100Gbps for NexGen Content Distribution Networks

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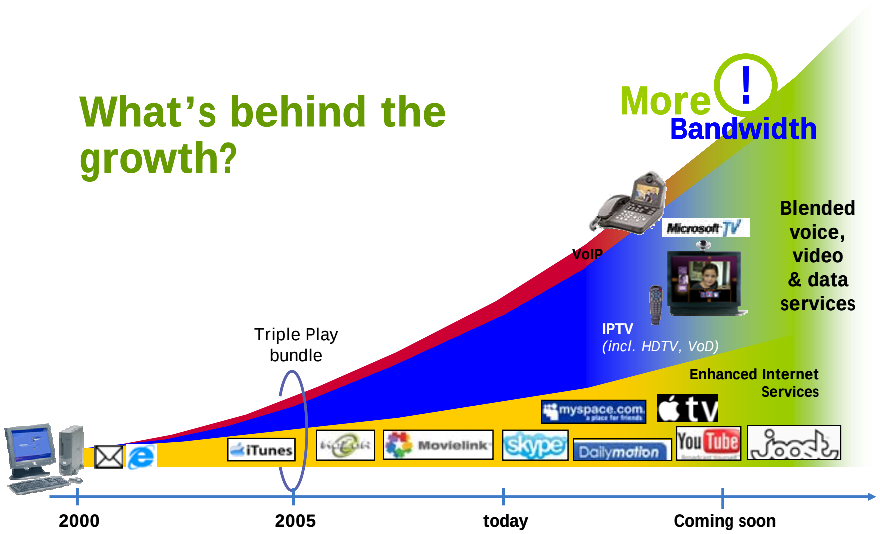
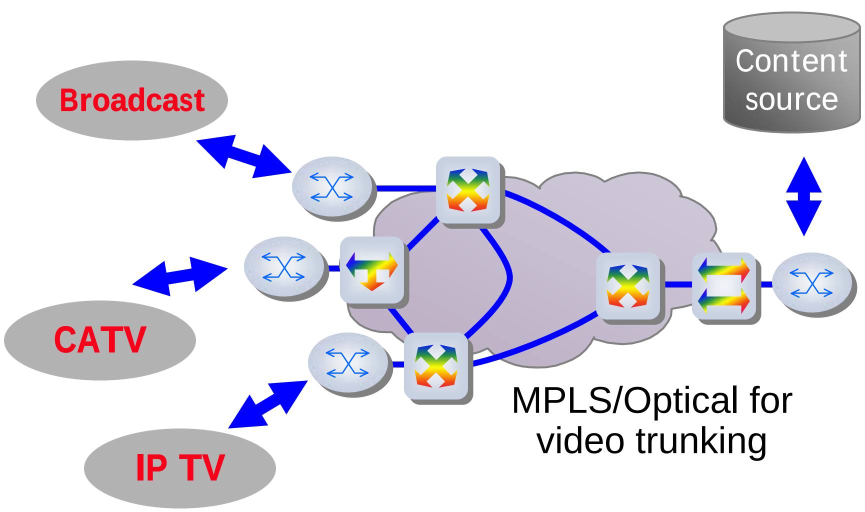
Bell Labs Research

Market Drivers for 100G





Digital video trunking:

- Part of growing "**triple play**" consumer packages
- Video bandwidth is easier to **monetize** (compare with p2p traffic)
- Requirement for **high definition** drives
  - High data rates per channel
  - Transport of uncompressed video for access network specific compression
- Explosive **growth in programming content** (estimated ~90% of BW in NG networks)

Video traffic:

- Requires minimal latency for effective delivery
- Requires resilient transport (MPLS and transport layer)
- Benefits from multicast and from "asymmetric" design

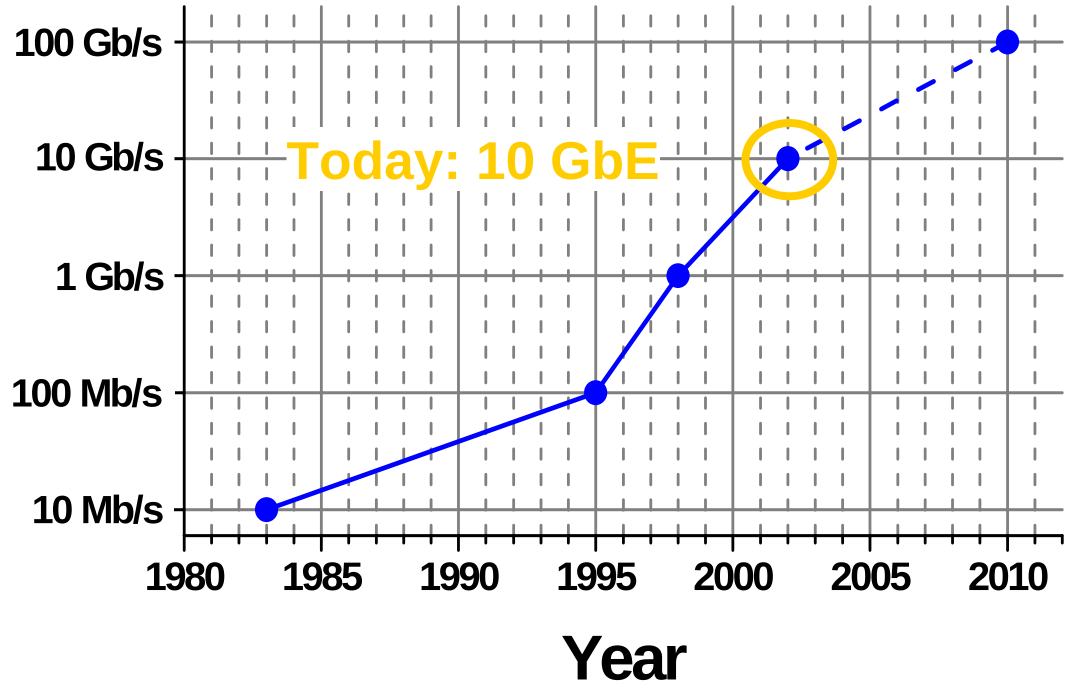
Other factors: storage networking, carrier wholesaling, science applications, grid computing

NexGen Ethernet will be 40GbE and 100GbE

Good support for 100GbE in standards

- IEEE to adopt a OTN compatible standard for 40GbE/100GbE
- IEEE and ITU-T timelines target mid-2010 for standards completion

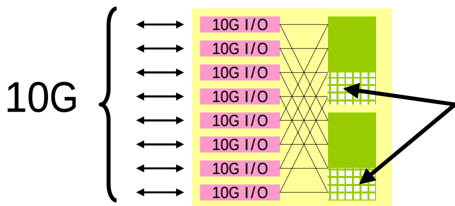
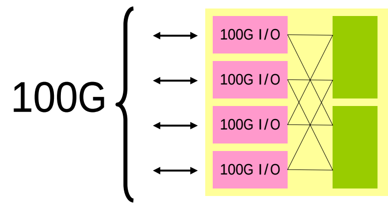
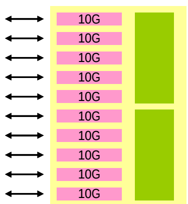
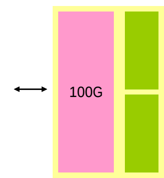
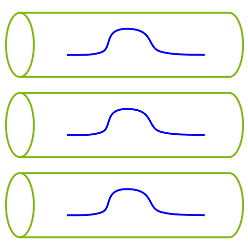
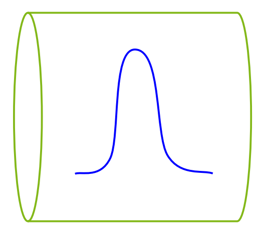
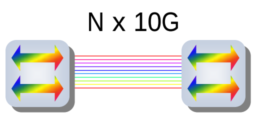
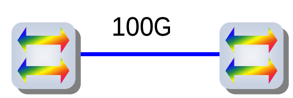
Service providers and equipment OEMs also support 100 GbE



100G transport cost effective compared to 10G

A side-effect will be that 40G transport will also become more cost-effective as 100G techniques begin to be implemented in 40G transmission

Benefits of 100G Networking

10G interfaces	100G interfaces
 On high-end core routers: Fabric capacity is poorly utilized with lower speed I/O (*)	 Better utilization of fabric bandwidth due to improved access into it
 On high-end core routers: 10 x 10G interfaces subscribe 100G of BW	 The price of 100G interface on router will be much lower than 10 x 10G for the same capacity
 Smaller wavelengths limit BW bursts LAG groups are limited to 17 members	 A higher speed wavelength is better able to accommodate peak BW Much larger LAG BW!!
 Large wavelength count consumes DWDM grid, represent higher cost for “commons”	 Efficient use of DWDM grid. No parallel wavelengths means lower OAM cost and fewer managed entities

(*) Example: Juniper T-1600

The boundary conditions of capacity growth

Growth of transport requires

→ Higher spectral efficiency or

→ Wider amplification bands or

→ Light another fiber

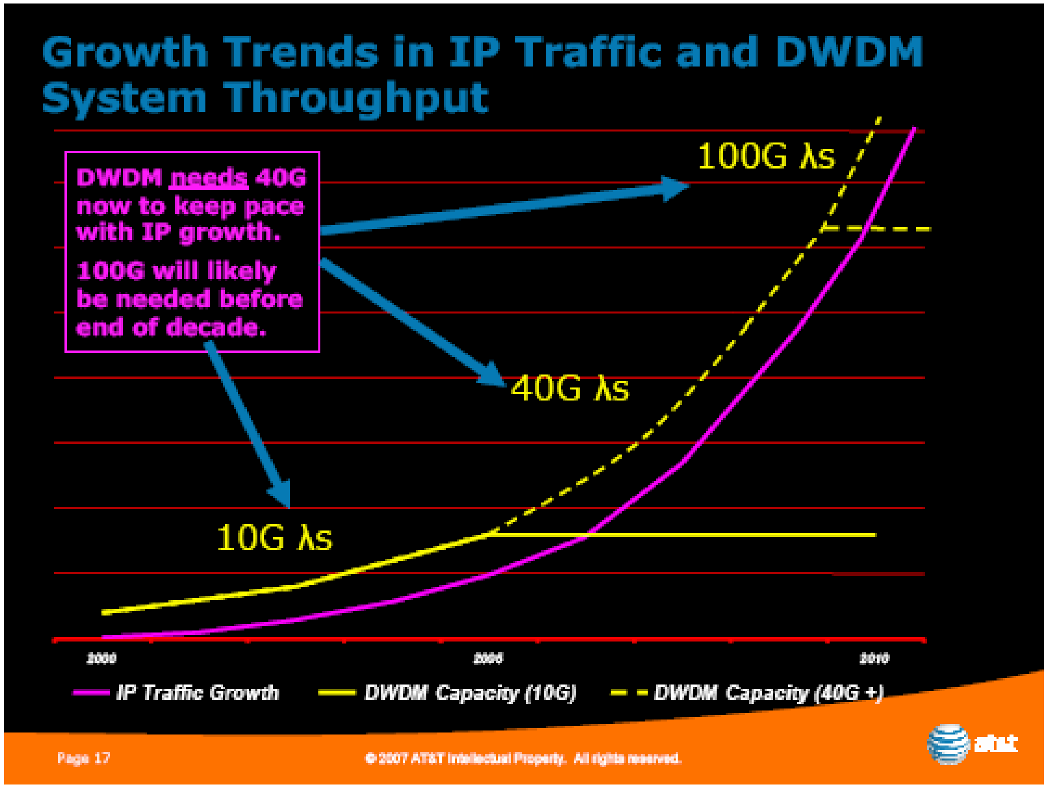
Latter two often too costly

Growth may have to be accommodated in existing systems

→ 50-GHz channel spacing

→ Multiple ROADMs

→ Optical Reach



Capacity Growth based on 100G with advanced modulation format will lead to very high spectral efficiency and be compatible with existing systems

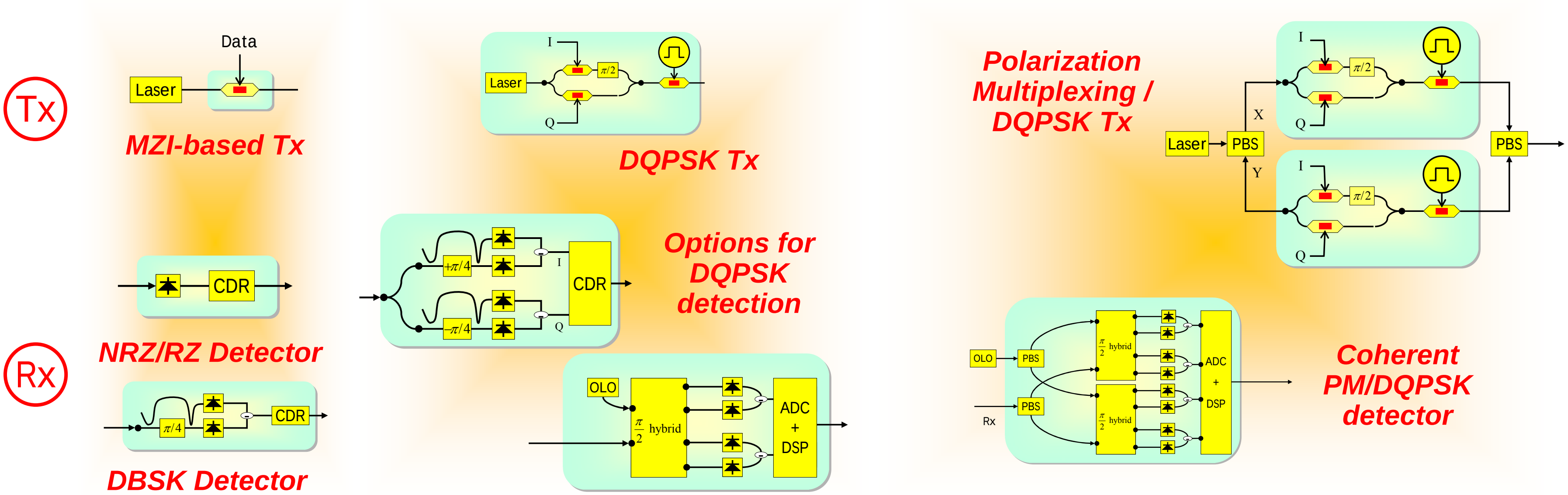
Multi-level Modulation Formats in Optics

~112 Gbaud	~56 Gbaud	~28 Gbaud
1 bit/symbol	*2 bit/symbol*	*4 bit/symbol*

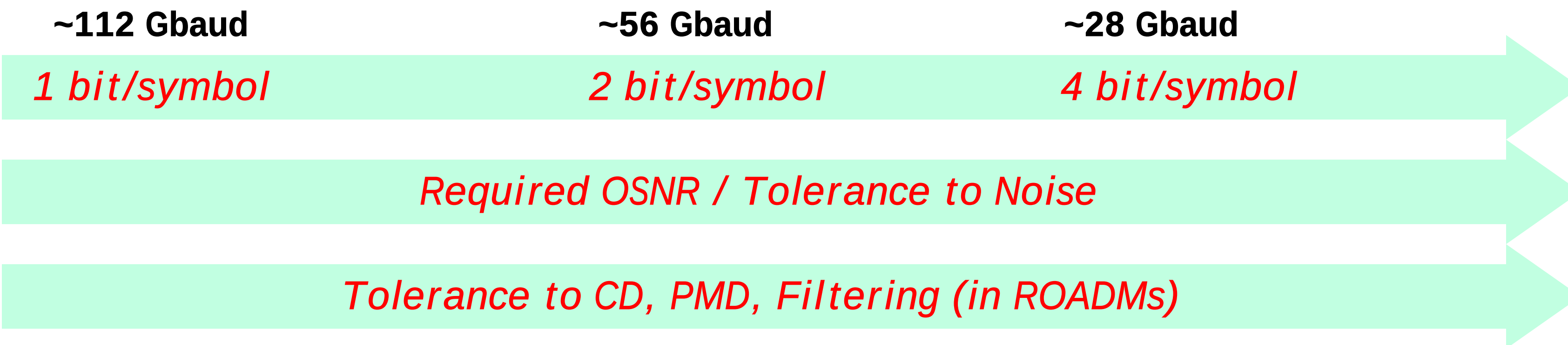
Required OSNR

Tolerance to CD, PMD, Filtering (in ROADMs)

Complexity of implementation



100 Gb/s serial modulation format choices



	100G NRZ	100G Duobinary	100G (RZ-)DQPSK	100G PDM-QPSK	40G (Binary)	10G (Binary)
DGD tolerance (1-dB penalty)	~ 3 ps	~ 3 ps	~ 8 ps	Very large (*coherent, oversampled*)	~ 10 ps	~ 40 ps
CD tolerance (2-dB penalty)	± 8 ps/nm	± 25 ps/nm	± 26 ps/nm	Very large (*coherent, oversampled*)	± 50 ps/nm	± 800 ... 2000 ps/nm
Supported grid w/ ROADMs	150 ... 200 GHz	150 ... 200 GHz	100 GHz	50 GHz	50 ... 100 GHz	25 ... 50 GHz

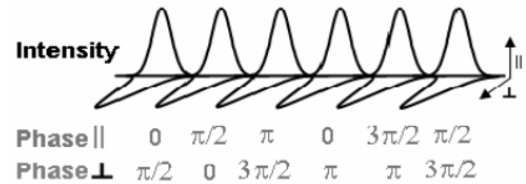
PMD-QPSK … Polarization-mode dispersion quarternary phase shift keyed
DGD … Differential group delay

CD … Chromatic dispersion
ROADM … Reconfigurable optical add/drop multiplexer

100G Transmission: Picking the best modulation format

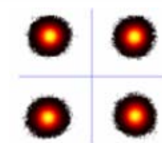
At 100G impact of some fiber propagation effects (dispersion, PMD, single-channel nonlinearities) is so high that decreasing the baud-rate is mandatory

This requires necessarily the use of more complex modulation formats and receiver architectures



The combined use of:

- **Polarization-Division Multiplexing (PDM)**
- **Quadrature-Phase Shift Keying (QPSK)**



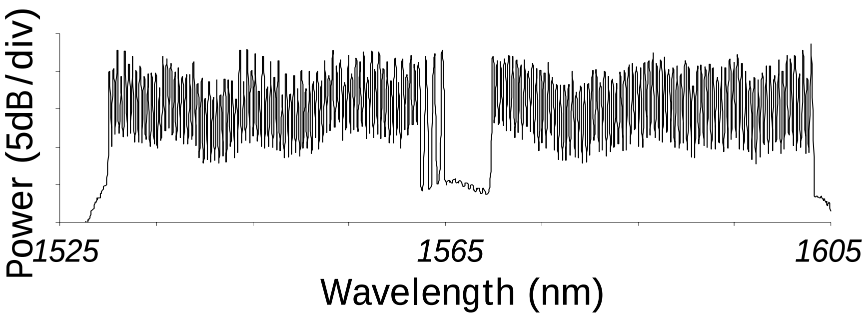
allows to decrease baud-rate by a factor of four (100 to 25 Gbaud)

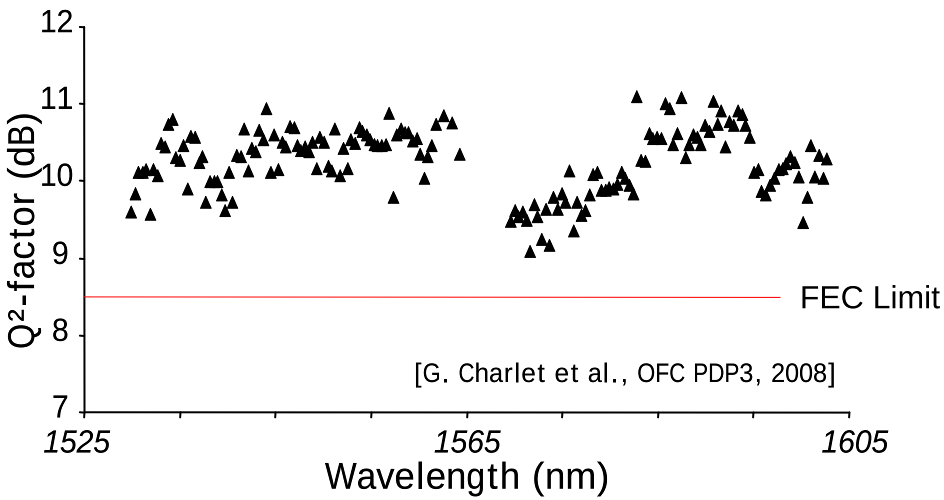
- Coherent detection + processing ➔ to compensate for linear impairments
- At 100G, PDM-QPSK **does not suffer from nonlinear effects** induced by 10G and 40G neighbors
- PDM-QPSK having important issues at 40G becomes recommended at 100G!

PDM-QPSK with Coherent Detection offers the best option for 100G

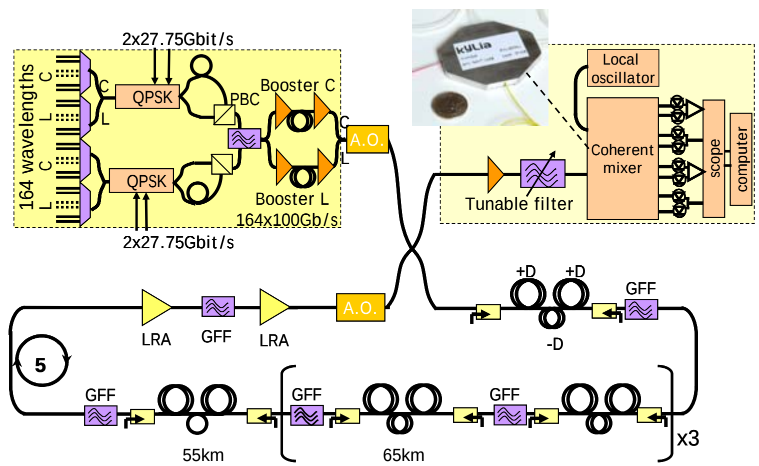
Support for 100G Multi-wavelength Transmission

16.4 Tbit/s: 164ch x 111Gb/s over 2,550km



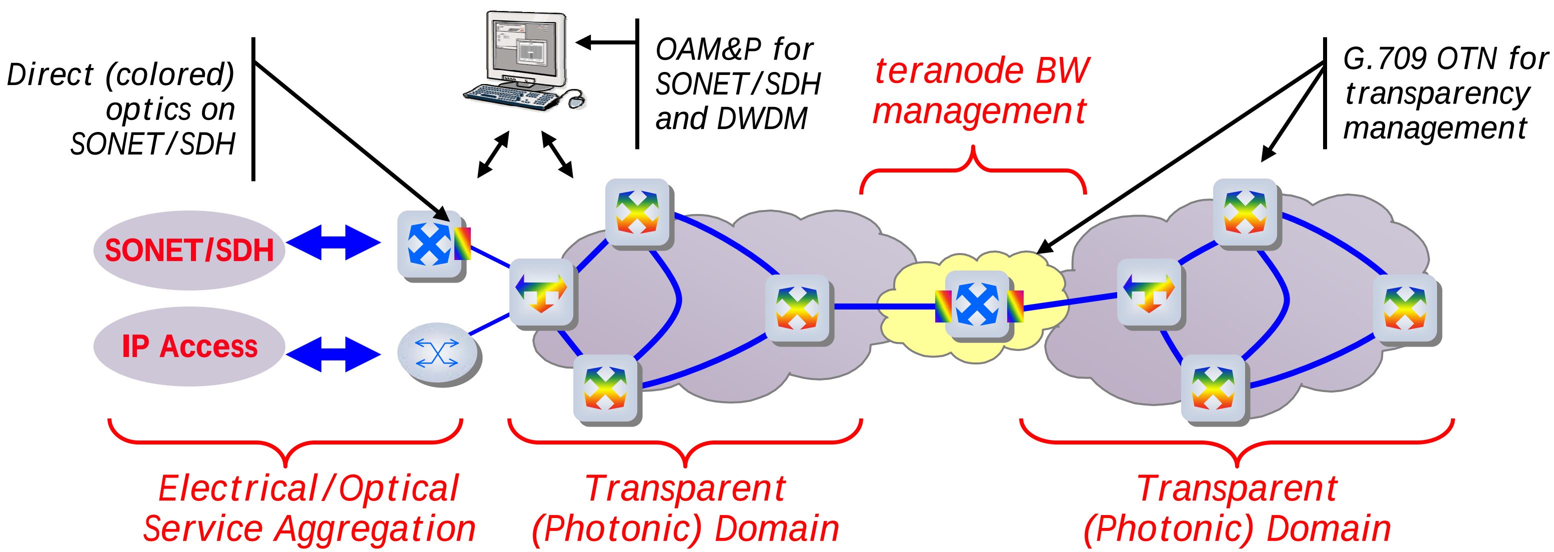


Our optical test-bed has shown support for 16.4 Tbps transmission over 164 channels at greater than 2,500 km



Test-bed for 164 channels

The Network Evolution Strategy Supporting 100G

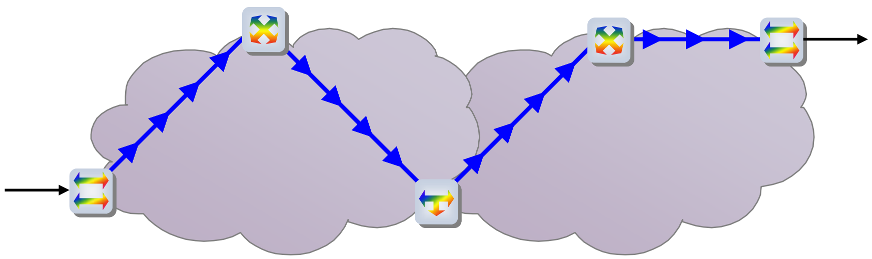


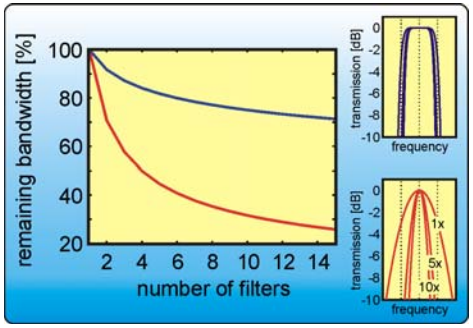
Evolution to 100G is assured through a transparent photonic core which does not hinder introduction of higher bit-rates. Adherence to ITU-T OTN principles ensures non-intrusive wavelength management

Introduction of **new capabilities** is achieved at the edges through the introduction of transponder (OT) capabilities and enhancements to electrical domain BW management such as the Teranode OXCs

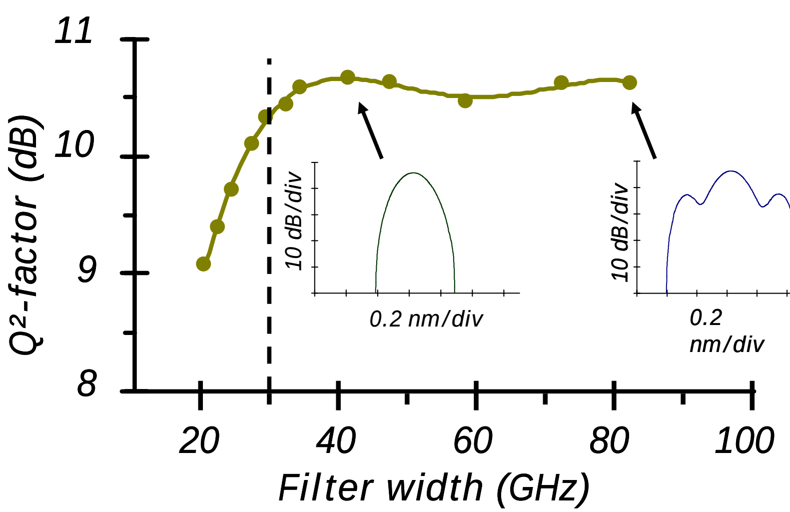
Consolidation of functionality is achieved through integration via a common management and control plane and usage of colored optics on client devices

Impacts of Filters on 100G and Existing Systems





Optically transparent channels see decreasing channel BW after traversing each filter (ROADM, WSS, etc.)

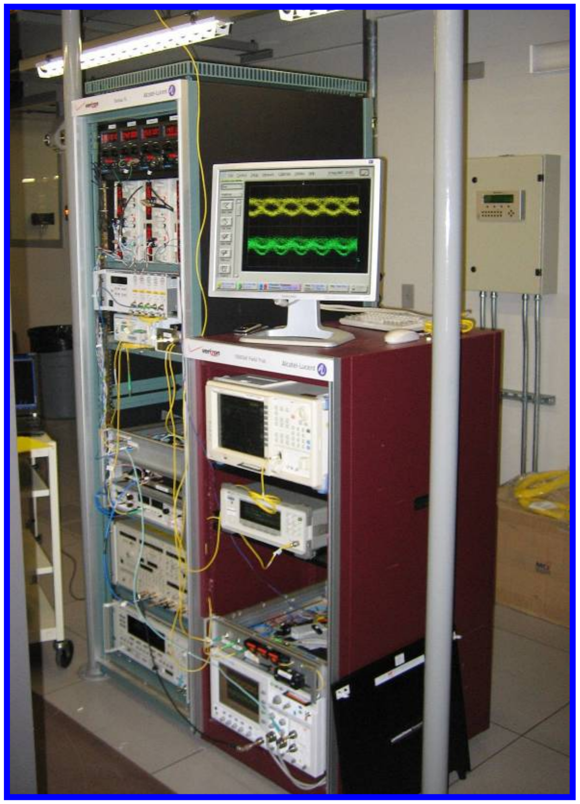


Our test-beds show

- Almost constant performance obtained for optical receiver bandwidth above 35GHz.
- No crosstalk from adjacent channels when filter width is above 50GHz thanks to coherent detection and sharp filtering provided in the electrical domain
- Conclude that we can expect tolerance to ROADM cascades

Advanced modulation format allows flexible deployment of 10/40/100G channels

100G Field Trial over installed, live Verizon system

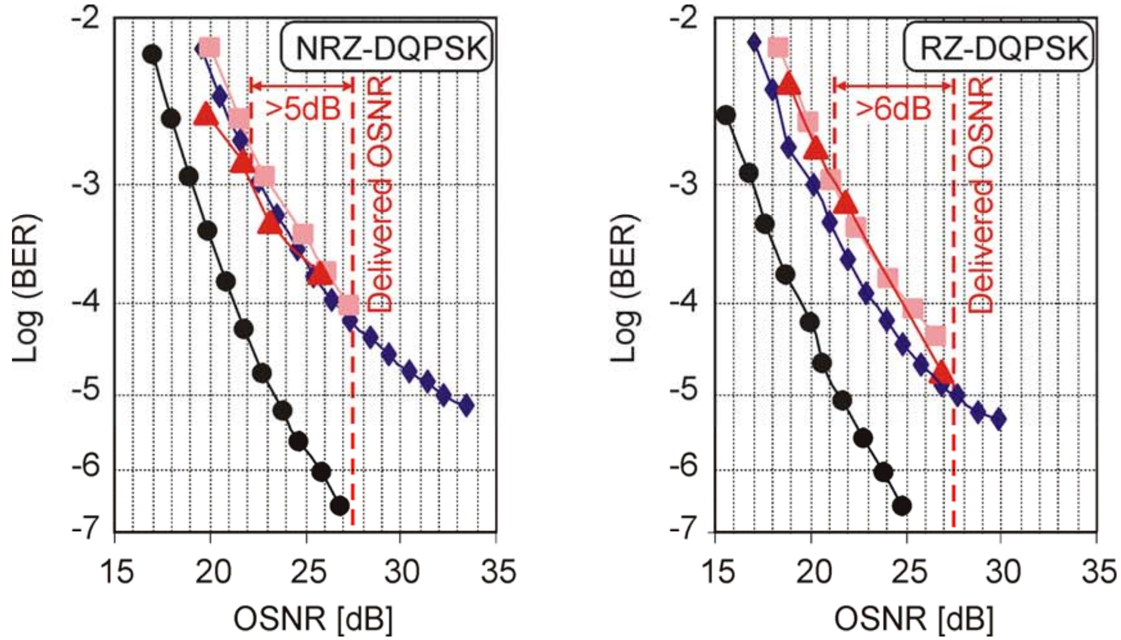


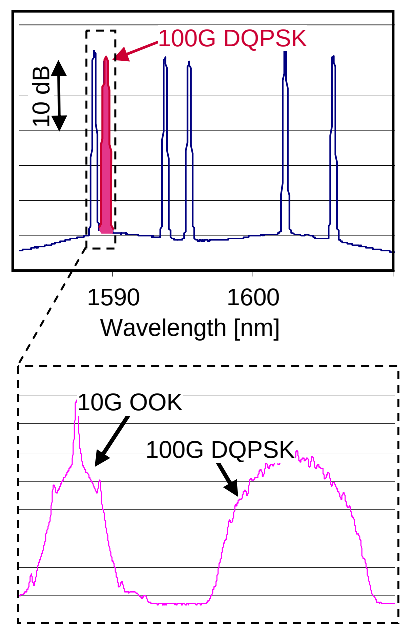
100G Transmitter at the
Tampa Central Office

Tampa to Miami 504-km field route operating LambdaXtreme®

100G Receiver next to LambdaXtreme®
at the Miami Central Office

100G Field Trial continued

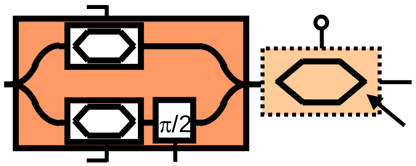




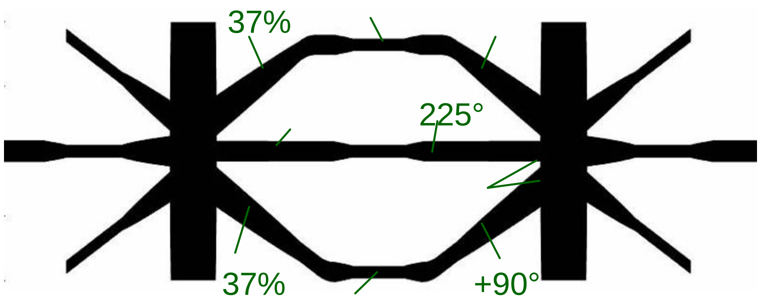
- Trial included transport of HDTV channel in 100G signal

Fully Integrated Transmitter/Receiver for DQPSK

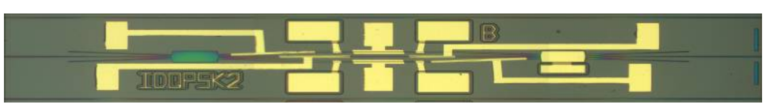
Transmitter



Schematics



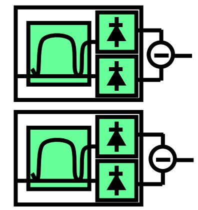
InP chip



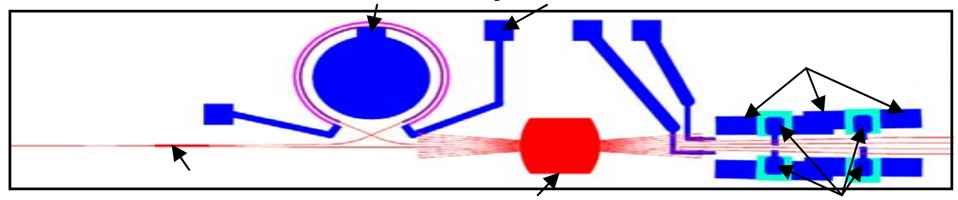
1.7 mm

OFC2008 postdeadline

Receiver

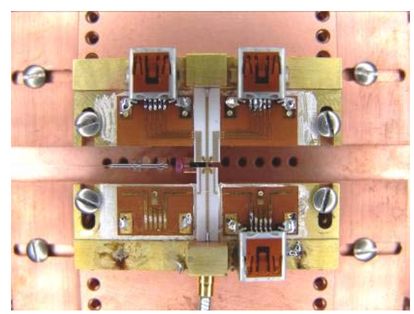


Mask Layout

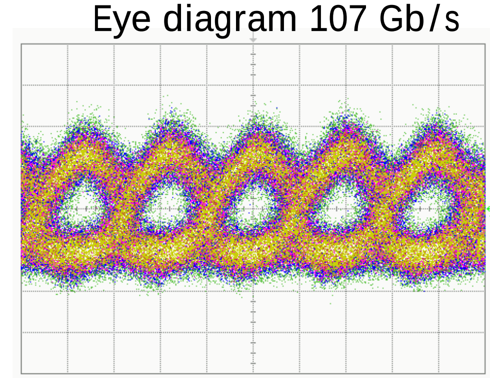


3.2 mm

submount



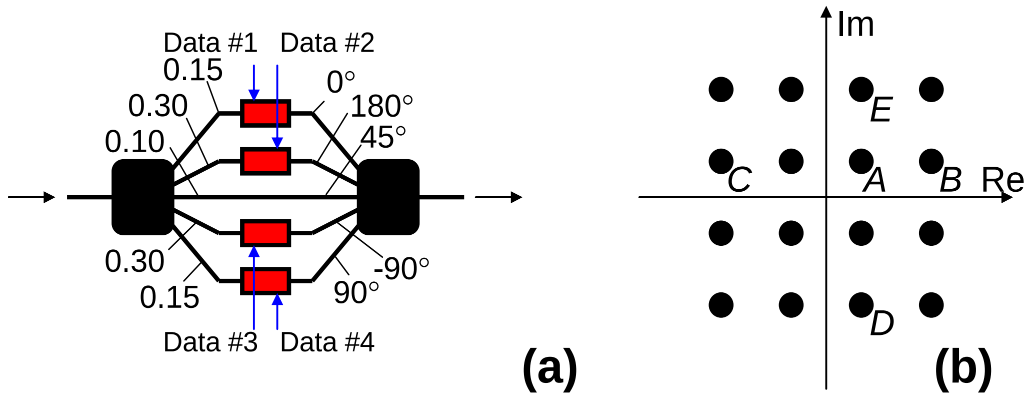
Eye diagram 107 Gb/s

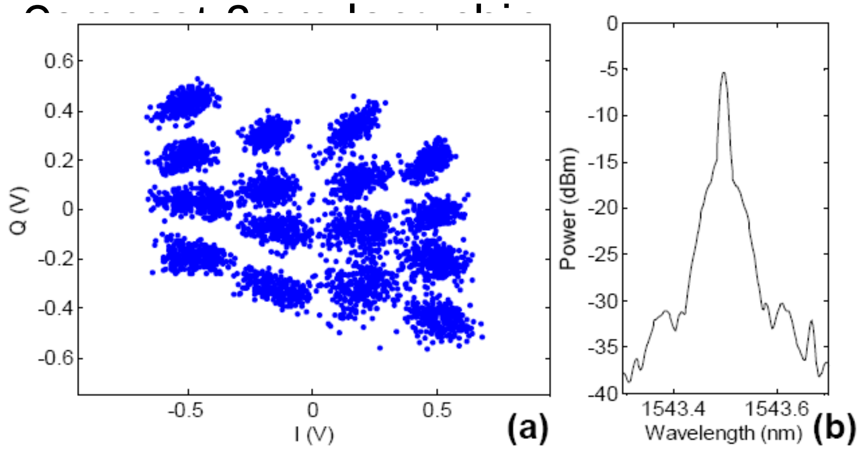


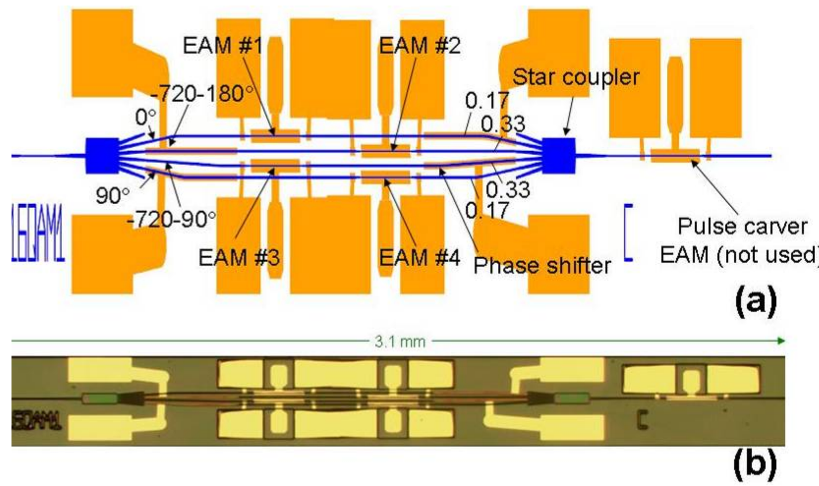
16 QAM Transmitter for High Spectral Efficiency

EAM based MZM modulator

- 16-quadrature amplitude modulation (QAM) modulator and demonstrate it at 43 Gb/s (10.7Gbaud)
- Scalable to higher rates
- 4 modulators to drive







OFC2008 postdeadline

Future: 100G Optical Packet Switching

Metro Ring Node without WDM

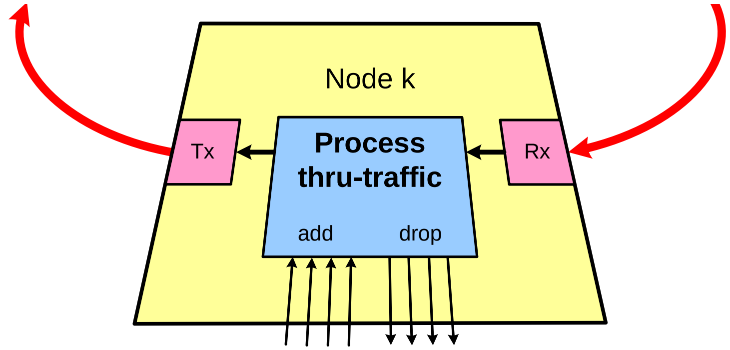
- Static optical links between next-neighbor nodes
- Requires only one transponder per node
- But Thru-traffic reduces add/drop capacity
- Scales poorly for large number of nodes N

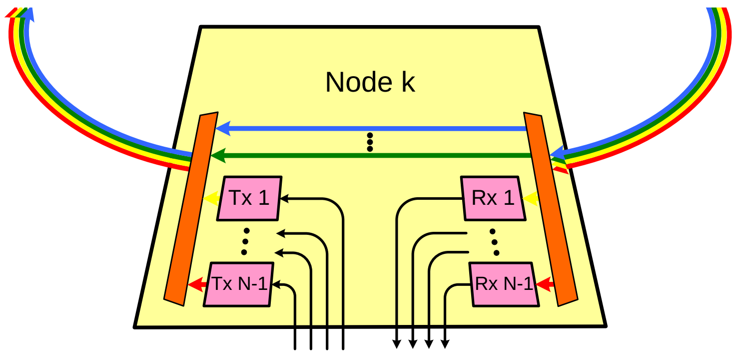
WDM Metro Ring Node

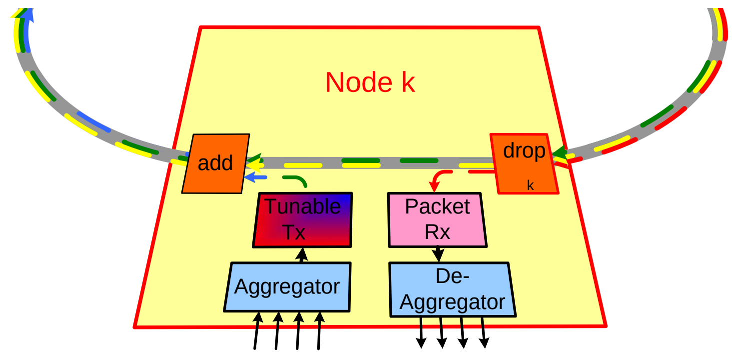
- Static optical links between any two nodes (full mesh)
- Eliminates thru-traffic
- But requires N – 1 transponders
- ROADMs can reduce the number of transponders, but reintroduce thru-traffic

Optical Packet Ring Node

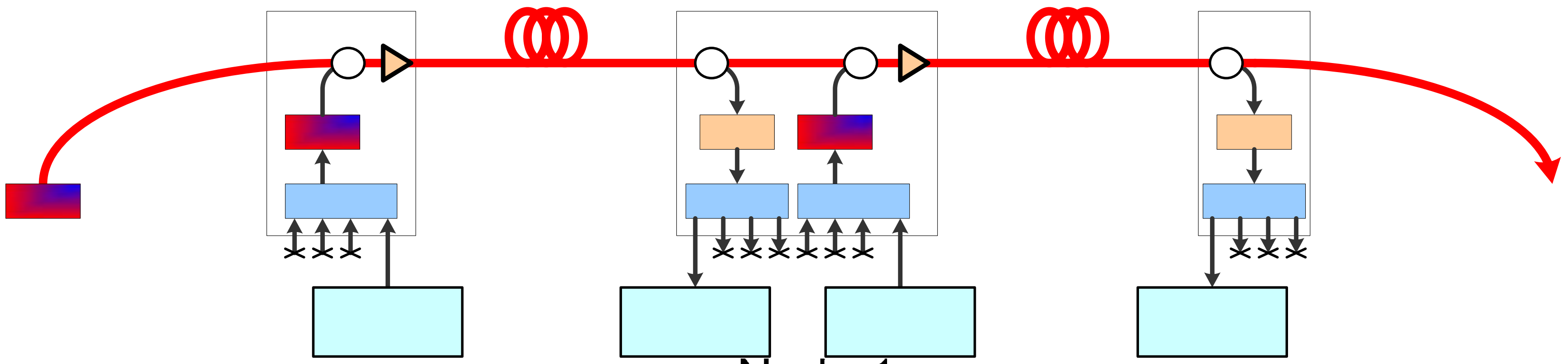
- Dynamic optical packet links between all nodes
- Requires only one (tunable) transponder per node
- Thru-traffic is bypassed, doesn't reduce add/drop
- Adjusts to rapid changes in traffic patterns



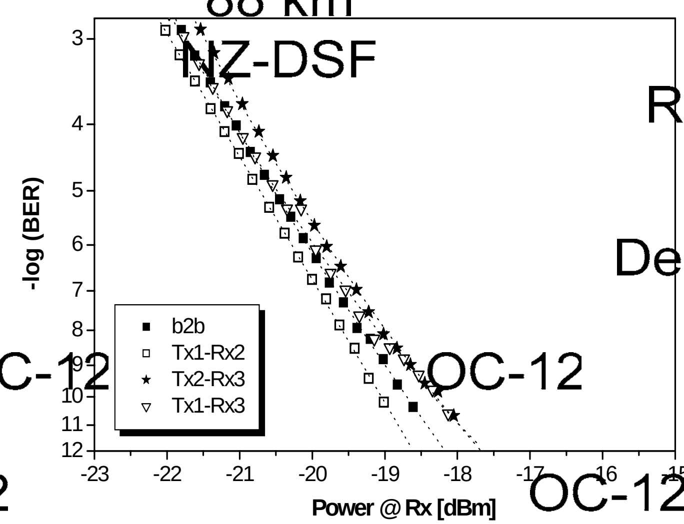




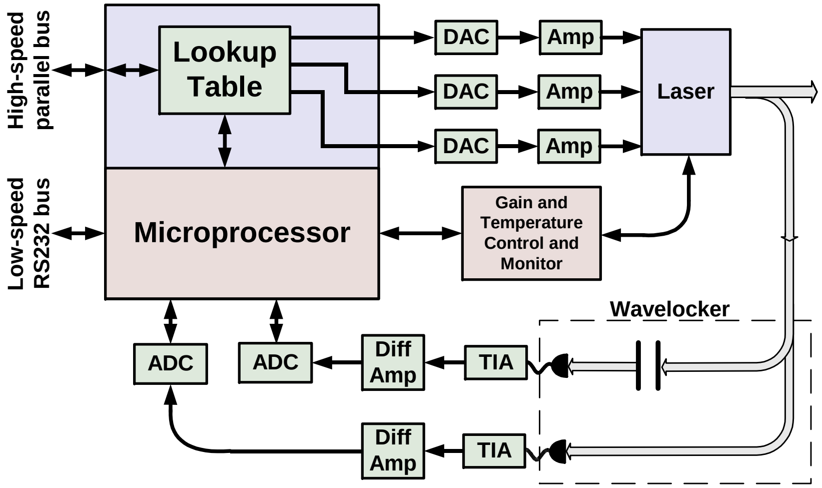
Optical Packet Switching Demonstration at 10G

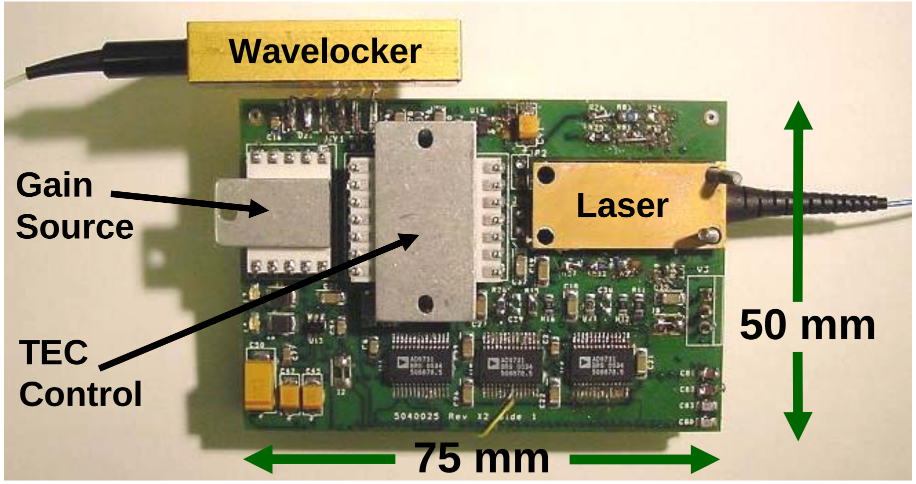


- OC-12 generator produces scrambled SONET frames with PRBS 2^{31}-1 payload
- Unused 10 Gb/s time slots are filled with dummy packets
- All Tx's switch packets based on a global, periodic schedule
- De-aggreators reassemble packets with SONET data back into OC-12 stream
- BER measurements on OC-12 outputs, < 0.5 dB penalty
- Span 1: 21 dB, +400 ps/nm. Span 2: 22 dB, -100 ps/nm



Bell-Labs fast-tuning laser module





Two double-sided PCB boards, including

- FPGA w/ look-up table & microprocessor
- Fast D/A converters
- TEC controller
- Bus interfaces

External wavelength-locker:

- ADC is sampled once per packet to update look-up table
- Improves frequency accuracy from ±6 GHz to ±3 GHz , correcting for temperature & aging
- Feedback is slow (order of seconds)

Switching between all combinations of 64 channels in < 50 ns

Improved laser design and advanced current driving for < 5 ns switching

- Not implemented in small module
- Accuracy ±12 G

Take Away Messages

- Video will dominate network traffic and require another order of magnitude more bandwidth
- 100G will be necessary to cost-effectively satisfy network demands
- Advanced modulation formats will allow 100G to have similar reach and ROADM cascadability as 10/40G and to be compatible with 50GHz spacing thus allowing edge upgrade of current and future transparent networks
- Photonic Integrated circuits will make 100G transmitters/receiver compatible with los cost, low footprint and high reliability
- Optical packet switching may become attractive at 100G to allow for sub-channel connectivity in optical domain