Optical DWDM Networks

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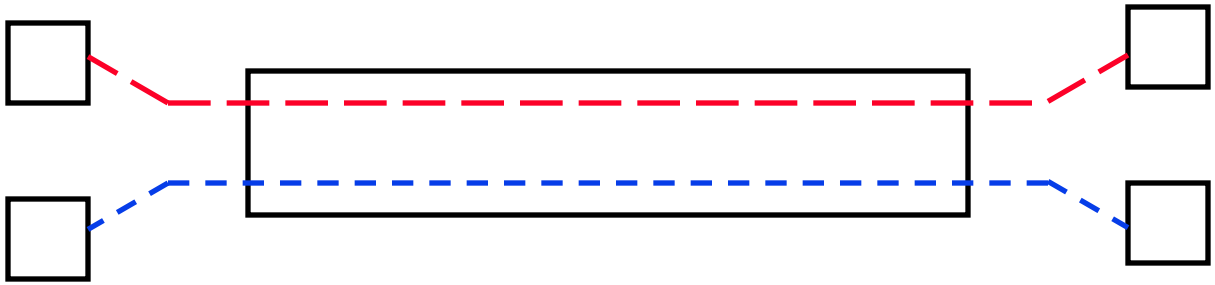
Overview

- Sparse and Dense WDM
- Recent WDM Records
- WDM Applications and Sample Products
- Key Technologies
- Types of Fibers
- Amplifiers
- Upcoming Technologies

Sparse and Dense WDM



- 10Base-F uses 850 nm
- 100Base-FX uses 1310 nm
- Some telecommunication lines use 1550 nm
- WDM: 850nm + 1310nm or 1310nm + 1550nm
- Dense ⇒ Closely spaced ≈ 1nm separation

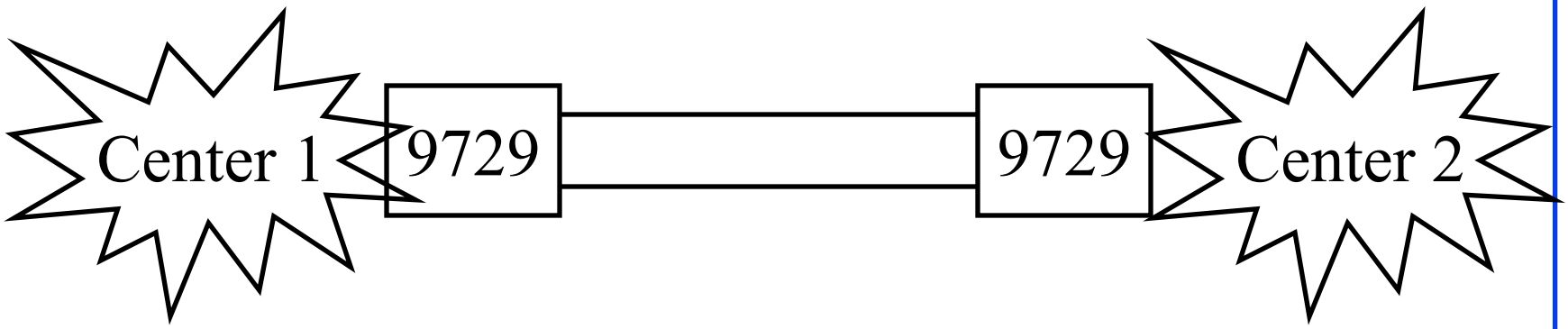
Recent WDM Records

- 40 Gbps over a single wavelength upto 65 km demonstrated by Alcatel in Summer of 1998. Modulation gave 20 GHz at 3-dB point. The distance limitation was due to PMD.
- 2.64 Tbps to 120km (NEC'96): 132 λ × 20 Gbps
- 1.4 Tbps 600 km (NTT'97): 70 λ × 20 Gbps
- 1 Tbps 400 km (Lucent 97): 100 λ × 10 Gbps using TrueWave Fiber
- 320 Gbps 7200 km (Lucent 97): 64 λ × 5 Gbps

WDM Applications

- WANs: Fiber links ⇒ WDM ⇒ DWDM Links
- Undersea Links: Amplifiers ⇒ High maintenance cost ⇒ Can't put too many fibers
- DWDM highly successful in long-haul market.
- Not yet cost-competitive in metro market.
- Bandwidth demand is low and more dynamic.

Sample Products



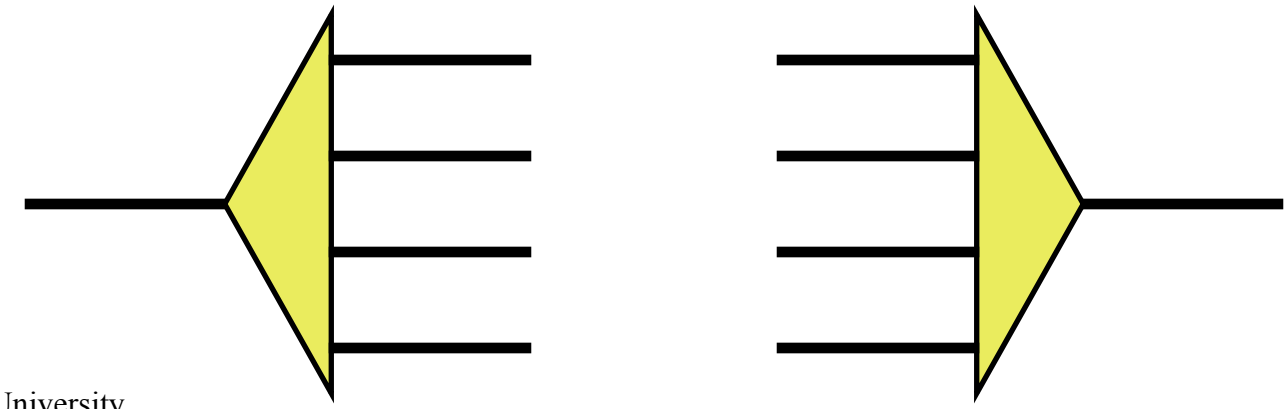
- 1994: IBM 9729. First commercial system.
- Allows 10 full-duplex channels in one fiber upto 50 kms. Designed to connect large mainframe datacenters.
- Channel spacing is 1 nm
- Distance limited to 50km to avoid amplifiers.

Products (Cont)

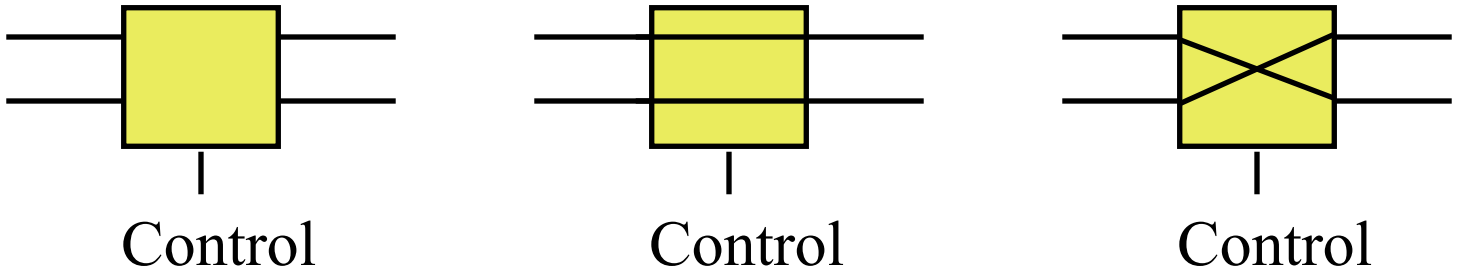
- Lucents's WaveStar product allows 400 Gbps over a single fiber using 80 channel DWDM (January 1998)
- Lucent's LazrSPEED allows 10 Gb/s up to 300 on LazrSPEED multimode fibers using low cast short-wavelength (850nm) vertical cavity surface-emitting laser (VCSEL) transceivers. Demoed at May 99 Interop.
- Monterey make wavelength routers that allow mesh architecture and use OSPF or PNNI like routing.

Key Technologies

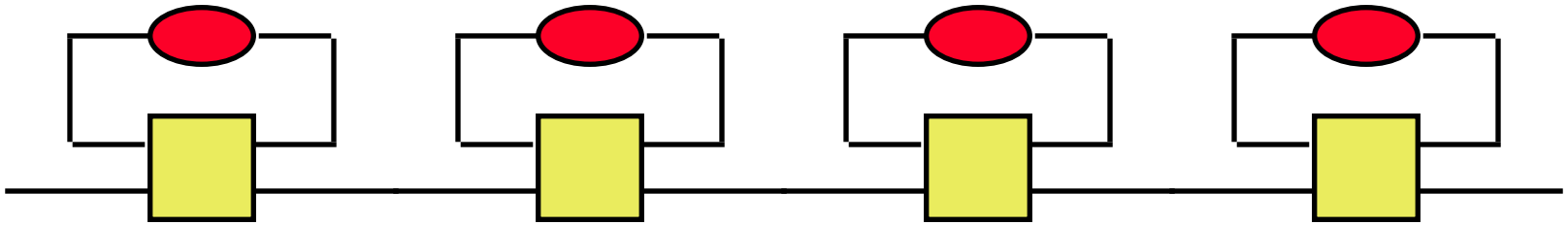
- Tunable Lasers
- Fast tuning receivers
- Frequency converters
- Amplifiers
- Splitters, Combiners



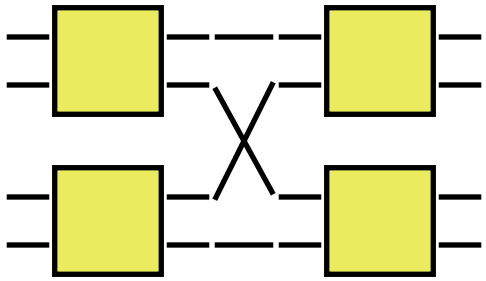
Directional Couplers



- Can be used in bus networks:

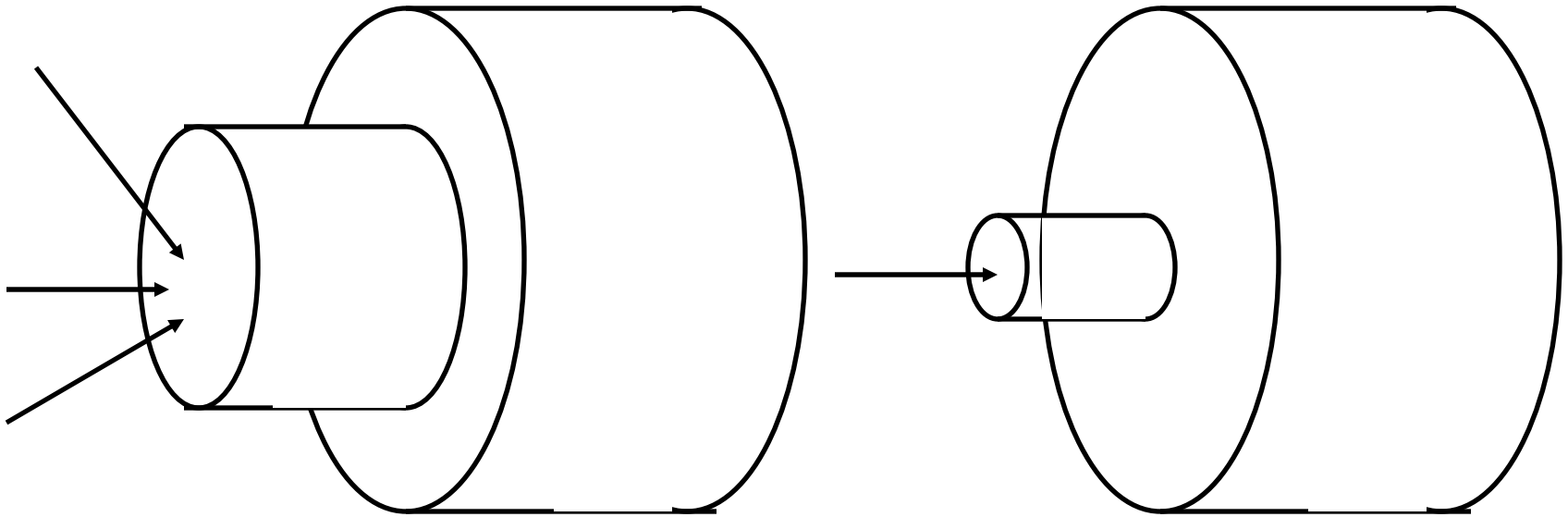


- Larger switches can be built out of 2×2 switches



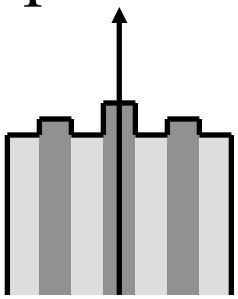
Types of Fibers

- Multimode Fiber: Core Diameter 50 or 62.5 μm
  Wide core ⇒ Several rays (mode) enter the fiber
  Each mode travels a different distance
- Single Mode Fiber: 10-mm core. Lower dispersion.

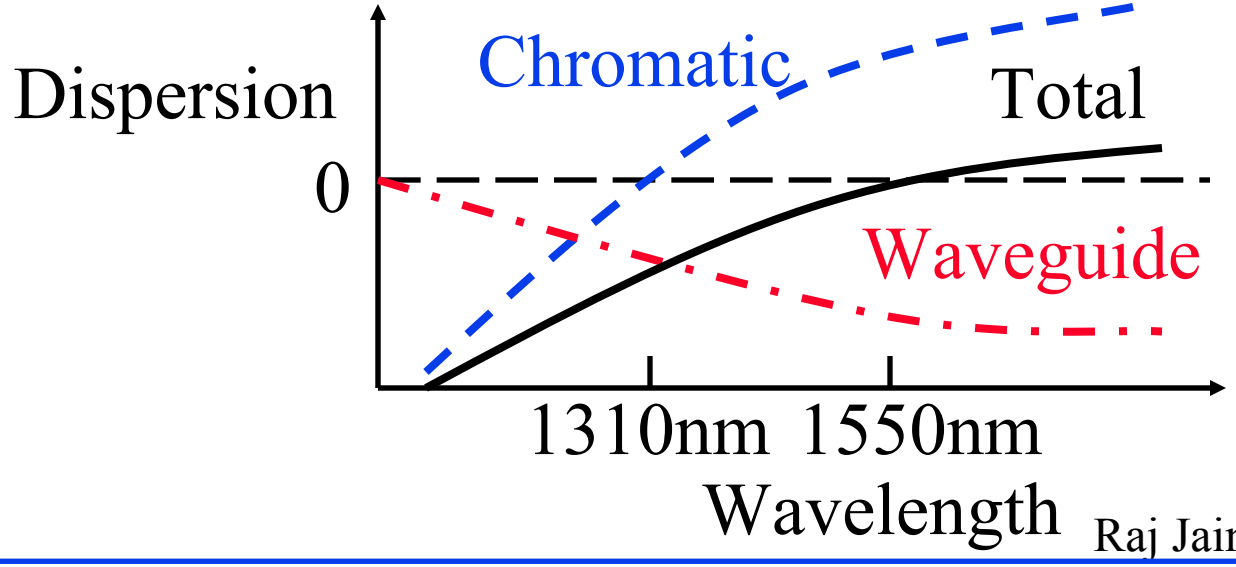


Dispersion Shifted Fiber

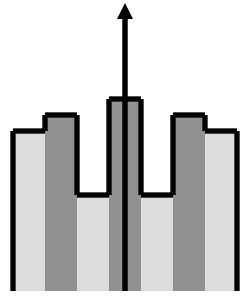
- Zero dispersion at 1310nm
- 1550 nm has a lower attenuation
- EDFAs operate at 1550 nm ⇒ DWDM systems at 1550 nm
- Special core profile ⇒ zero dispersion at 1550 nm



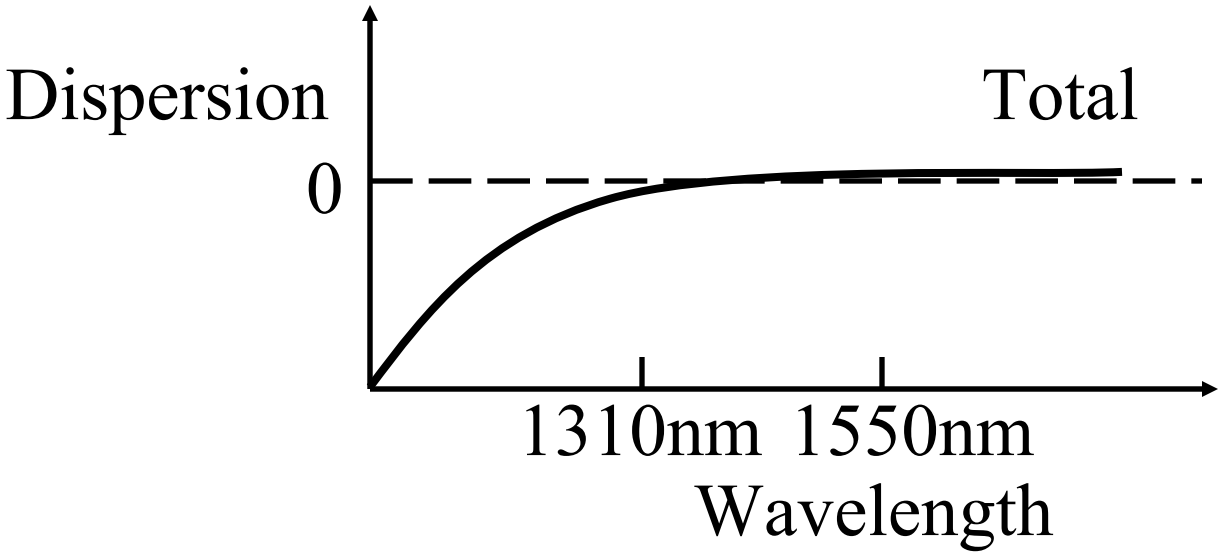
Dispersion Shifted



Dispersion Flattened Fiber

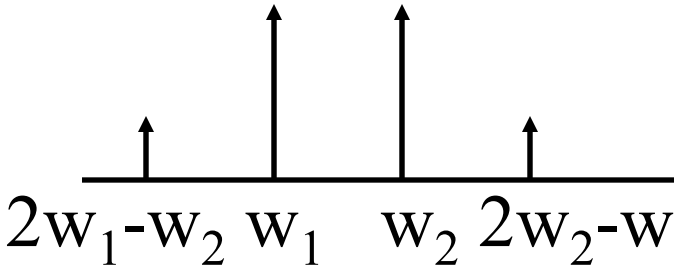


Dispersion Flattened



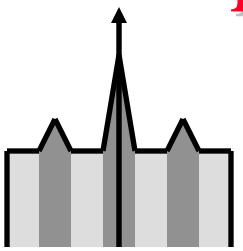
- Less than 3 ps/nm/km over 1300-1700 nm
- Use 1300 nm now and 1550 in future
- Low dispersion causes four-way mixing
  $\Rightarrow$ DSF/DFF not used in DWDM systems

Four-way Mixing (FWM)



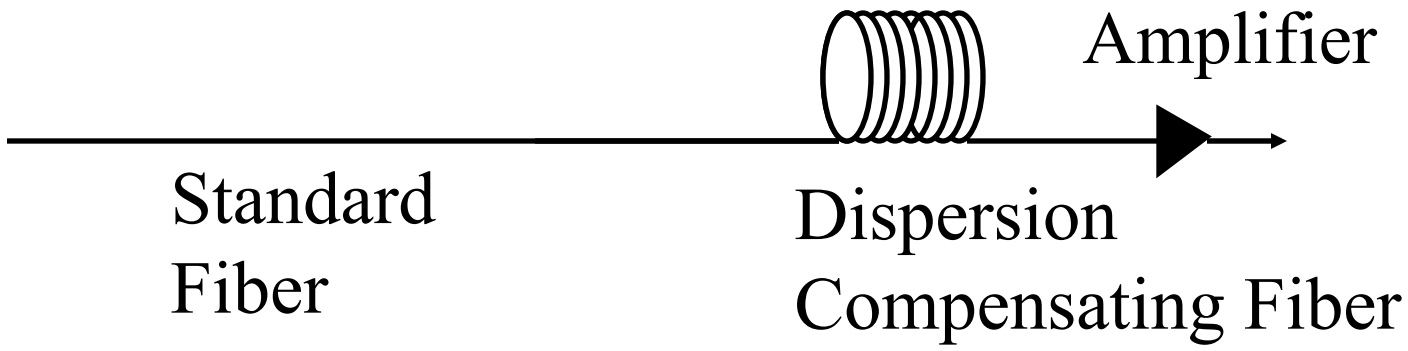
- Caused when multiple wavelengths travel in the same phase for long time
- New signals are generated at the same frequency spacing as original: $w_1, w_2 \Rightarrow 2w_2-w_1, 2w_1-w_2$
- Closer channels $\Rightarrow$ More FWM
- More power $\Rightarrow$ More FWM
- Less dispersion $\Rightarrow$ More time same phase $\Rightarrow$ More FWM

Dispersion Optimized Fiber



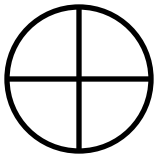
- Non-zero dispersion shifted fiber (NZ-DSF)
  $\Rightarrow$ 4 ps/nm/km near 1530-1570nm band
- Avoids four-way mixing
- Different vendors have different characteristics:
- Tru-Wave from Lucent. SFM-LS from Corning
- Dispersion shifting reduces the effective area of core
  $\Rightarrow$ increases power density $\Rightarrow$ More non-linearity
- Large effective area fibers (LEAF) from Corning:
  DOF with larger effective area

Dispersion Compensating Fiber



- Standard fiber has 17 ps/nm/km
- DCF has -100 ps/nm/km
- 100 km of standard fiber followed by 17 km of DCF ⇒ zero dispersion
- DCF has much narrower core ⇒ More attenuation and non-linearity ⇒ Need to amplify

Polarization Mode Dispersion



- Each light pulse consists of two orthogonally polarized pulses.
- These polarizations experience different delays through the fiber.
- Polarization Mode Dispersion (PMD) limits distances to square of the bit rate
  $\Rightarrow$ OC-192 to 1/16th of OC-48, OC-768 to 1/256th.
- Need Regenerators to compensate for PMD
  $\Rightarrow$ Expensive
  $\Rightarrow$ Most DWDM systems operate at OC-48

Plastic Fiber

- Original fiber (1955) was plastic (organic polymer core rather than glass)
- 980μ core of PolyMethylMethyelAcrylate (PMMA)
- Large Dia ⇒ Easy to connectorise, cheap installation
- Higher attenuation and Lower bandwidth than multimode fiber
- Can use 570-650 nm (visible light) LEDs and lasers (Laser pointers produce 650 nm)
- OK for short distance applications and home use
- Cheaper Devices: Plastic amplifiers, Plaster wave guide grafting routers, plastic lasers

Hard Polymer Clad Silica Fiber

- 200 micron glass core ⇒ Easy to join
- Uses same wave length (650nm) as plastic fiber
- Lower attenuation and lower dispersion than plastic fiber
- 155 Mbps ATMF PHY spec for plastic and HPCF up to 100m.

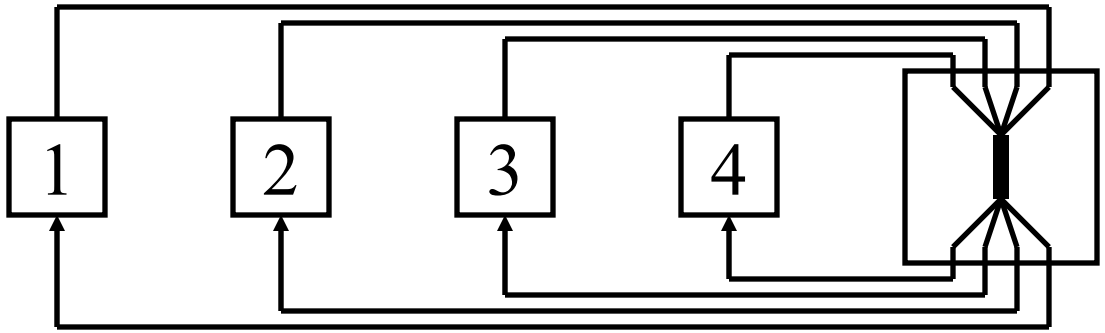
Amplifiers

- Erbium-Doped Fiber Amplifiers (EDFAs)
- Flat response in 1535-1560 nm
  Can be expanded to 40 nm width
- Dynamic Non-linearity: Response changes if one channel is not used ⇒ problem as channels are dropped and added
- Causes rapid transient power fluctuations if there are multiple EDFAs in a link

Upcoming Technologies

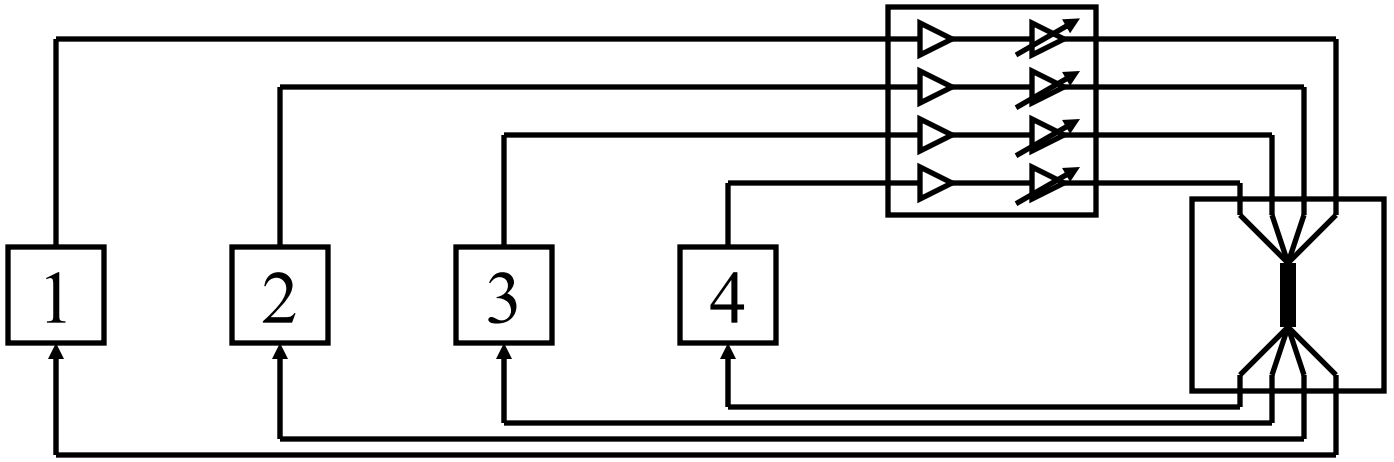
- Simple Optical Networks: Wavelength add-drop, broadcast and select
- Wavelength Routed Networks: One wavelength end-to-end
- Optically Switched Networks: Wavelength routing with conversion
- Optical Time Domain Multiplexing (OTDM): SONET-like synchronous connections
- Optical Packet Switching: Need optical logic

Broadcast and Select Networks



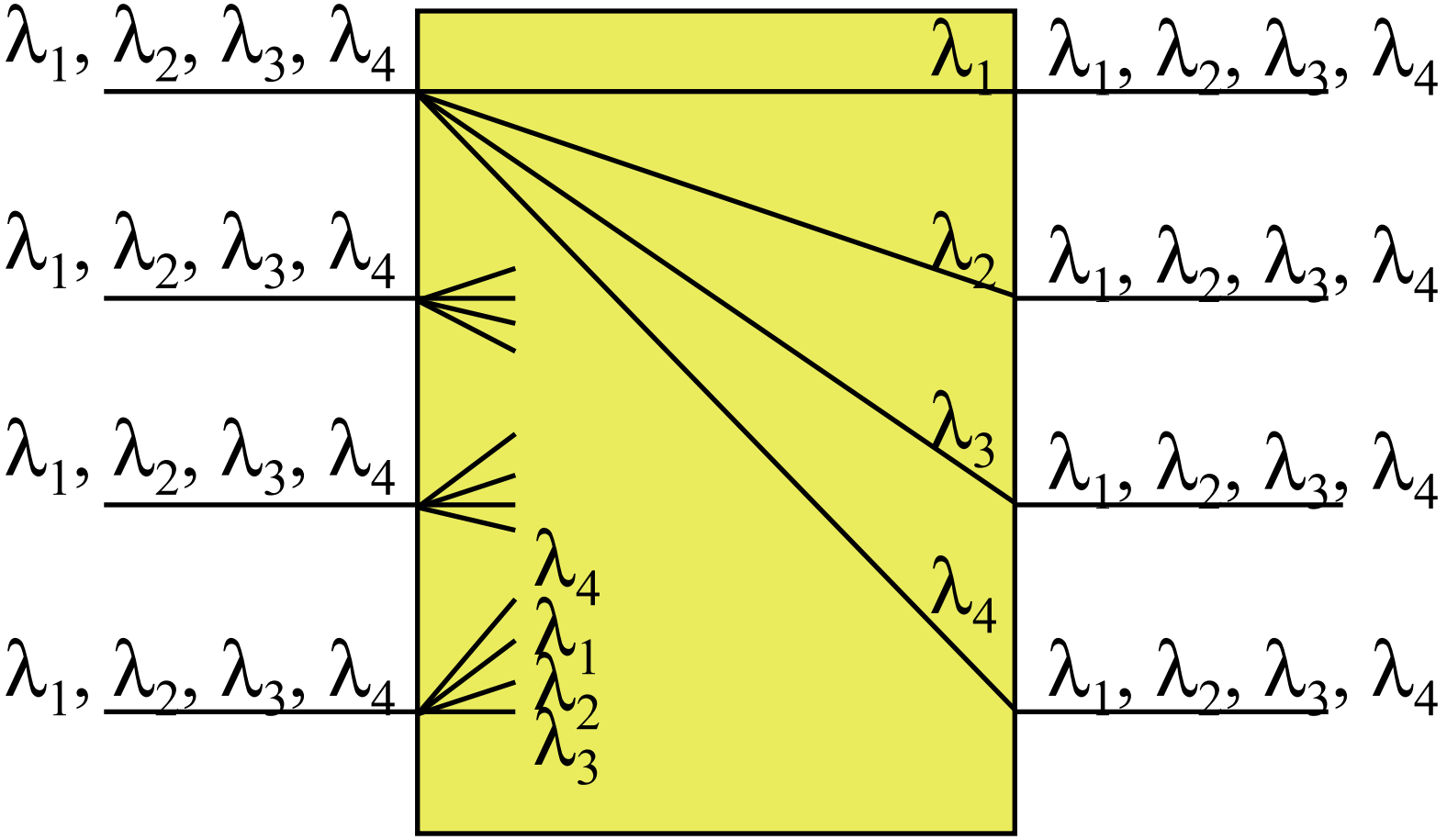
- Early 1990 used in LANs, e.g., Rainbow-1
- Propagation delays ⇒ Limited to LANs
- Non-tunable transmitters and receivers
  Tunable transmitters □ Space division switch
  Tunable receivers □ □Allows multicasts
  Both tunable □ □Allows more nodes than λs
- Broadcast □ Power wasted
  □ Amplifiers just before the receiver filter

Centralized WDM Switch



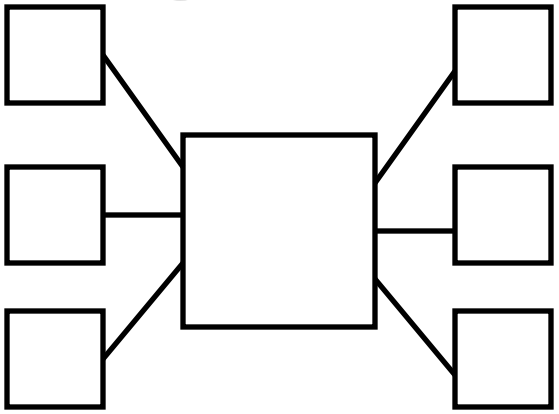
- Tunable components moved to a central switch
- Each station has a preassigned receive wavelength
- Switch converts the signal to receiver wavelength

Wavelength Router



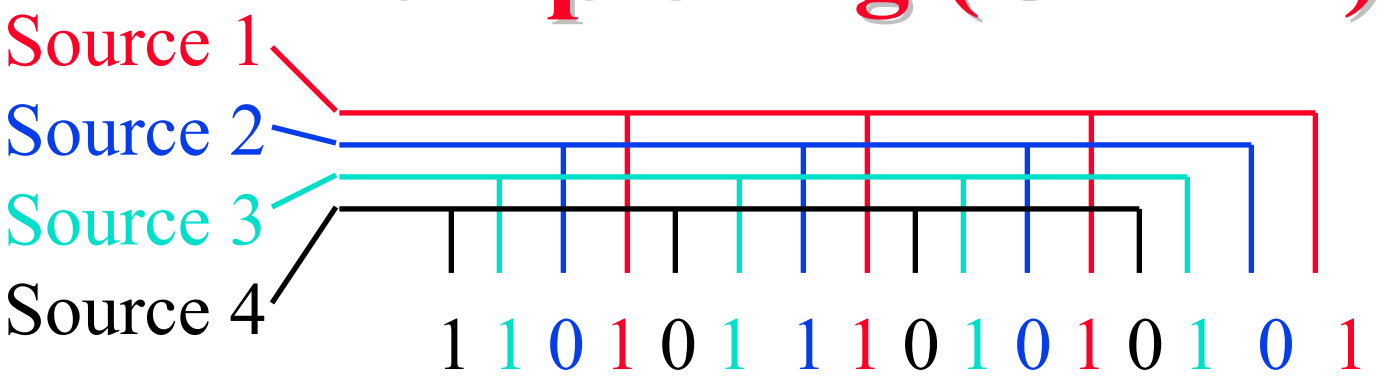
- Router = Crossconnect with wavelength conversion

Wavelength Routed Networks



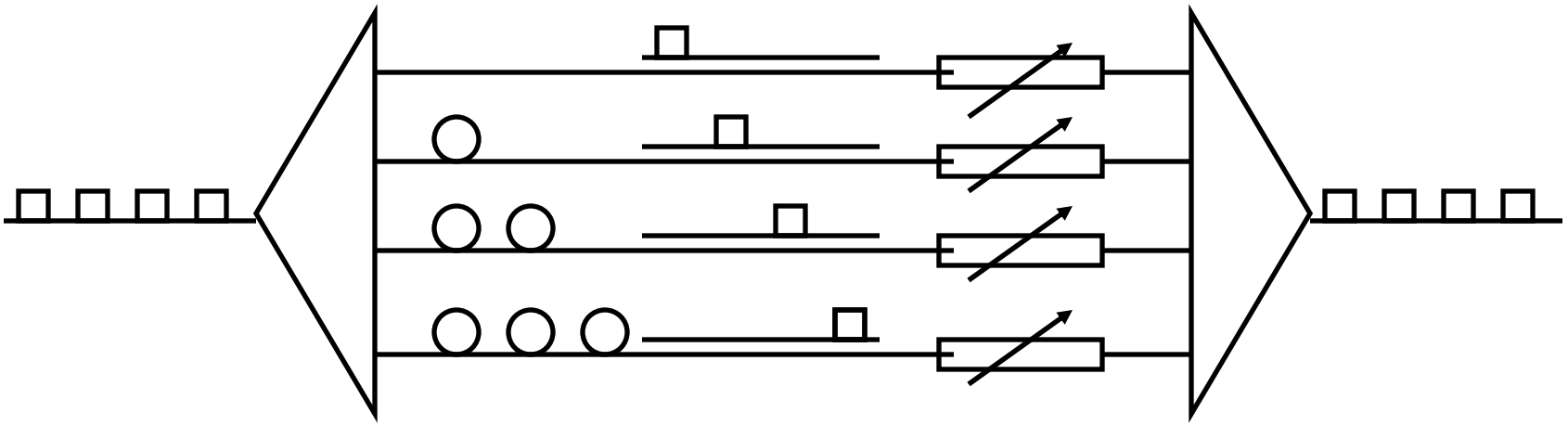
- Either transmitters, receivers, or both tunable.
- Switches are programmable.
- Signaling channel could be electronic or optical
- Wavelength collisions ⇒ Suitable for medium size networks.
- Wavelength converters help avoid wavelength collisions

Optical Time Division Multiplexing (OTDM)



- Optics faster than electronics ⇒ Bit multiplexing.

OTDM Implementation

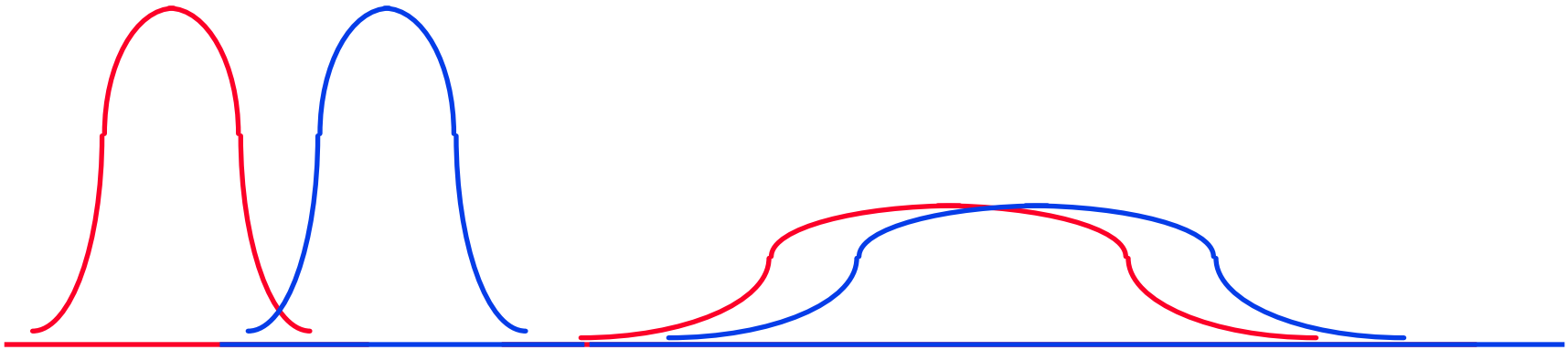


Splitter Delay lines Modulators Combiner

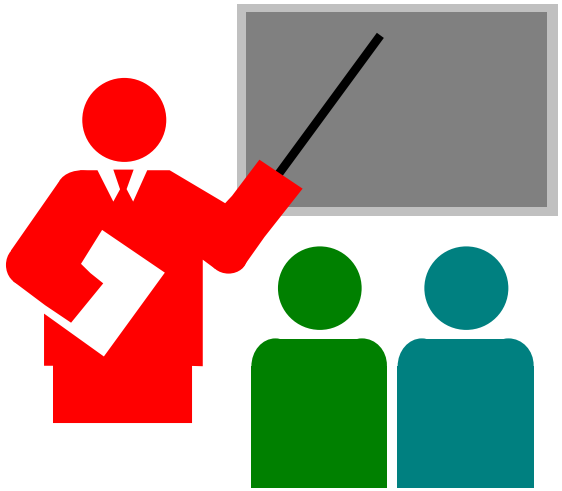
- A laser produces short pulses.
- Pulse stream divided in to 4 substreams
- Each substream modulated by different source
- Substreams combined.

Solitons

- Light velocity is a function of amplitude
  $\Rightarrow$ Index of dispersion is non-linear:
  - $n=n_0 + n_2E^2$, Where, E=field strength
  - No dispersion if the pulse is sech(t)
- Need high amplitude pulses (100 mW) and high non-linearity



Summary



- DWDM allows 32- to 64- channels per fiber
- Several new types of fibers with different dispersion characteristics
- Wavelength routers will allow all-optical networks
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References:

- See references in http://www.cse.ohio-state.edu/~jain/refs/opt_refs.htm
- Recommended books on optical networking, http://www.cse.ohio-state.edu/~jain/opt_book.htm
- Newsgroup: sci.optics.fiber

Organizations

- National Transparent Optical Network Consortium (NTONC) connects San Fransisco and Los Angeles at 10 Gbps. Link is a part of DARPA's SuperNet. NTONC members include Nortel, GST Telecomunications, Lawerence Livermore National Laboratory, and Sprint
- Data Aware Transport Activity (D.A.T.A.) for data over SONET