

PCS layer or OLT layer with alarms, errors and new issues like VL skew.

OTN layer with double stage multiplexing supporting ODU0 and ODUflex.

Client application MAC & IP or SDH/SONET. Everything from simple connectivity tests through to complex QoS over 256 flows!

CFP MDIO Interface

100/112 Gbps
Physical Layer Validation

- Quickly resolve issues in H/W & photonic integration

- Standard 10x10 or special JDSU gearbox transparent mode for true end-to-end validation

- Wide range of patterns to fully stress aspects such as crosstalk, DC-balance, clock-recovery etc

Extensive PCS Layer Testing

- Total Blocks, Data, Control Blocks

- Types of Control Blocks
PCS Lane Rotator

- Validation of end to end lane mapping on PCS layer VLs

Lane rotator allows real time VL lane re-assignment

Clear indication of how each VL is mapped at the receiver

Naturally parameters such as skew can be adjusted as well!

CFP Verification: Gearbox & Skew Testing

- Fully test lane skew (static + dynamic)
  - PCS alignment markers used to correct lane skew at Rx. ONT provides:
    - Injection/measurement of static & dynamic skew to validate PCS receiver and gearbox (in 4x25G transponders)
Unique CFP Stress test

- CFP Stress Test varies several PHYS parameter for an automated test

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QSFP Adaptor

- QSFPs will be the dominant form factor for pluggable 40G Optics from 2011 onwards
- The adapter allows the ONT 40/100G CFP solution to take QSFP modules and run tests on the physical, PCS and Ethernet layer.
- The adapter will be an optional accessory work only with our 40/100G ONT solution.
- It is designed to support all standard optical (short & long reach) QSFPs in all our standard test applications.

Benefit----No need to have two testers in order to support both CFP and QSFP!
Deep Ethernet Analysis with ONT-503

Overview on 256 streams

Packet Jitter per Stream

Latency per Stream

Statistiv per Stream

MAC/IP Analysis at 10 Gig (ModuleE) and 100 Gig

► 10GigE LAN Layer BERT and Layer 2/3 traffic
► Sophisticated PCS layer testing with dynamic block errors, coding statistics and block capture
► Additional VPLS and MAC-in-MAC Ethernet frame formats
► Up to 256 traffic flows and independent receiver filters
► Up to 10 mixed VLAN/MPLS tags
► Online hitles traffic control
► Real-time QoS, service disruption and packet jitter analysis per flow
► IPv4/v6 and packet capture
► RFC 2544 Conformance Testing
**RFC-2544 with comfortable operation**

- Standard measurements plus Jitter analysis
- One page setup, one page result
- Numerical, Graph and Bar Graph results

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**MTM Multiport / ONT-601**

- Overview of all 4 ports
Highlights of ONT-600 Platform

► Provide common platform for more "energy-hungry" future applications (Multiport 10G; 100G and others)

► Maintain SW (GUI and CLI) compatibility to installed ONT-500 base

What need to be tested?
- Field Deployment
Field High-Speed Strategy

- **Positioning**
  - Offer the smallest integrated test unit on the market
  - Goal: become the standard for field high-speed testing
    - Get tied with NEMs

- **Strategy:**

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size / Cost</td>
<td>Smallest 100G size today Move to 6000 in future</td>
</tr>
<tr>
<td>Rate Integration</td>
<td>40GE / 100GE / OTU3 / OTU4 today Add 40G SONET/SDH Eventually integrate 10G in 1</td>
</tr>
<tr>
<td>Service Activation</td>
<td>RFC 2544 today, interworks with MSAM 10 streams today Add SAMComplete Add OWD &amp; ODU Muxing</td>
</tr>
<tr>
<td>Troubleshooting</td>
<td>Ping/ traceroute IPv4/6 for routers today One-way traffic today Consider capture</td>
</tr>
</tbody>
</table>

MTS 8000 Applicability

**Field Solution for use by:**
- Service Providers
- Network Equipment Manufacturers
- Network integrators
- Government and defense

**Applications**
- Activate New Services
- Troubleshoot network errors and connectivity
- Traffic loading

- Handoff point 100G or 40G
- OSA, Fiber Char.
- OSNR, WL, Spacing, BW
The 8000 40/100G Transport Module

The ideal solution for Service Activation and troubleshooting

Unique Elements:
- Most compact 100G solution on the market
- Field ruggedness with battery operation
- Multiple streams (10) with CoS testing → Y.1564-ready
- High-accuracy Frame Delay (<150 nsec) measurements
- On-board Integrated optics: CFP and QSFP+
- Full Integration with 10G testing
- Layer 3 apps: IPv4/v6, ARP, ping, traceroute
- Hardware-ready for 40G SONET/SDH

Adaptable Service Activation Solution

100GE, OTU4, 40GE, and OTU3 in one

Service Activation testing
- RFC 2544: Throughput, Latency, Packet jitter, Frame Loss, Bursting
- Easy far-end loop up/down operation
- BERT burn-in tests

The Right Hardware Options:

- CH040103 → Base
  - 100GE + OTU4 Bulk + 40GE + OTU3 Bulk
- CH043112 → Added Client support
  - All of base capabilities
  - 100GE into OTU4

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## 40/100G TM Feature Breakdown

### Environment
- CFP & QSFP+ Optics
- Native T-BERD/MTS User Interface & Upgrades
- Battery Backup
- Can be combined with other 8000v2 modules

### Ethernet
- Layer 1 (max skew reporting, PCS/OTL statistics)
- 100GE: single stream PRBS & 10 streams QoS
- 40GE: single stream PRBS & 10 streams QoS
- VLAN/Q-in-Q & 2-level MPLS labels
- IPv4: Ping/Traceroute & ARP
- IPv6: Ping/Traceroute & address resolution
- ATPv2 & ATPv3 (low-latency 100nsec) Support
- Logical Loopback: Loop up/down
- RFC 2544

### OTN
- OTL4.10/OTU4 bulk
- OTL3.4/OTU3 bulk
- OTU4 with full 100GE client (CH043112)

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**More on Service Activation**
40GE/100GE Service Activation Testing

Fundamental differences between 10GE & 40GE/100GE
- Are at layer 1 making testing critical

How do customers turn up services?
- RFC 2544 fills the need, just as in GE/10GE
  QoS testing: Throughput, Latency, Frame Loss Rate, Packet Jitter

What about Y.1564 / SAMComplete?
- Same concepts will apply at 40GE/100GE
- JDSU to implement SAMComplete at 40GE/100GE

SAMComplete
Service Configuration Test
  - Each service tested individually
  - Test BW against CIR, EIR
  - CIR = Committed Information Rate

Service Performance Test
  - All services tested concurrently at CIR
  - Multiple concurrent streams

Why TCP Layer Testing?
- Running RFC2544 or other Layer 2/3 installation tests is always the first step
- Even with L2/3 “test pass”, end-customers can still complain that the “network is slow”, cause is often L4 and above
- With JDSU’s RFC 6349 compliant TrueSpeed™, L4 activation & troubleshooting tests can be run by the same technician in 3-5 minutes!
  - Save up to 30% OPEX costs by eliminating or quickly resolving issues

TrueSpeed™ on MSAM and soon on 5800
IETF RFC 6349: methodology to measure end-to-end TCP Throughput in a managed IP network.

- JDSU and two (2) Network Providers co-authored this RFC

"0": Run traditional RFC2544 (or SAMComplete)

1. Path MTU Detection (RFC4821)
   - Verify network MTU with active TCP segment size testing to ensure TCP payload does not get fragmented

2. Baseline Round-trip Delay and Bandwidth
   - Predict optimum TCP window size to automatically calculate the TCP Bandwidth Delay Product (BDP)

3. Single and Multiple TCP Connection Throughput Tests
   - Verify TCP window size predictions to enable automated “full pipe” TCP testing

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Which Applications use TCP?

HTTP, FTP, E-mail, Sharepoint, Communicator, etc.
Lack of TCP Testing is a Turn-up Gap!

- Table highlights typical network problems detected by RFC2544 or Y.1564 and others that are NOT

<table>
<thead>
<tr>
<th>Turn-up Related Problem</th>
<th>RFC2544</th>
<th>Y.1564</th>
<th>TrueSpeed™, RFC 6349</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Service, Layer 2/3 SLA Issues (loss, jitter, etc.)</td>
<td>X</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>Multi-service, Layer 2/3 SLA Issues (service prioritization, loss, jitter, etc.)</td>
<td>X</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Effect of End customer TCP Window size on throughput (CPE issue)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inadequate device buffers to handle bursty customer applications</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Policing effects to TCP performance</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Policing: TCP versus Layer 2 Testing Results

In this example, a 10Mb/s SLA is enforced with a 10Mb/ policing function

Traditional Layer 2 test showed “green” results when tested at 10 Mbps

The TCP throughput result was quite different!

5.28 Mbps!
TB/MTS 8000 40/100G TM Key Attributes

- A full member of the TB/MTS family
  - Exact same GUI looks / feel / scripting as 10G
  - Integrated RFC 2544 and reports

- Key elements:
  - Most compact solution on the market supporting 100G
    - Full field ruggedness
  - Comprehensive QoS testing and low-latency accuracy
  - Integrated CFP and QSFP+ optics support
    - Support of 100GE, OTU4, 40GE, OTU3 in one
    - Layer 3 features for router applications

40/43G Feature Highlights

- Intrusive through for OTN (transparent through for SONET/SDH)
- SONET/SDH down to STS-1 / VC-3
- 10usec Round Trip Delay
- APS and Service Disruption with triggers
- ODU1 /2 Multiplexing on OTU3
- BERT analysis
MTS 8000 Scalable Offering

MTS 8000 is modular and scalable
Can combine in one TB/MTS 8000 chassis:
100G + 40G + 10G + 2.5G + 1G + PDH

Transport Testing Integration
The MSAM (Multi Services Application Module) fits in both TB/MTS 8000 & 6000A
Up to 4 10G ports in one slice!
Carrier Ethernet + OTN / SONET/SDH/PDH + Fiber Channel

New MTS-8000 V2 Versus V1
- The 40/100G TM runs on the new MTS 8000 v2
- New look base User Interface
- Improved speed
  - 12 seconds switch between applications on 40/100G TM
- 70% Faster MSAM performance
  - 2 ½ minute boot time for MSAMs
- Supports up to 6 MSAMs
- Upcoming wifi
40/43G solution in the MTS-8000

- Dedicated for 40/43G field installation and maintenance
- Testing applications for
  - OC-768/STM-256
  - OTU-3 (43G) bulk, with SONET/SDH or ODU-1/2 client
  - 40/43G unframed
- Field portable and rugged design (~18lbs / 8kg)
- Platform and GUI based on market leader TB/MTS-8000
- Based on JDSU proven 40/43G technology
- Terminate and Through Mode

100GE BERT Product Portfolio

- **ONT**
  - PowerBox
  - Early Adopter solution
  - Highest feature Depth
  - Technology Leader
  - Standard for NEMS

- **MTS 8000**
  - Smallest 100G in industry
  - Portable with Battery
  - CFP and QSFP+ optics
  - Easily combined with 10G
  - Integrated Touchscreen UI

Price

Size

Ethernet ➔ Performance ➔ Transport
Combining 100G with Optics

Transport & Optics Combination in TB/MTS 8000

Can combine Transport & Optics in One
Combine the 40/100G TM & OSA in one unit
Optical Testing
- Fiber Characterization with MTS/TB-8000
- Optical Spectrum Analysis with advanced analysis SW
- Fiber Inspection w/ IEC pass/fail Analysis (P5000i probe)
- IL/ORL, OTDR, CD, PMD, AP, OSA

| 'True' OSNR | ✅ |
| Wavelength & power level | ✅ |
| PMD & CD | ✅ |
| Fiber length | ✅ |
| Reflectance & ORL | ✅ |
| IL, splices, att. Profile (AP) | ✅ |
| Connector Inspection | ✅ |
Field: 40/100G Client Optical Power & Wavelengths

- Testing 40/100G client interfaces optically involves
  - Optical power and optical wavelength for each channel

- 40G SR4 / 100G SR10
  - Power at 850nm (MMF): => OLP-34 or OLP-55

- 40G LR4 (SMF) 4 CWDM wavelengths (20nm spacing)
  - Power and wavelength per channel: => OCC-55, COSA-4055 or OSA-110M

- 100G LR4 / ER4 (SMF) 4 wavelengths (4.5nm spacing)
  - Power and wavelength per channel => OSA-110M

- 100G Santur optics 10 wavelengths (8nm spacing)
  - Power and wavelength per channel => COSA-4055 or OSA-110M

JDSU - Addressing the High-Speed Product Life Cycle

"Vision: Deliver Next Generation technologies across the entire product life cycle"

R&D and Validation
Feature depth & completeness

Manufacturing
Simple, cost-effective solution for fast test cycle

Deployment
Small-sized solution for service activation and troubleshooting

ONT
100G shipping for 2 years
40G shipping for 10 years

OPL-34 / OLP-55

TB/MTS 4000
COSA-4055

TB/MTS 6000
OSA-110M

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Summary I

- We are currently in a transitory 40G backbone stage
- Market will transition to 100G (Optical & Ethernet) by 2013
  - 100G market to be long-lived
- OTN gains greatly in importance with high-speed
- JDSU with complete life cycle portfolio
  - ONT series for lab & manufacturing
  - MTS 8000 40/100G Transport Module

Summary II

- **100GigE**
  - Evolutionary on the Ethernet and higher layers
    - Full Ethernet client with deep Ethernet analysis: RFC 2544, 256 streams
  - OTN Layer
    - all OTN Multiplexing including ODU0, ODUflex. One, two or three stages on multiplexing; GMP AMP BMP mapping procedures
  - Revolutionary on the physical layer
    - Introduction of parallel optics into the network
    - PCS layer with 20 virtual lanes
- **JDSU provides a well-rounded 100G portfolio**
  - ONT for layer 1-2-3 testing
  - MAP for optical stimulus/response
  - MTS-8000 for CD/PMD
ONT-506/503 cover all applications in Transport Networks from 1.5 Mbit/s to 112 Gbit/s.

Status on 100 Gig Ethernet – Technology and what & how to test?
World of 100 Gb/s – The Lower Layers

OTN acc. ITU G.709

World of 100 Gb/s

To learn more, visit www.jdsu.com/otn

JDSU takes you to new shores
You know us because you depend on our technology every day.