Advances in Optoelectronic Technologies for ROADM Subsystems

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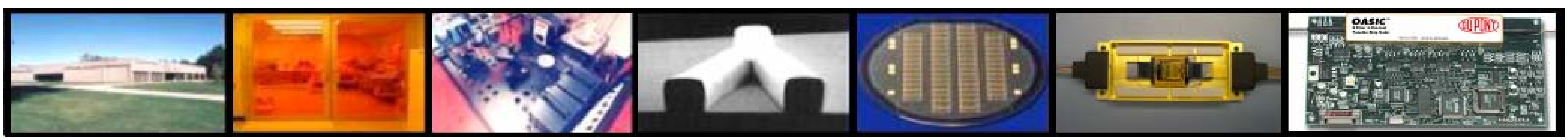

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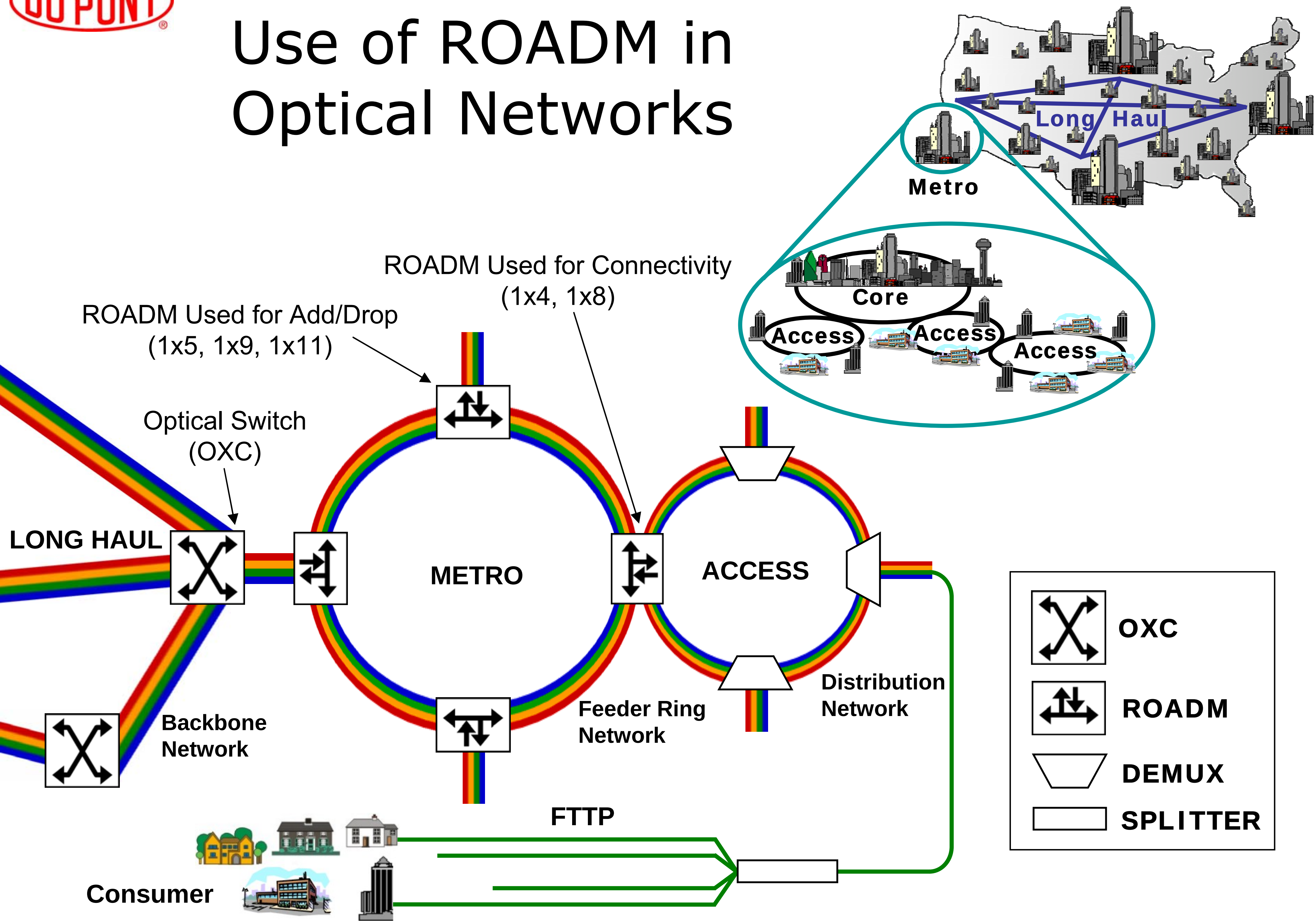
Use of ROADM in Optical Networks



Migration Toward Agile Optical Networks

Optoelectronic functions needed in agile optical networks:

- Tunable Lasers
- ROADMs

Network Function	Justification	Compatibility	New Components
Fixed functions			Fixed DWDM lasers, Fixed OADM
Narrow tunable laser	Inventory reduction	Drop-in for fixed laser	Thermal-tuned DFB
Full-band tunable laser	Inventory system simplification	Drop-in for fixed transponder	External-cavity laser
Type I ROADM Limited flexibility	Stranded capacity reduction, simple engineering rules	Dual-use as DGE	λ blocker + fixed filters or Demux / Switch / Mux PLC
Type II ROADM Any λ to any port Degree 2	No manual intervention, monitor & control	Retain blocker, add tunable laser, no impact to thru path; or all PLC solution, can be more cost-effective; or WSS	Tunable filters / lasers or OXC or WSS
Higher-Degree ROADM Any combination of λ's to any port	Ring-interconnect w/o OEO	Select locations only; interop with other nodes, same lasers	WSS
Optical Switch (aka OXC)	Mesh protection, etc.	Select locations only	Large WSS
Autonomous Agility	Optimum utilization Minimum OpEx	Same physical layer hardware	Integrated management

RHK (partial)

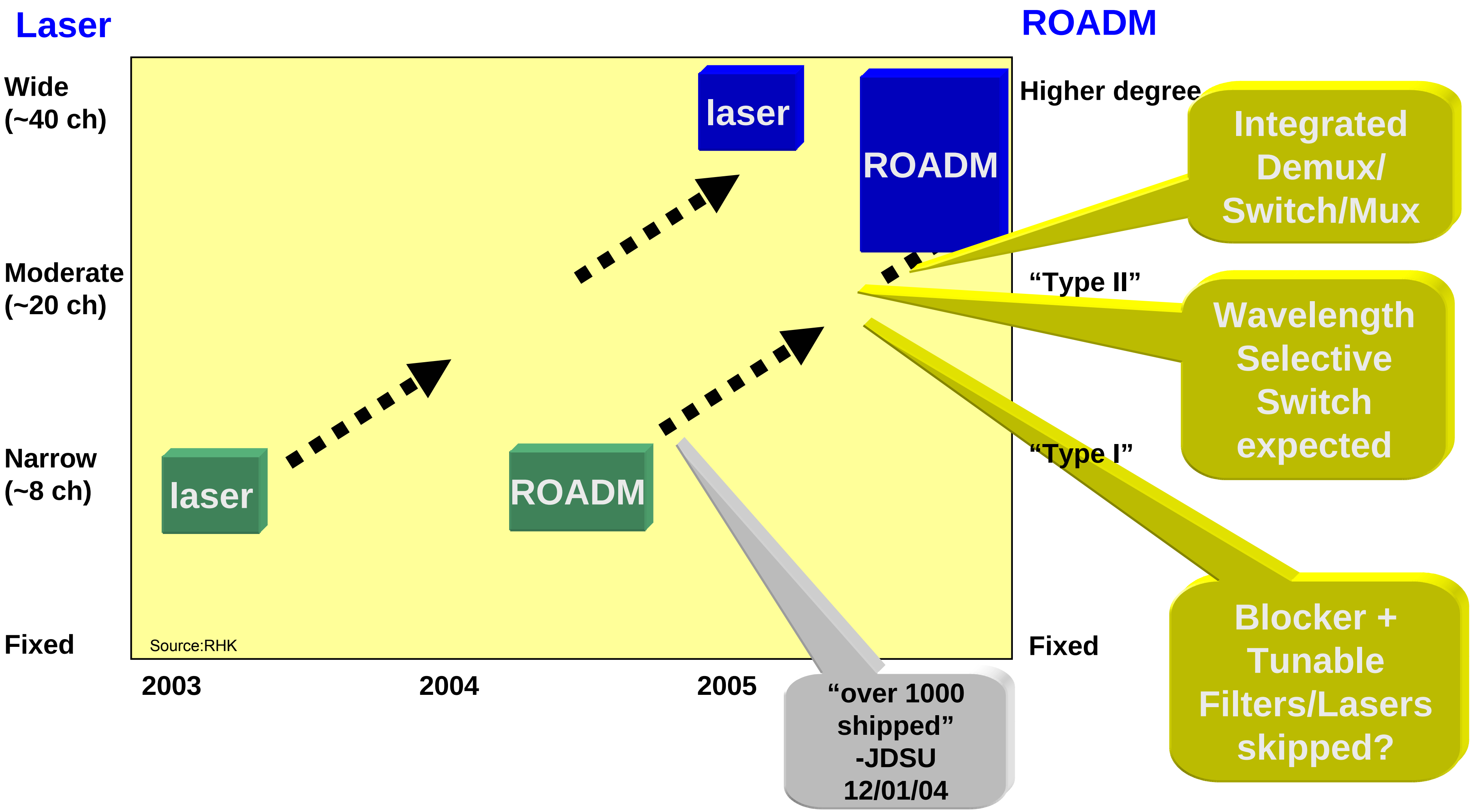
ROADM Use in Networks

Market (Technology)	**Component Vendors**	**System Vendors**	**Carriers** (System Suppliers)
Long-Haul (Wavelength Blocker)	Avanex, JDSU, DuPont, LightConnect	Lucent, Ciena, Marconi, Siemens	Qwest (Lucent), Verizon (Lucent), GigBE project (Ciena), MCI (Ciena), BT (Marconi), MCI (Siemens), AT&T (Siemens), Broadwing (Corvis)
Metro (Wavelength Blocker)	Avanex, JDSU, DuPont, LightConnect, CoAdna, Polycromix, Xtellus	Alcatel/Tropic, Lucent	Verizon, MCI, SBC (Alcatel/Tropic), BellSouth (Tellabs), NTT
Metro (Demux/Switch/Mux)	JDSU, DuPont, OpTun, Chromux, Neophotonics, NEL	Cisco, Tellabs, Hitachi	Comcast, Cox , Brighthouse (Fujitsu), Shaw
Metro (WSS)	JDSU, DuPont, CoAdna, Engana, Metconnex, LichtConnect, Capella	Fujitsu, Meriton	

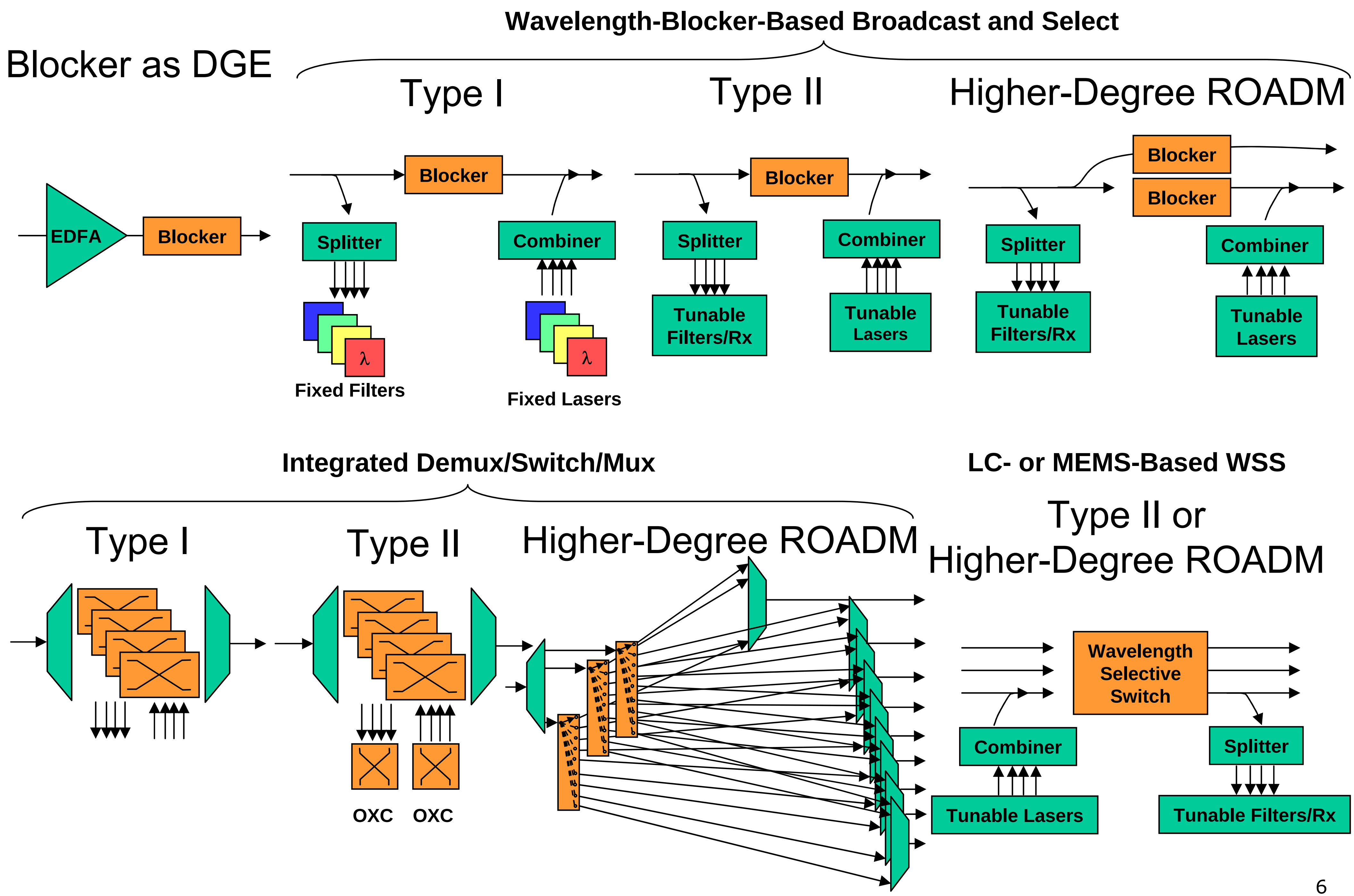
RHK (partial)

About 700 ROADM nodes were deployed in 2004, mostly in the second half of the year. The majority of these nodes were 32-channel systems from Fujitsu and Cisco, with the largest deployments being in Japan and North America.

ROADM path lags tunable laser by 2 years



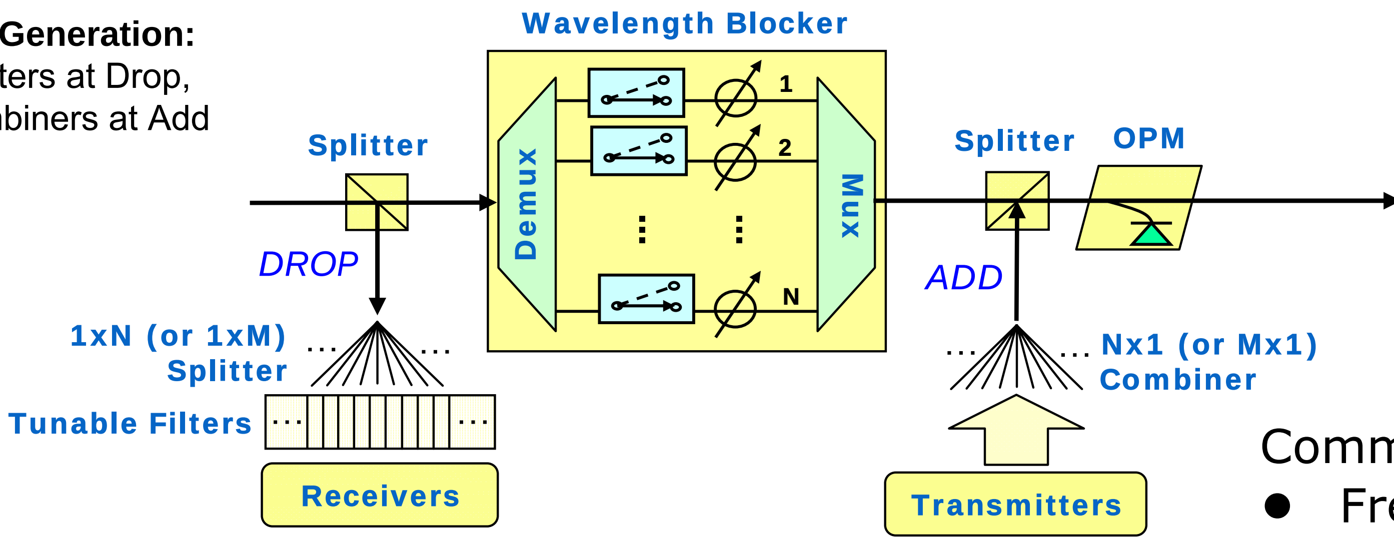
ROADM Types



Wavelength-Blocker-Based Broadcast and Select
Blocker as DGE
EDFA
Blocker
Type I
Blocker
Splitter
Combiner
λ
Fixed Filters
λ
Fixed Lasers
Type II
Blocker
Splitter
Combiner
Tunable Filters/Rx
Tunable Lasers
Higher-Degree ROADM
Blocker
Blocker
Splitter
Combiner
Tunable Filters/Rx
Tunable Lasers
Integrated Demux/Switch/Mux
Type I
Type II
OXC
OXC
Higher-Degree ROADM
LC- or MEMS-Based WSS
Type II or Higher-Degree ROADM
Wavelength Selective Switch
Combiner
Splitter
Tunable Lasers
Tunable Filters/Rx

Wavelength-Blocker-Based Type I ROADM

Old Generation:
Splitters at Drop,
Combiners at Add



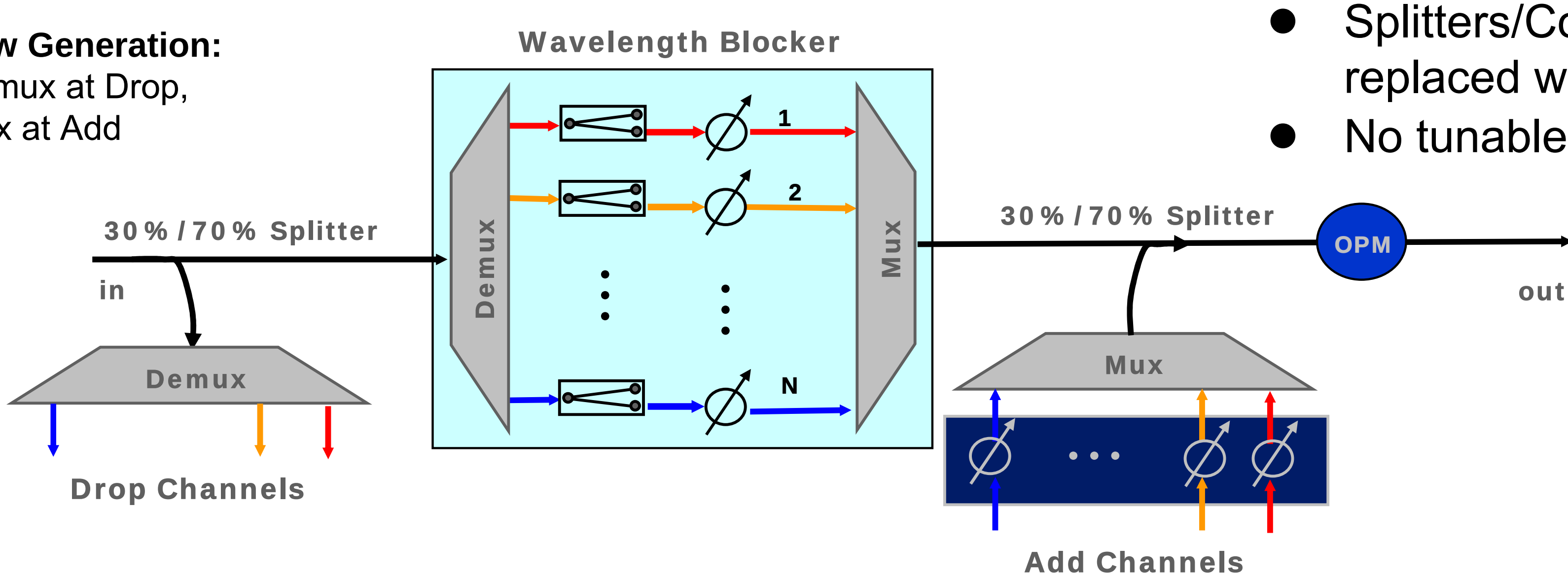
Common Characteristics:

- Free-space (MEMS, LC)
- For full reconfigurability: Tunable lasers at ADD

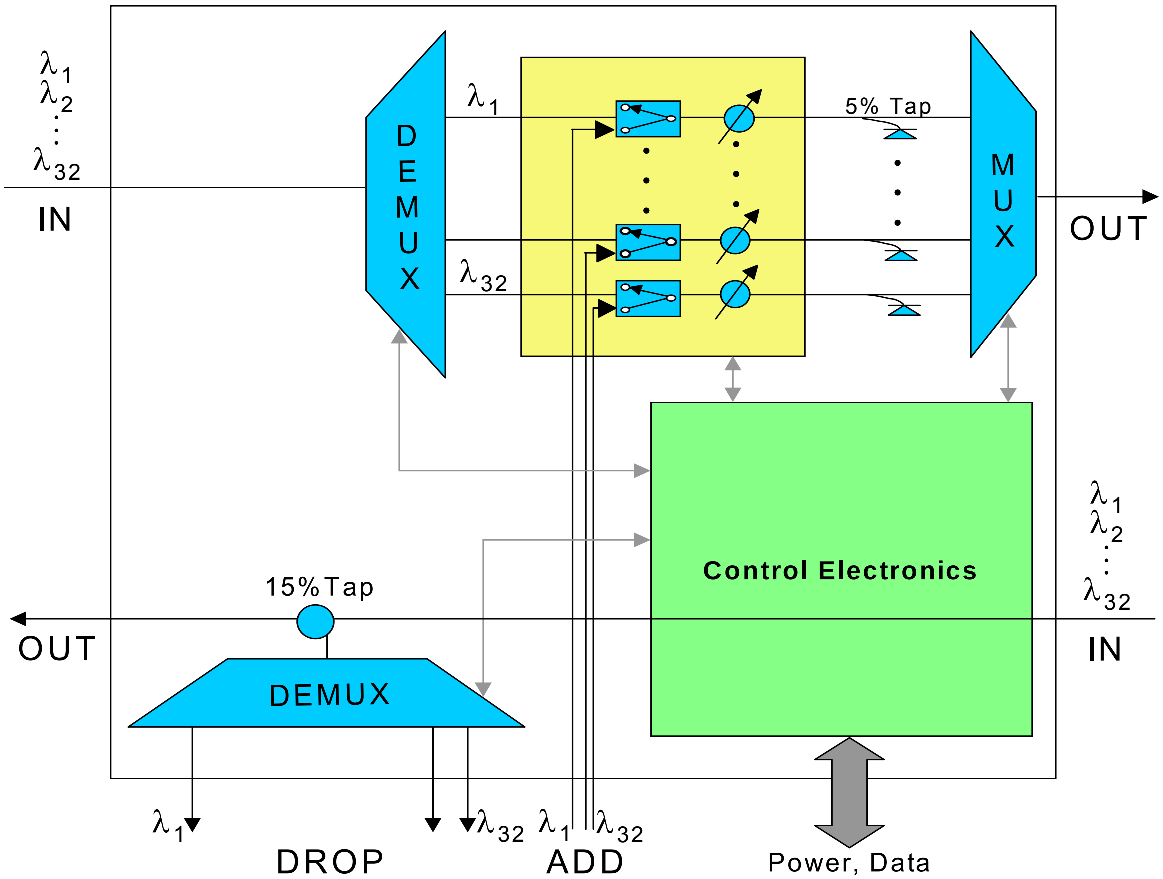
New Gen:

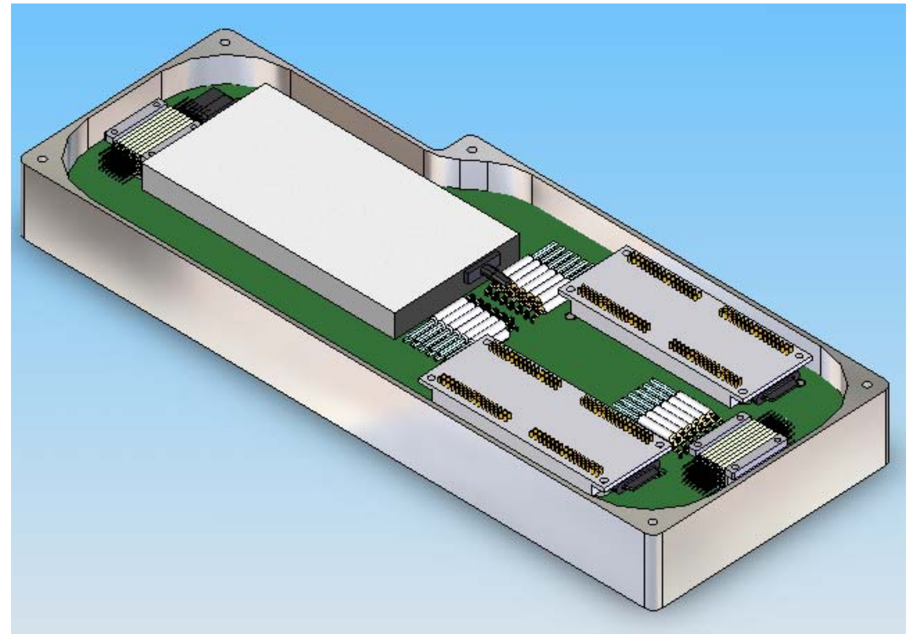
- Splitters/Combiners replaced with Demux/Mux
- No tunable filters at DROP

New Generation:
Demux at Drop,
Mux at Add



PLC-Based Type I ROADM



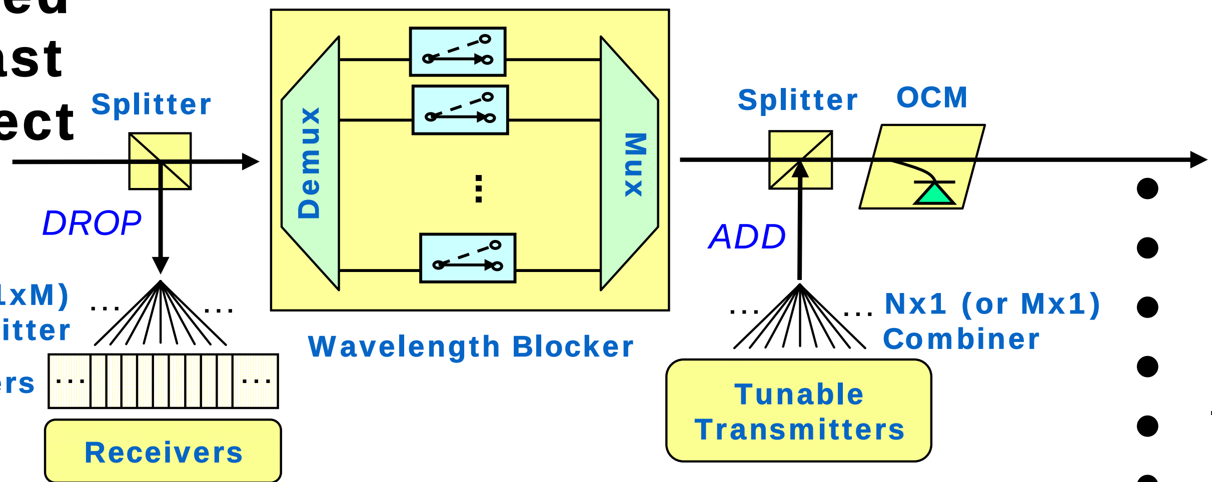


Note: Both express and "Add" channels are balanced with the built-in VOA array

Type II ROADM Configurations

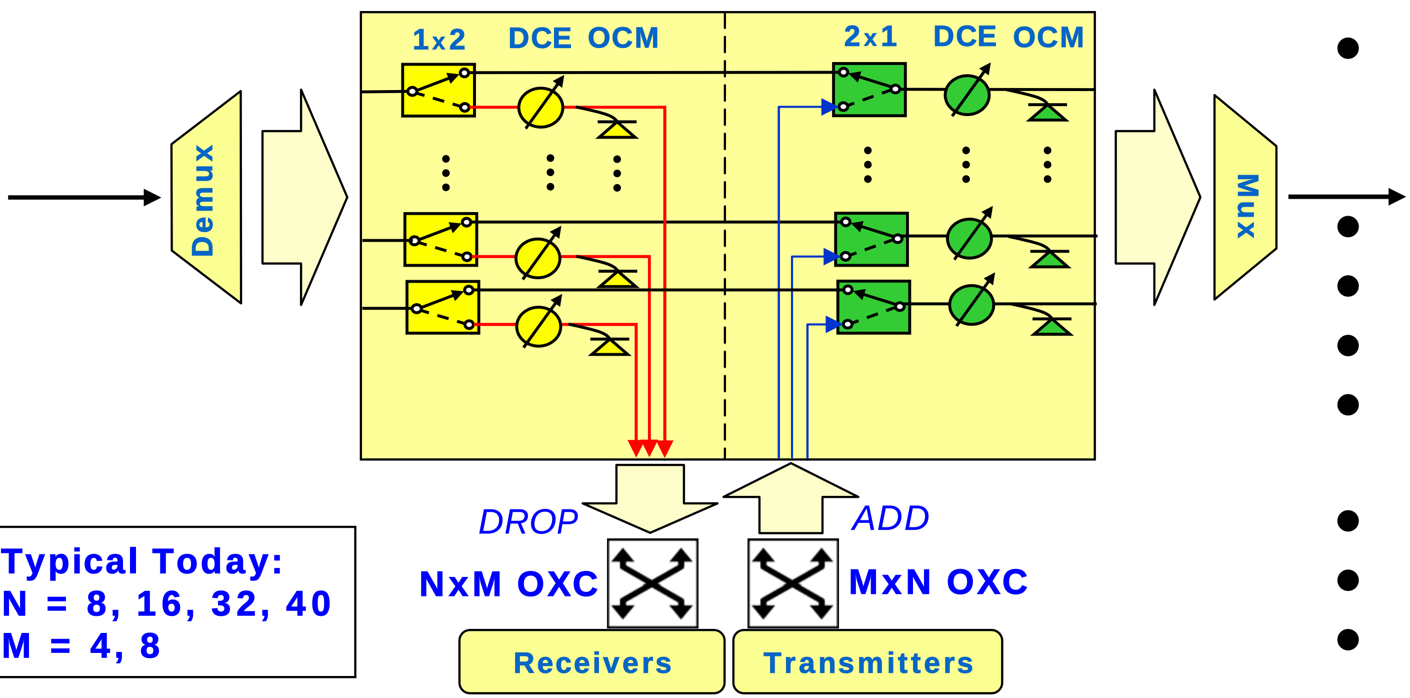
Full N (or M of N) Reconfigurability

WB-Based Broadcast and Select



- Free-space, MEMS, LC
- Higher IL ▼
- Difficult to upgrade ▼
- Reliability issues ▼
- Tunable filters at DROP ▼
- For full reconfigurability: Tunable lasers at ADD ▼
- Large component count ▼
- Expensive ▼

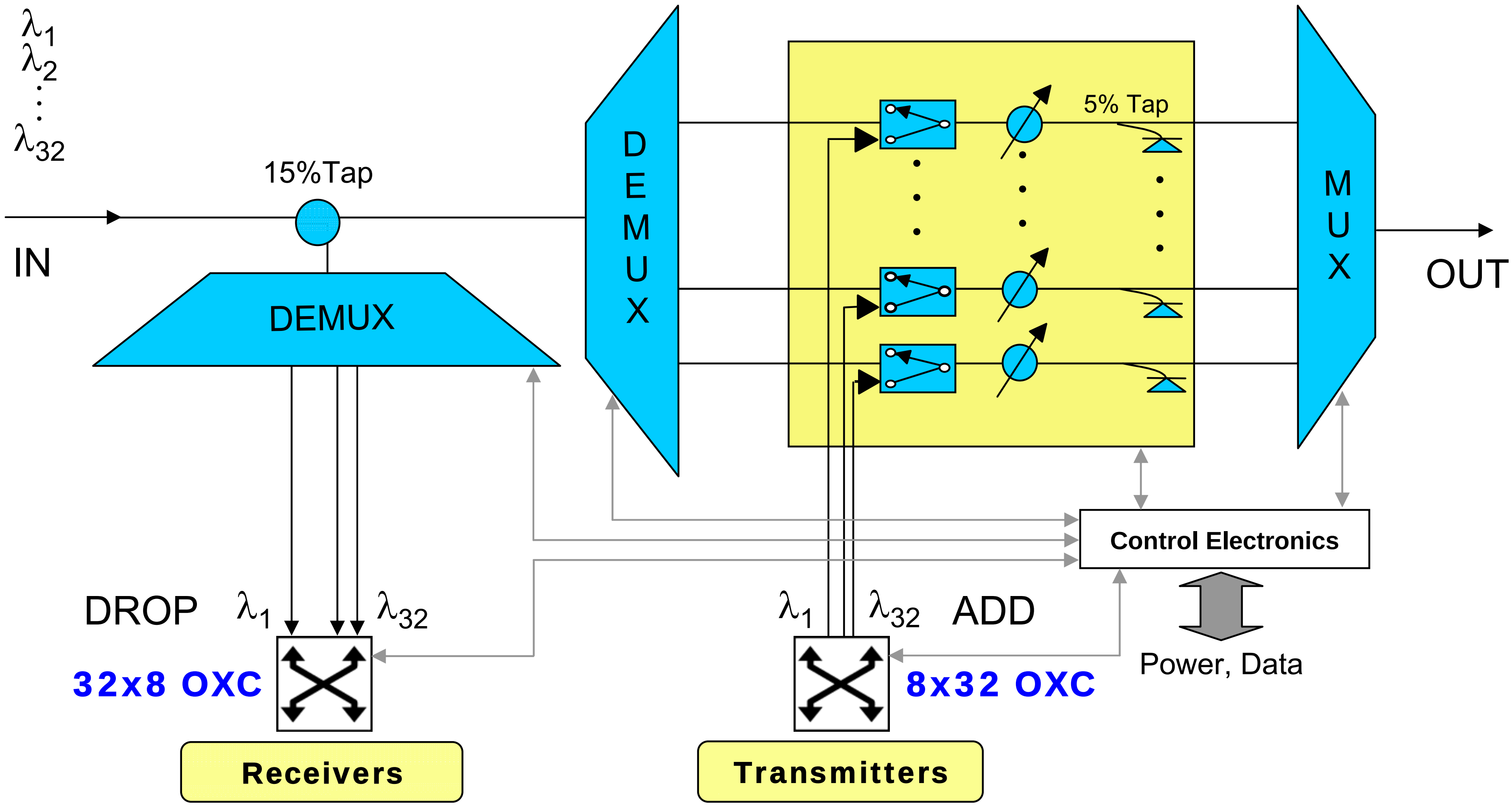
PLC-Based Demux / Switch / Mux



Typical Today:
N = 8, 16, 32, 40
M = 4, 8

- Can be single PLC ▲
- Lower IL ▲
- Easy to upgrade ▲
- NxM & MxN at A/D give full reconfigurability ▲
- Integration-friendly ▲
- Small component count ▲
- Low cost ▲

PLC-Based Type II ROADM

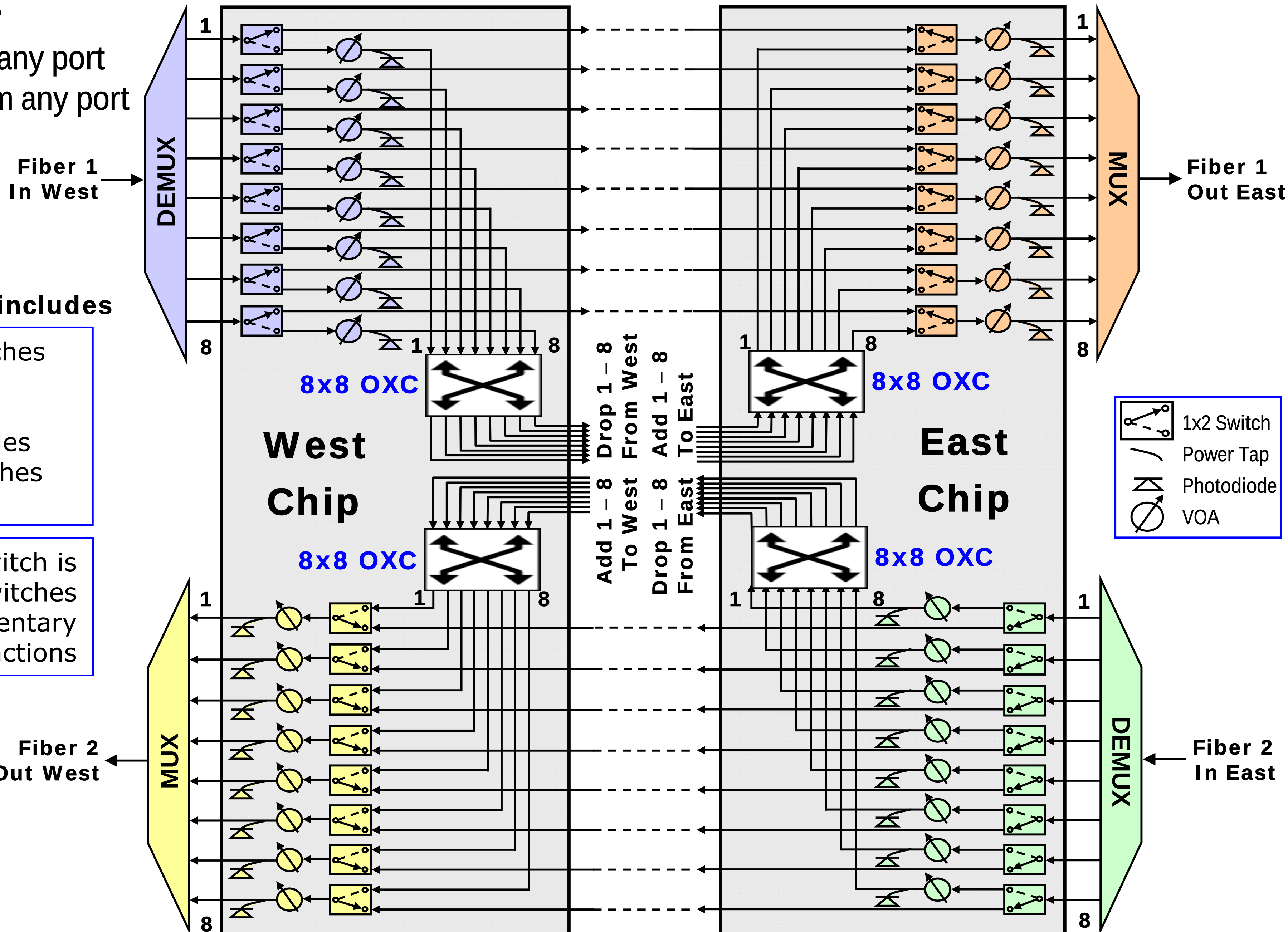


Demux/Switch/Mux Type II ROADM

Fully Reconfigurable East/West Separated Architecture

8 λ / Fiber

Drop any λ to any port
Add any λ from any port

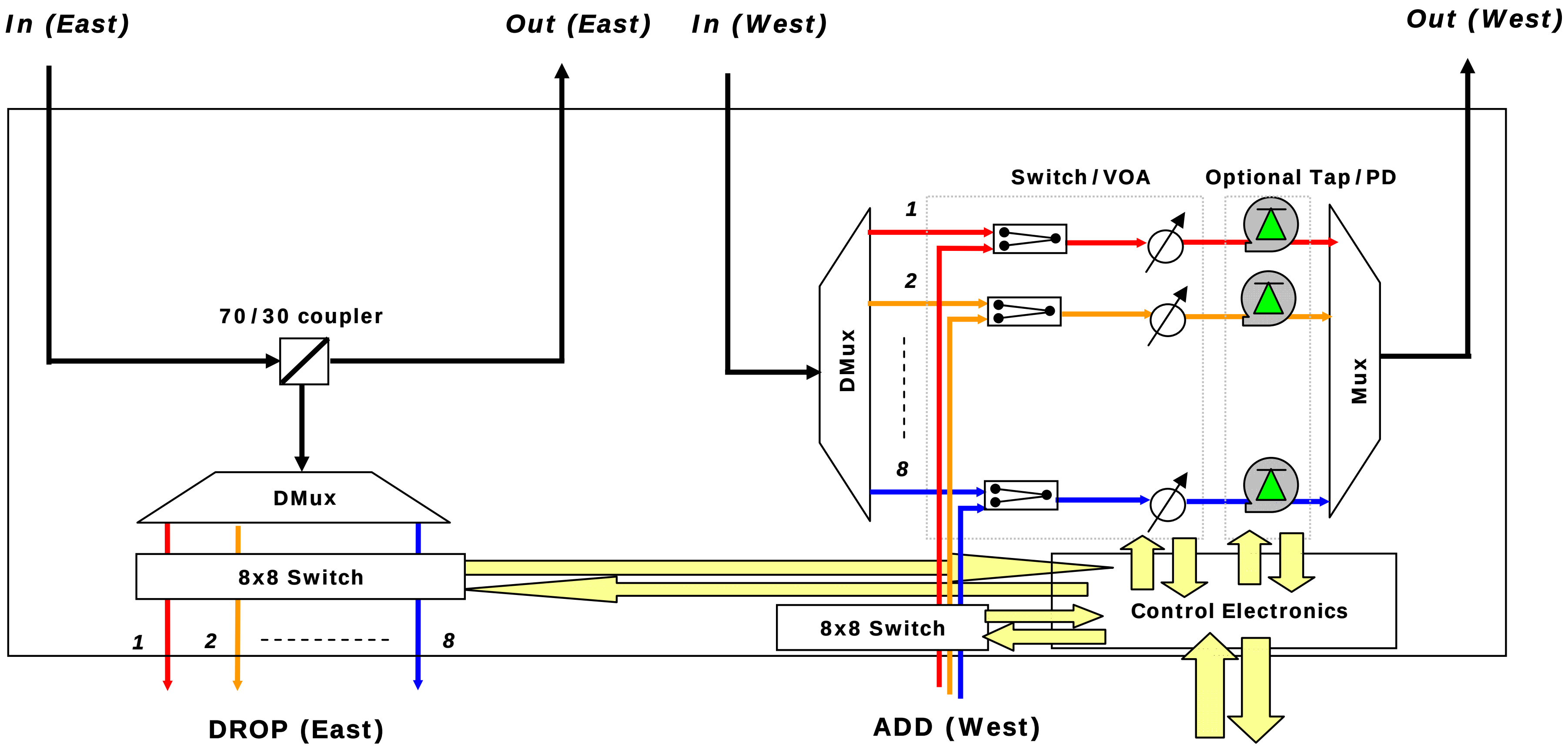


Polymer PLC includes

16 1x2 Switches
16 VOA's
16 Taps
16 Photodiodes
2 8x8 Switches
66 Functions

Each 8x8 Switch is
112 1x2 Switches
→ **288** Elementary
Functions

Fully Reconfigurable PLC-Based 8-Channel Demux/Switch/Mux Type II ROADM



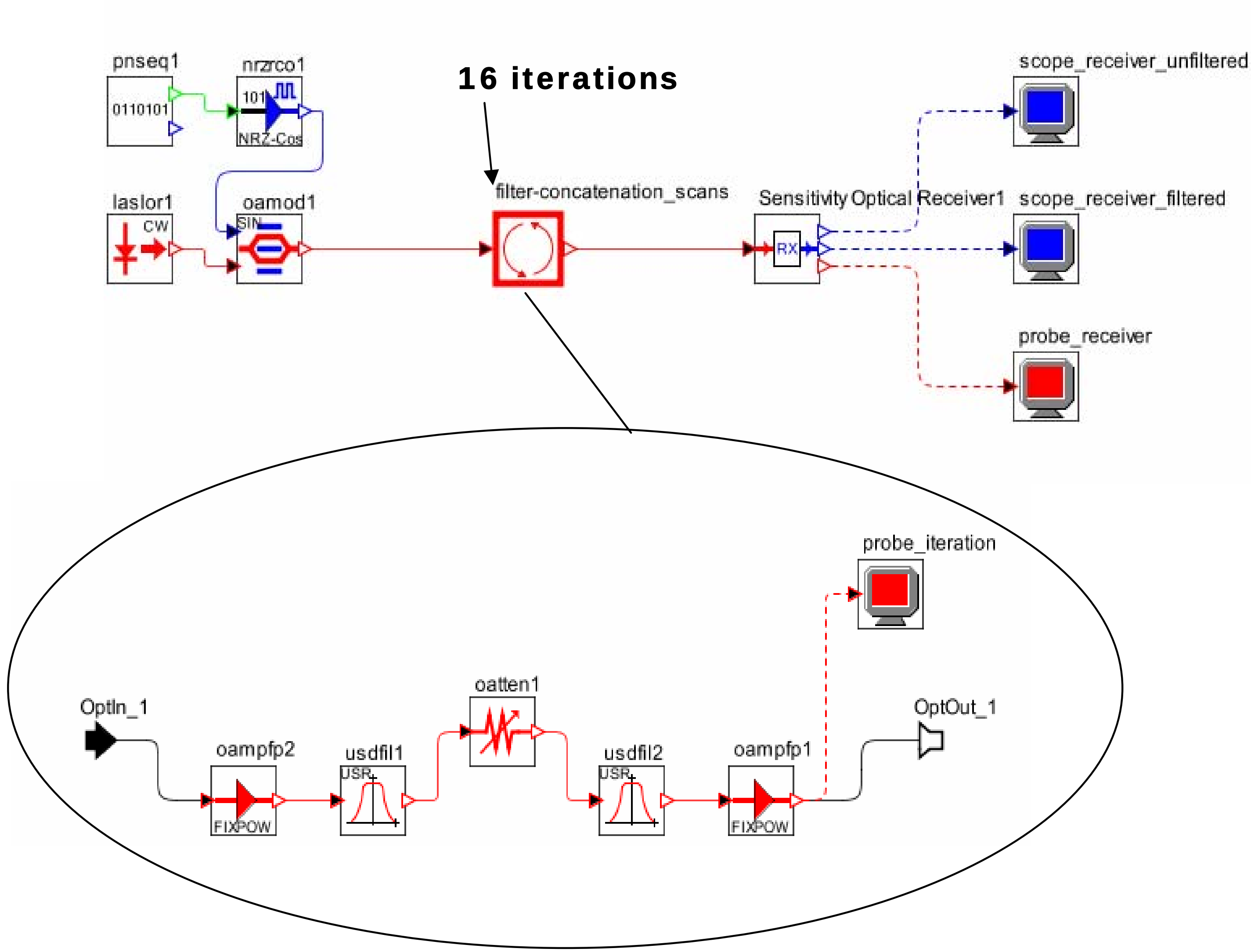
Note: Mux and Demux are based on thin film filters

Node Cascading Simulation Layout

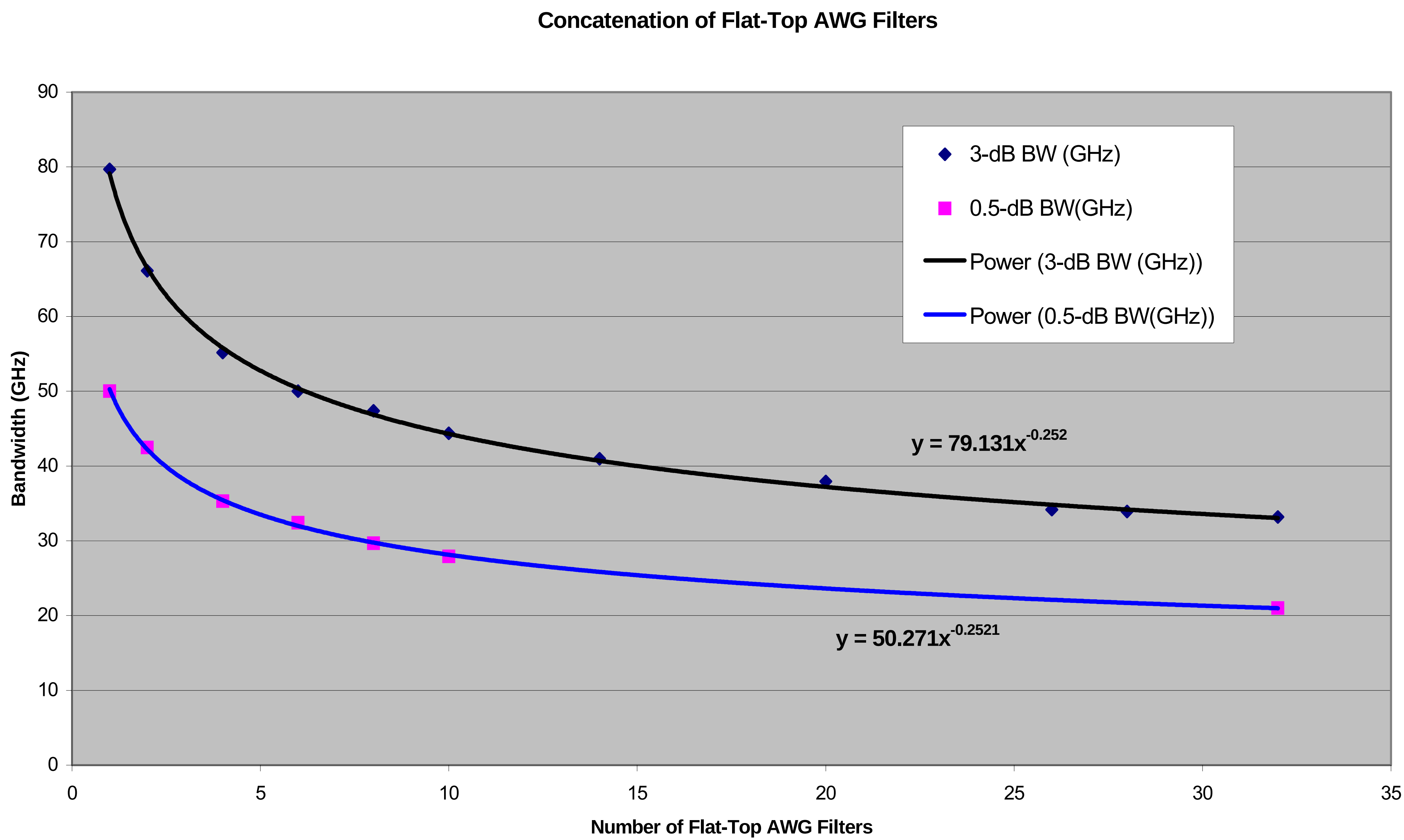
Cascade of 16 ROADM nodes (32 AWG's)

Simulation tools and assumptions:

- Rsoft OPTSIM simulation tool is used
- Measured spectral IL and CD of Flat Top AWG filters are used
- Two optical amplifiers are used at each node
- Worst case narrowing of ROADM passband due to temperature variation and center frequency inaccuracy of AWG filters is used



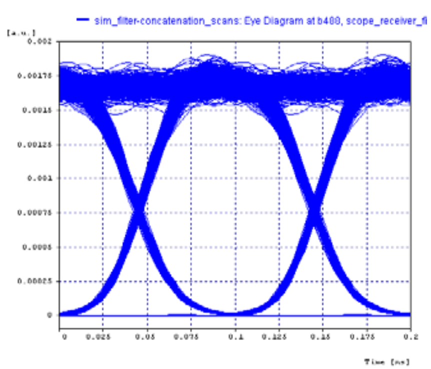
Bandwidth of Cascading AWG Filters



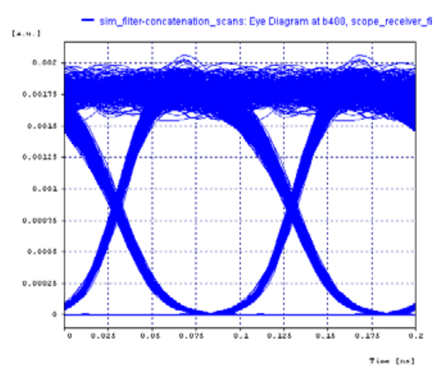
Simulation Conditions (16 Nodes)

	Laser center frequency(THz)	Demux filter 3-dB center (THz)	Mux filter 3-dB center (THz)	ROADM Total Loss (dB)
Run1	194.0000	194.0000	194.0000	10.0
Run2	194.0111	194.0000	194.0000	10.0
Run3	194.0111	194.0050	193.9950	10.0
Run4	194.0111	194.0050	193.9950	20.0

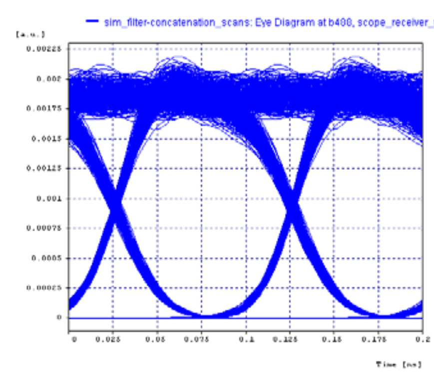
Run 1



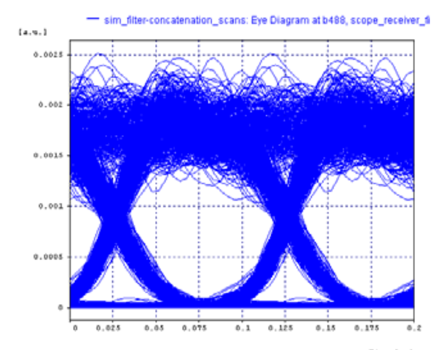
Run 2



Run 3

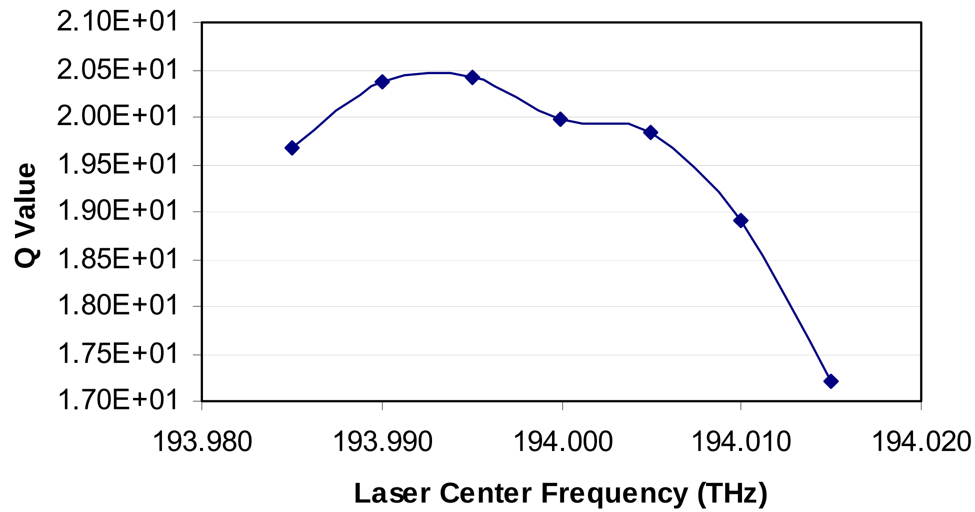


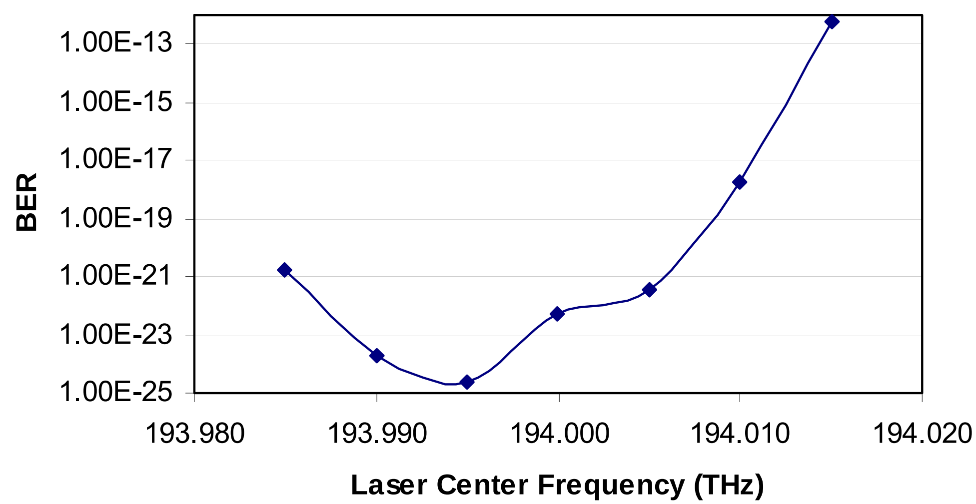
Run 4



Cascading Simulation Conclusions

- DuPont PLC ROADM meets bandwidth requirements for 16-node DWDM rings
  - Bandwidth at 0.5dB is over 40 GHz for each ROADM
  - Bandwidth at 0.5dB is over 20 GHz after 16 cascading nodes (32 AWG's)
- DuPont PLC ROADM allows use of low cost, low accuracy lasers for 16-node rings
  - Bit error rate (BER) lower than 10^{-17}
  - Lasers with +/-10 shift of center frequency can be used without any system performance degradation after 16 cascading nodes

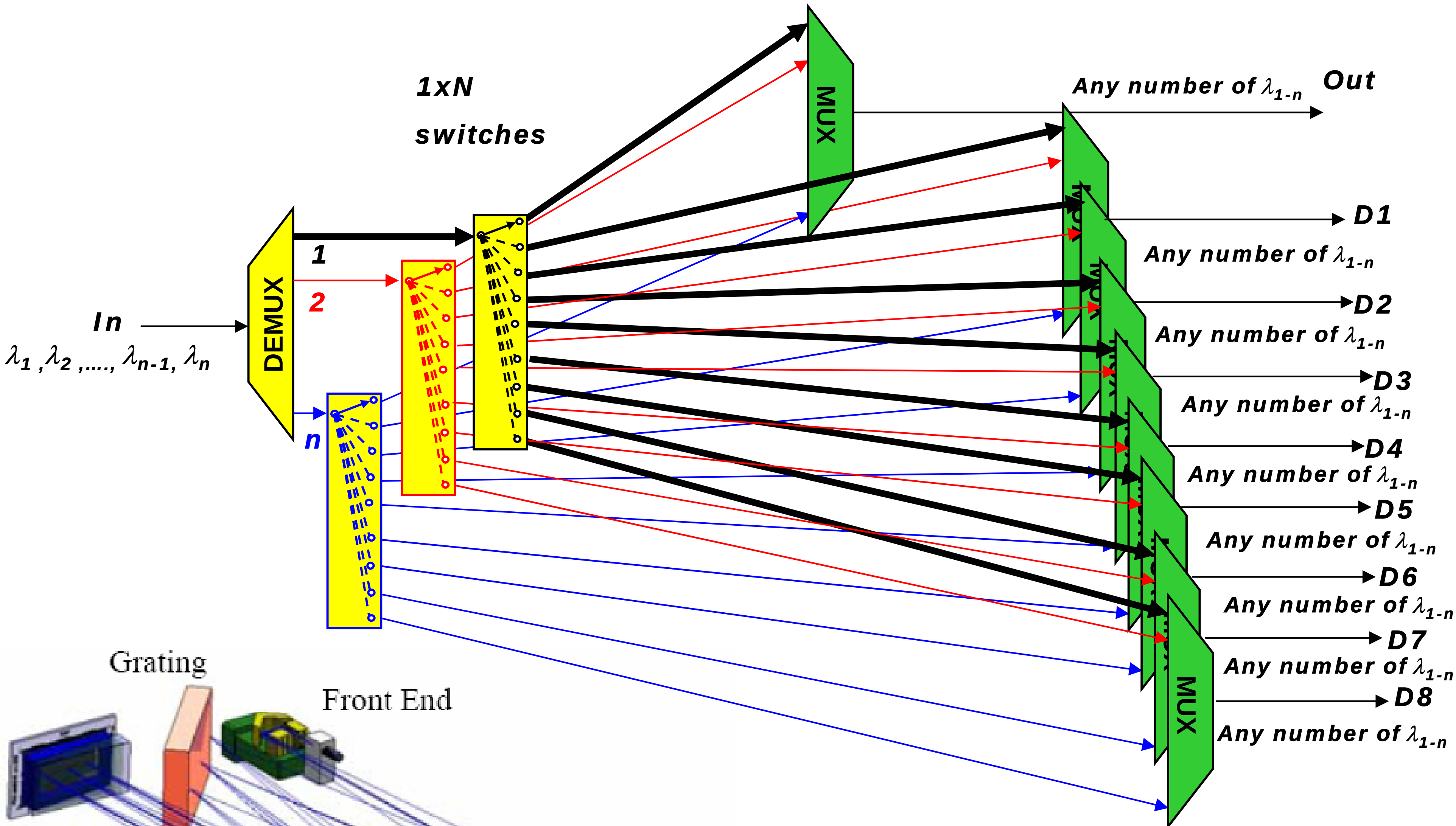


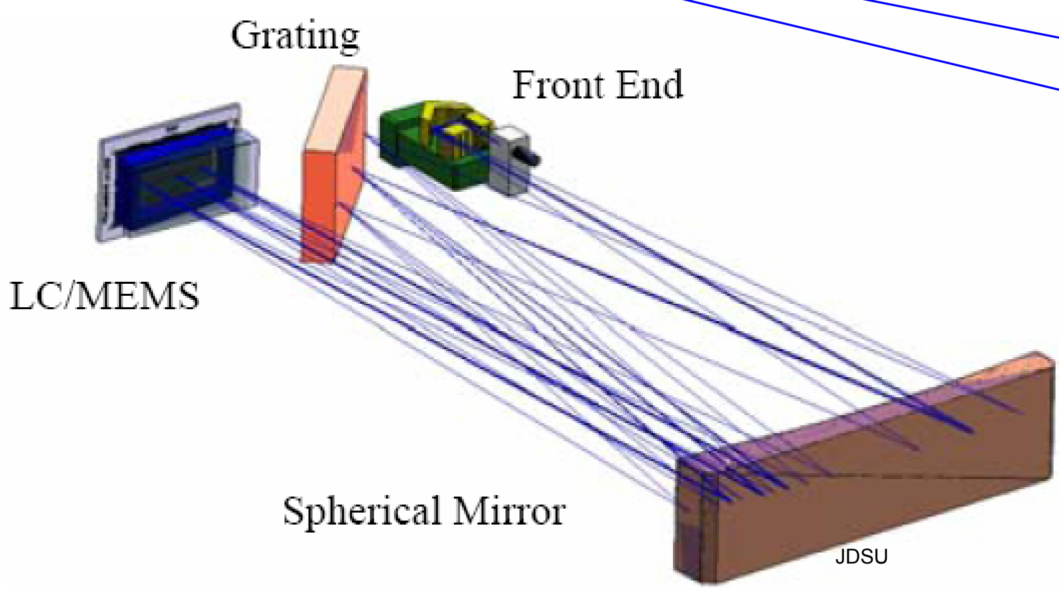


Comparison of PLC and λ Blocker Approaches for ROADM

Parameter	PLC ROADM	λ Blocker ROADM
Number of Channels	≤ 40	> 40
Channel Spacing	≥ 100 GHz	< 100 GHz
Insertion Loss (in-out)	< 12 dB	< 11 dB
Insertion Loss (Add-out)	< 10 dB	< 13 dB
Insertion Loss (in-Drop)	< 10 dB	< 10 dB
Add/Drop Time delay	< 10 ms	< 50 ms
PDL (in-out) at min attenuation	< 0.5 dB	< 0.5 dB
Passband Ripple	< 0.3 dB	< 0.3 dB
Size	Two slots	Four slots
Technology Platform	Solid state optics (waveguides)	Free space optics
Stability and Reliability	Excellent	Average
Cost	$X/2	$X
Potential for Cost Reduction	High – automated manufacturing	Low – manual assembly

Liquid Crystal & MEMS Based WSS





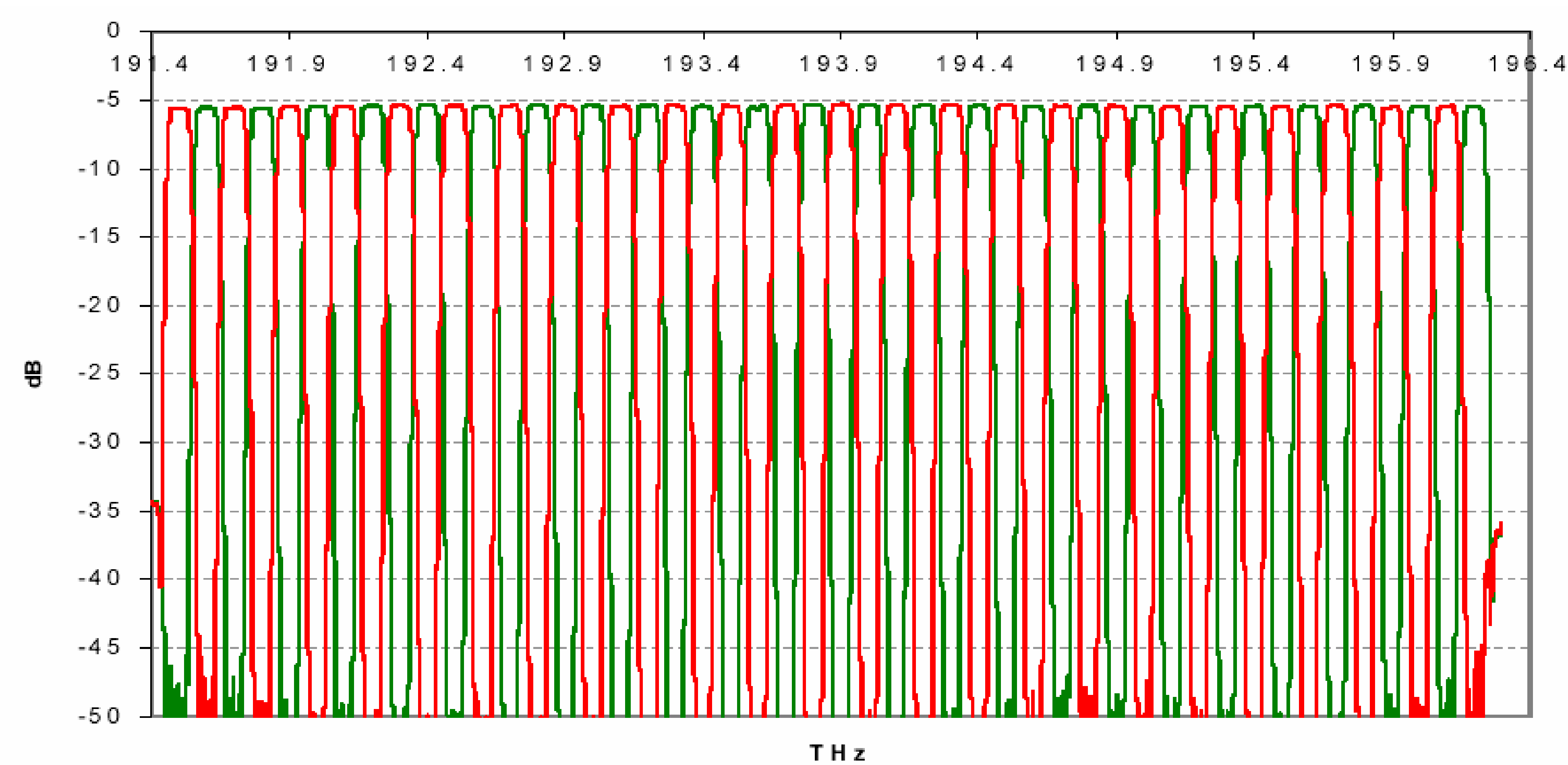
Shared bulk grating for all Mux's and Demux's

Advantages of LC vs MEMS WSS

- Mature components and proven technology (same technology as wavelength blockers in commercial use)
- Lower cost (simpler alignment and calibration, high yield)
- No notches between channels (for higher cascadability and upgradability to smaller channel spacing)
- Higher reliability (no moving parts)
- No vibration sensitivity issues
- No sticking and static damage issues
- Telcordia qualified technology platform
- Lower design and supply risk

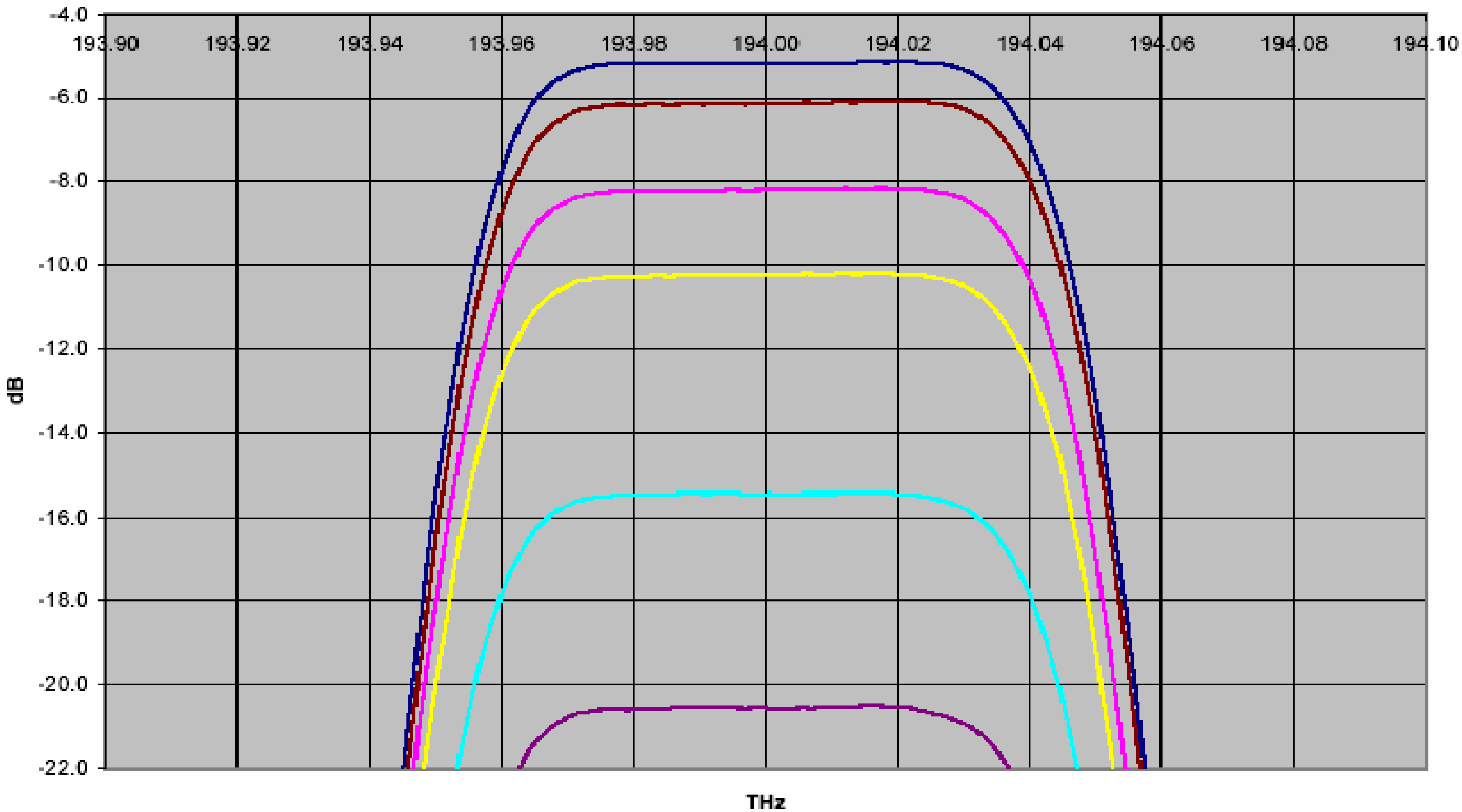
Performance of 1x4 Liquid Crystal WSS

Typical Interleaved Channel Spectra at Drop Port



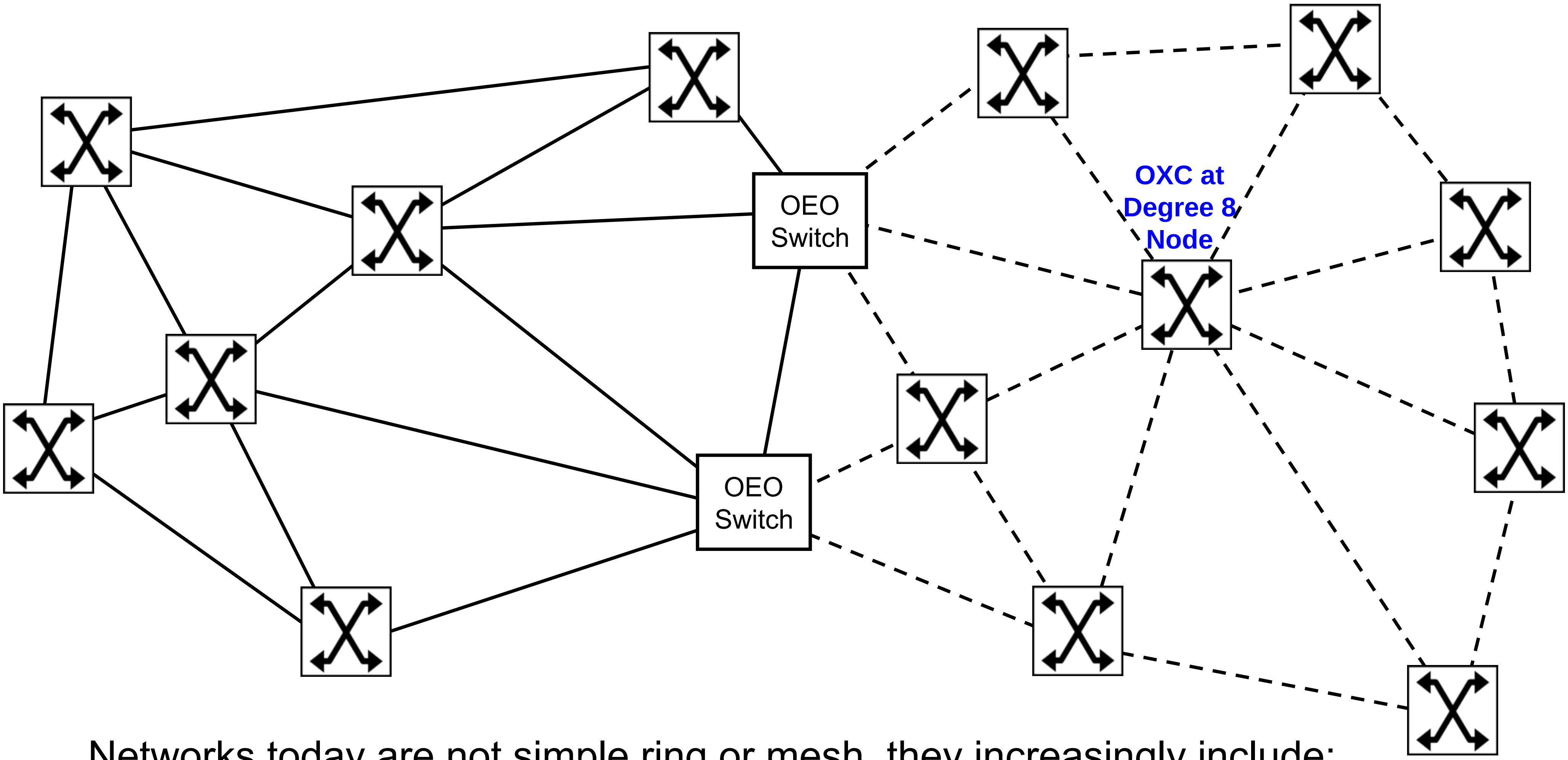
Performance of 1x4 Liquid Crystal WSS

Spectra at Different Attenuation Levels



Optical Crossconnects
Use in Mesh Networks

Reconfigurable mesh network made up of two interconnected sub-networks, each being an island of transparency



Networks today are not simple ring or mesh, they increasingly include:
- Ring-mesh hybrids
- Stacked rings

Optical Crossconnects
Use in Mesh Networks

OXC's are particularly useful in reconfigurable mesh networks where nodes have to route traffic from different directions

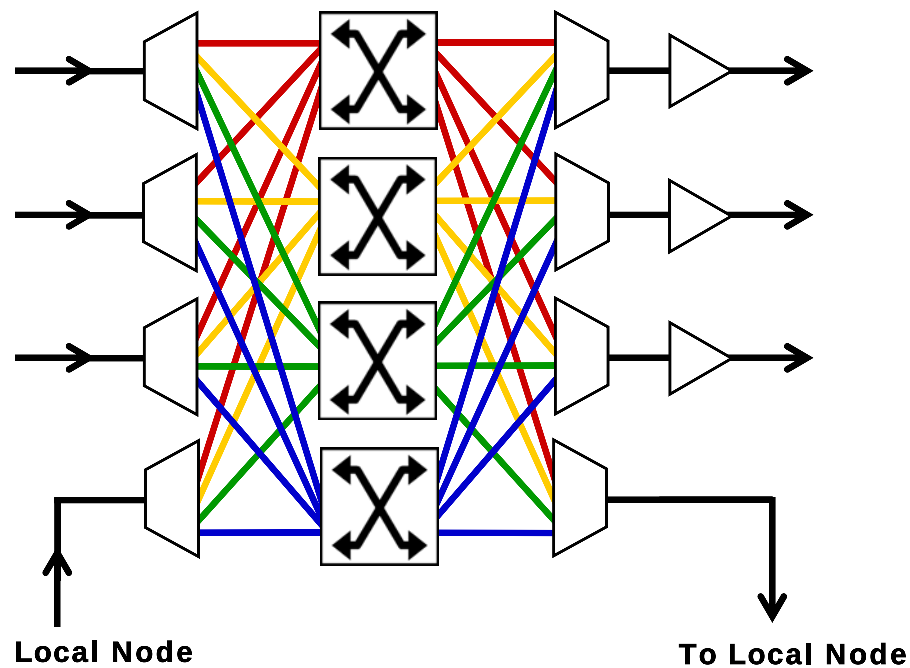
Important criteria:

- Non-blocking reconfigurable node
- Reliable configuration (several medium size switch matrices)
- Optical properties (IL, XT, etc.)
- No regeneration, no wavelength conversion

For N fibers (degree N node) and M wavelengths per fiber, M NxN switches are needed

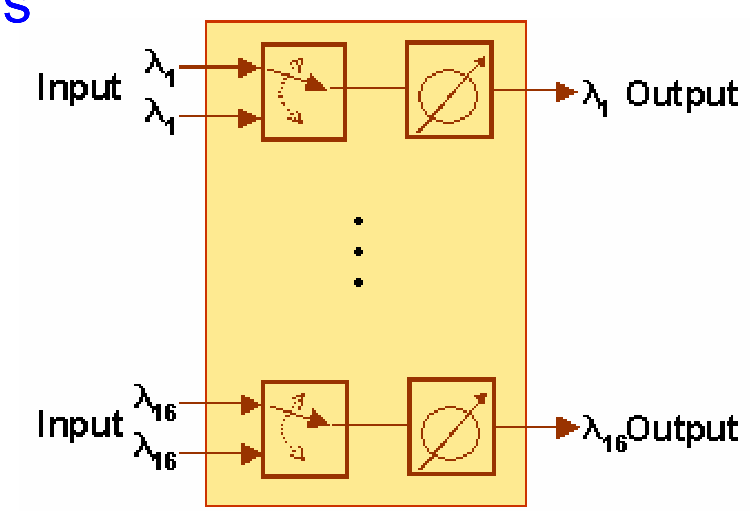
Degree 4 Node for Meshed Architecture

4 Fibers → 4x4 Switches
4 λ / Fiber → 4 Switches

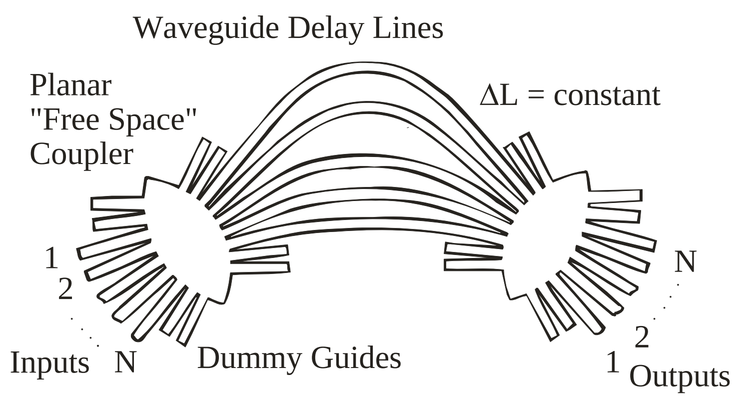


Enabling PLC Technologies

- Polymer Based Integrated Switch-VOA Arrays
  - Add Switch(2x1)/VOA & OXC(8x8, 32x8)
  - Low Loss, Low PDL
  - Low power consumption
  - Wavelength independence
  - Telcordia qualified

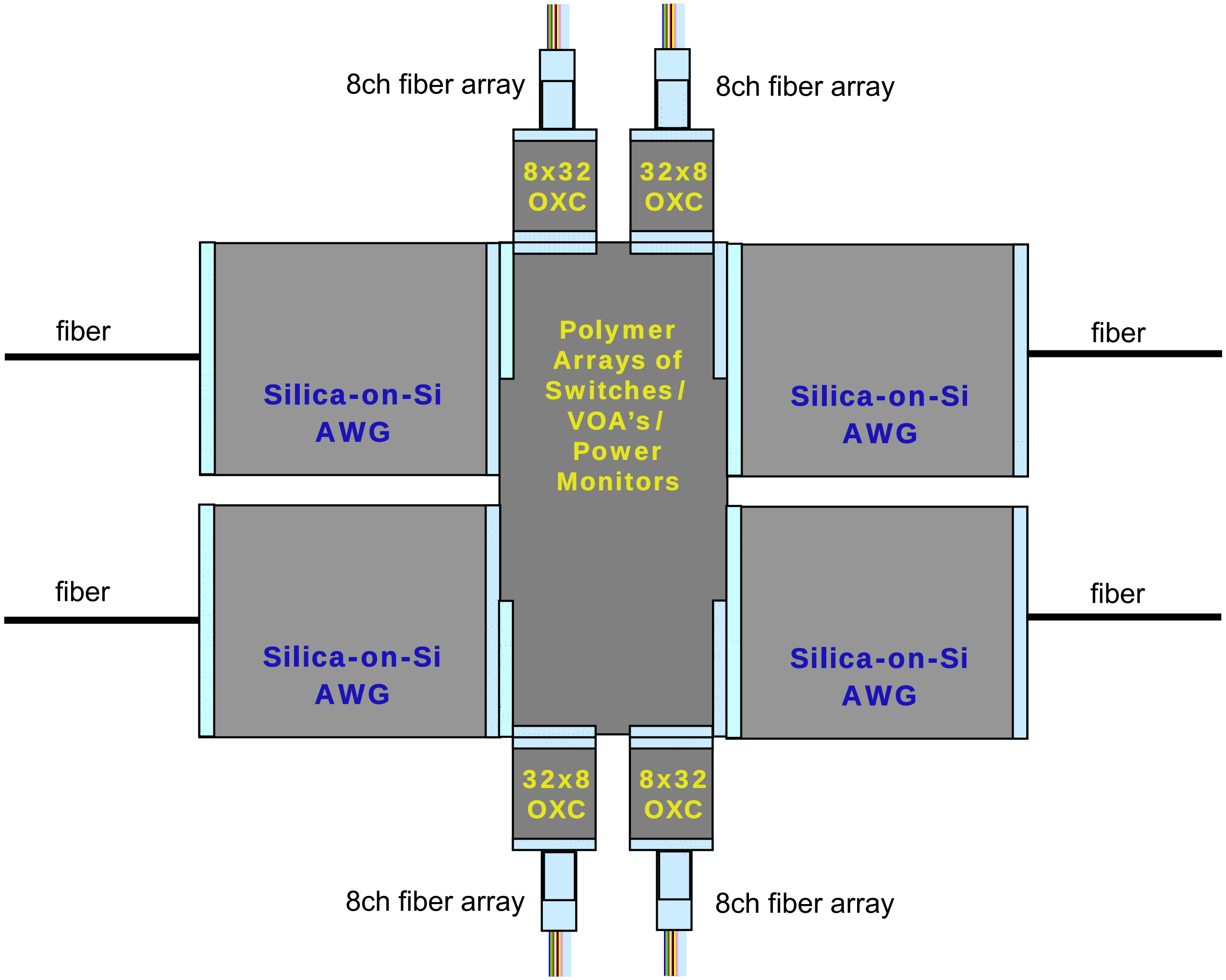


- Silica Based AWG (Mux/Demux)
  - Flat top
  - Low loss
  - Low CD
  - Low PDL
  - Tight center frequency accuracy (5 GHz)
  - Wide bandwidth (80 GHz at 3 dB)
  - Telcordia qualified

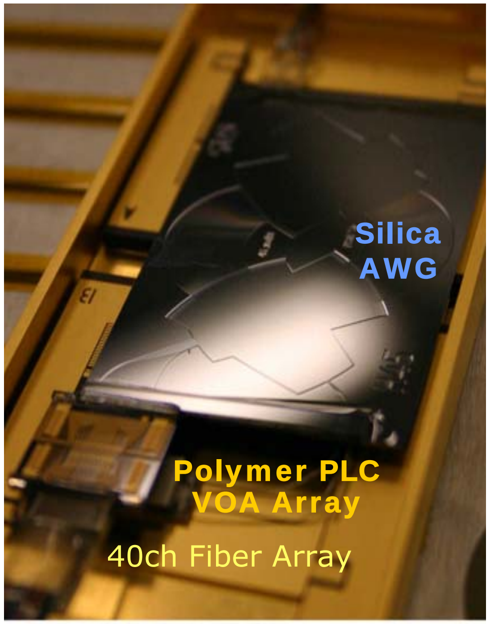


Chip-to-Chip Integration

Chip-to-Chip integration:
- Eliminates fiber arrays, reducing cost
- Eliminates space needed for fiber ribbons and splices
- Eliminates excess loss due to pigtailing
- Improves reliability due to reduced number of interfaces

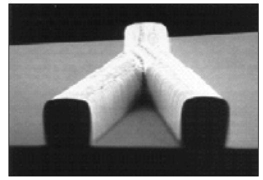


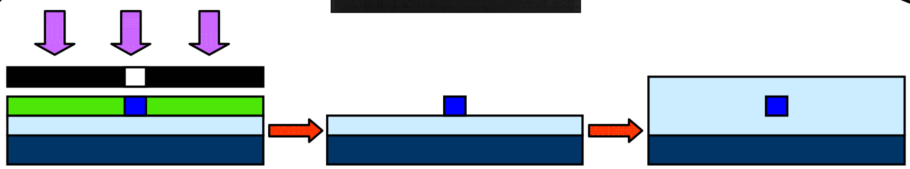
Example: 40ch VMUX



Measured chip-to-chip excess loss: <0.1dB

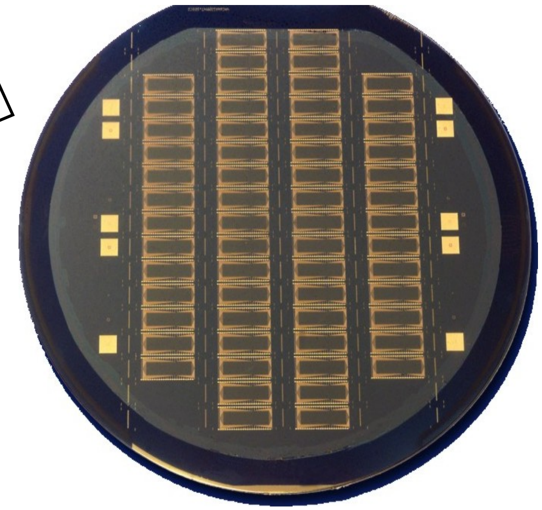
Dynamic IC Fabrication





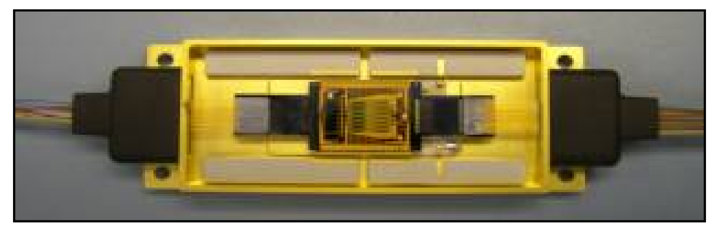
Polymer Waveguide Fabrication

Metalization

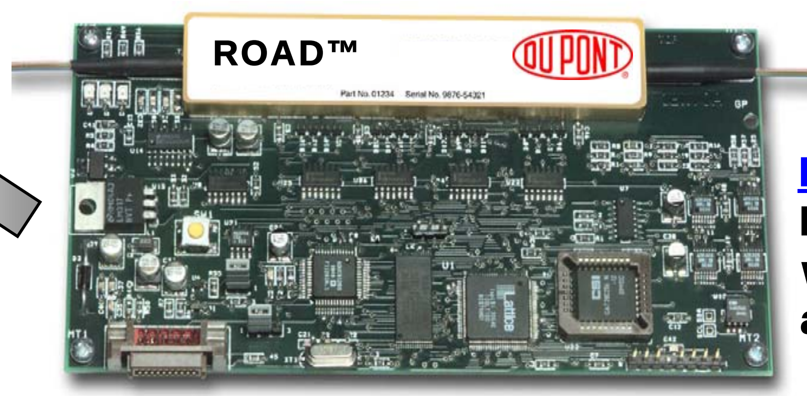


Blank Wafer to Diced Chips in 6 Hours

Dicing, Packaging



Form 1:
Packaged chip



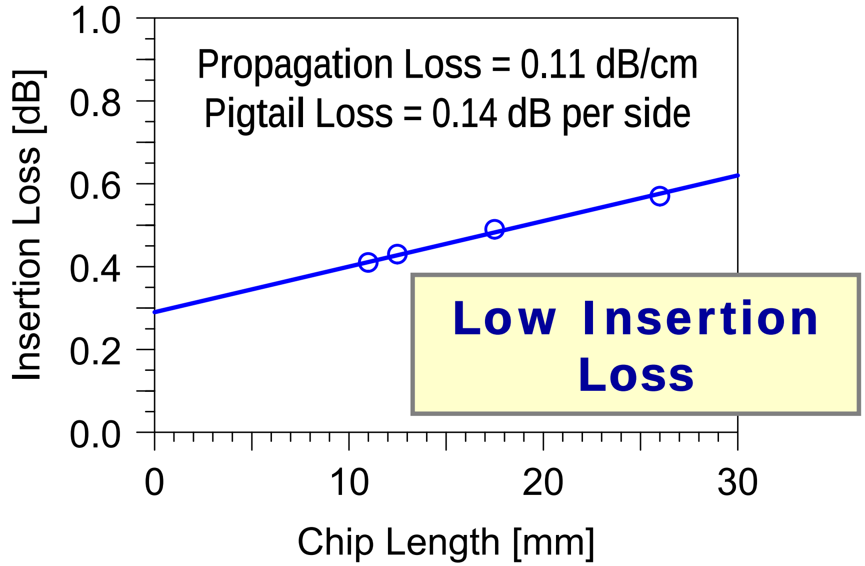
Form 2:
Packaged chip on PCB with control electronics and firmware

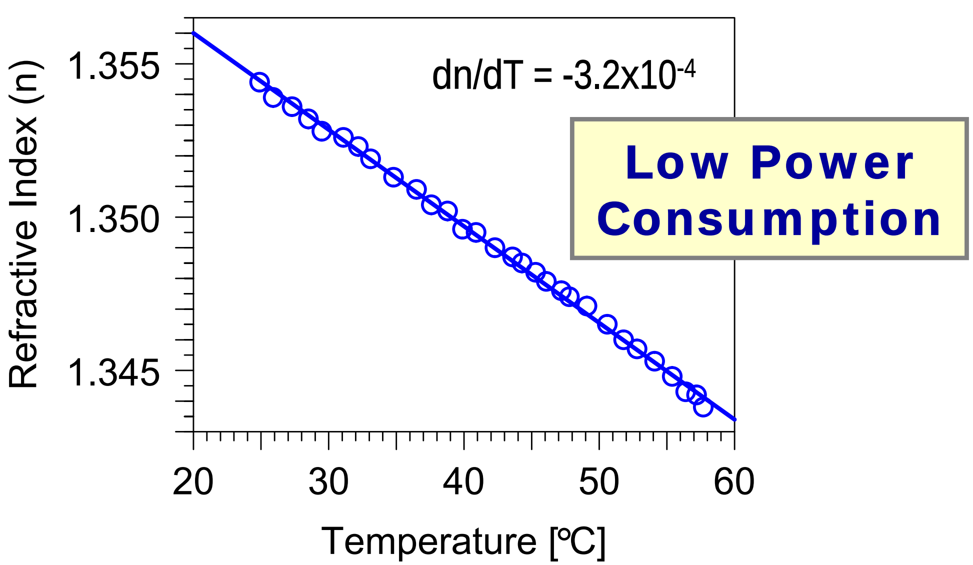
Form 3:
Black box with optical and electrical connectors

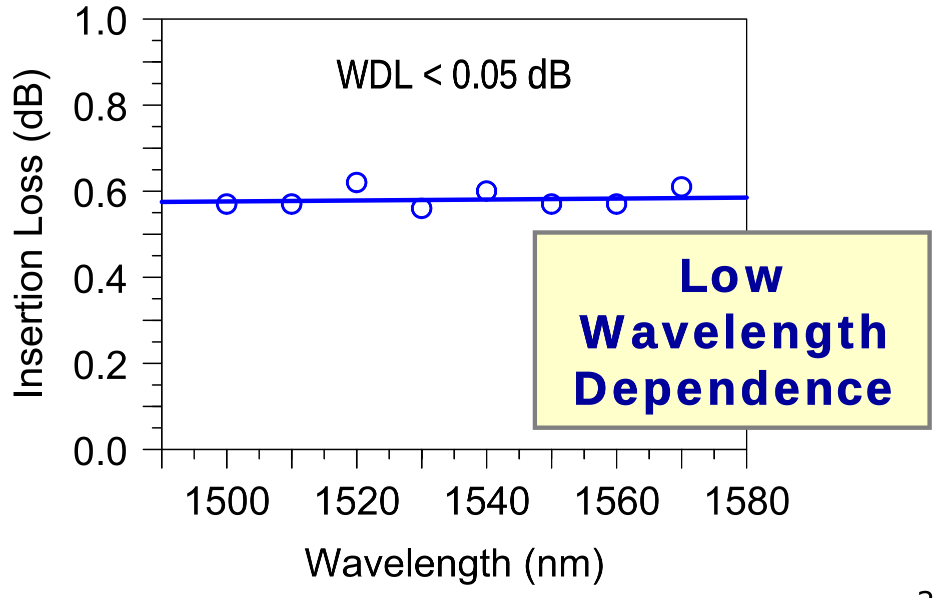
DuPont Polymer Photonic IC's

Key Properties at 1550 nm

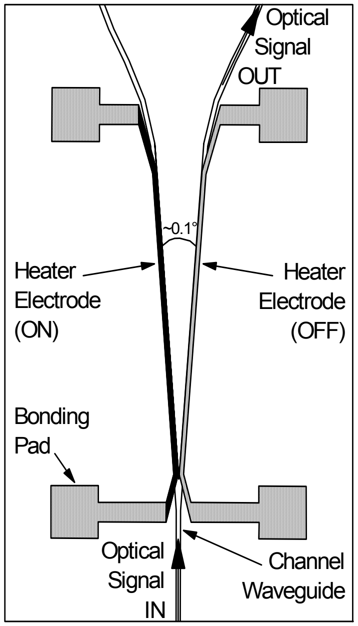
Cycle Time	Minutes/wafer
Propagation Loss	0.11 dB/cm (sm wg)
Polarization Effects	Birefringence = 10^{-6} PMD = 0.01 ps (1 cm sm wg) PDL = 0.01 dB (1 cm sm wg)
Dynamic Provisioning	dn/dT = -3.2×10^{-4}
Compactness, Density	Δn = 0-30%
Reliability	Proven
Function Availability	Static & Dynamic in Polymer Active by Hybrid Integration

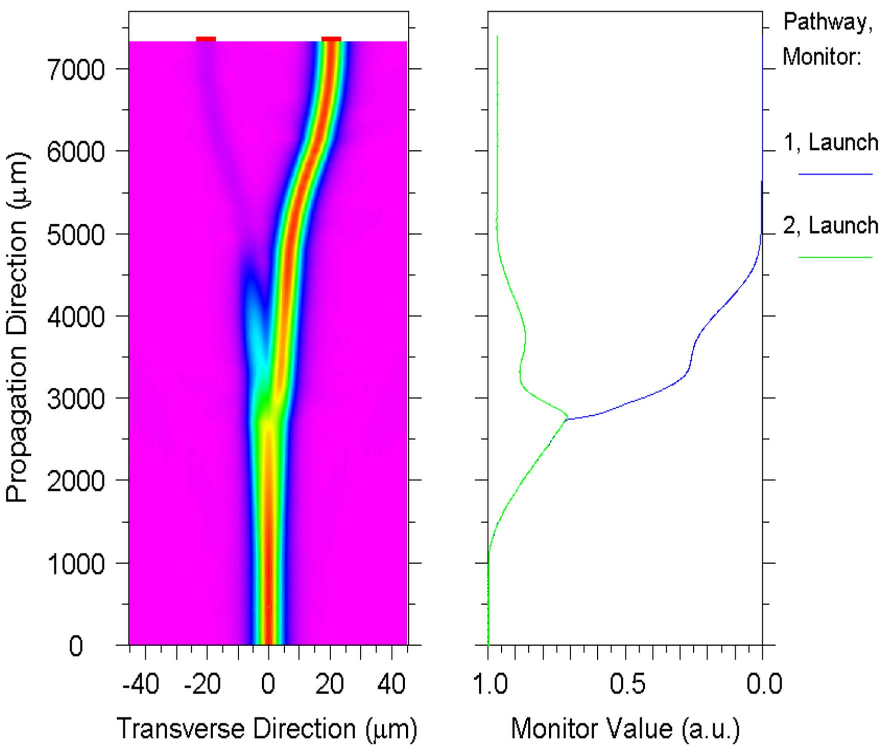


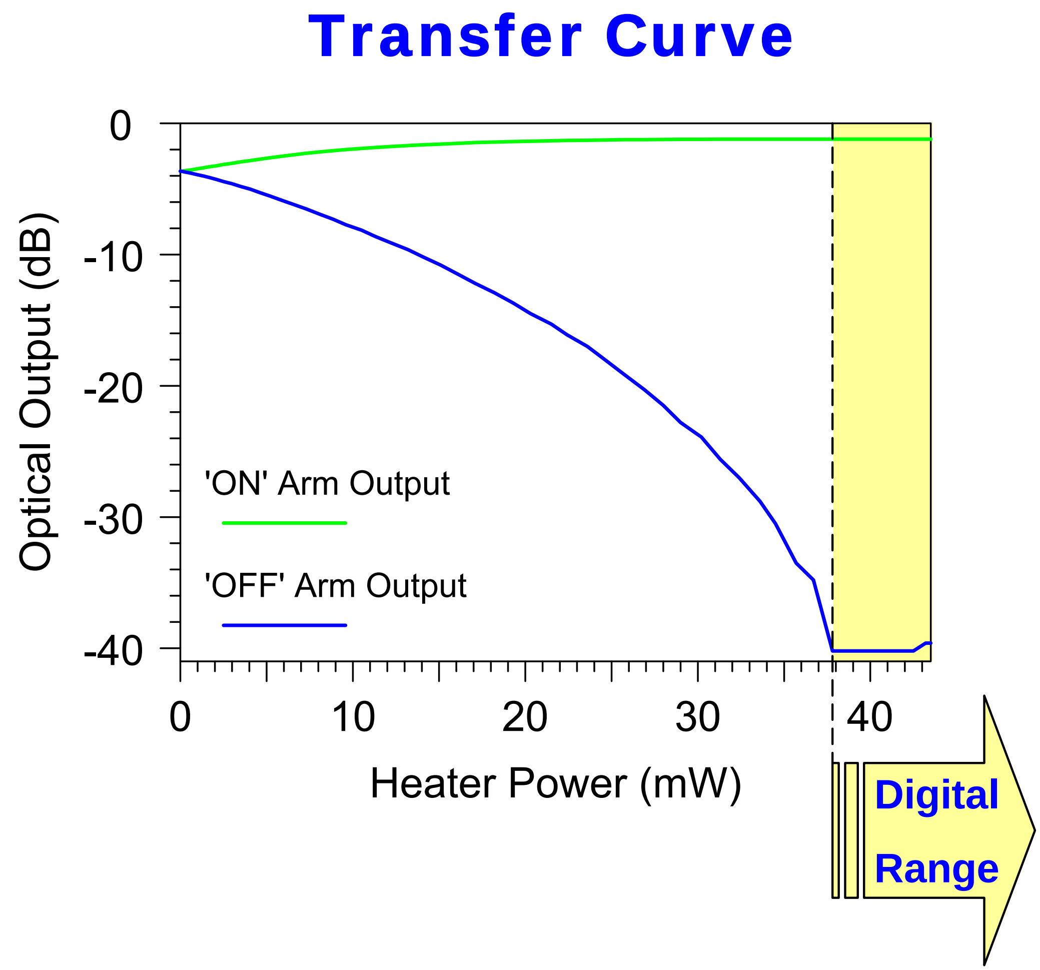




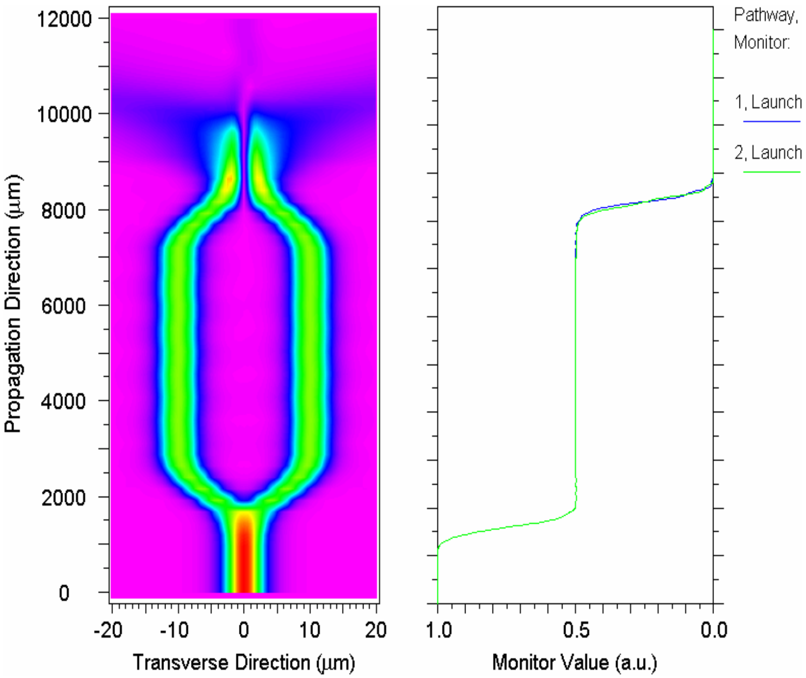
Polymer 1x2 Digital Optical Switches

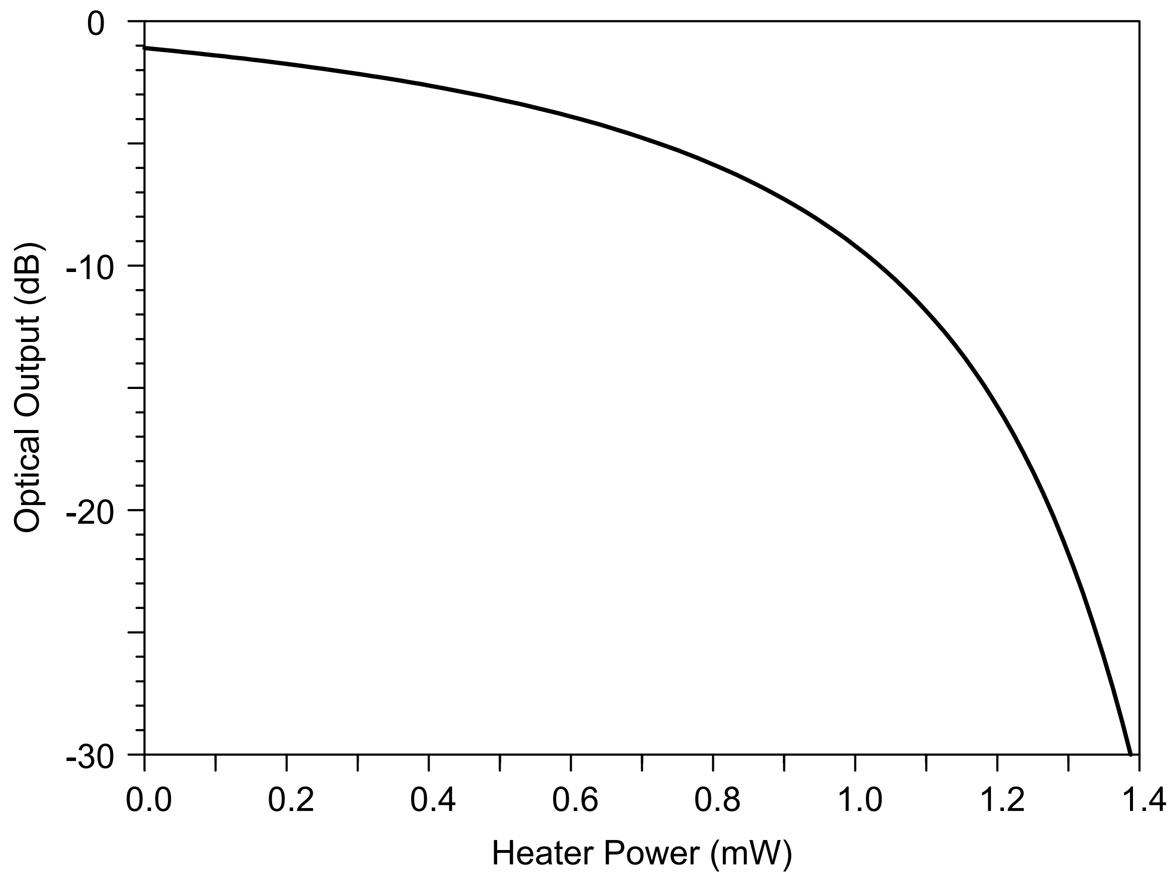






Low Power Polymer MZI VOA



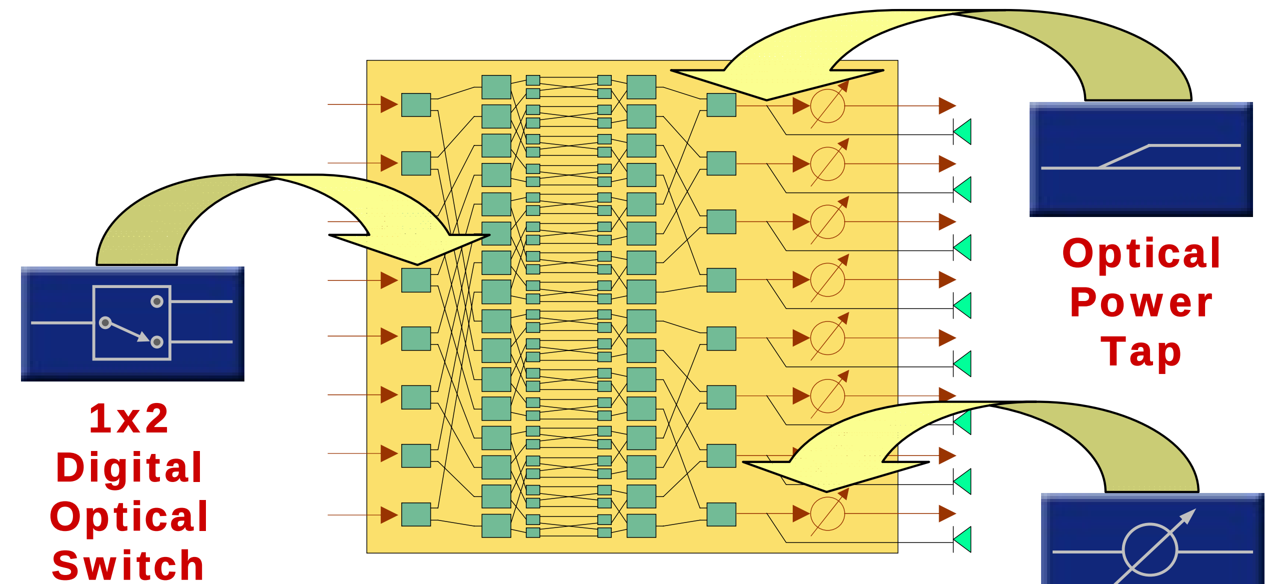


Attenuation: 30 dB
Sensitivity: 20 dB/mW
Max. Power Consumption: 1.5 mW
Response Time: 3 ms

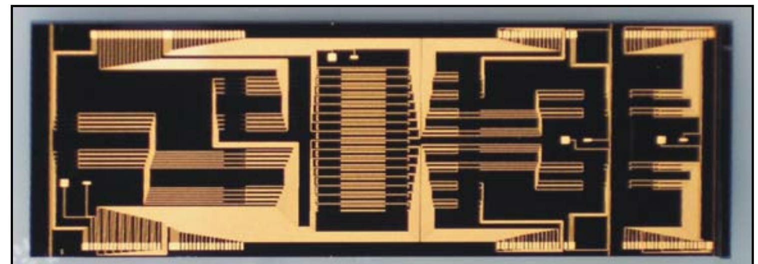
Polymer-Based 8x8 Intelligent OXC

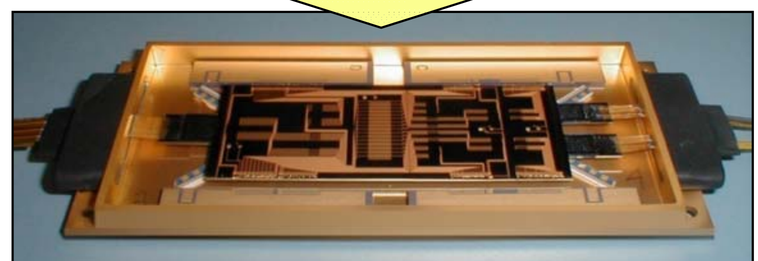
Intelligent OXC

8x8 Switch (112 1x2 Switches) **+ 8 Taps + 8 VOAs**



- **Strictly non-blocking OXC**
- **Power monitoring**
- **Channel balancing**





Performance Characteristics

- Insertion Loss (fiber to fiber): 5 dB
- PDL @ 0 / 15 dB Atten: 0.1 / 0.3 dB
- WDL (1528 – 1610 nm): 0.1 dB
- TDL (-5 – 70°C): 0.1 dB
- ODL (-30 – +20 dBm): 0.1 dB
- Extinction: 45 dB
- Crosstalk (any port to any port): 50 dB
- Return Loss: 50 dB
- Power Consumption: 2.5 W
- Response Time: 3 ms
- CD: 0.1 ps/nm, PMD: 0.01 ps

Simple control of switching elements from common drive voltage

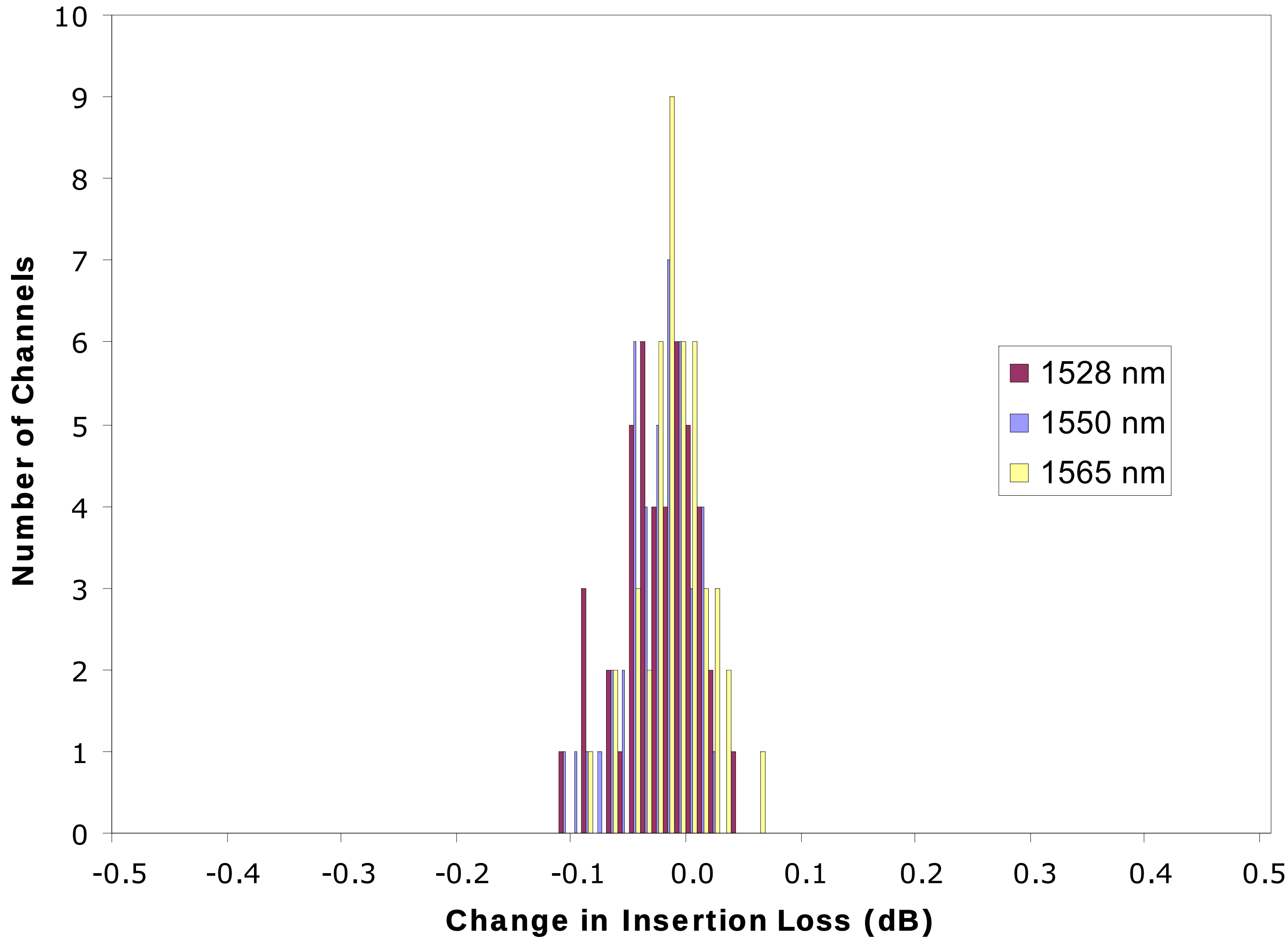
Total Footprint with PCB: 10 in^2

Telcordia Qualification

Passed GR-1209-CORE / GR-1221-CORE

Telcordia Tests GR-1209-CORE/GR-1221-CORE	Test Result
Temperature-Humidity Aging (85°C/85%RH, 336 hours)	PASS
Temperature Cycling (-40°C to 85°C, 100 cycles)	PASS
Thermal Shock (0°C to 100°C, 15 cycles)	PASS
Vibration (20-2000 Hz, 3 axes, 4 cycles/axis)	PASS
Mechanical Shock (500 G, 6 directions, 5 times/direction)	PASS
High Temperature Storage (85°C, 2000 hours)	PASS
Lifetest (70°C, 2000 hours, *in-situ* operation & test)	PASS
Cable Retention (3.4 lb load, 1 minute)	PASS
Fiber Side Pull (0.5 lb load, 90° angle)	PASS

Telcordia Qualification Results



Passed Telcordia qualification with large margin

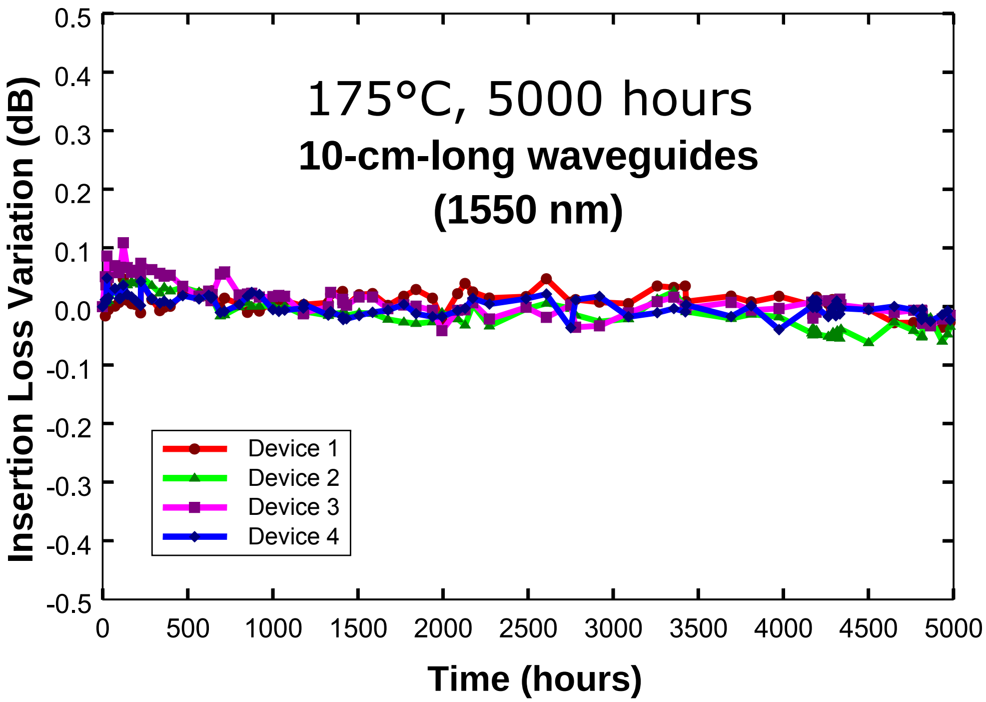
Narrow data distribution around 0 dB IL change

Changes are on order of measurement error

Reliability of Polymers and Devices

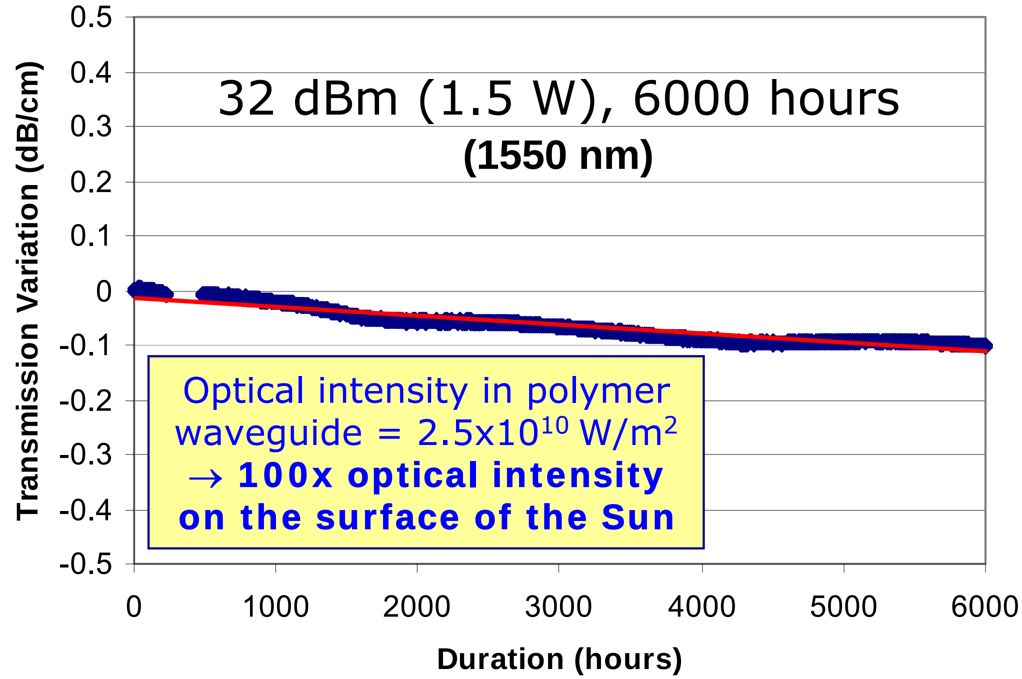
Highly Accelerated Stress Tests (HAST)

Stability with High Temperature



Lifetime > 20 years at maximum operating temperature of 150°C

Stability with High Optical Power



20-year degradation

<0.08dB/cm at 17 dBm input power

<0.02dB/cm at 10 dBm input power

Polymer lifetime well over lifetime of other components in system

Thank You

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