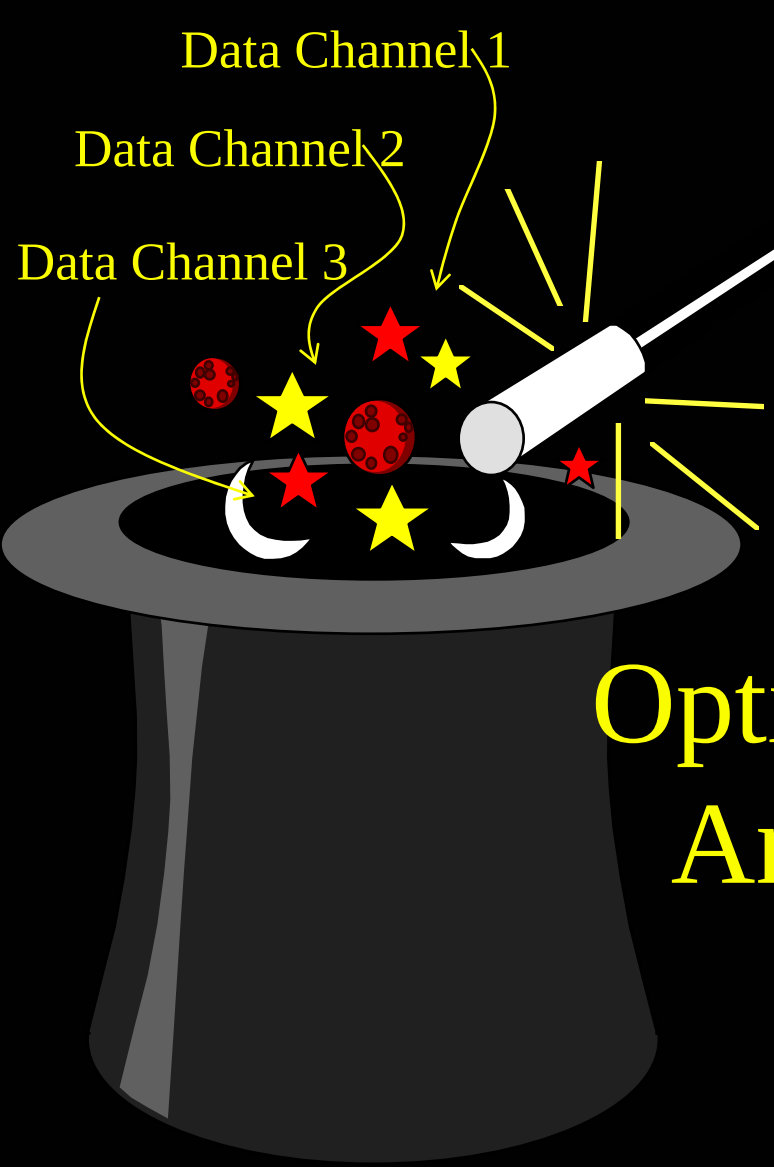


Optical Networking
And There Was Light ....

What is Optical Networking?

Optical Networking (ON): *A networking concept which relies on Optical Network Elements (e.g. DWDM, Amplifiers, OADM & OXC) to manage various types of traffic at discrete wavelengths.*

It goes beyond simple point-to-point transport networks to much more complex topologies with intelligence, to perform add/drop, restoration, and performance monitoring (all optically).

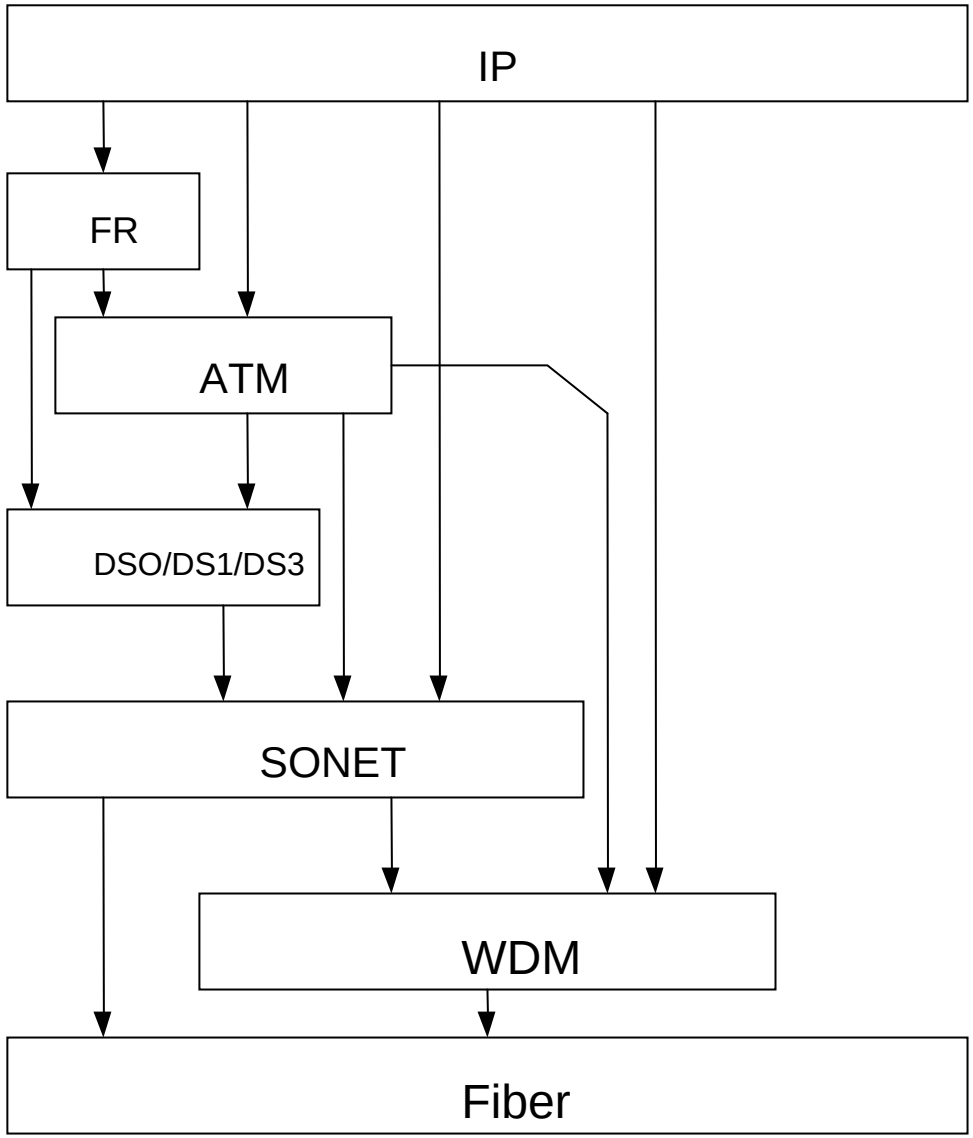
Ultra Long Haul Transport is one of the enabler for ON

Optical Networking

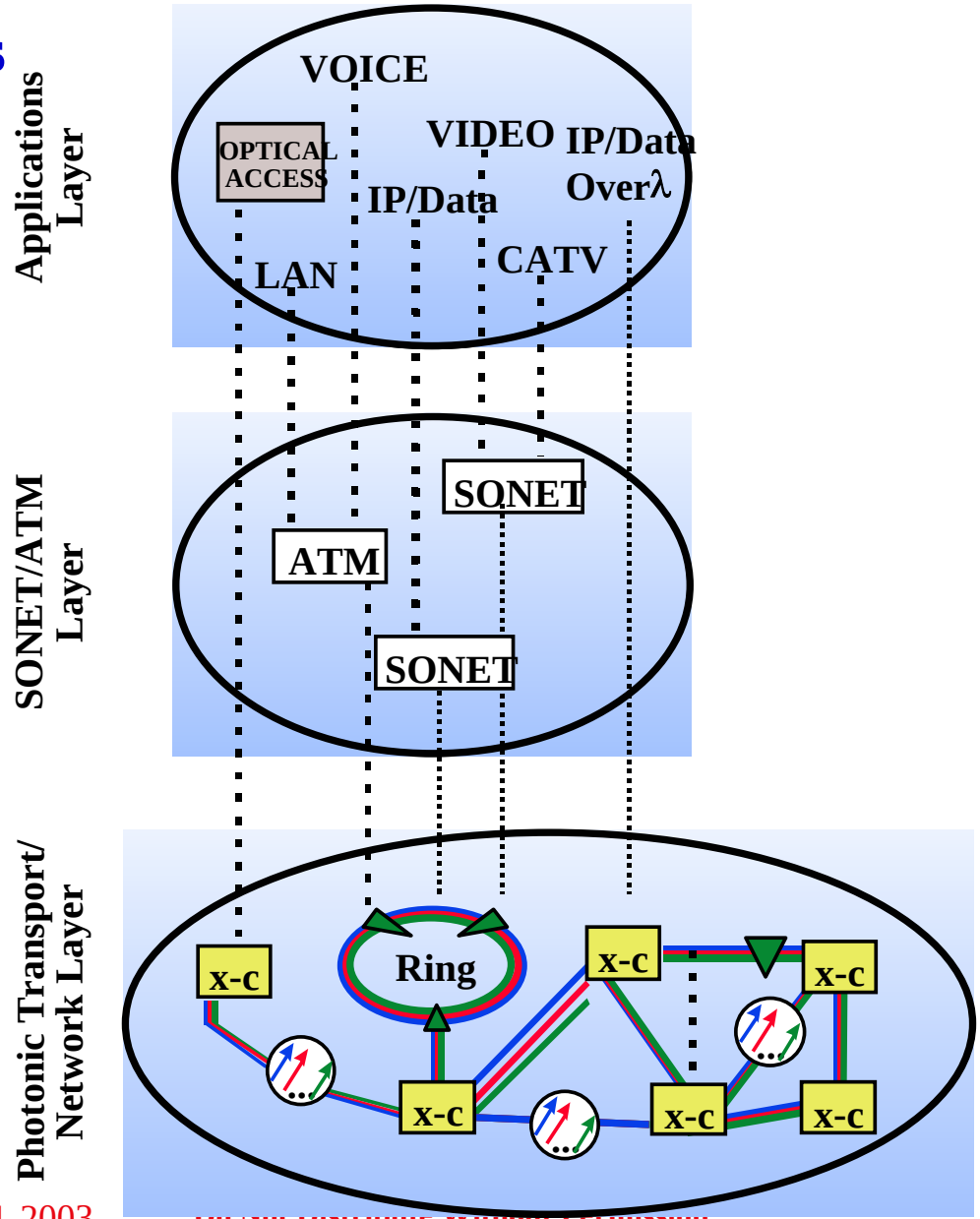
Offers

- Economical alternative for high capacity networks
- Protocol Transparency
  - Bit-Rate, Format and protocol Independence
- Flexible Networking Topologies
  - Point-to-Point, Rings, Mesh, Hub ...
- Restoration and Survivability comparable to SONET
- Reduced risk from technology churn

The Protocol Stack (review)

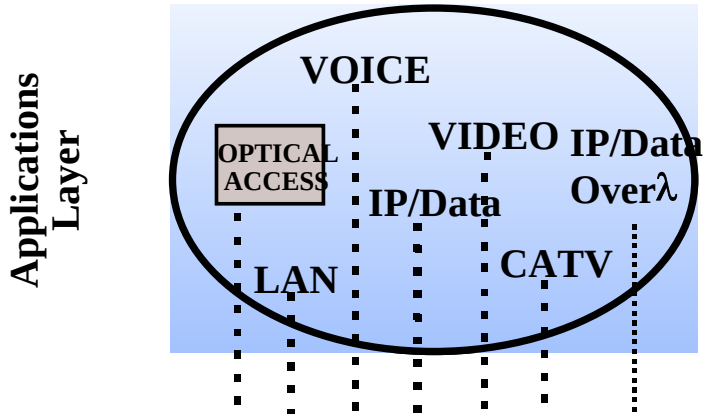


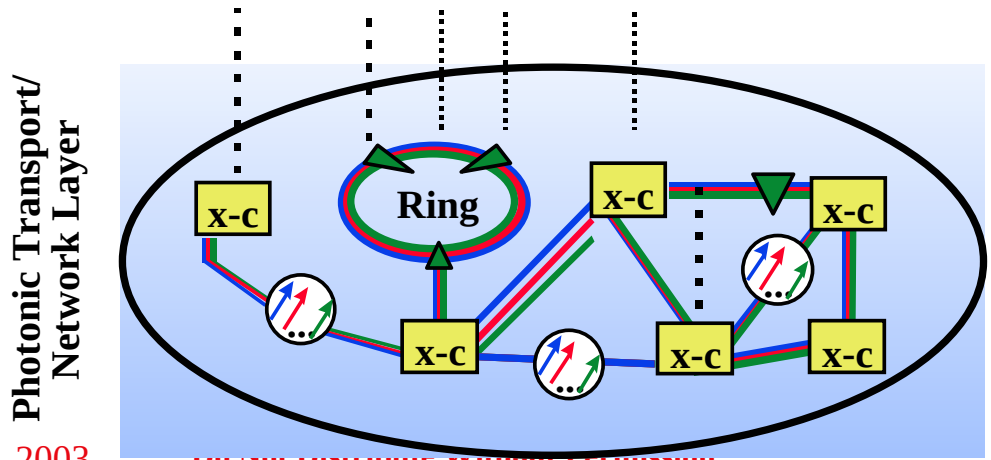
The Evolutionary Vision:
Networking Layers



Evolve to All-Optical Layer

The Evolutionary Vision: Networking Layers





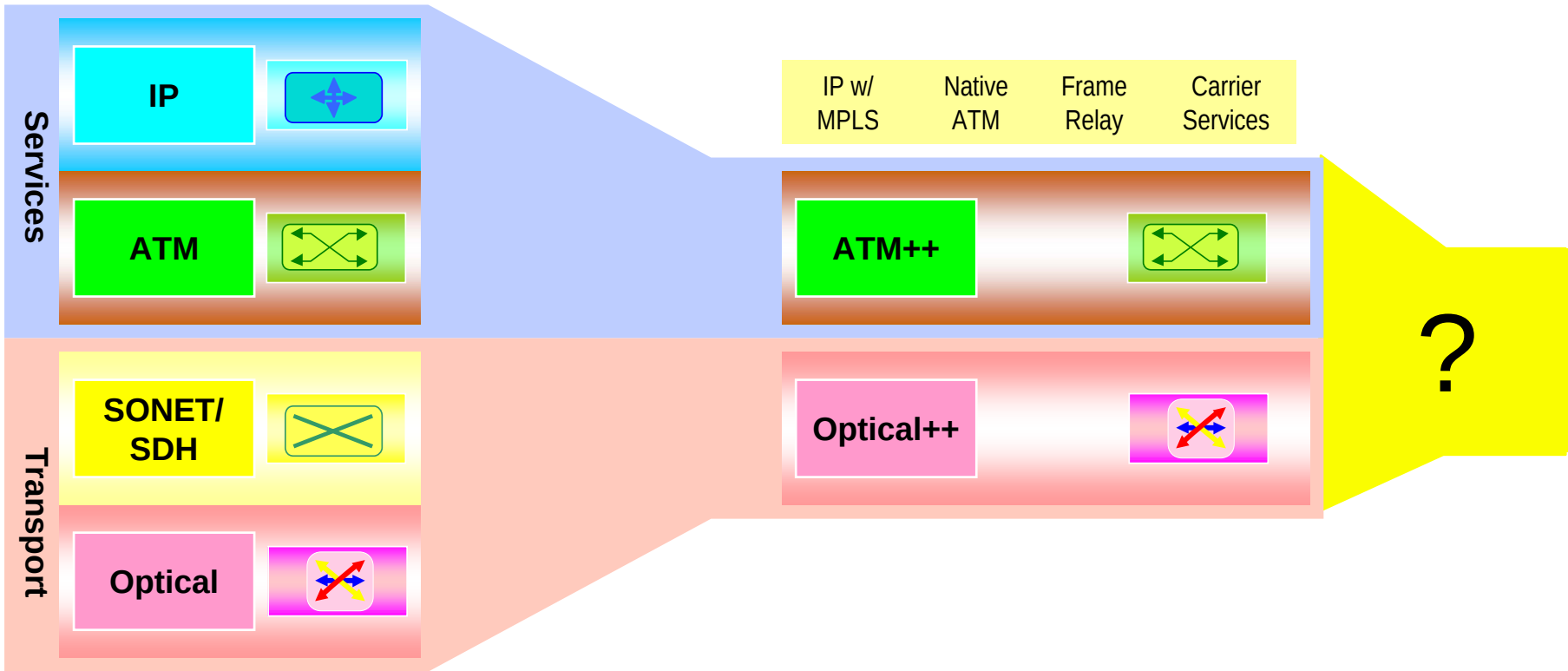
Evolve to All-Optical Layer

Market Forces

Lucent Technologies
Bell Labs
Innovations

Driving Networking Trends

Market forces driving towards a collapse of the protocol stack...



TDM or WDM

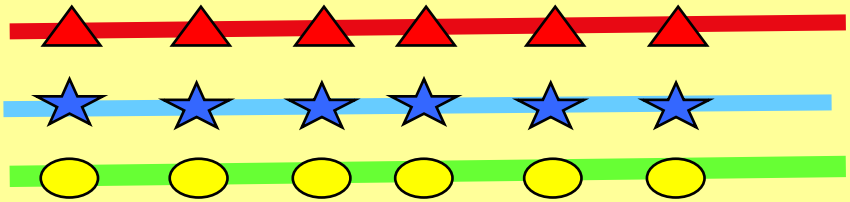
- Some debate in industry as whether to use TDM or WDM to increase throughput
- Both technologies needed...
  - OC-48 & OC-192 plus WDM offer best technical and economic solution
  - Currently OC-48 (2.5 Gbps) is the base rate for WDM… OC-192 (10 Gbps)/OC-768 (40 Gbps) in future
  - Terabits per second networking speeds possible with proper TDM-WDM multiplexing architectures
- Different multiplexing schemes (generalized) discussed in next few slides

$$\sum_{i=1}^{N} \lambda i$$

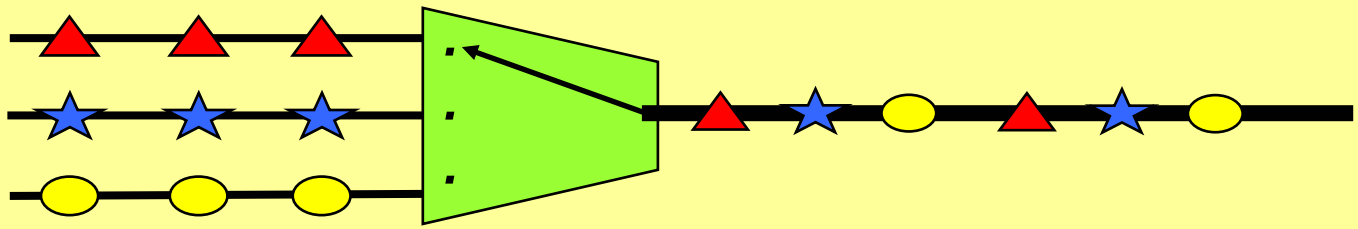
Multiplexing Concepts

Lucent Technologies
Bell Labs
Innovations

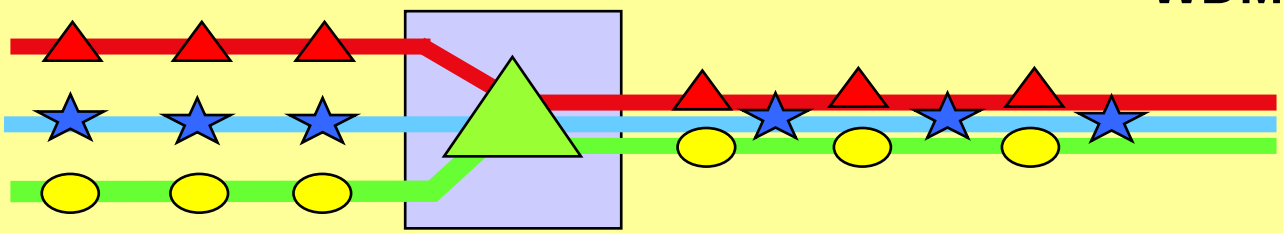
No Multiplexing or **"Space-Division Multiplexing"** (Requires Separate Lines) **SDM**



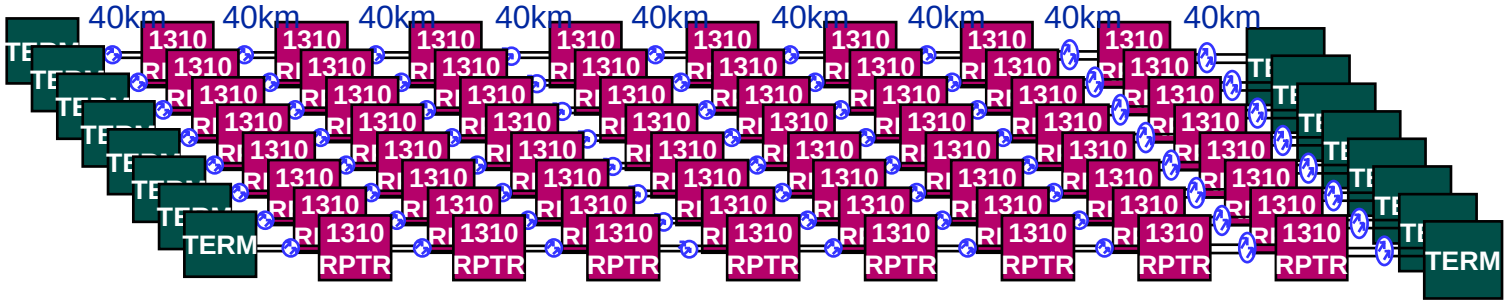
Individual Time Slots - (Requires Electrical Multiplexing/Demultiplexing) **TDM**



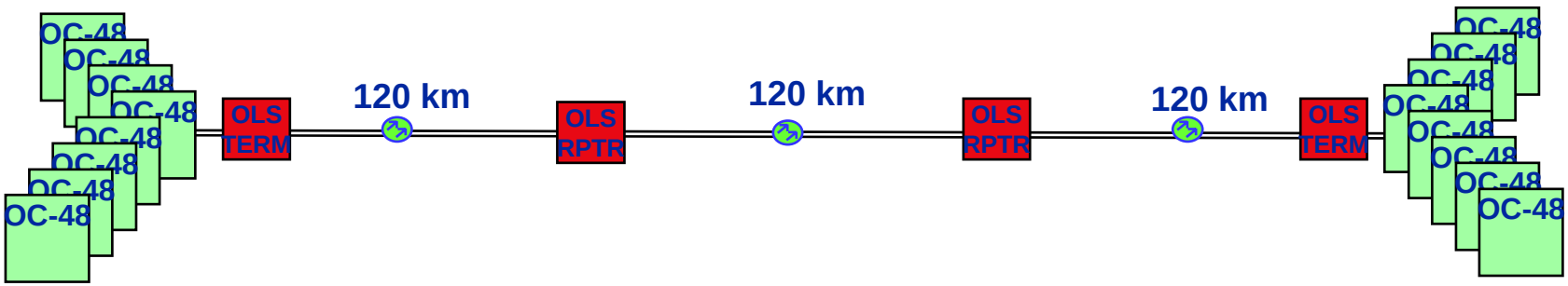
Individual Wavelengths - (No Electrical Multiplexing/Demultiplexing) **WDM**



Optical Fiber Amplifier Revolution



Conventional Optical Transport - 20 Gb/s

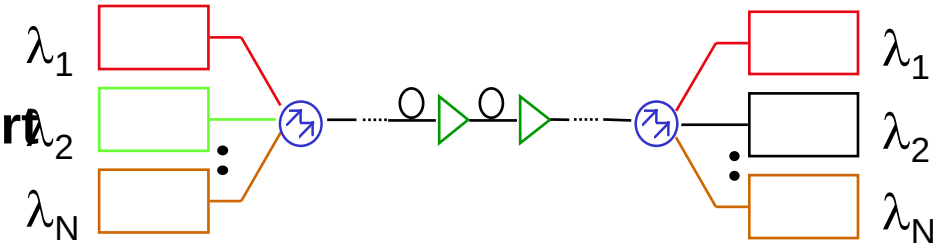


DWDM Fiber Amplifier Based Optical Transport - 20 Gb/s

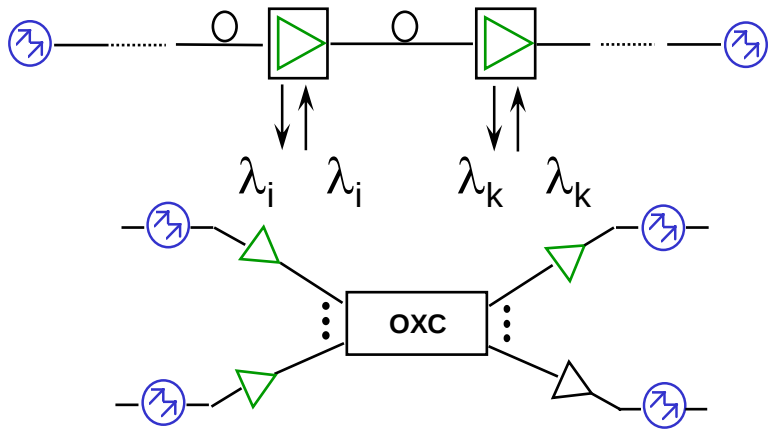
Pictorially, compare the number of repeaters for the same capacity

Evolution: Optical Transport → Optical Networks

WDM Pt-to-Pt Optical Transport

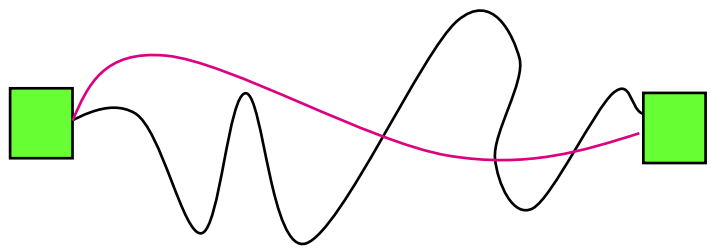


Fixed WDM/Multipoint Network



Optical XC Reconfigurable WDM/Multipoint Network

Ultra-long Haul All-optical Transport



How ? →

ON Evolution Enabled by

A

Enabling Technologies

- Broadband Fiber Optical Amplifiers
- WDM Laser Improvements
- Passive Optical Components
- Fiber Improvements
- Increasing Device Density and Speed

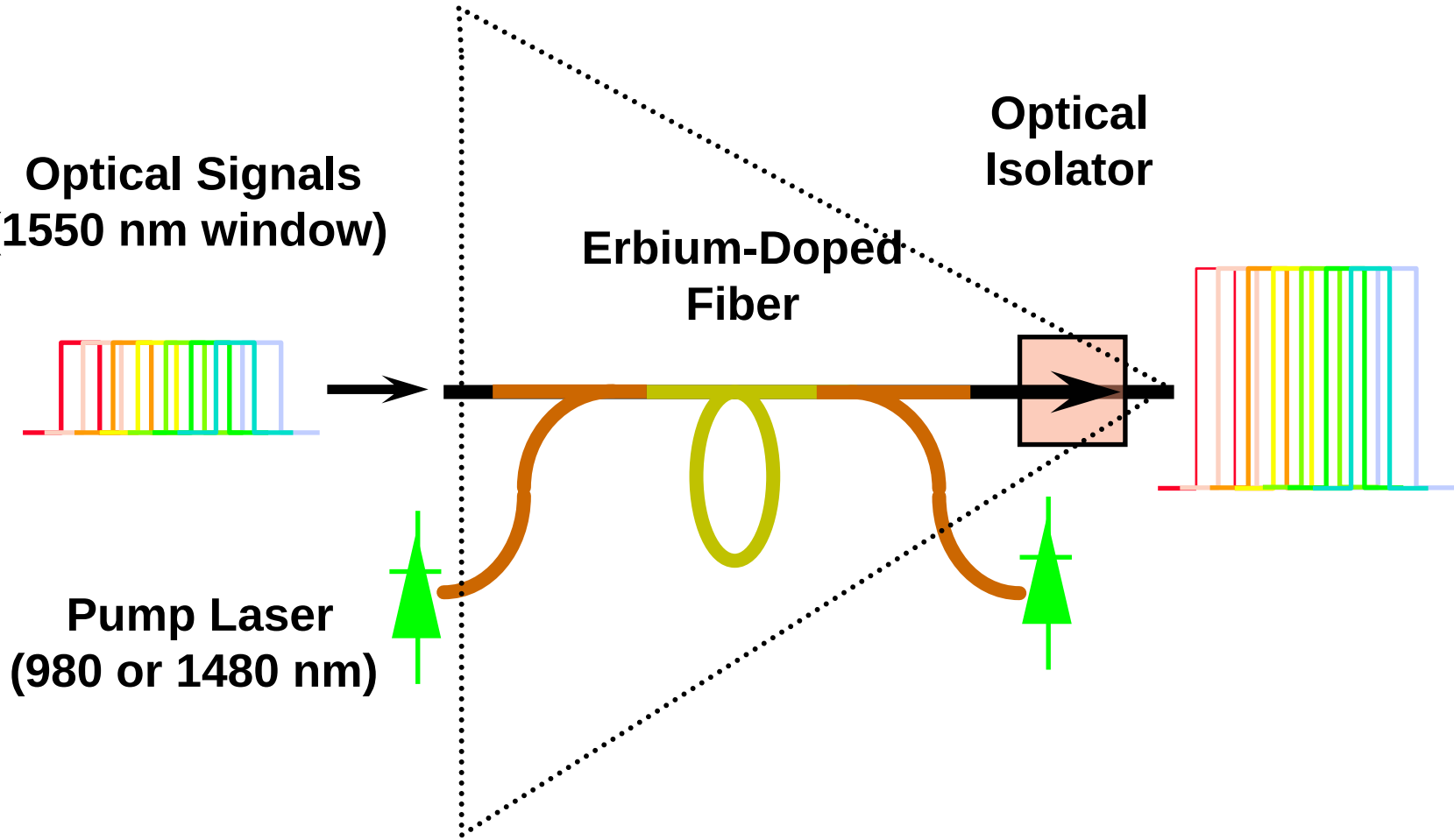
B

Optical Network Elements

- Wavelength Division Multiplexers
- Optical Add/Drop Multiplexers
- Optical Cross-Connects
- λ-Changers / Optical Translators
- Management Systems

Key Enabler Of DWDM Transport

Optical Fiber Amplifier



EDFA bandwidth must be extended…

another 35 nm to take advantage of the 1550 nm wavelength window

- Three new types of amplifiers have been proposed:
  - EDFAs based on other glass materials such as fluoride or tellurite,
  - Raman amplifier, and
  - standard silica erbium fiber-based dual-band fiber amplifier (DBFA)
- EDFAs based on new glass materials such as fluoride exhibit a flatter and wider gain profile
- But have two major problems
  - Not compatible with transmission fiber, and thus cannot be fusion-spliced
  - Sensitive to humidity and show large gain variation with temperature change
- As a result, reliability, packaging, and manufacturing issues must be addressed before they can be widely deployed

Recent Advances in Optical Amplifier Technologies

- EBFA: Extended-band EDFA
  - L-band EDFA
  - Wide Band Gain Flattened EDFA (using GFF)
  - Wide Band Dynamic Gain Flattened EDFA (using DGEF)
  - High power EDFA (> 1W output)

- Raman Amplifier
  - Gain Flattened Raman Amplifier
  - Dynamic Gain Flattened Raman Amplifier
  - Co- and Counter Pump Raman Amplifier
  - Distributed or Discrete Raman Amplifier

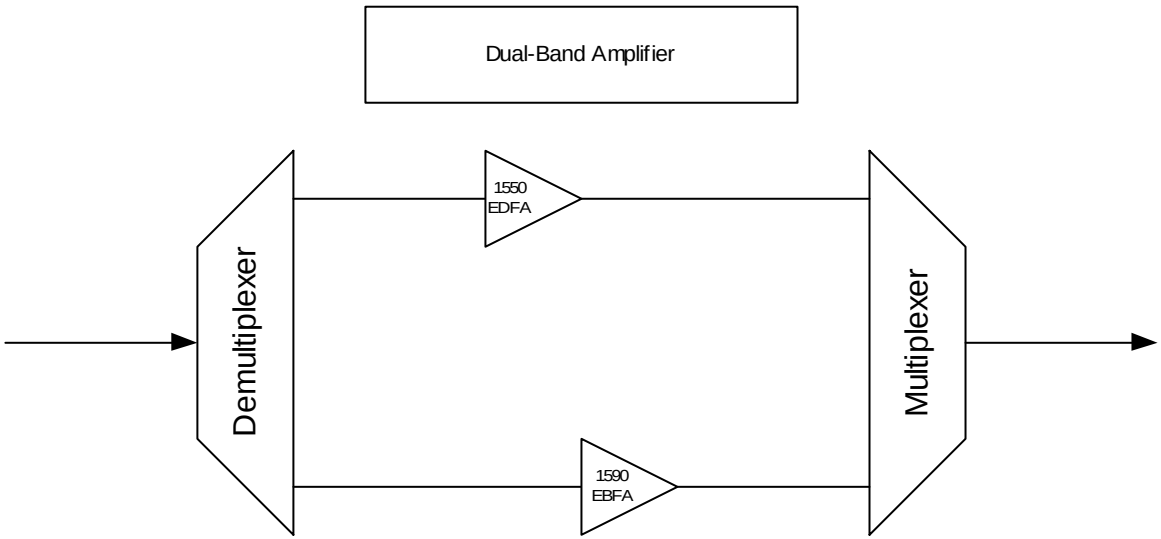
Approach

- 1590-nm EBFA uses standard off-the-shelf components, making large-volume manufacturing cost-effective
- Can be integrated into exactly same module package widely used by EDFA manufacturers
- Compatibility allows 1590-nm EBFAs to be plugged directly into existing or new WDM systems, either to work as an independent amplifier or to extend bandwidth of existing EDFA systems

EDFA bandwidth must be extended…another 35 nm (con't)

- Silica erbium fiber-based DBFA is attractive because of its similarity conventional EDFA
- Erbium fiber can emit light beyond 1570 nm under 980-nm or 1480-nm pumping (a phenomenon less known that 1550-nm amplification, due to its extremely low efficiency)
- Researches at Bell Laboratories (Murray Hill, NJ) and Nippon Telegraph & Telephone (NTT-Tokyo) have constructed experimental DBFAs based on two sub-band amplifiers with silica erbium fiber
- …Demonstrated terabit transmission experiments in lab using DBFAs, and results appear to be very encouraging
- But due to low pump efficiency, up to 500 mW of pump power have been sent to pump erbium fiber by combining a master oscilliator-pump amplifier and/or high-power pump lasers, so that performance similar to that of EDFAs can be obtained
- First commercial high-efficiency 1528-to 1610-nm DBFA was introduced only recently at OFC '98
- DBFAs consist of two separate sub-band amplifiers: One is conventional 1550-nm EDFA (1530-1560 nm) and other is 1590-nm extended band fiber amplifier (EBFA), which has an operating wavelength from 1570 to 1605 nm
- When 1550-nm EDFA and 1590-nm EBFA are multiplexed/demultiplexed in a parallel circuit, they offer a total of more than 75 nm of bandwidth
- See figure

Dual-Band Amplifier



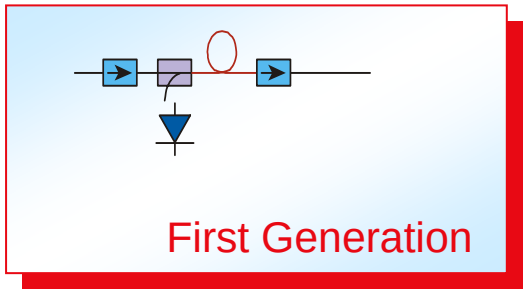
Amplifier Advances - DWDM

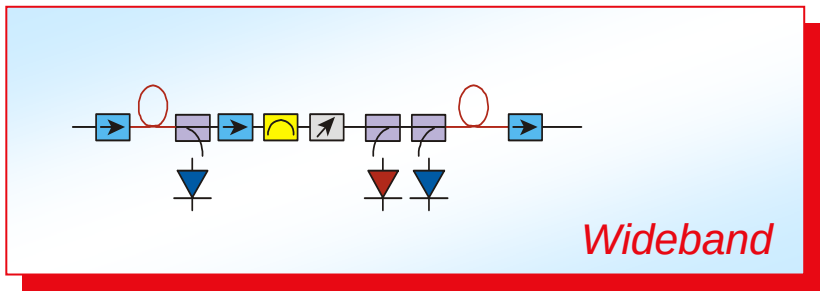
$\sum_{i=1}^{N} \lambda_i$

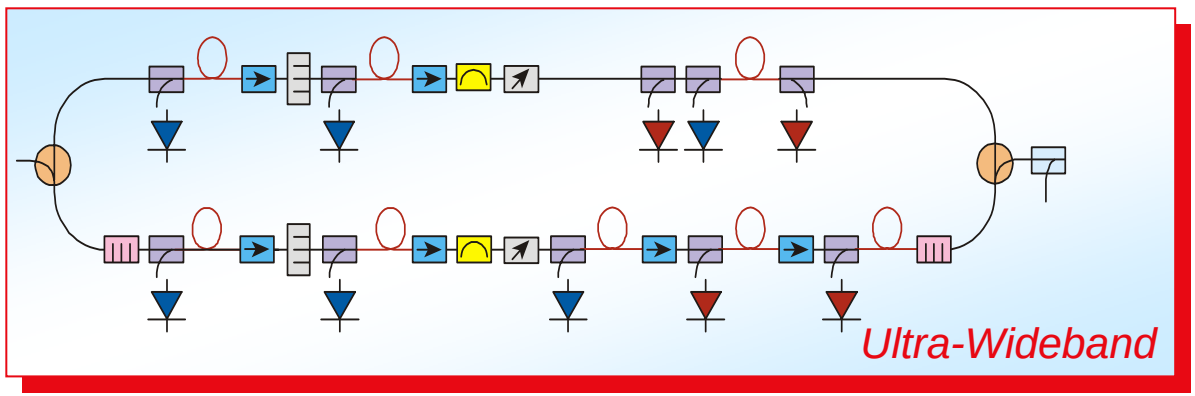
Lucent Technologies
Bell Labs Innovations

Capacity Advancements

	Bandwidth	No. of Wavelengths
First Generation	12nm	16
EBFA	35nm	80
DBFA	80nm	200





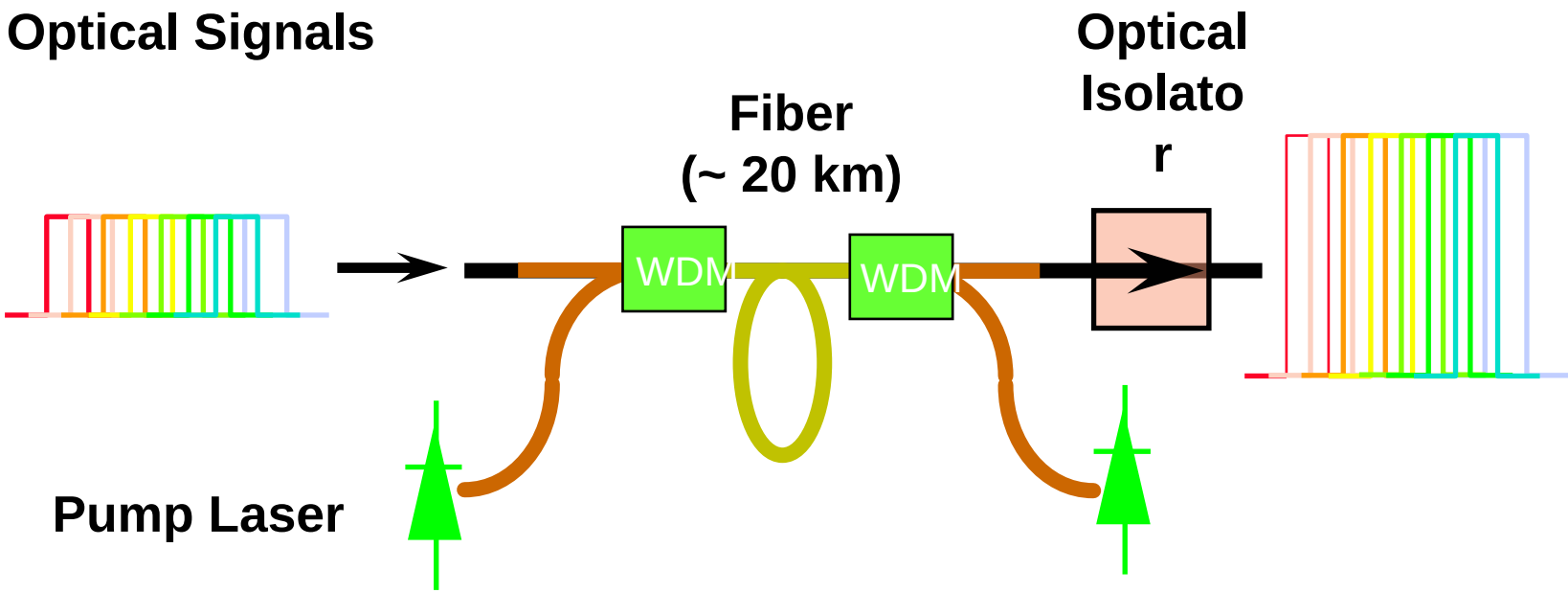


Raman Gain

- Raman amplifiers use stimulated Raman scattering that occurs in silica fiber when used an intense pump beam propagates through it
- Due to its nonlinearity, energy-transfer is very low
- Large amount of pump power is needed, laser safety is an issue
- Also Raman amplifier needs tens of kilometers of transmission fiber to obtain any relevant amplification

Key Enabler of Wide-Band Ultra-long Haul DWDM Transport

- Fiber Raman Amplifier



EDFA vs Raman Amplifier

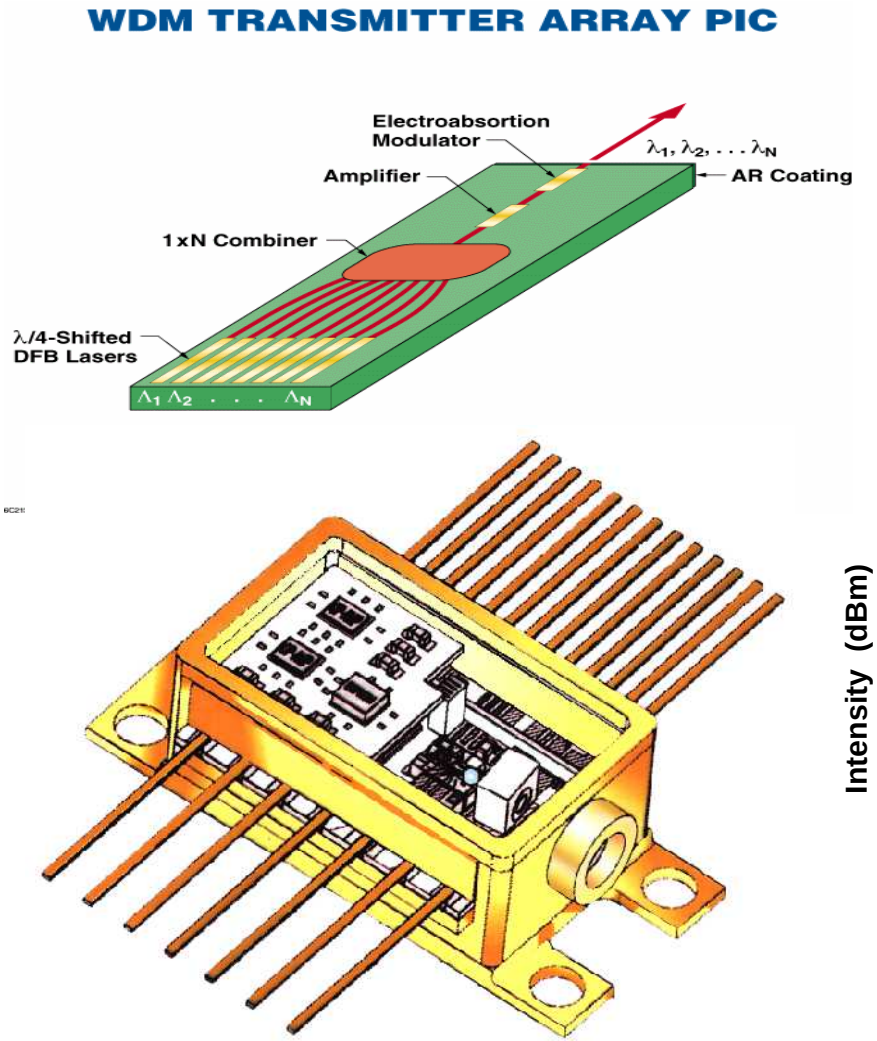
- EDFA
  - high gain (~30 dB)
  - need modest pump power
  - useful between 1520-1610 nm
  - discrete amplifier
  - higher noise figure
- Raman Amplifier
  - modest gain (<20 dB)
  - need high pump power
  - no wavelength limitation
  - distributed amplifier
  - low noise figure

EDFA ~~OR~~ Raman

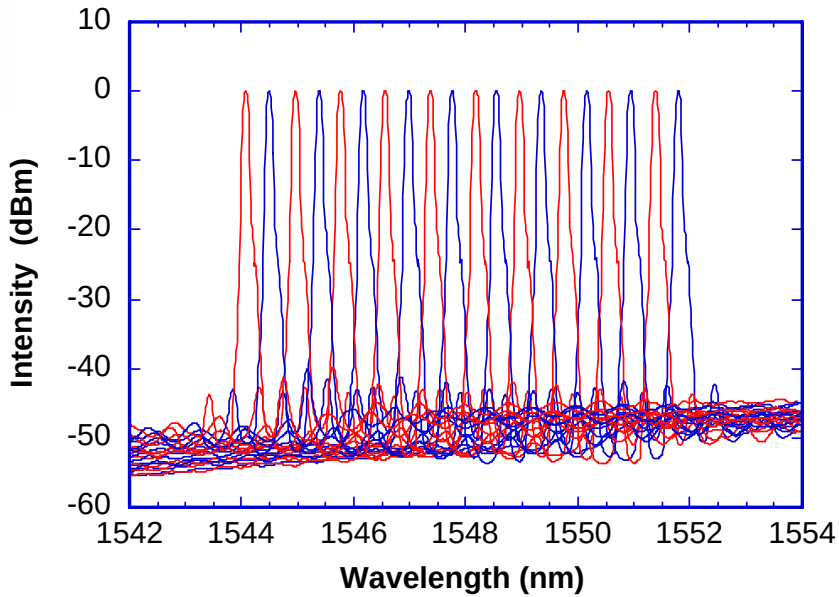
AND!

OTN Enablers

Tunable Lasers/Laser Arrays

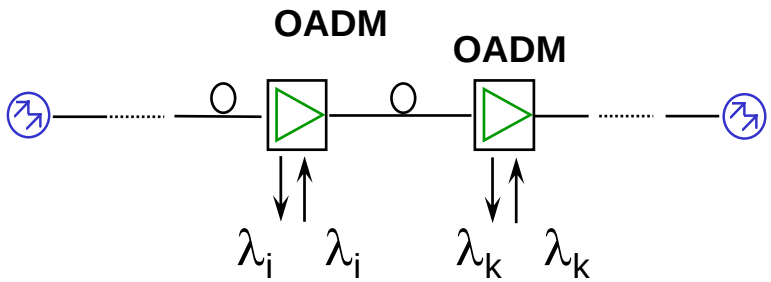


- 9.1 nm tuning range: 20λ x 50 GHz
- >680 km transmission @ 2.5 Gb/s
- Laser chip size: 1700 x 500 µm

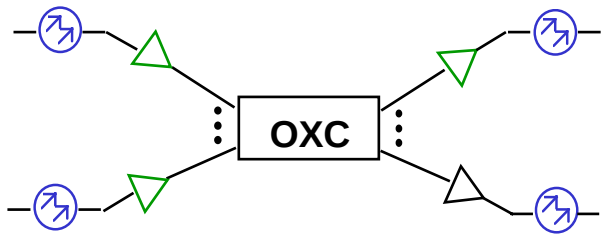


Step 2 of
Evolution: Optical Transport → Optical Networks

Fixed or Flexible WDM Multipoint Network



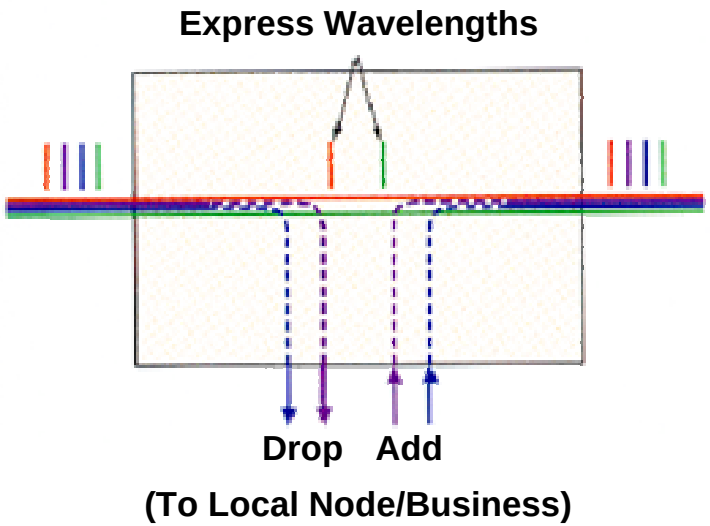
Optical XC Reconfigurable WDM/Multipoint Network



Ultra-long Haul All-optical Transport

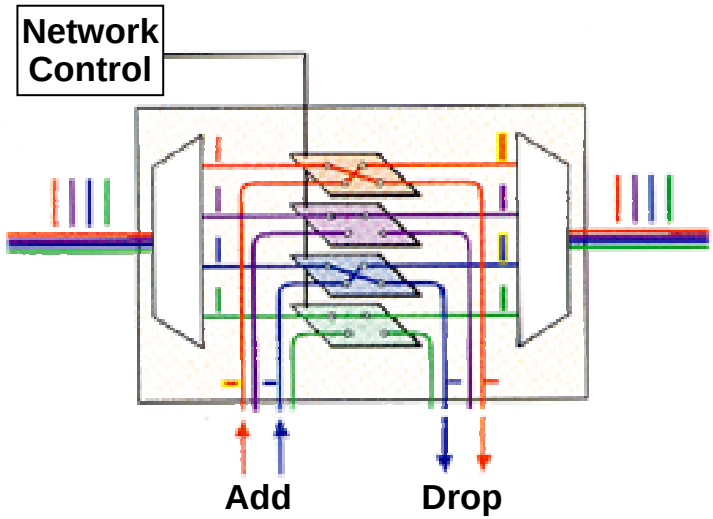
Evolution of Wavelength Add/Drop Multiplexers

Fixed Add/Drop



Configurable Add/Drop

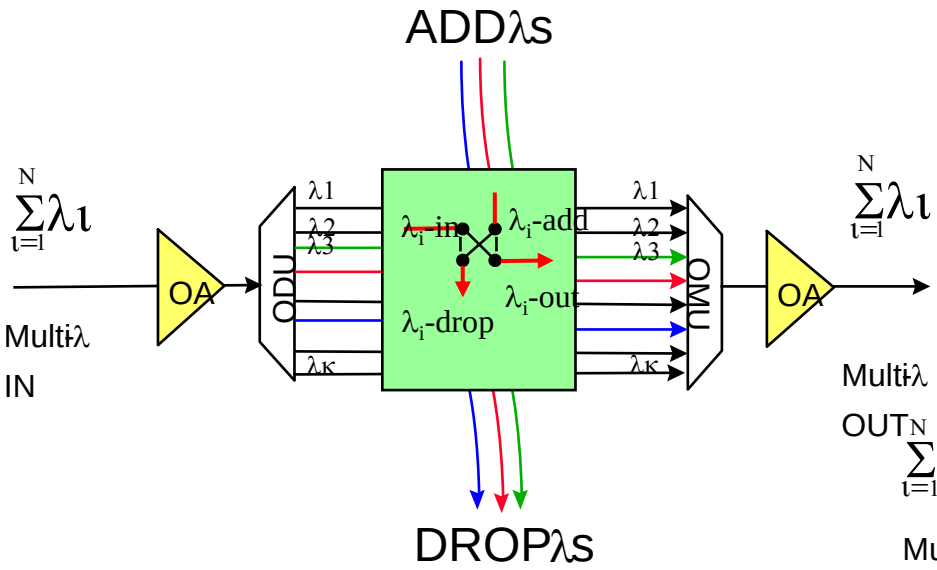
(Network Control Channel Dropped/Added)



- **Low Cost, Passive Component**
- **Handle Multiple Bit Rates, Formats**
- **Avoids Electrical Termination for Express Wavelengths**

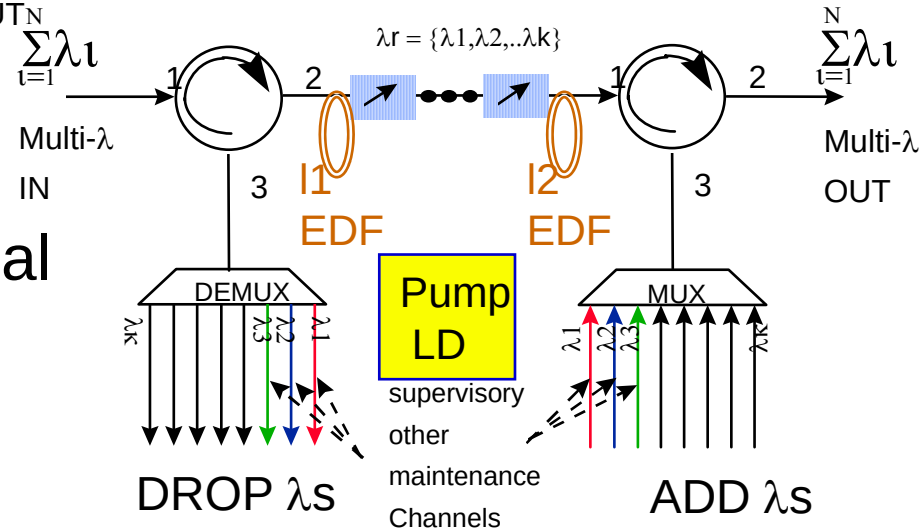
- **Flexible, Automated Network Configuration, Upgrade and Self-Healing**
- **Change Number and which channels Added/Dropped**
- **Requires Network Management and Control Systems**

OADM



Conventional add/drop terminal

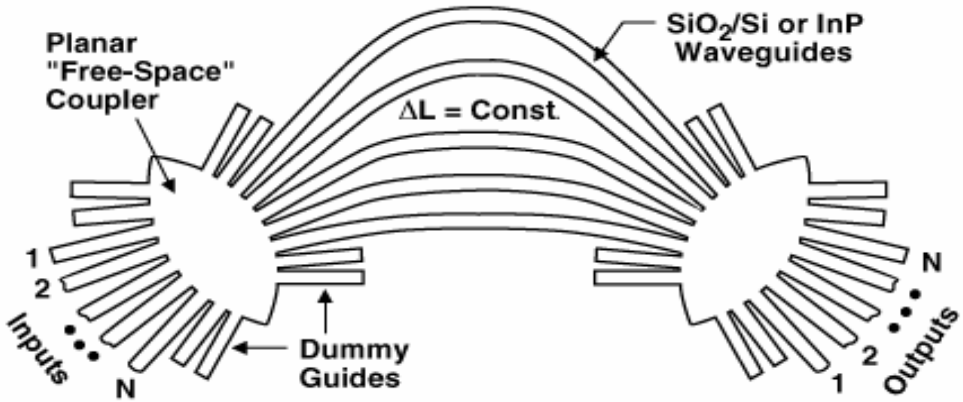
Loss-Less

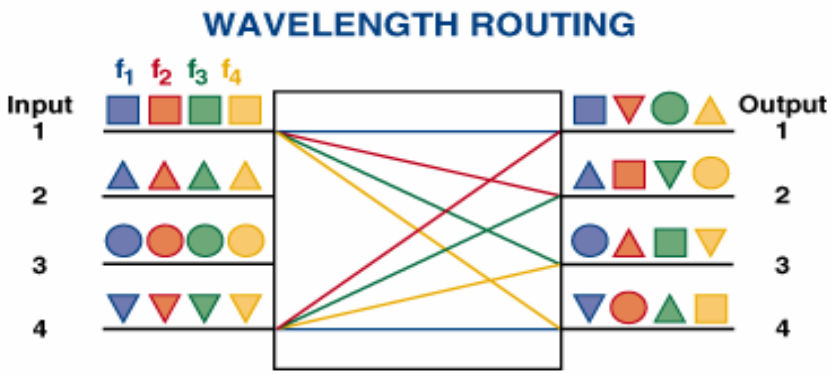


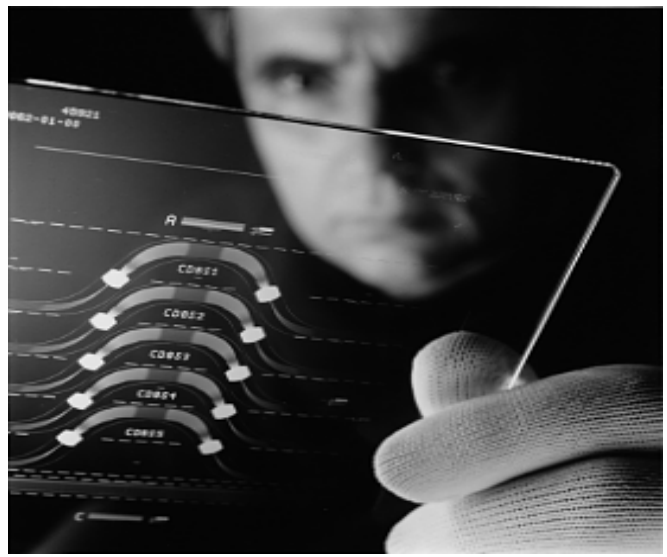
Programmable Optical Add/Drop

OTN Enablers

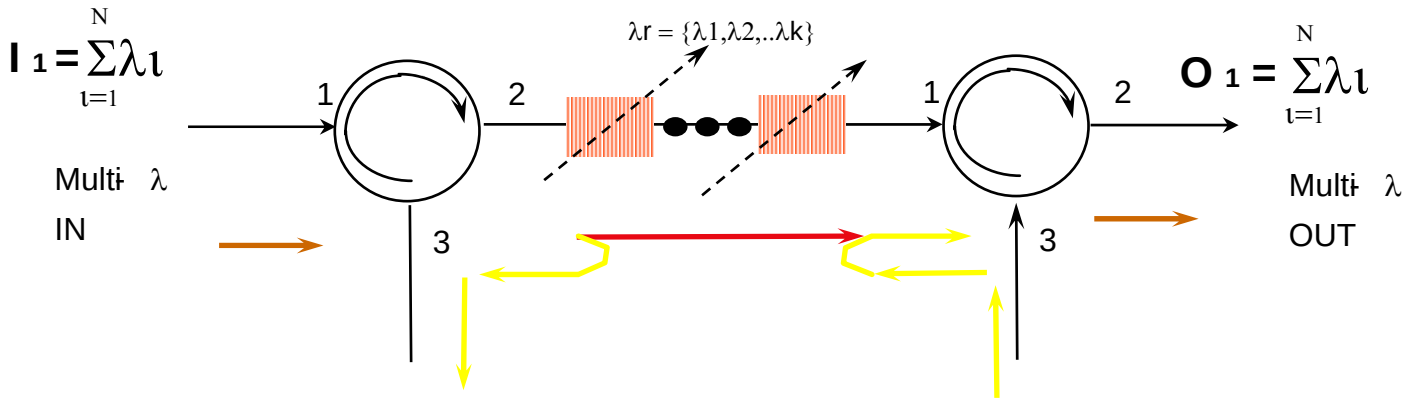
NxN Wavelength Division Multiplexer







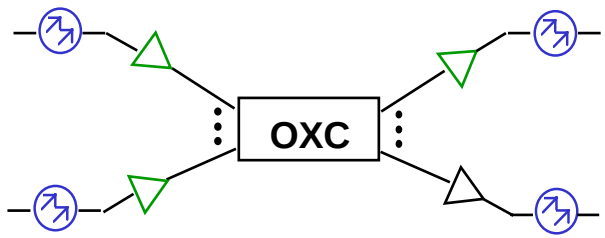
Basic OADM



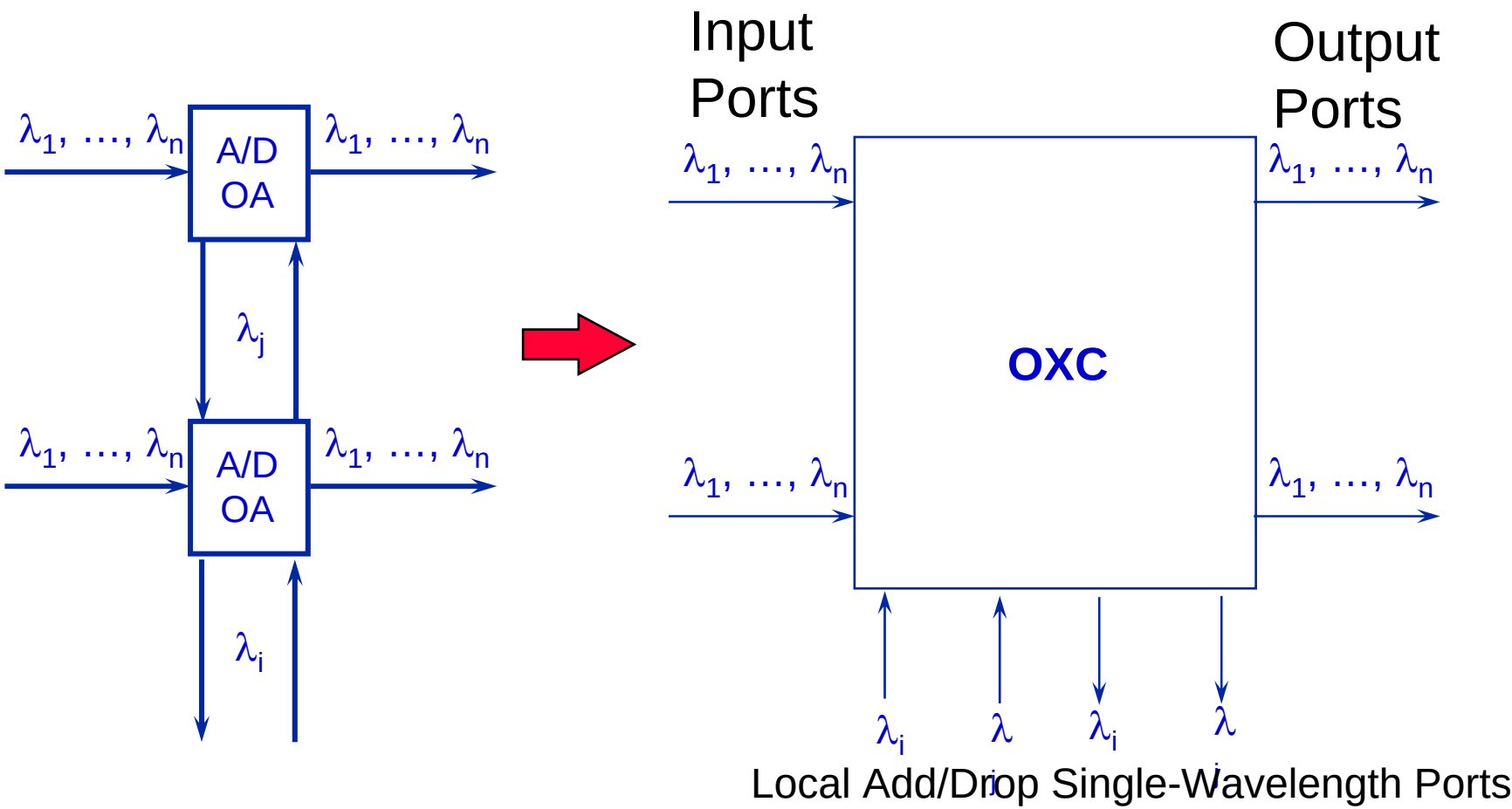
Basically, acts as controlled mirror for each wavelength

Step 3 of
Evolution: Optical Transport → Optical Networks

Optical XC
Reconfigurable WDM/Multipoint Network



Evolution to Optical Cross-Connect (OXC)



Provision Wavelength Channels. Provide Rapid Optical Layer Restoration.

1994-1996 MONET: Multiwavelength Optical Networking

The Mission:

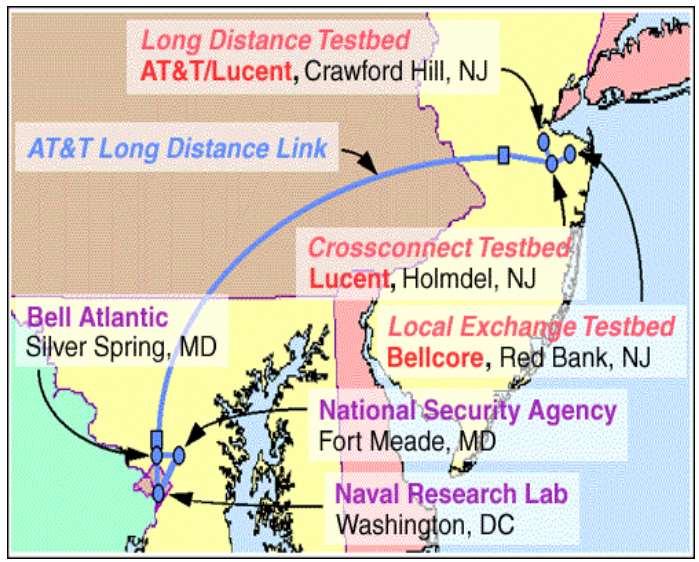
The realization of a seamless, fully configurable, transparent ("all optical"),

WDM, regional/national infrastructure,

and means to access it.

External Funding:

$50M over 5 years (ARPA)



Wavelength Selective Cross Connect (WSXC)

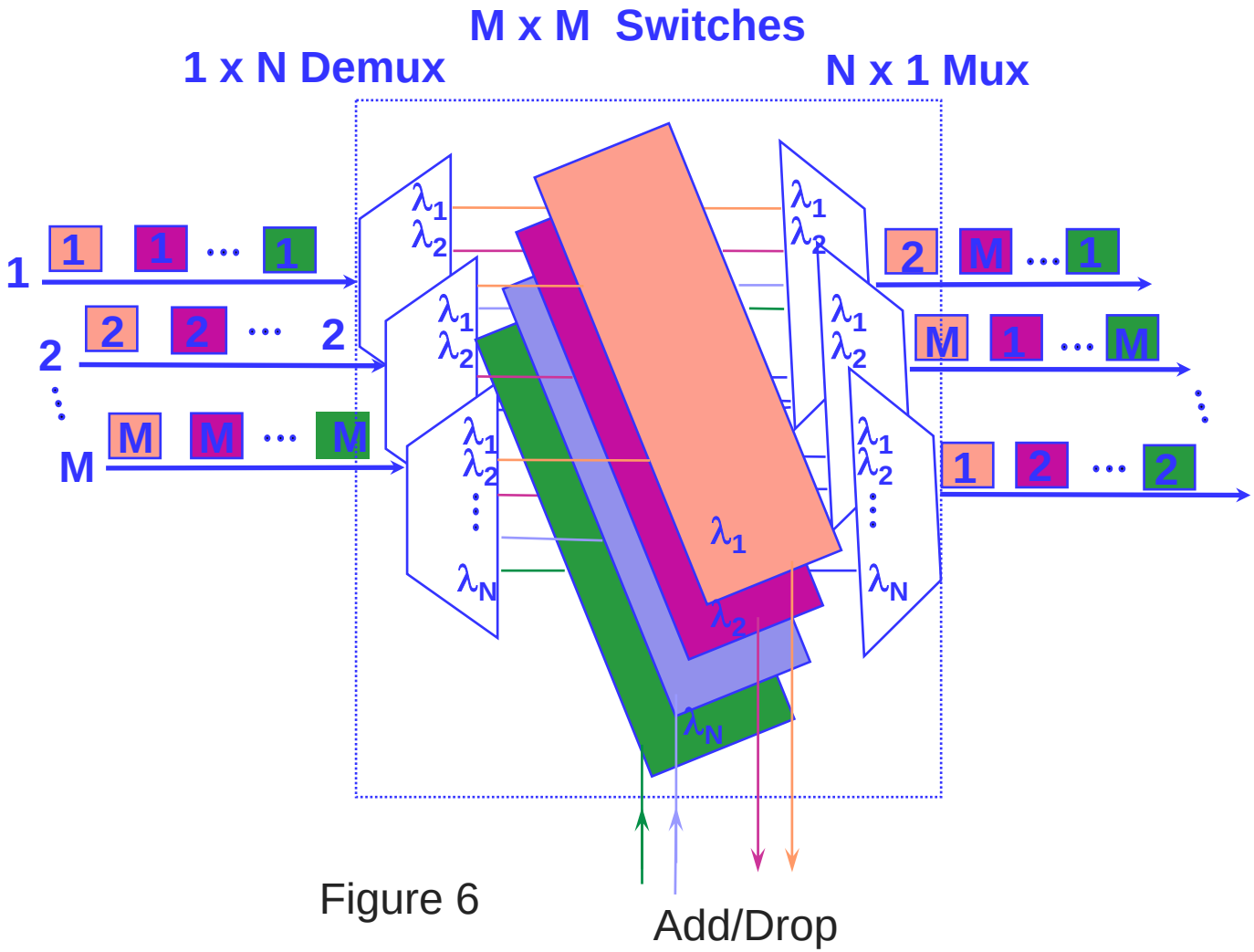
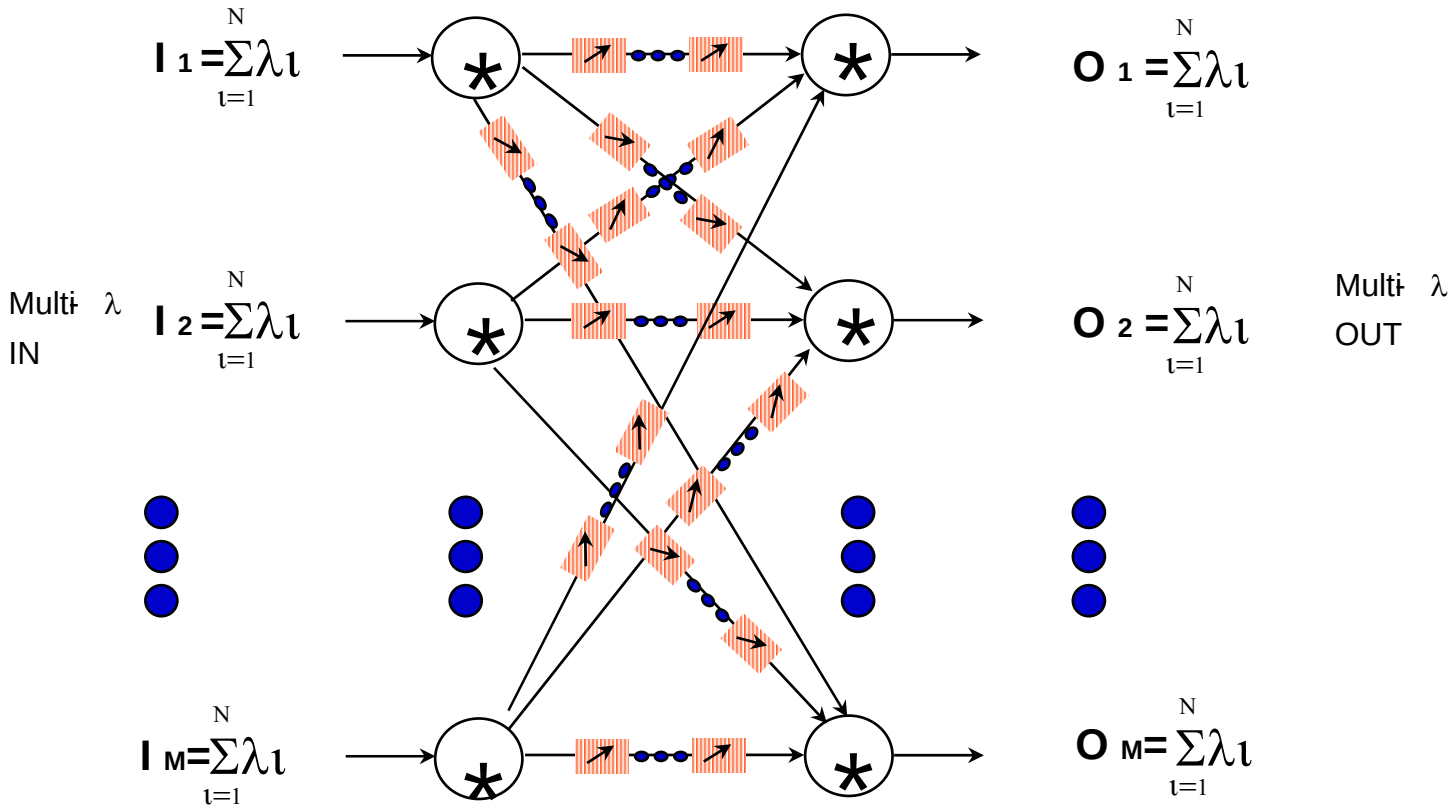


Figure 6

An MxMxN WSXC Implementation Example

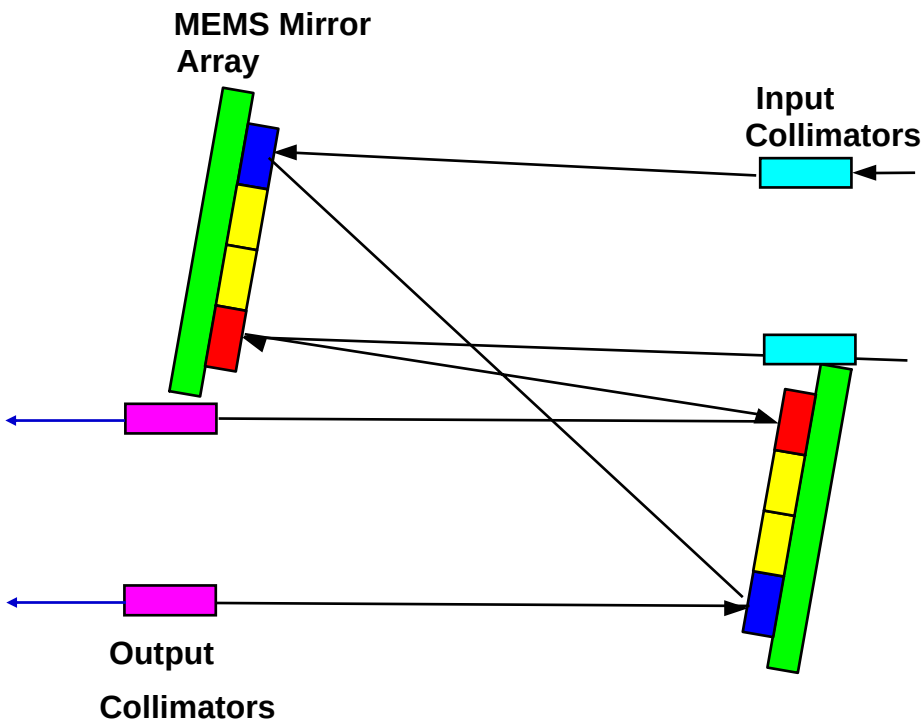


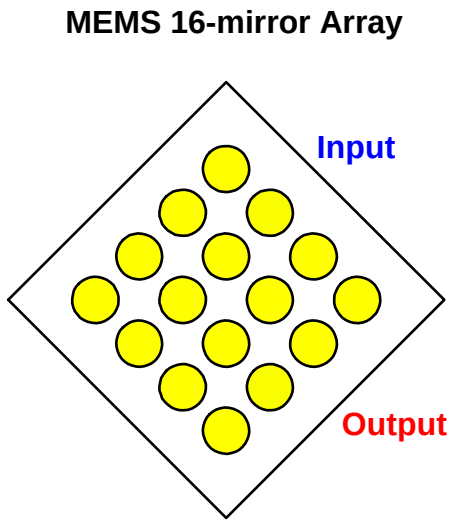
Notes:

1. M^2 Interconnections exits

3. NxM^2 Fiber Filters are needed for the system.

MEMS 2-axis Mirror Array OXC Configuration

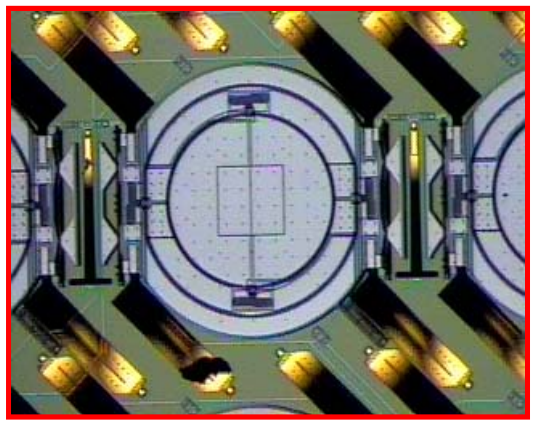




- **Design for low loss,**
- **Scalable fabric to 1024**

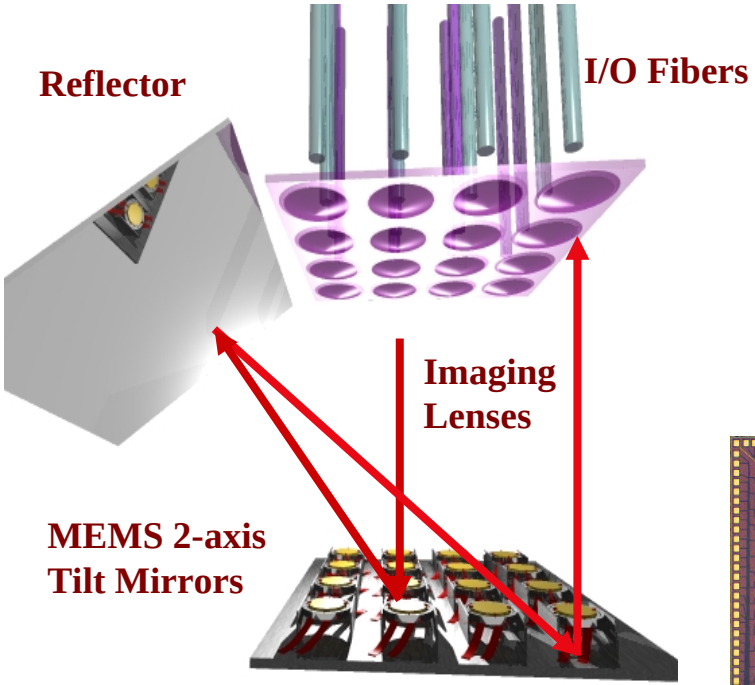
Optical Switching Technology

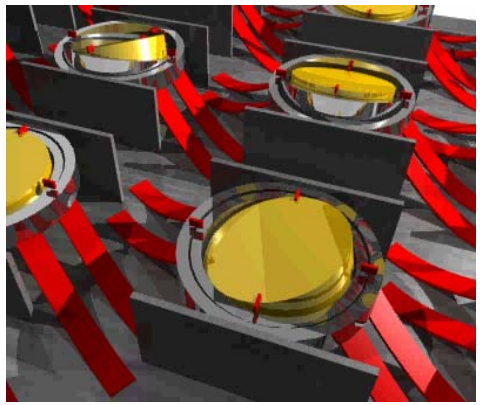
- **Key Element: MicroStar Photon Switch**
  - MEMS technology (micro electro-mechanical system)
  - 10Tbit/s total switching capacity

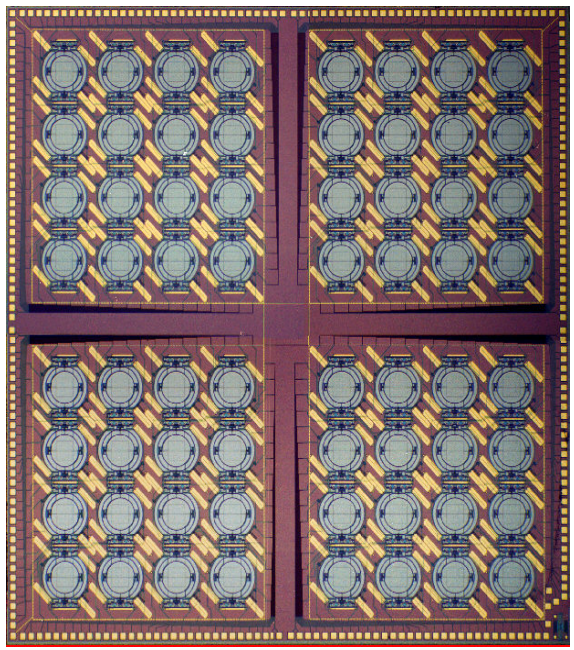


- **Dynamic Wavelength Management**
  - Transparent
  - Protocol independent
  - Granularity: Wavelength Level
- **Enabler of All Optical Networking**

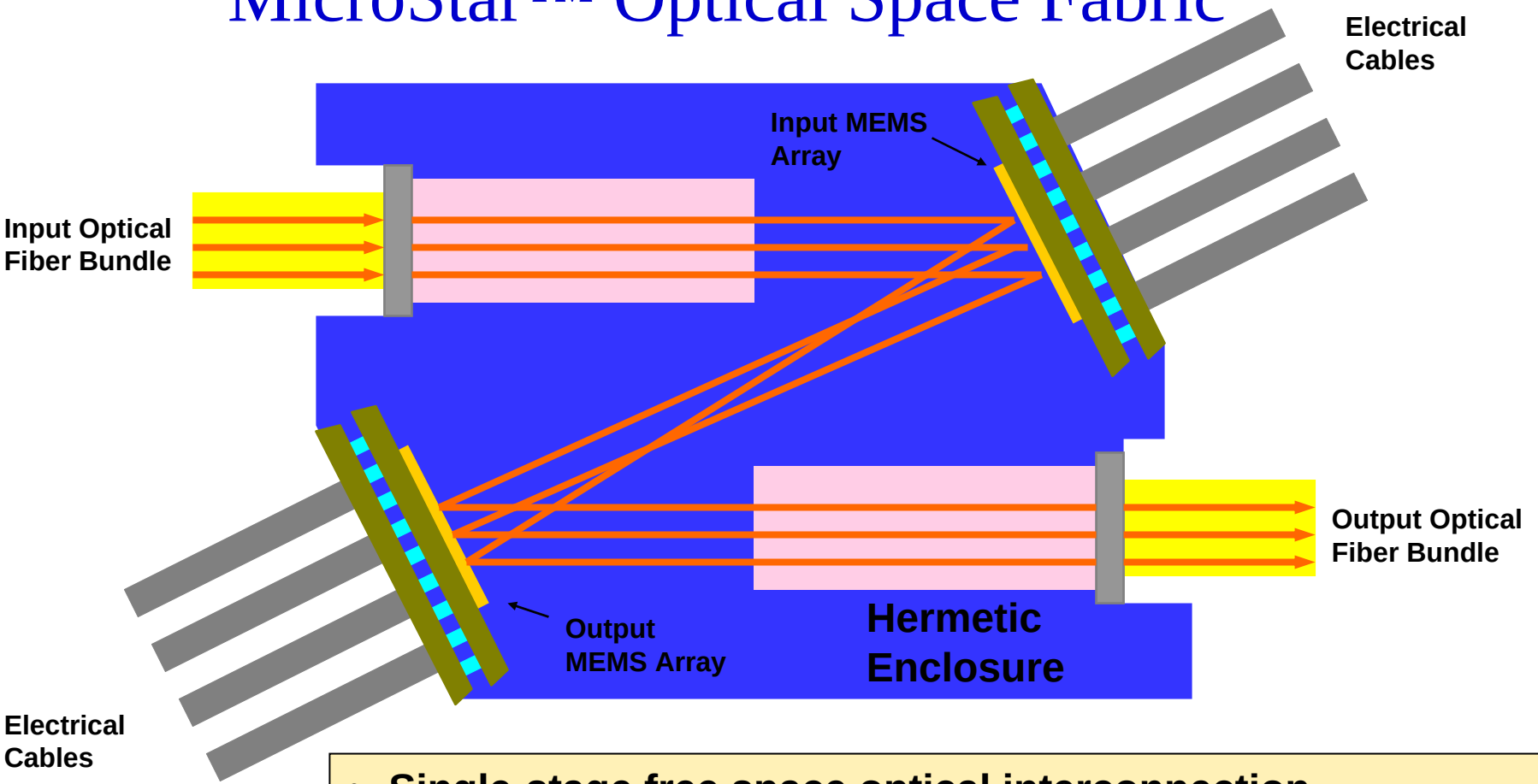
Optical Switching with MEMS





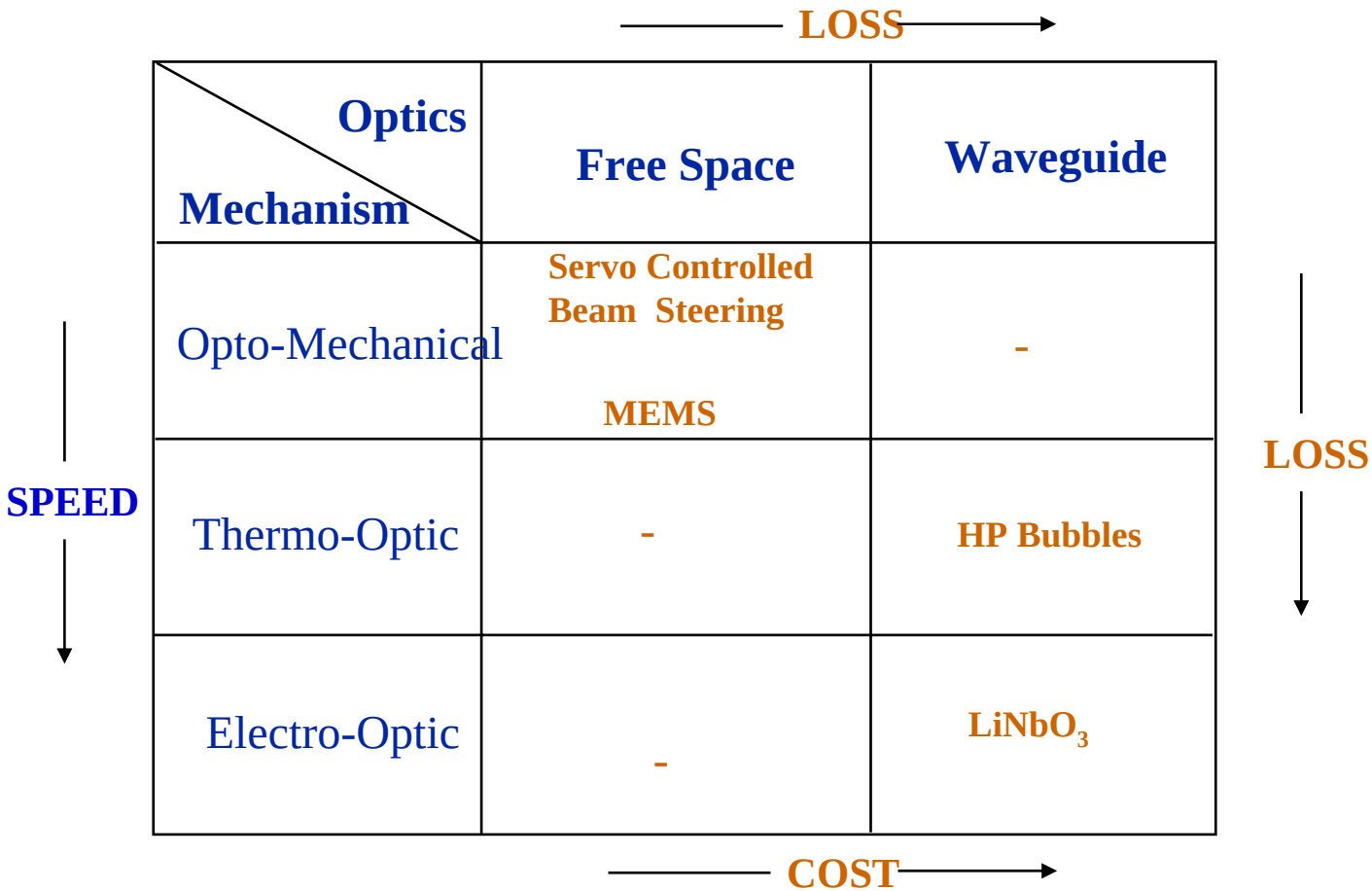


MicroStar™ Optical Space Fabric



- Single-stage free space optical interconnection
- Compact optics (~25mm x 50mm x 50mm for 256x256 OXC).
- < 5msec switching.
- ~ 6dB single-mode fiber insertion loss
- <-50dB crosstalk

Comparison of Optical Crossconnect Fabric Technologies



MEMS Based OXF is the Primary Technology for an OXC-NE.

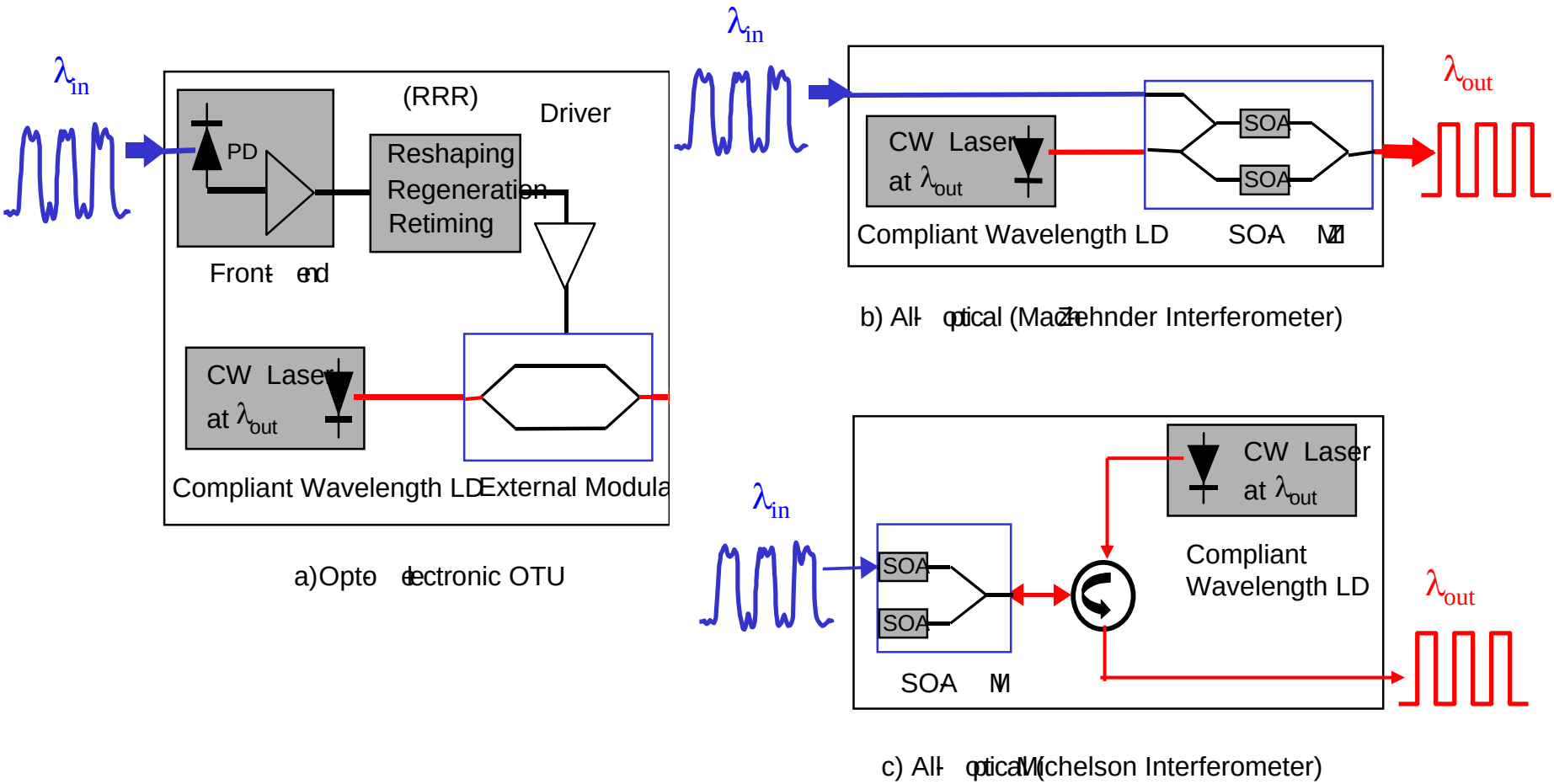
Opaque-vs-Transparent optical Cross-connect.

- Transparent optical Crossconnect
  - Has protocol transparency … bit rate, format, protocol, modulation scheme independence
  - Usually without signal conversion to electrical domain (O-E-O). O-O only
  - Essential for all-optical networking
- Opaque optical Crossconnect
  - Does not require protocol transparency
  - Designed for specified bit rate, format, protocol, modulation scheme
  - May use signal conversion to electrical domain (O-E-O allowed)

Q: What is meant by O-E-O and O-O?

Give an example of an Opaque optical cross-connect

Wavelength Conversion, Optical Translator Units (OTU) And Their Trends



End of Module 3

- Did you understand it all?
- Please provide a summary for this Module.
- Please read the assignments in preparation for Module 4.