



APPLIED OPTOELECTRONICS CENTRE

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# Optical Networking



School of Electronic and  
Communications Engineering

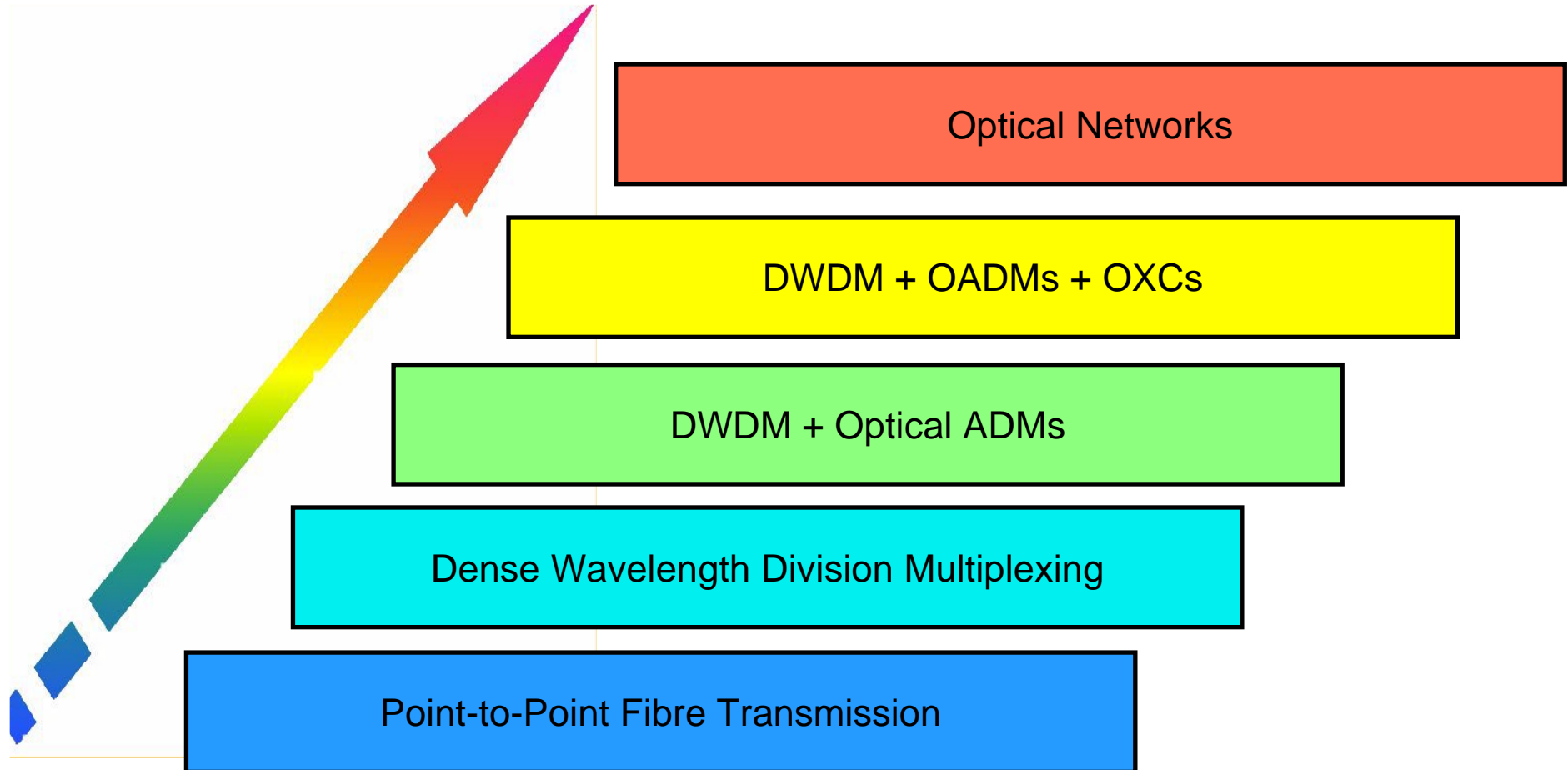




- Introduction: What and why....
- Implementing Optical Networking
- Developments in  $\lambda$  conversion
- Future developments....



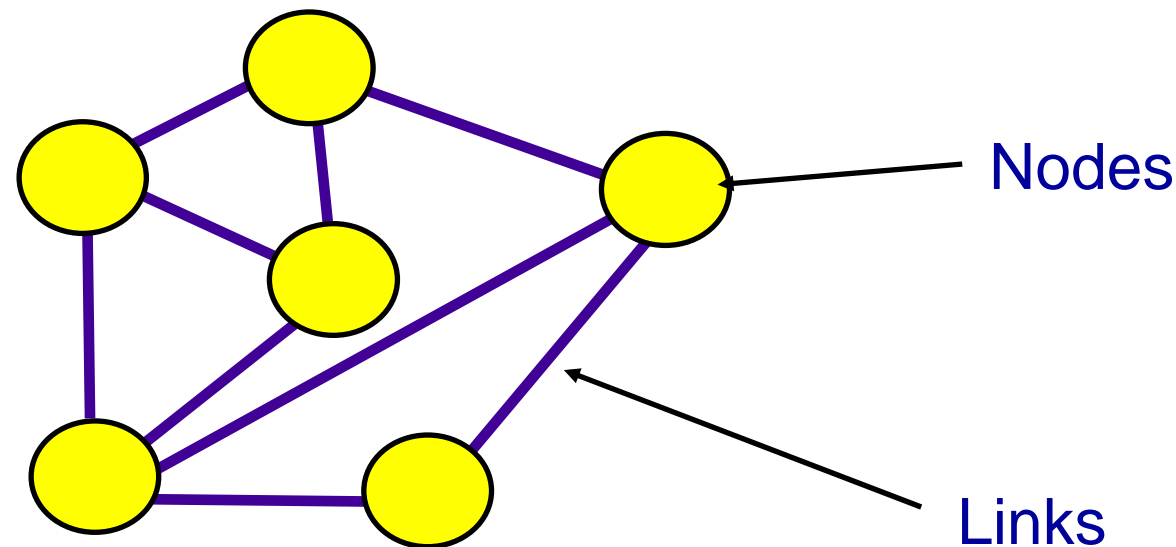
# Evolution of Optical Networking





# Optical Networking

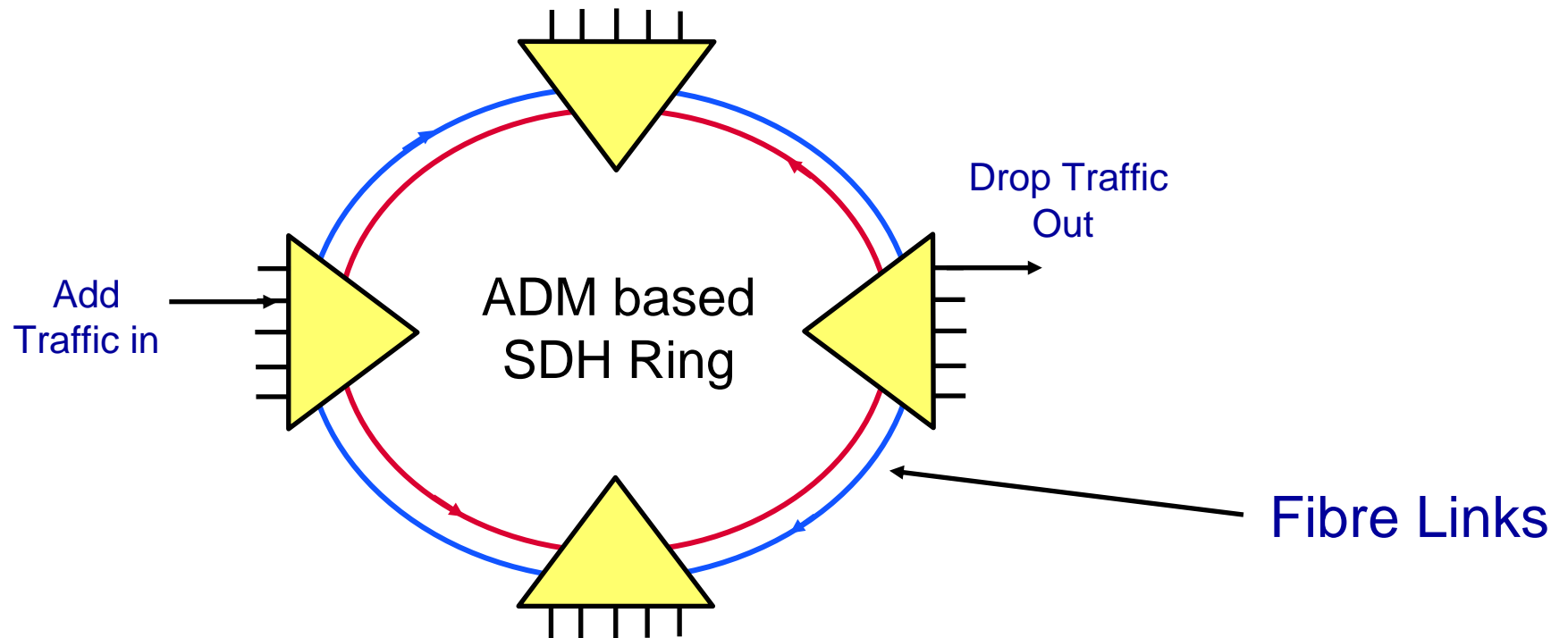
- In most existing networks optical technology is used on links to *transport* signals
- Most *processing* is carried out electrically, so called node-by-node electrical processing
- Moving toward all-optical networks, where transport and processing is optical.





# Conventional Electronic & Optical Networking

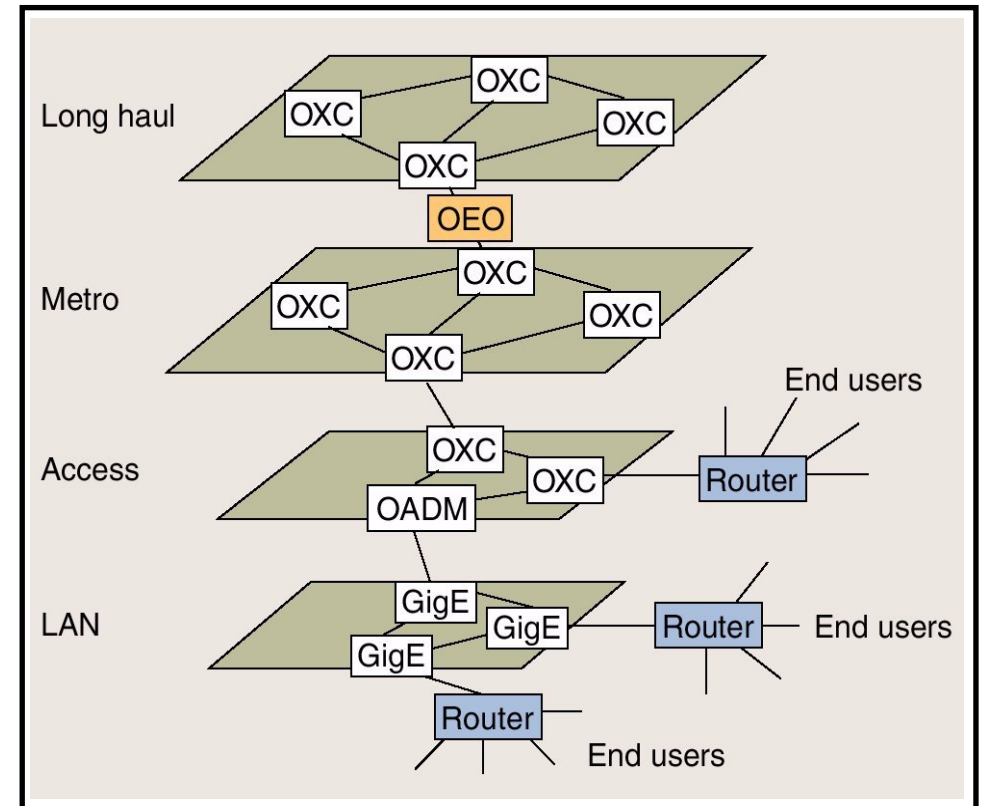
- In most existing networks optical technology is used to *transport* signals across links
- Most *processing* is carried out electrically, so called node-by-node electrical processing
- Demands many expensive Optical to Electronic to Optical (OEO) conversions
- Not bit rate transparent
- Classic example is an SDH (Synchronous Digital Hierarchy) ring





# Optical Networking

- Optical technology is used to *transport* and *process* signals
- Reduces need for **OEO** conversions, replaced by **OOO** conversions, bit rate transparent
- But control of processing remains electronic.
- Optical processing is taking place in a time frame  $\gg$  bit interval
- Signals are ultimately converted to an electronic form at the network edges
- "Photonic" networks is often used as alternative title



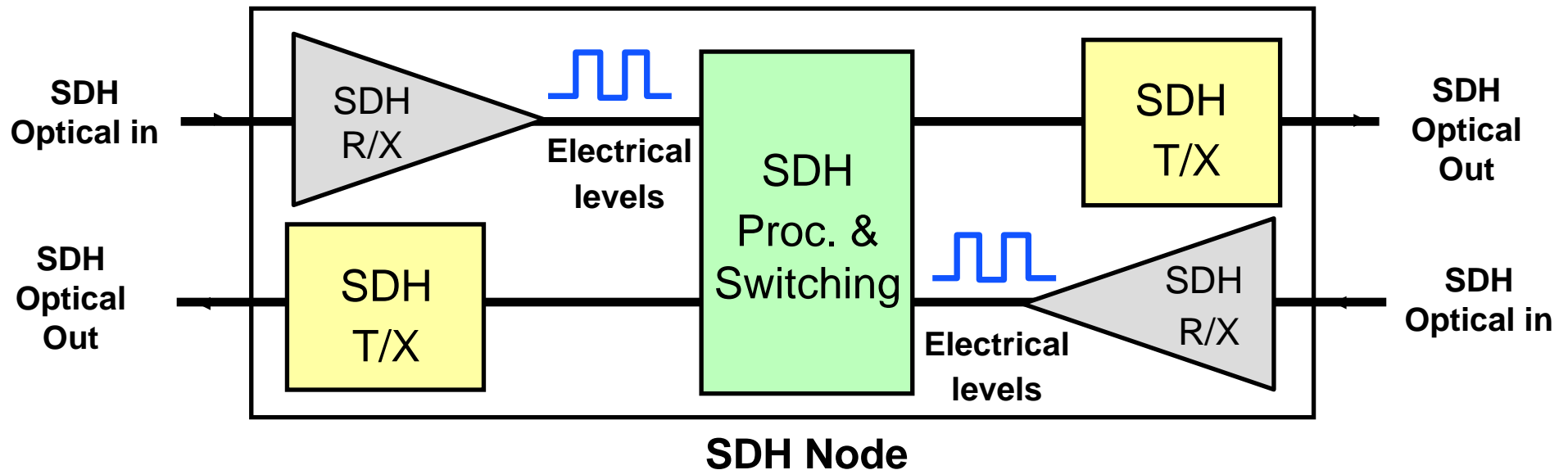
## Optical Network

**OXC: Optical Cross Connect**

**OADM: Optical Add-drop multiplexer**





# Disadvantages of Hybrid Electronic/Optical Networking

- Demands Optical to Electronic to Optical (OEO) conversions at each node
- Significant cost implication
- Not bit rate transparent
- Power dissipation and physical space are also issues
- But does allow very fine bit level control





# Taking stock of where we are: The Fourth Quadrant

	Electronic	Photonic
Analog	<p>FDM: manipulation of modulated carriers 1950s</p> 	<p>DWDM: manipulation of modulated carriers 1990s - 2000s</p> 
Digital	<p>Electronic digital processing: direct manipulation of bits 1960s to 1990s</p> 	<p>Optical digital processing: direct manipulation of bits 2000s</p> 





# Why Optical Networking?

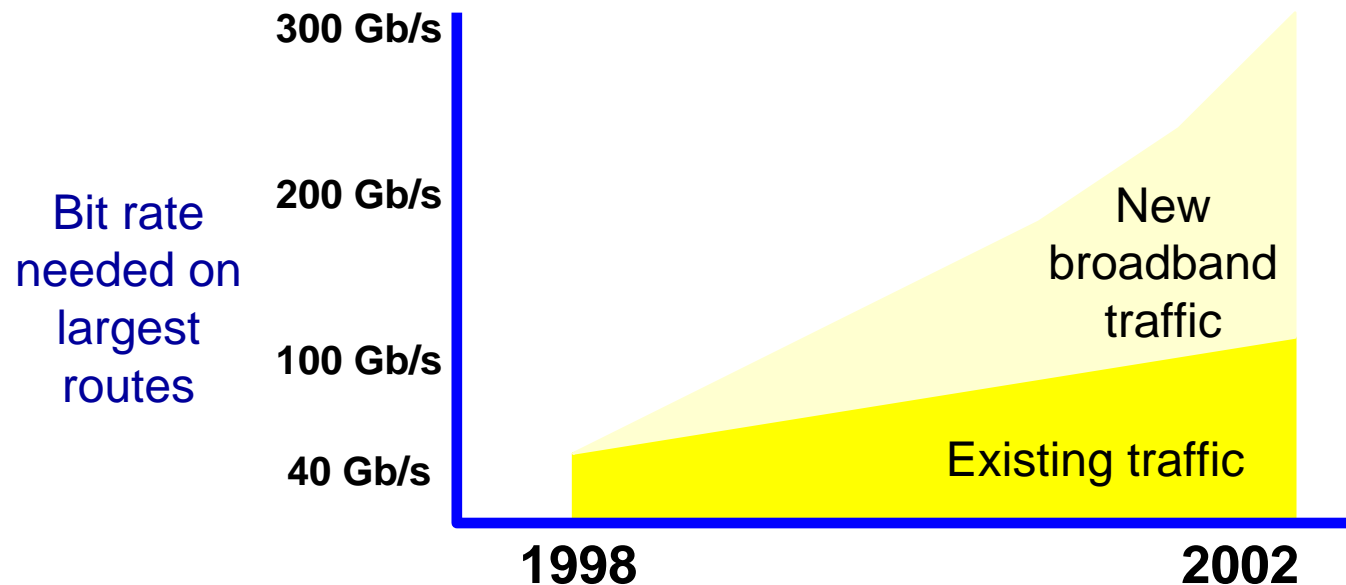
## Driving forces:

- The "electronic bit-rate bottleneck"
- The complexity/inflexibility/cost of hybrid electronic/optical systems
- The demand for more bandwidth
- Development of simple optical processing elements
- Widespread deployment of Dense Wavelength Division Multiplexing
- Potential for exploitation of the full capacity of singlemode fibre



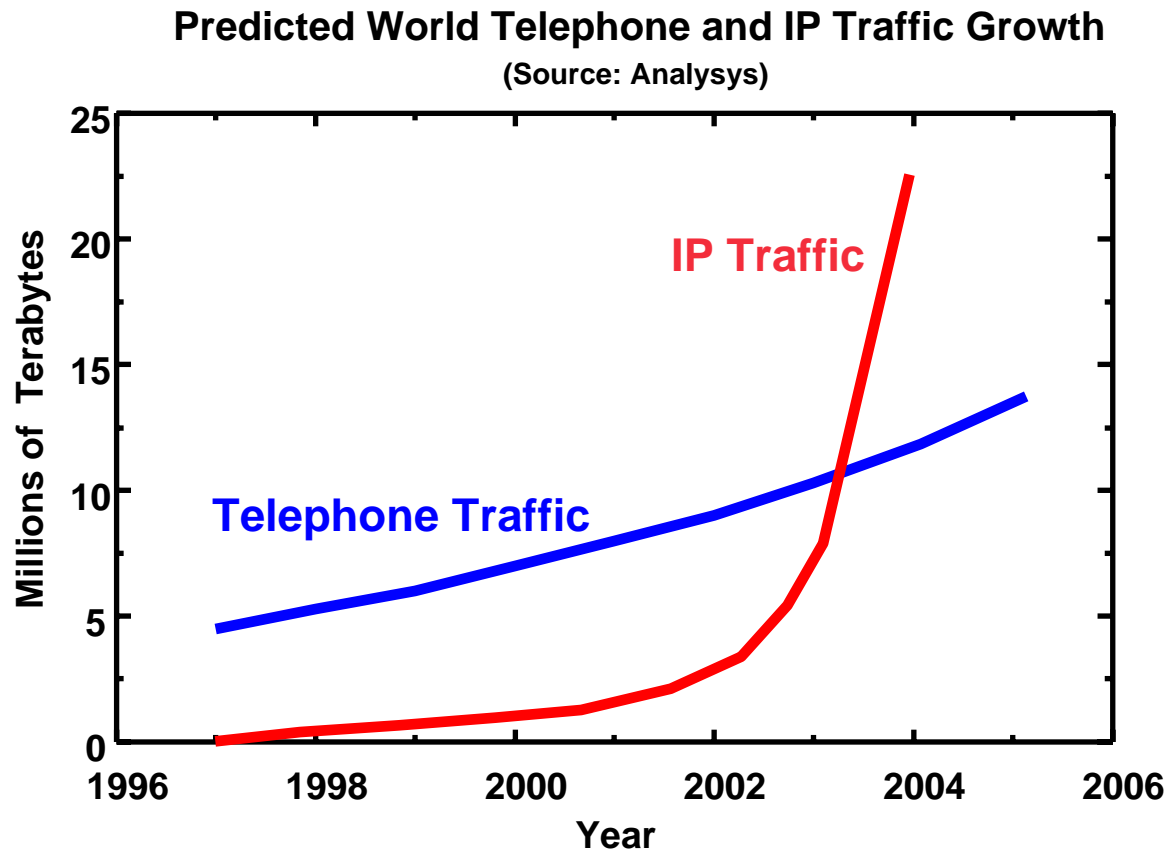
# Driving Forces

- Driving forces toward optical networking:
  - The demand for bandwidth
  - The "electronic bottleneck"
  - The complexity/inflexibility of hybrid electronic/optical systems
  - The availability of technologies such as Dense Wavelength Division Multiplexing





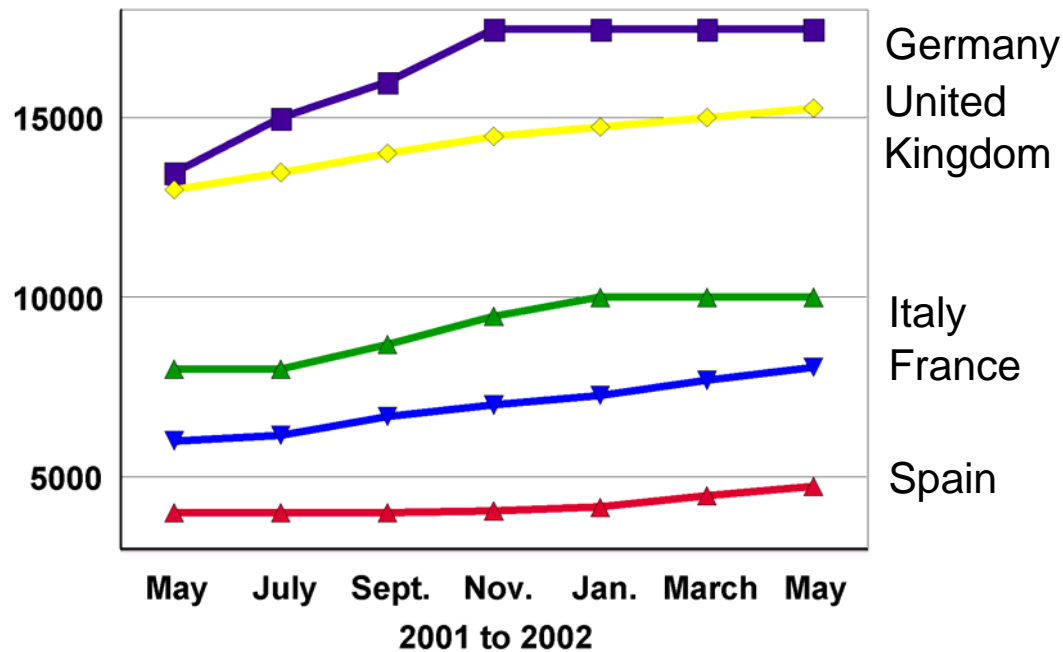
# The Demand for Bandwidth.....?



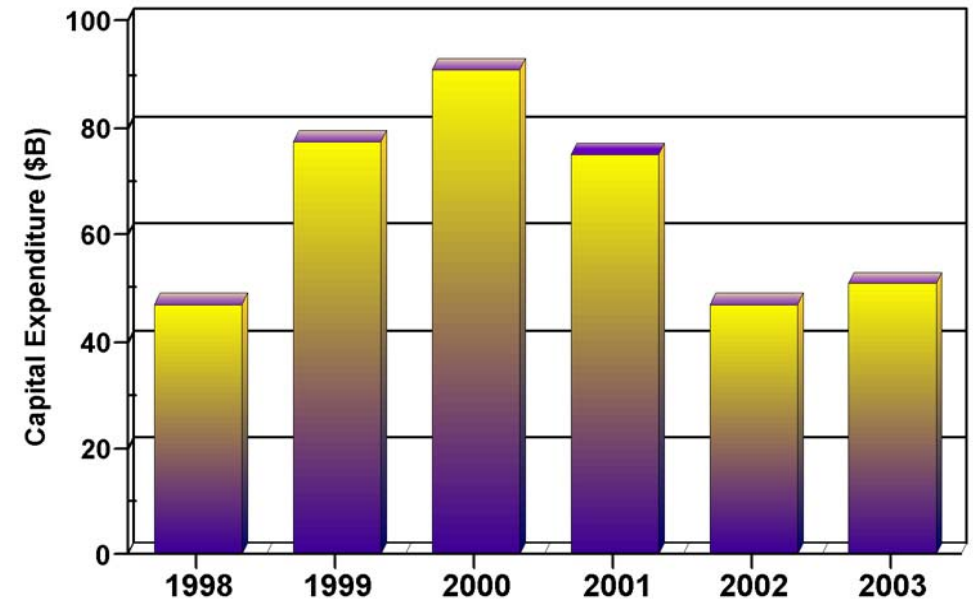
1999: What we thought would happen.....



# Looking back: Slowdown in Demand for Bandwidth & Equipment



1000's of people online in Europe



Capital expenditure by North-American telecoms carrier companies

(RHK Feb 2002)

- Demand for bandwidth does continue to grow, bandwidth costs much less
- Broadband to the home (eg. xDSL) technologies will raise demand in the core network
- Even worst case growth rates for internet traffic are 50%+ per year to 2008



# Optical Functions Required

- Ultra-fast and ultra-short optical pulse generation
- High speed modulation and detection
- High capacity multiplexing
  - Wavelength division multiplexing
  - Optical time division multiplexing
- Wideband optical amplification
- *Optical switching and routing*
- Optical clock extraction and regeneration
- Ultra-low dispersion and low non-linearity fibre



# Greater Availability of Optical Processing Elements

**Fixed  $\lambda$  Transmitter**  
**Receiver**  
**Fibre joints**

**Tunable  $\lambda$  Transmitters**  
**Receivers**  
**Fibre joints**  
**Optical Amplifiers**  
**AWG Mux/Demux**  
**Controllable attenuators**  
**Dispersion Compensation**  
**Simple Optical Switching**  
**Optical Filters**  
**Equalizers**  
**Isolators**  
**Couplers & splitters**

1992

1998

2008





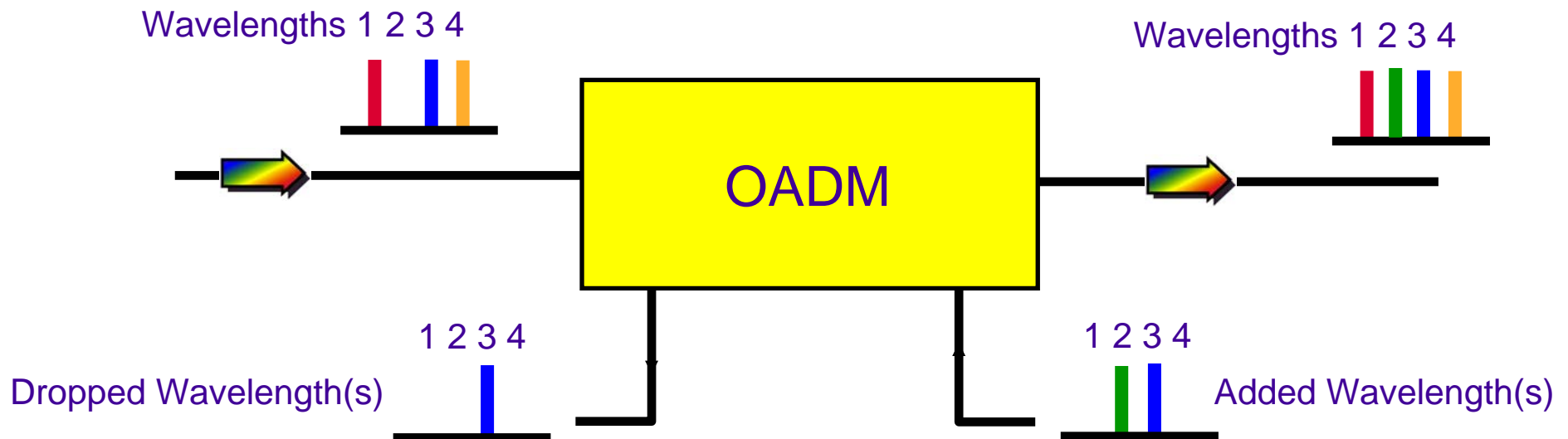
# Optical Add/Drop Multiplexers



# Optical Add-Drop Multiplexer

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- An Optical Add-Drop Multiplexer allow access to individual DWDM signals without conversion back to an electronic domain
- In the example below visible colours are used to mimic DWDM wavelengths
  - Wavelengths 1,3 and 4 enter the OADM
  - Wavelengths 1 and 4 pass through
  - Wavelength 3 (blue) is dropped to a customer
  - Wavelengths 2 (green) and a new signal on 3 (blue) are added
  - Downstream signal has wavelengths 1,2,3 and 4

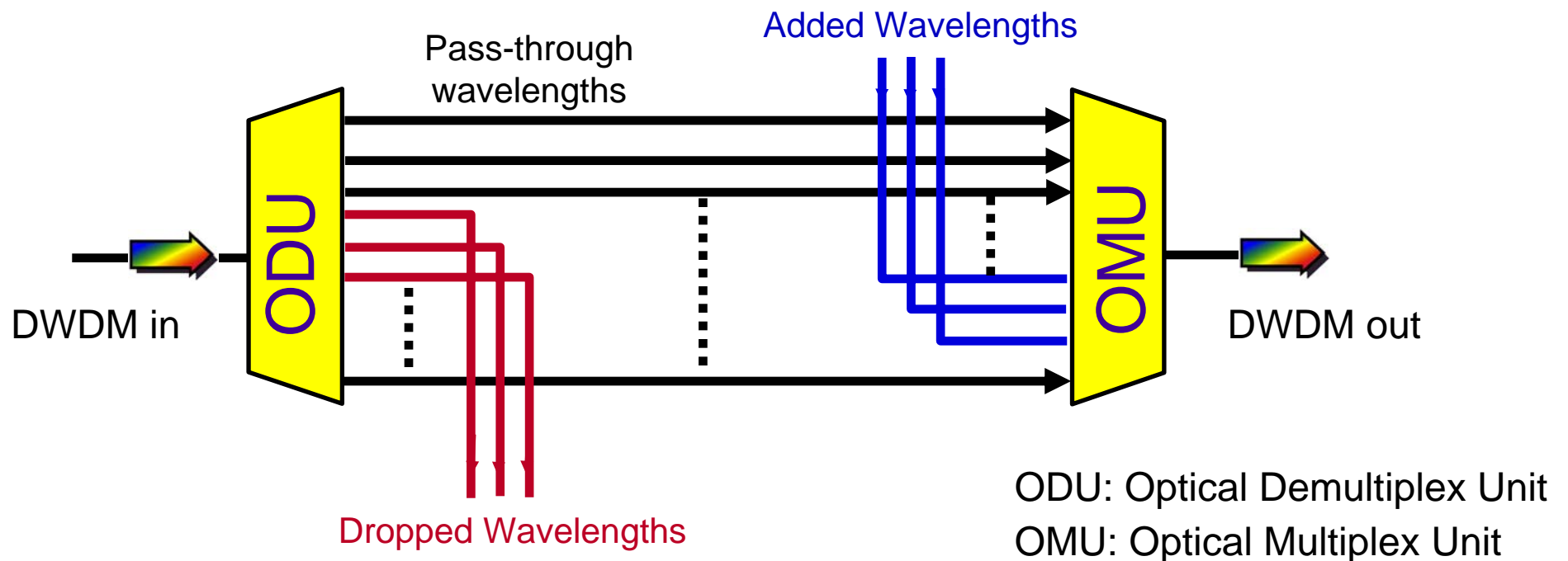






# First Generation Optical Add-Drop Multiplexer

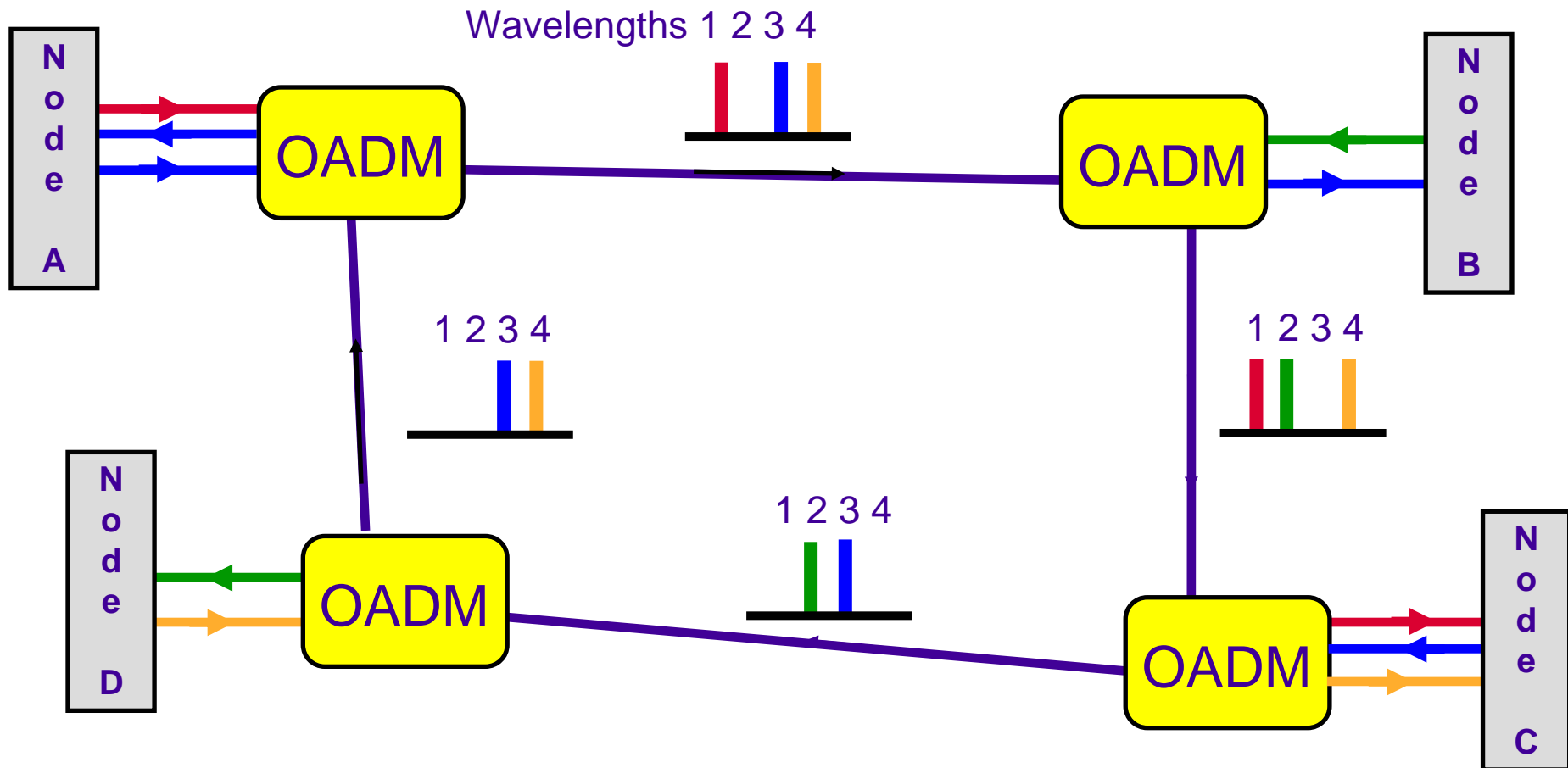
- Simple OADM structure
  - ODU demultiplexes all wavelengths and drops off wavelengths as required
  - OMU multiplexes added wavelengths as well as those that pass through
- Disadvantages:
  - Unnecessary demultiplexing and multiplexing of pass-through wavelengths
  - Typical number of drop channels is limited to 25-50% of total payload





# Simple Optical Network Example

*OADM: Optical Add-Drop Multiplexer*



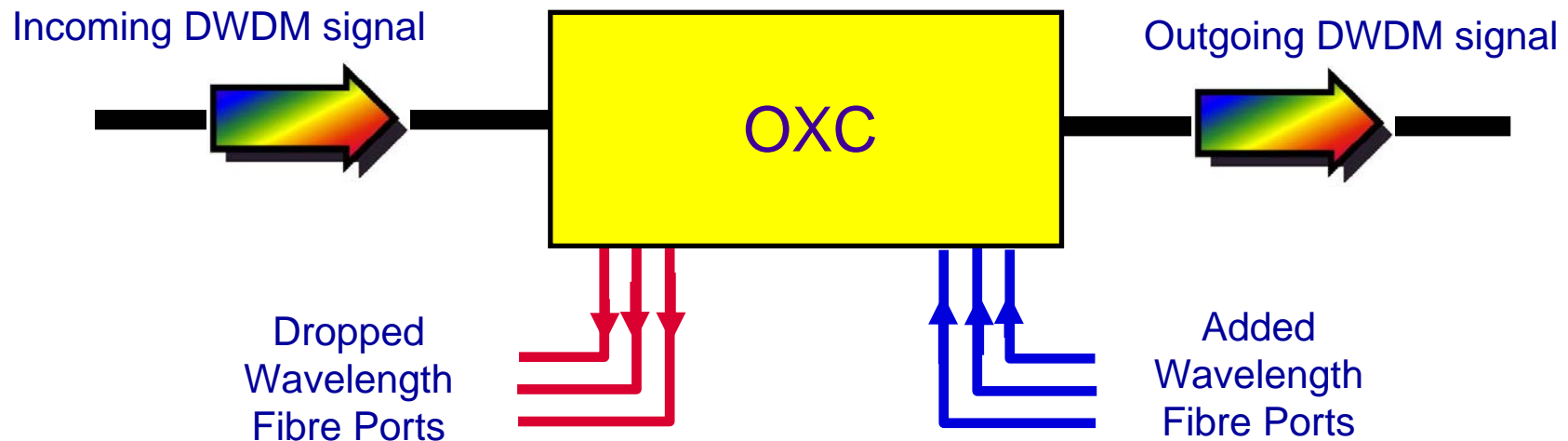
Note wavelength reuse of "blue" wavelength (no. 3), links Node A and B as well as Node C and A



# Optical Cross-Connect (OXC)

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- Need reconfigurable OADM, allows change to the added and dropped wavelengths
- OADM becomes an OXC (Optical Cross-Connect)
- Large number of DWDM wavelengths possible means a large number of ports
- Needs to be remotely configurable, intelligent
- Should be non-blocking, any combination of dropped/added possible
- In addition, insertion loss, physical size, polarization effects, and switching times are critical considerations.

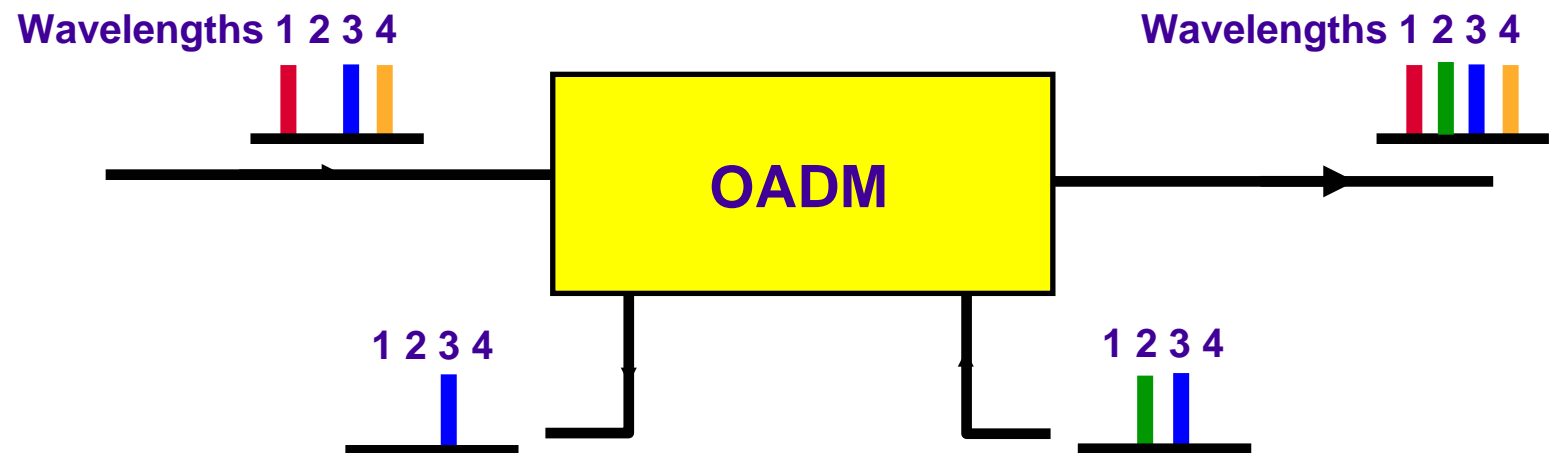




# OADM Requirements

In general an OADM should be able to:

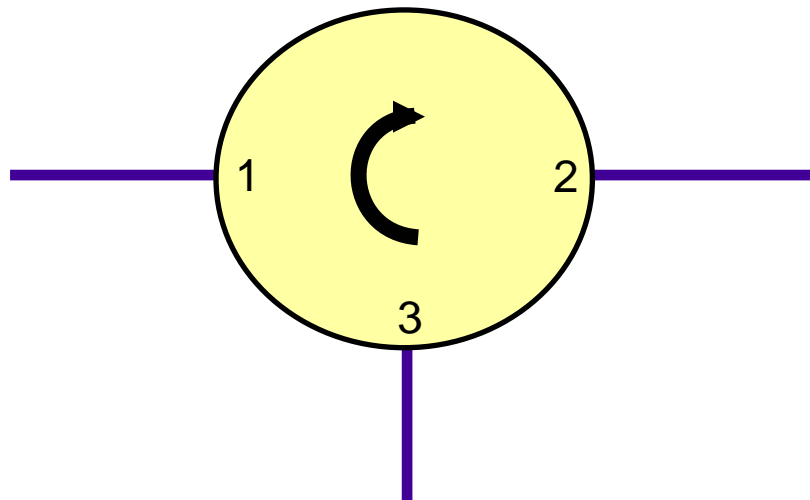
- Add/Drop wavelengths in any order
- Be locally and remotely configurable
- Pass-through wavelengths should not be demultiplexed
- Provide a low loss and low noise path for pass-through wavelengths
- Reducing disturbance to pass-through wavelengths reduces need for OEO regeneration





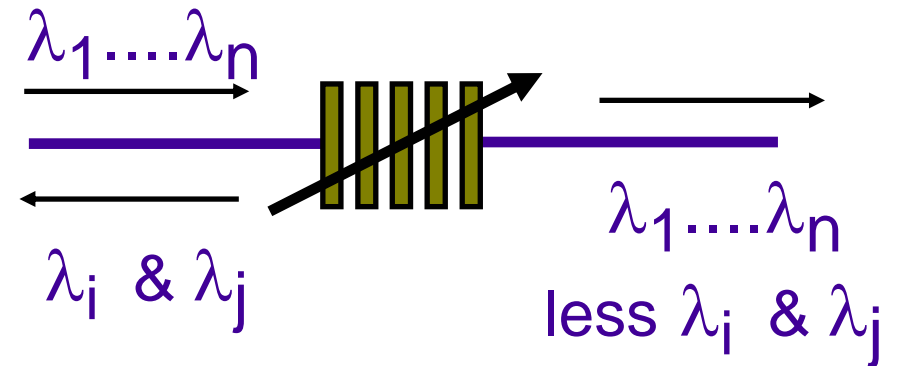
# Components for a 2nd Generation OADM

## Optical Circulator



Light in port		Light out port
1	→	2
2	→	3
3	→	1

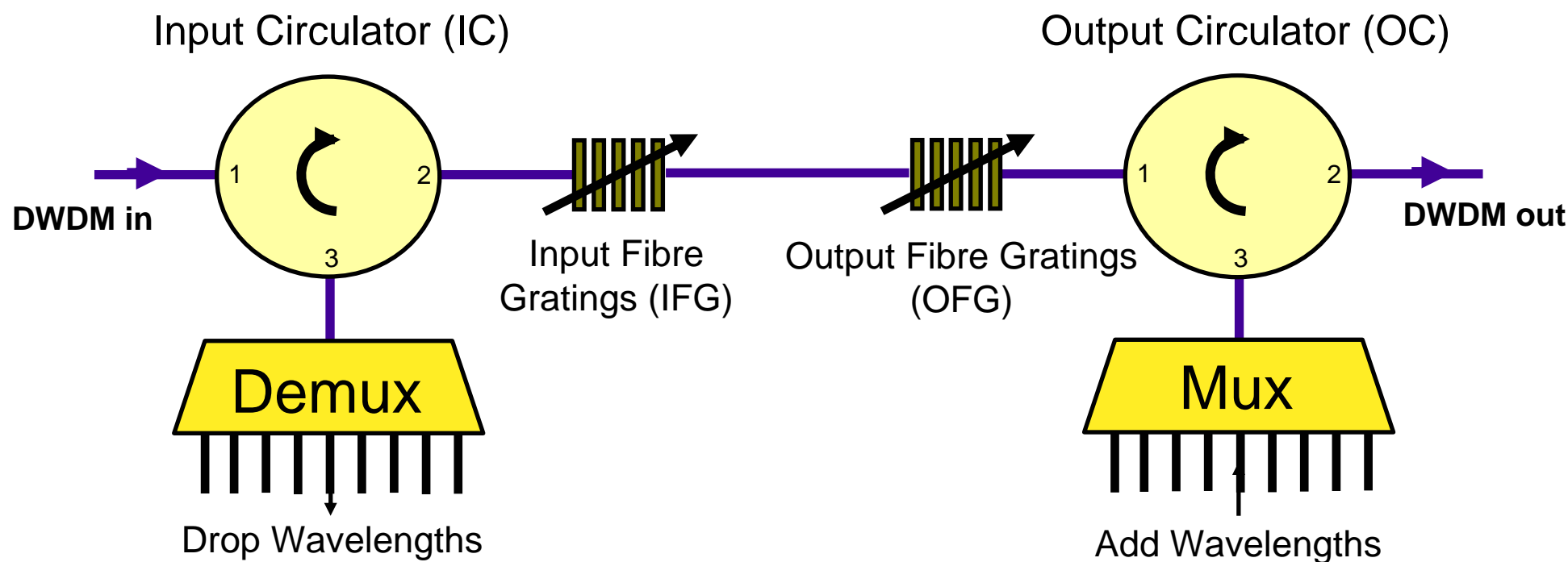
## Tunable Fibre Gratings



- Gratings etched in fibre
- Can pass or reflect selected wavelengths
- Wavelength selection is tunable (thermal or piezoelectric strain)
- Diagram shows a series of gratings reflecting two wavelengths  $\lambda_i$  &  $\lambda_j$



# Lucent 2nd Generation Programmable OADM



All incoming wavelengths pass through the IC from port 1 to 2. At the IFG pass-through wavelengths continue toward the OC. The tuning of the IFG selects drop wavelengths that are reflected back to the IC to port 2 and are passed to port 3 to be demultiplexed.

Add wavelengths are sent to port 3 of the OC and are passed to port 1 of the OC backward to the OFG. The OFG selects which, if any, of the add wavelengths are reflected forward to port 1 of the OC along with the pass-through wavelengths. At port 1 of the OC the selected add wavelengths and pass-through wavelengths are passed to the output at port 2.



# Sample Optical Networks



# Ciena MultiWave Metro System (I)

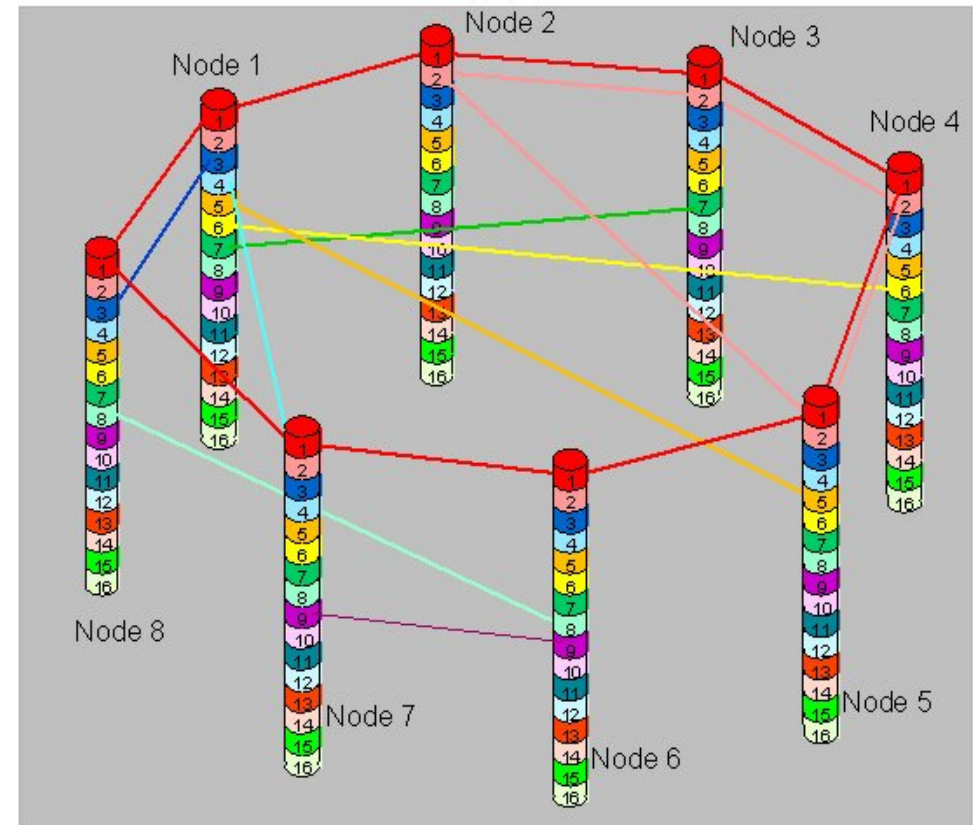
- MultiWave™ Metro is a Dense Wave Division Multiplexing (DWDM) system for use in metropolitan ring applications.
- The MultiWave Metro system consists of Optical Add/Drop Multiplexer (OADM) nodes connected together on a two fiber ring.
- It provides up to 24 duplex channels over a single fibre pair, allowing this single fibre pair to carry up to 120 Gb/s.
- ITU Compliant Channel Plan: MultiWave Metro uses 200 GHz channel spacing as specified in ITU G.692.
- Uses Standard fibre: MultiWave Metro operates on standard single mode fibre.





# Ciena MultiWave Metro System (II)

- The multi-colored columns in the figure represent MultiWave Metro nodes which are interconnected by a two-fiber ring.
- The different colors represent the different wavelengths available at each node.
- The colored lines interconnecting the nodes represent logical connections between nodes
- The connection formed by dropping wavelength 1 (red) at all nodes shows a typical SONET ring application where traffic is added and dropped at each node.
- The connection formed by dropping wavelength 2 (pink) at nodes 2, 3, 4, and 5 shows how a private SONET ring might be implemented

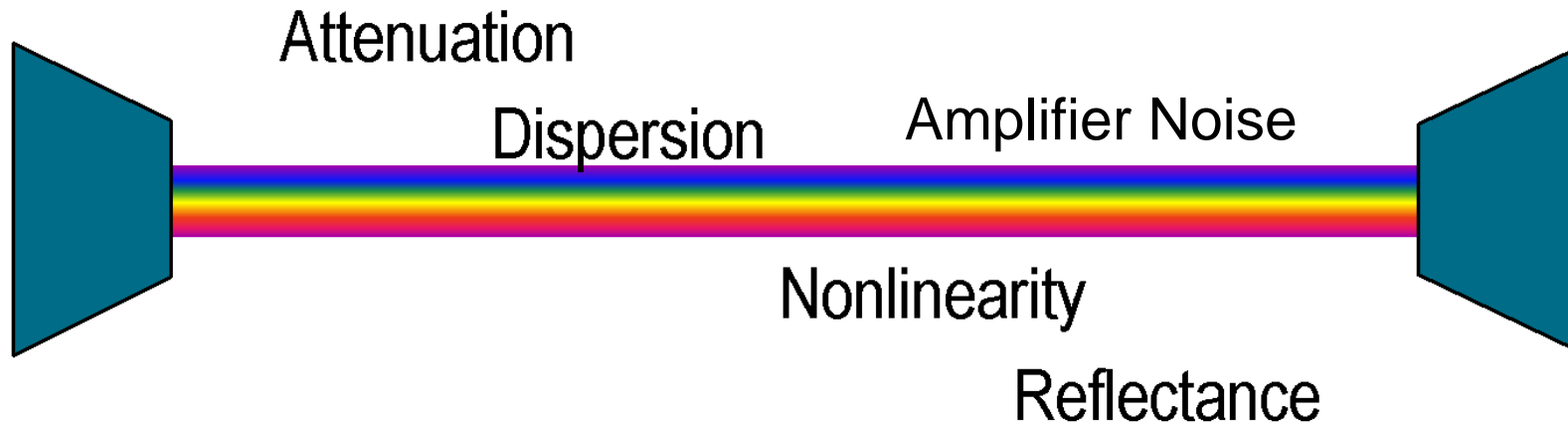




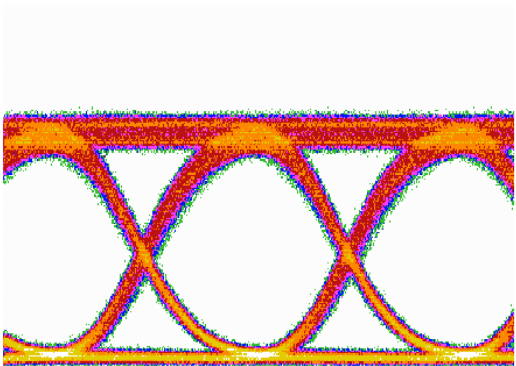
# Protection and Restoration in Optical Networks



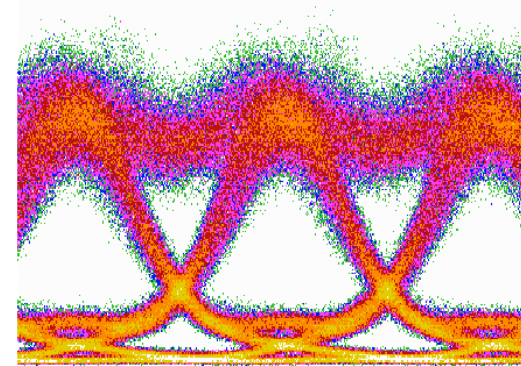
# Optical Networks and Noise



*Transmitted data waveform*



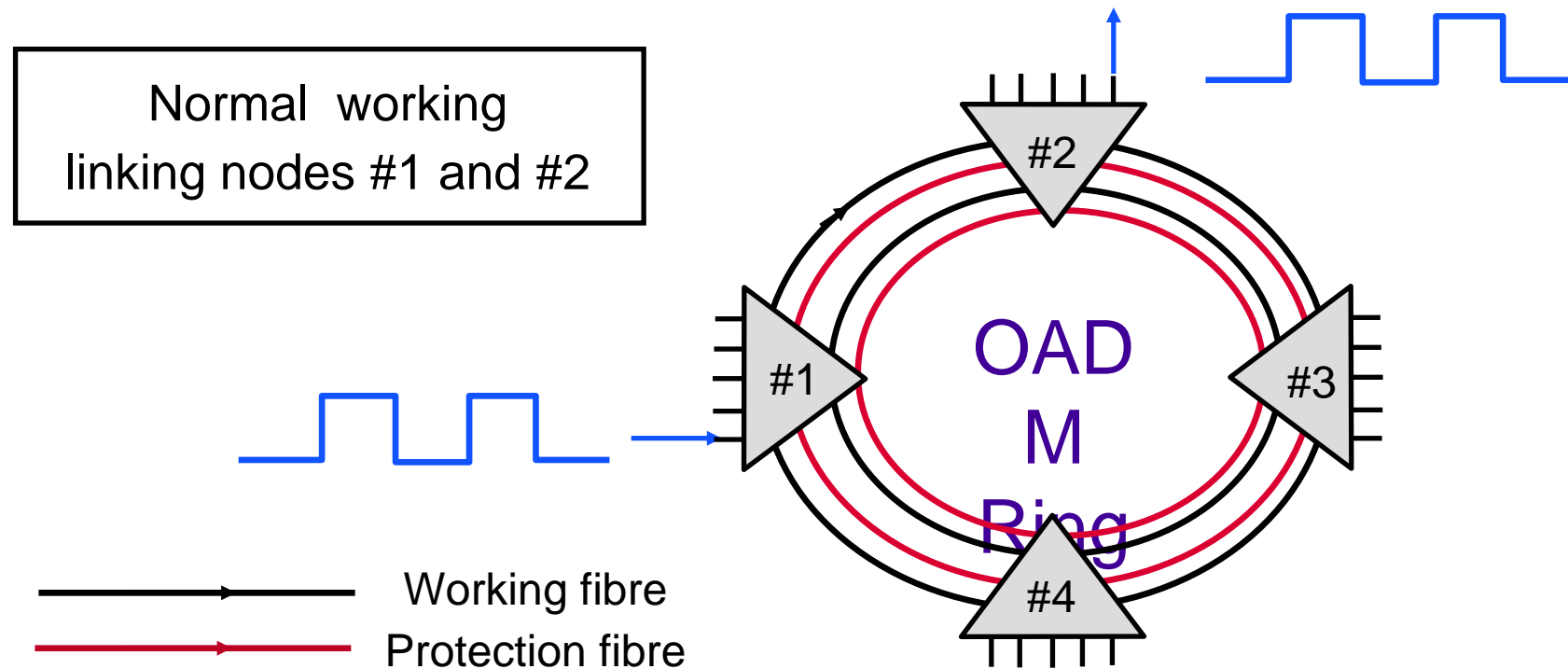
*Waveform after 1000 km*





# Protection Switching in Rings (I)

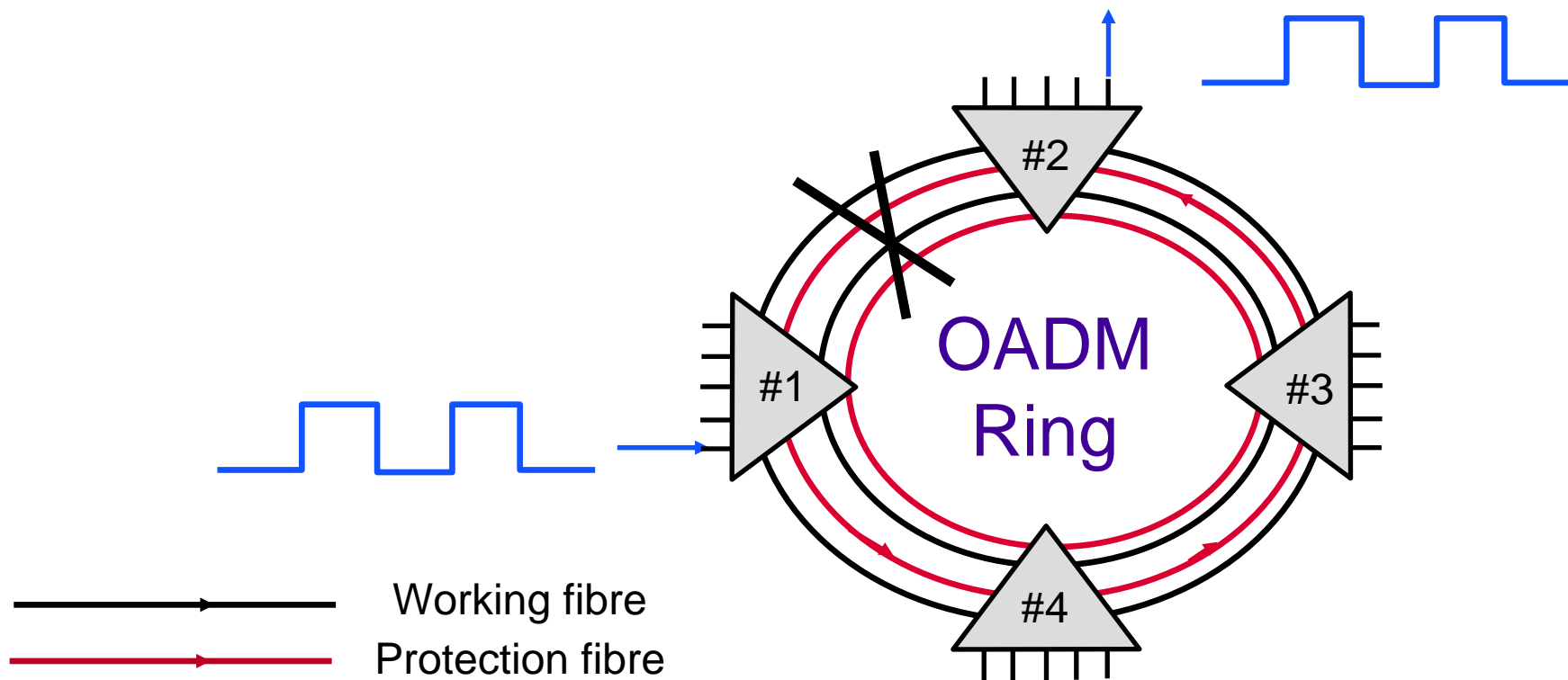
- Could use a classic 4 fibre bidirectional ring for protection
- Two fibres in each direction, one working, one backup or protection.
- In the event of a *Cable* fault signal is routed over an alternative fibre path





# Protection Switching in Rings (II)

- Assume a cable fault between OADM #1 and #2
- Signal is now re-routed over protection fibre via nodes #4 and #3





# Protection Switching Issues in Optical Networks

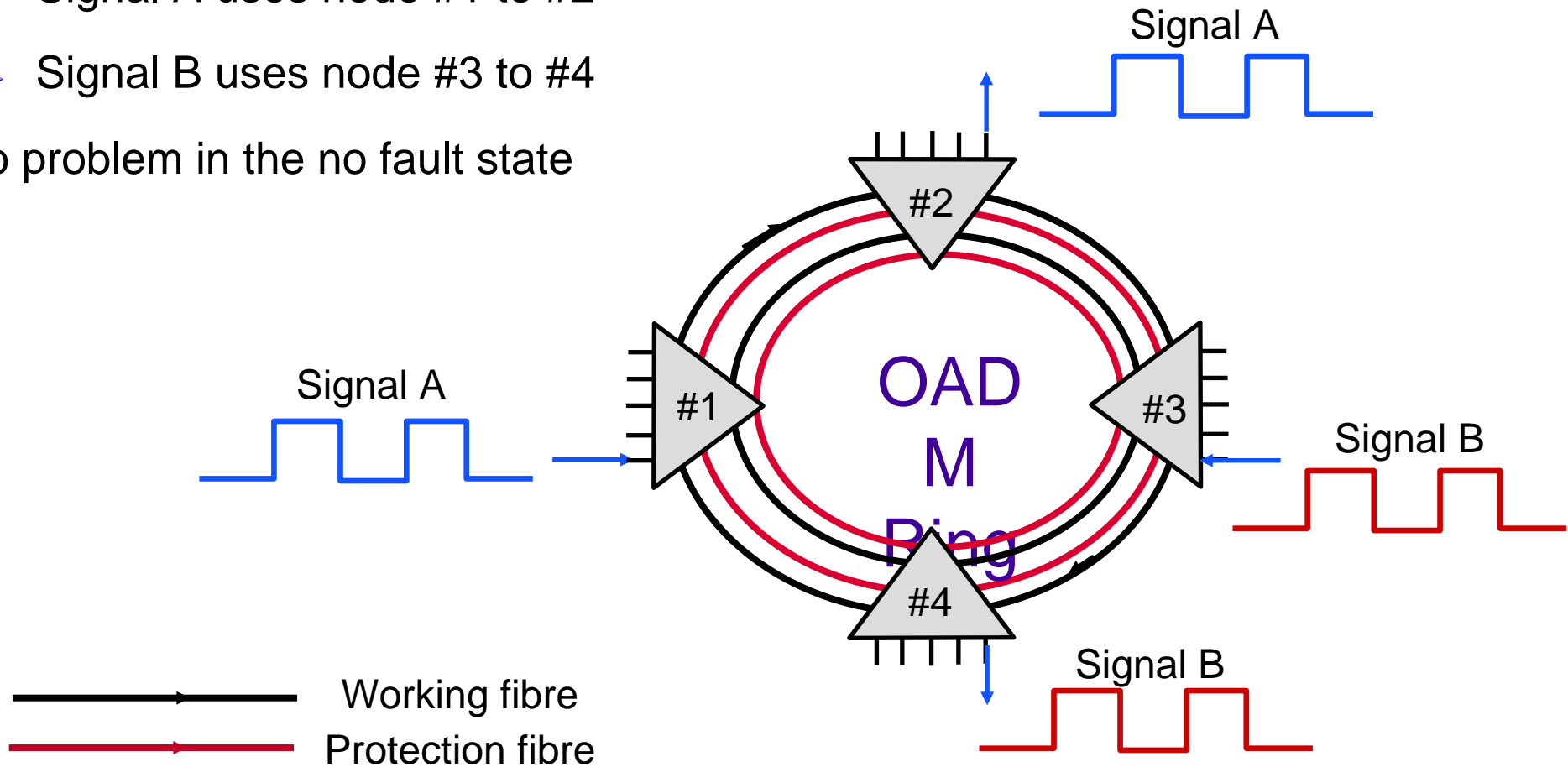
Three important issues arise in ring switching OADMs for protection:

- Wavelength reuse may mean a protection path is unavailable under certain conditions
- Signal quality may mean long protection paths are unworkable
- Mechanical switching reliability?



# Wavelength Reuse Issues (I)

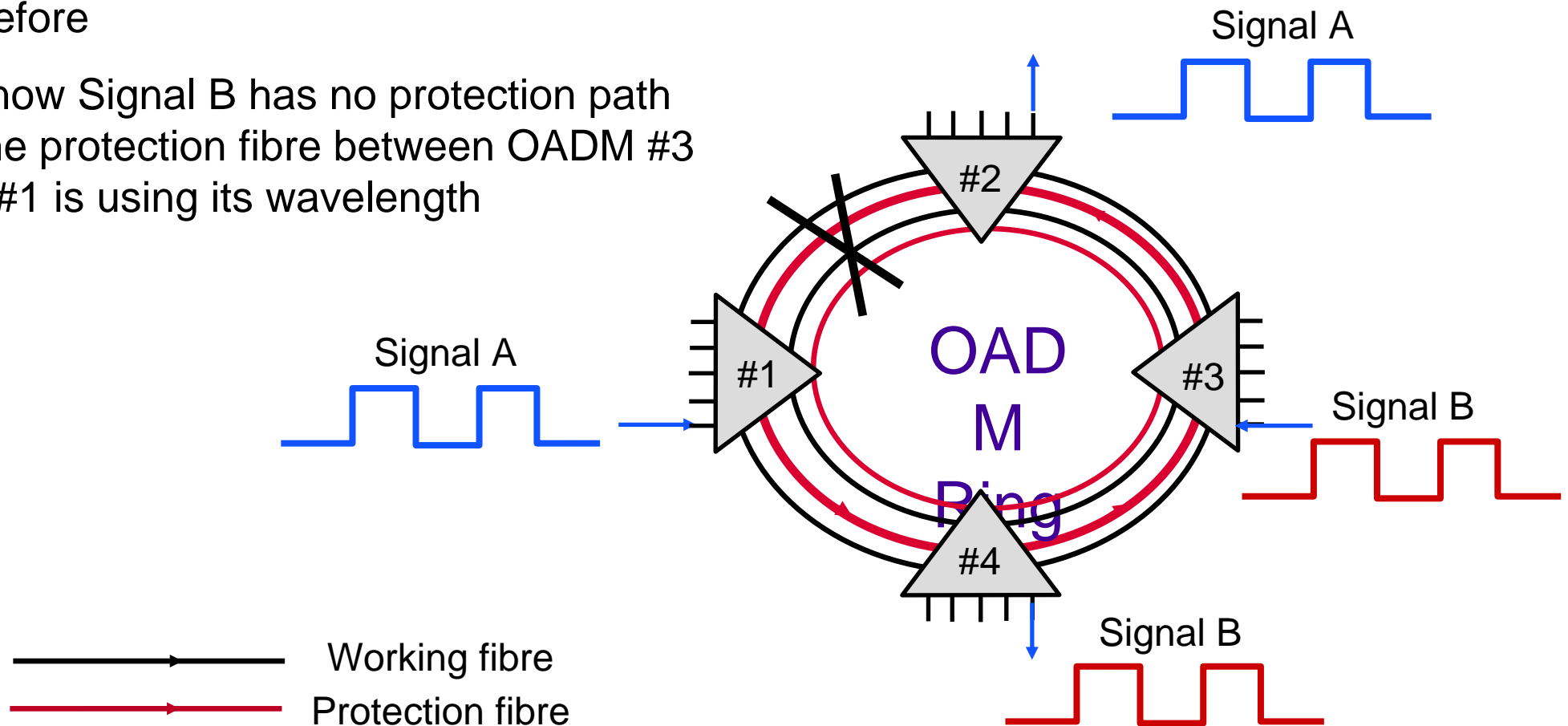
- Same wavelength is used twice:
  - Signal A uses node #1 to #2
  - Signal B uses node #3 to #4
- No problem in the no fault state





# Wavelength Reuse Issues (II)

- Assume a cable fault between OADM #1 and #2
- Signal is re-routed via OADM #4 and #3 as before
- But now Signal B has no protection path as the protection fibre between OADM #3 and #1 is using its wavelength





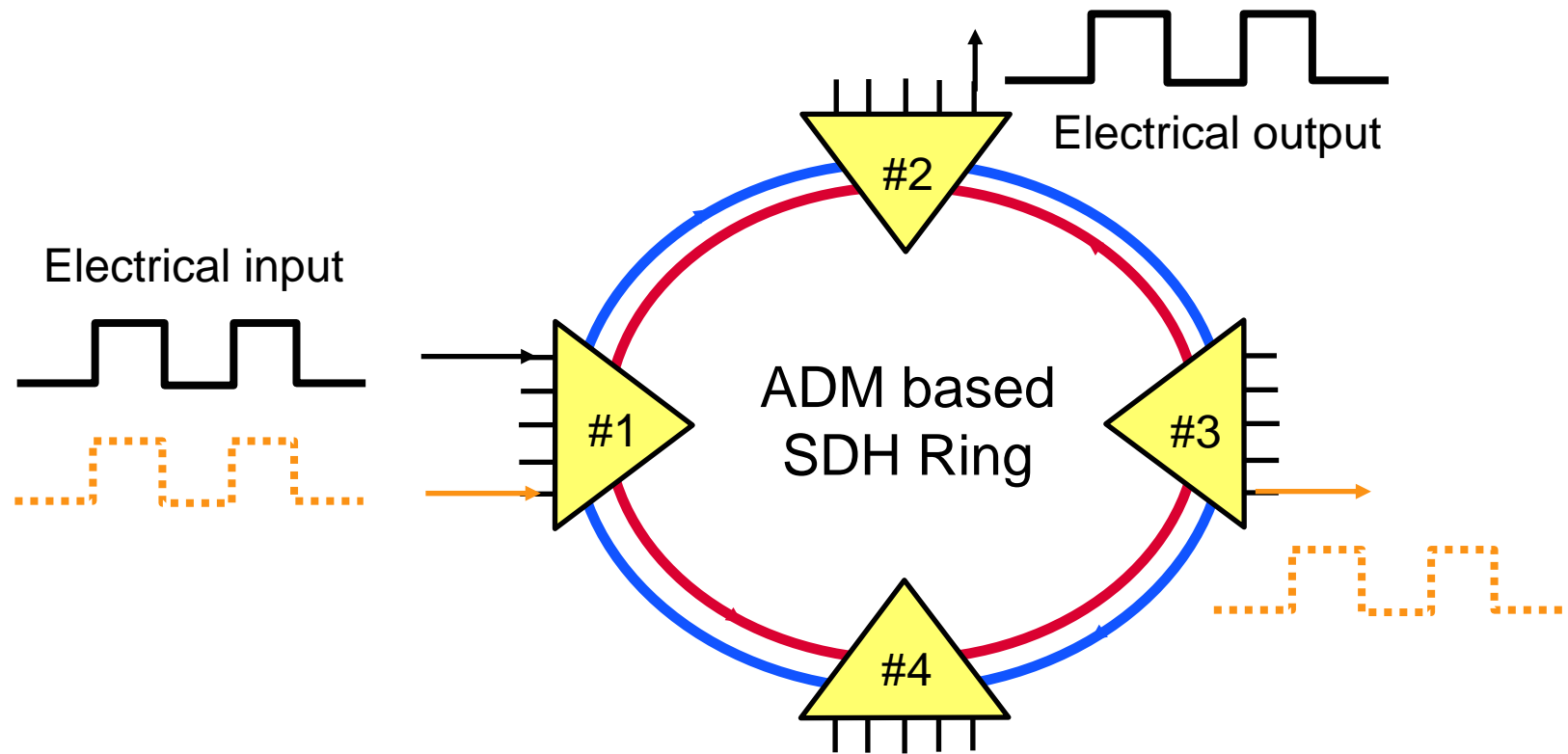
# Signal Quality Issues in OADM Rings

- Maintaining signal quality is a key issue, even without protection switching
- Protection switching makes signal quality even more difficult
- In SDH rings full regeneration takes place at ADMs but in an OADM this not so
- An optical wavelength transporting an SDH STM-N may pass through a number of amplifiers, fibre segments etc..
- Signal may progressively deteriorate due to amplifier noise, crosstalk, dispersion etc..



# Signal Quality on Conventional SDH ADM Rings

- In SDH rings full regeneration takes place
- Noise is completely removed at each ADM
- Quality of signal is independent of number of ADMs traversed

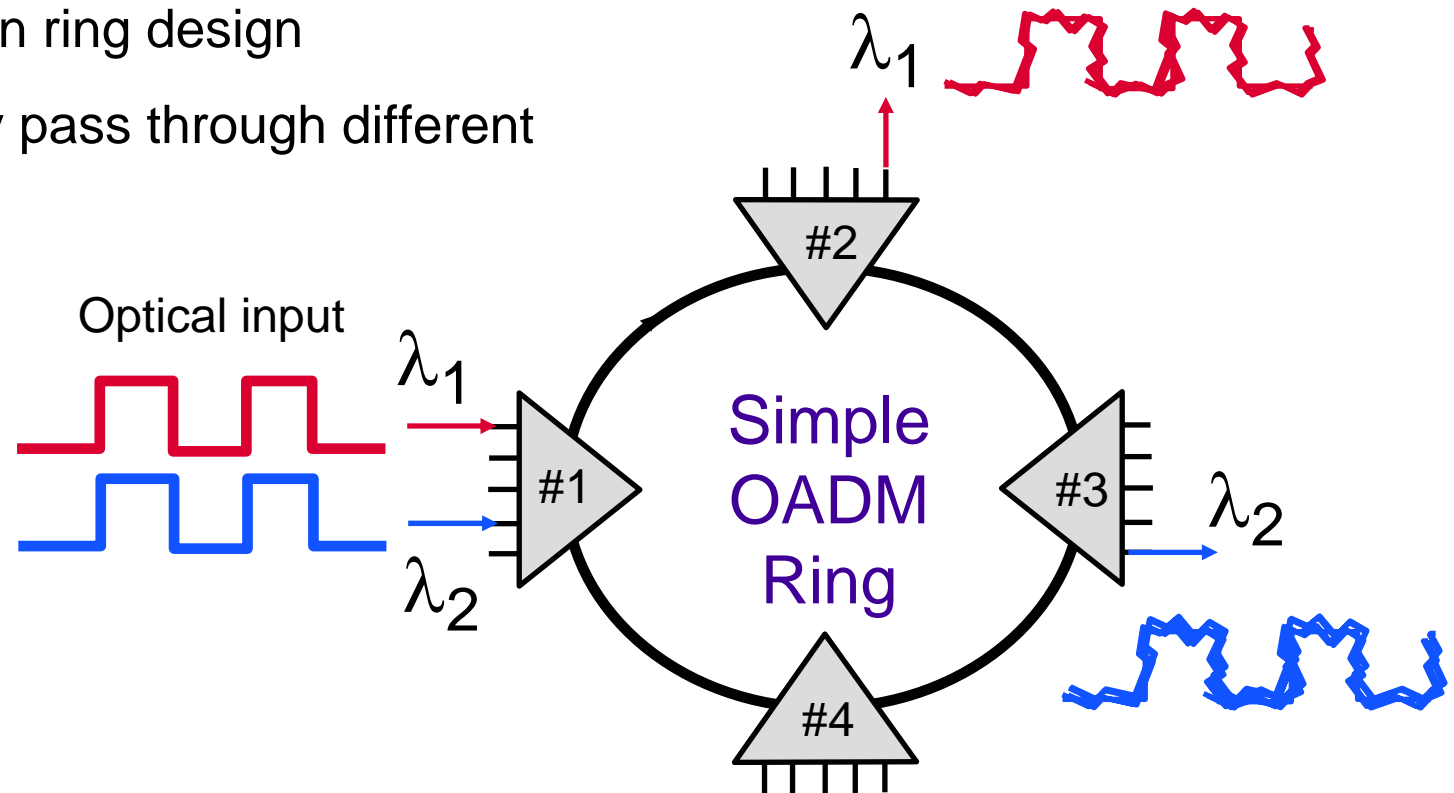




# Signal Quality on All-Optical OADM Rings

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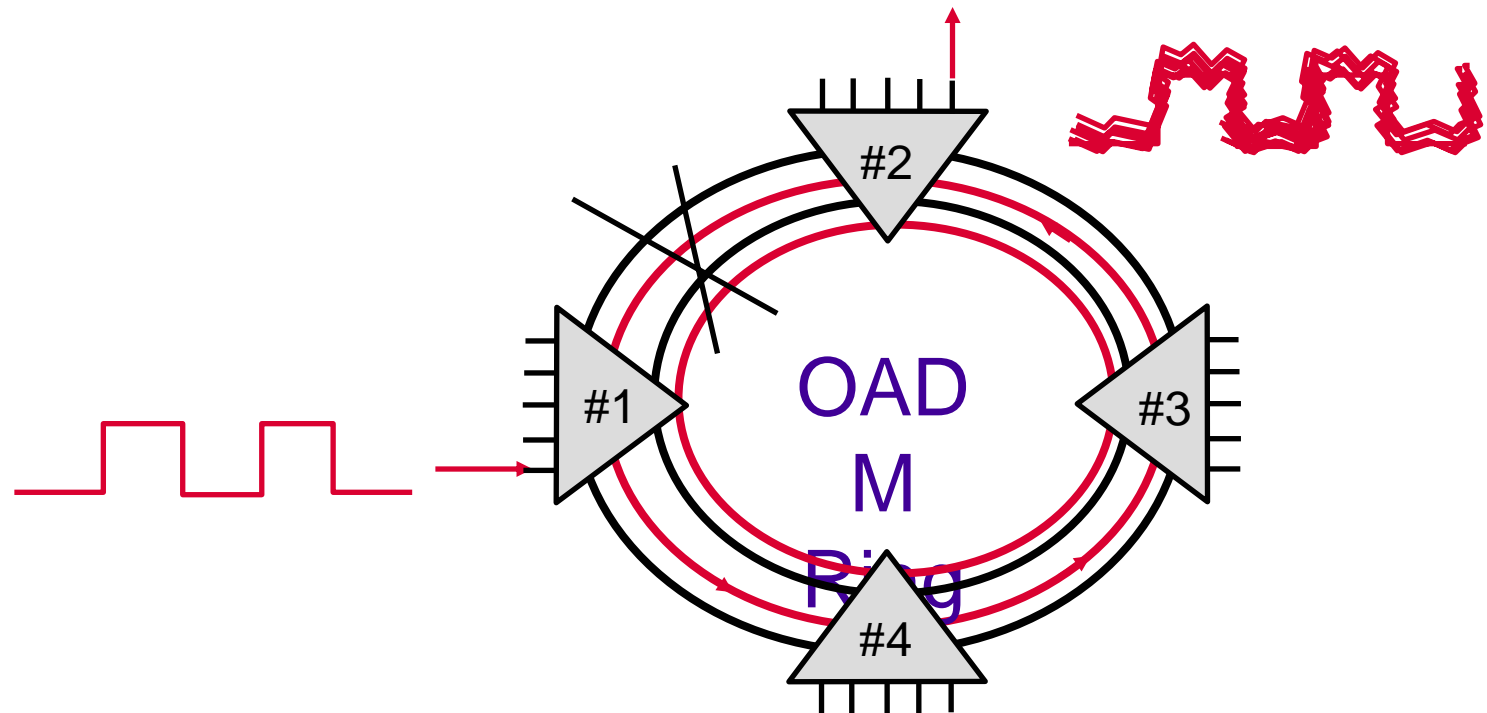
- Noise is added by amplifiers etc., both in-line and at OADMs
- Optical signal-to-noise ratio (OSNR) degrades as does the signal shape
- Must be taken account of in ring design
- Different wavelengths may pass through different numbers of OADMs





# Protection Switching and Noise

- Say we use a 4 fibre bidirectional ring for protection
- In the event of a *Cable* fault signal is routed over a larger number of OADMs than expected
- Signal degradation increases: may mean that some protection paths are **unworkable** as OSNR degrades too much





- **Optical networks are close to realisation**
- **Routing and switching technologies need to be improved**
- **Several WDM based optical network topologies proposed**
- **By 2010 it is estimated that most Telecoms networks will have moved to an optical core**



# Greater Availability of Optical Processing Elements

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**Fixed  $\lambda$  Transmitter  
Receiver  
Fibre joints**

**Tunable  $\lambda$  Transmitters  
Receivers  
Fibre joints  
Optical Amplifiers  
AWG Mux/Demux  
Controllable attenuators  
Dispersion Compensation  
Simple Optical Switching  
Optical Filters  
Equalizers  
Isolators  
Couplers & splitters**

**1992**

**1998**

**2004**

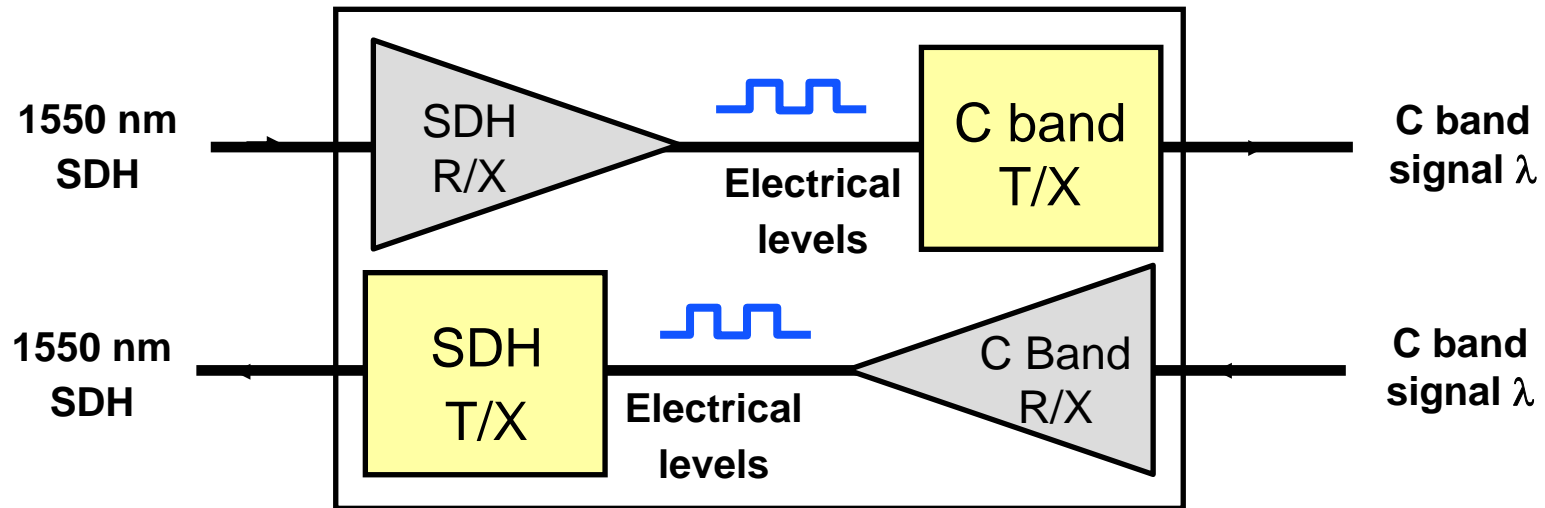




# All-Optical Wavelength Conversion



# Current DWDM Wavelength Convertors (Transponders)



- Transponders are frequently formed by two transceivers back-to-back
- So called Optical-Electrical-Optical (OEO) transponders
- Expensive solution at present
- True all-optical transponders without OEO needed





# Approaches to Wavelength Conversion

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## Requirements:

- Must preserve digital content, low BER penalty
- Must be agile, tunable, (band or individual wavelength possible)

### Highly non-linear fibre with a four wave mixer (Fujitsu)

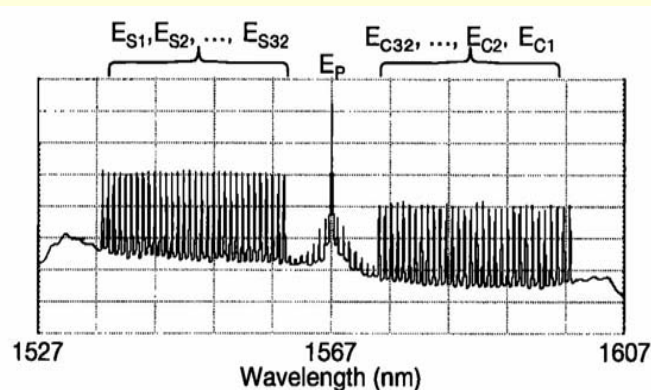
32 x 10 Gb/s DWDM

Converted band:

1535.8 -1560.6 nm

to

1599.4 - 1573.4 nm



### Cross-polarization modulation in a semiconductor optical amplifier (COBRA, NL)

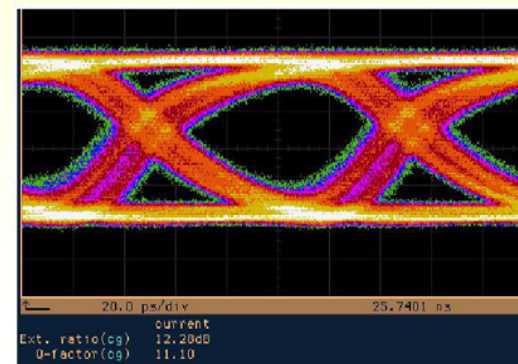
1 x 10 Gb/s DWDM

Converted single  $\lambda$

1550.92 nm

to

1552.52 nm

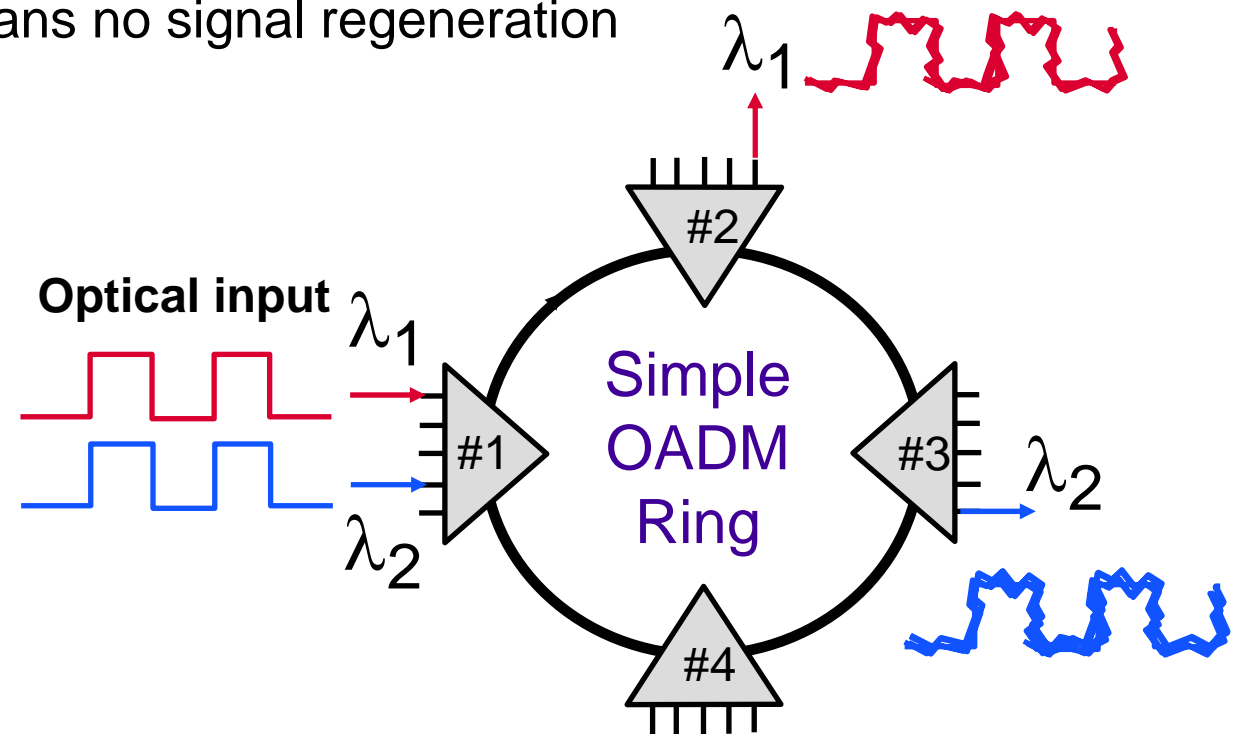




# Downsides of Present forms of Optical Processing

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- Optical processing is taking place in a time frame  $\gg$  a bit interval.
- This has several disadvantages:
  - No access to digital overhead as in SDH/Sonet ADM
  - Difficult to detect and isolate signal degradation
  - May involve separate out-of-band signaling channel
- Finally as we have no OEO this means no signal regeneration
  - Build-up of noise and crosstalk
  - "Analog transmission" problems





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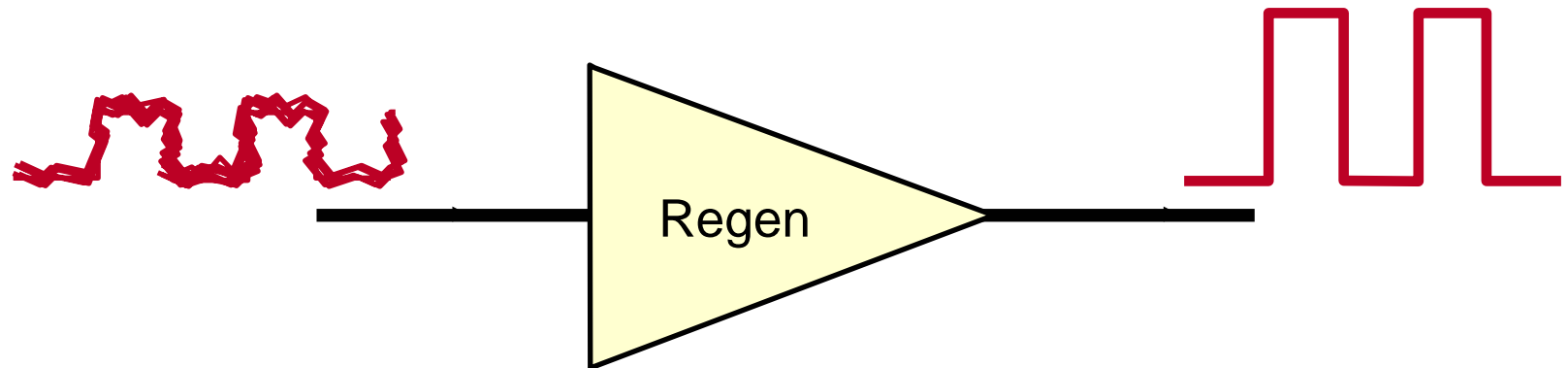
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# All-Optical Regeneration



# All-Optical Regeneration

- We will need to get beyond the speed limitations of electronics, eg. 160 Gbits/sec +
- This mean all-optical solutions operating at speeds comparable to bit level time
- Basic function is regeneration and optical clock extraction
- Allows us to avoid OEO, while still regenerating bits
- Regeneration actually involves three sub-functions (so called 3R)
  - All-optical clock extraction
  - Decision/threshold
  - Regeneration using simple optical logic

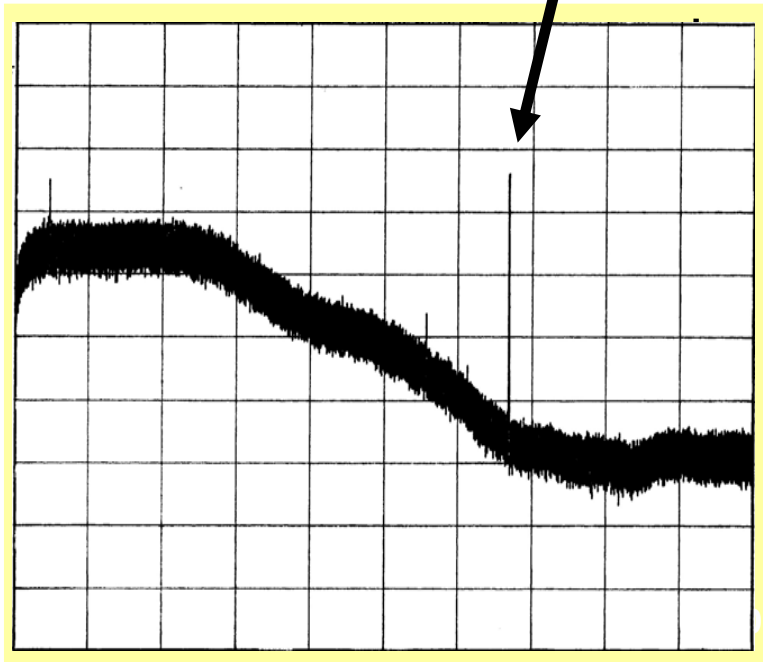




# All-Optical Clock Extraction with Division (TCD/DIT)

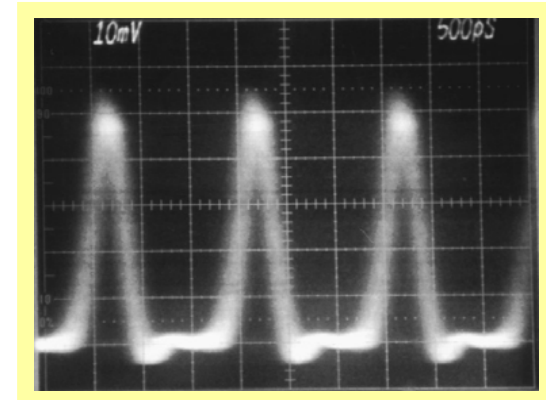
- Active research topic in many labs
- All-optical clock extraction demonstrated with Nortel
- Uses twin section self-pulsating laser

**678 MHz Clock Component**

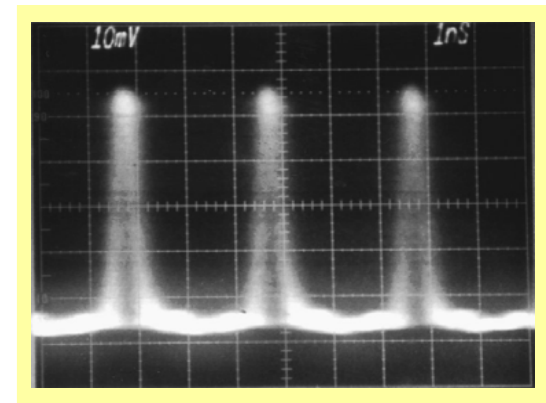


**Spectrum of 678 Mbit/s data**

Demonstrated with Northern Telecom



**Extracted clock 678 MHz**



**Extracted and divided  
clock at 339 MHz**



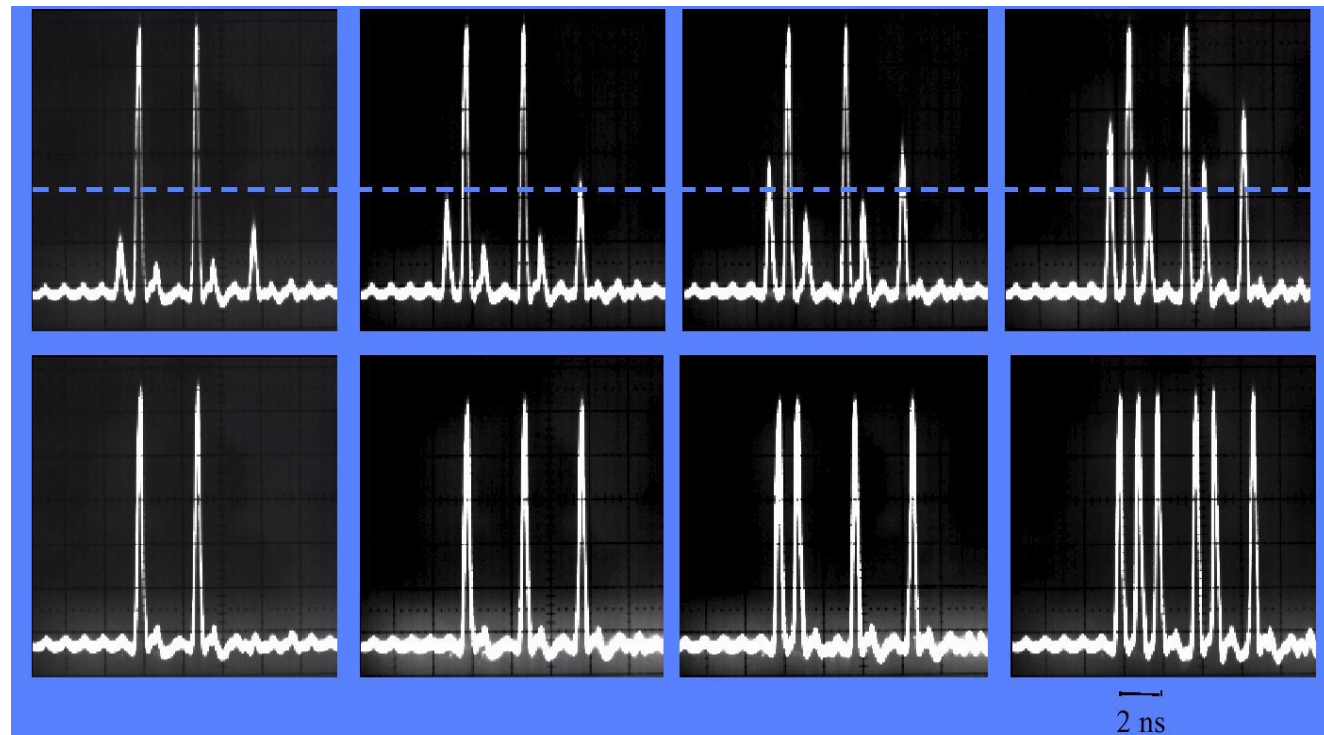
# Threshold System

- One current approach uses a Semiconductor Optical Amplifier (SOA)
- 40 Gbits/Sec demonstrated to date
- Other approaches involved fibre lasers, very fast

*Amplitude  
restoration of  
pulses with a  
threshold  
(BT Labs and  
Aston  
University)*

**Input**

**Output**



**Threshold**