MULTIPLEXING

Wavelength Division Multiplexing WDM

- Coarse and Dense Multiplexing – (C)(D)WDM

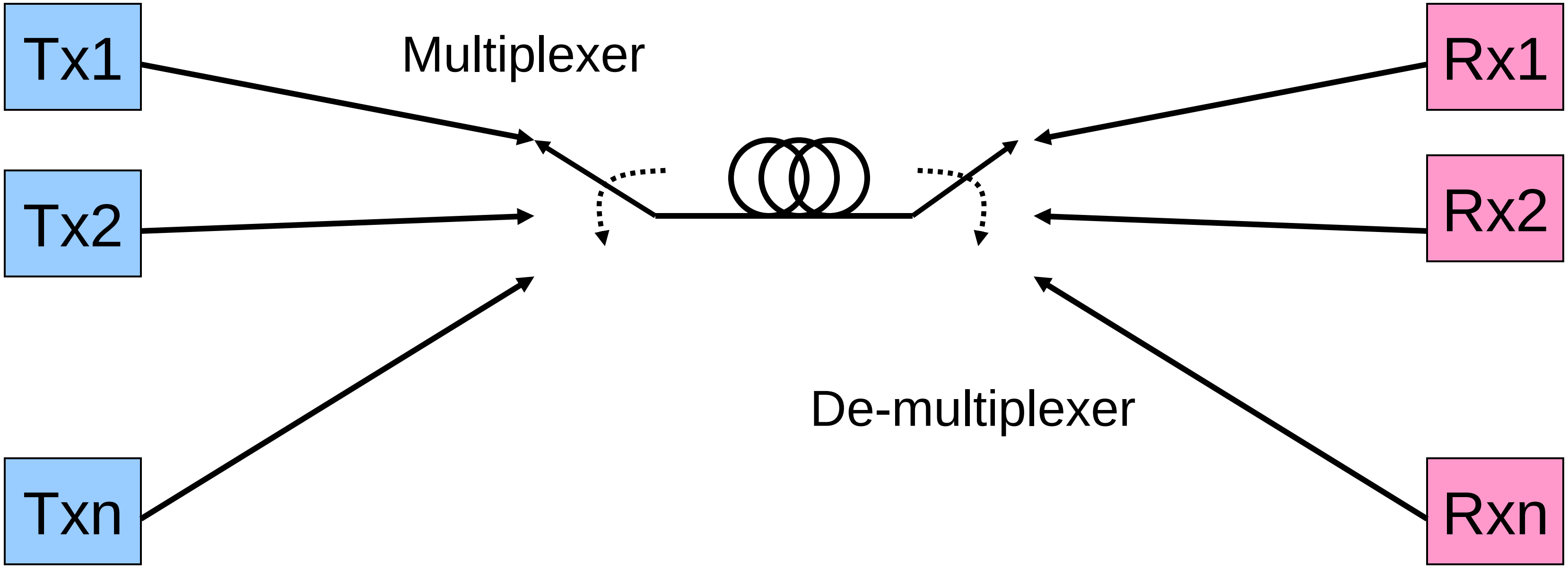
WDM Components (1)

- Wavelength Filters

Multiplexing

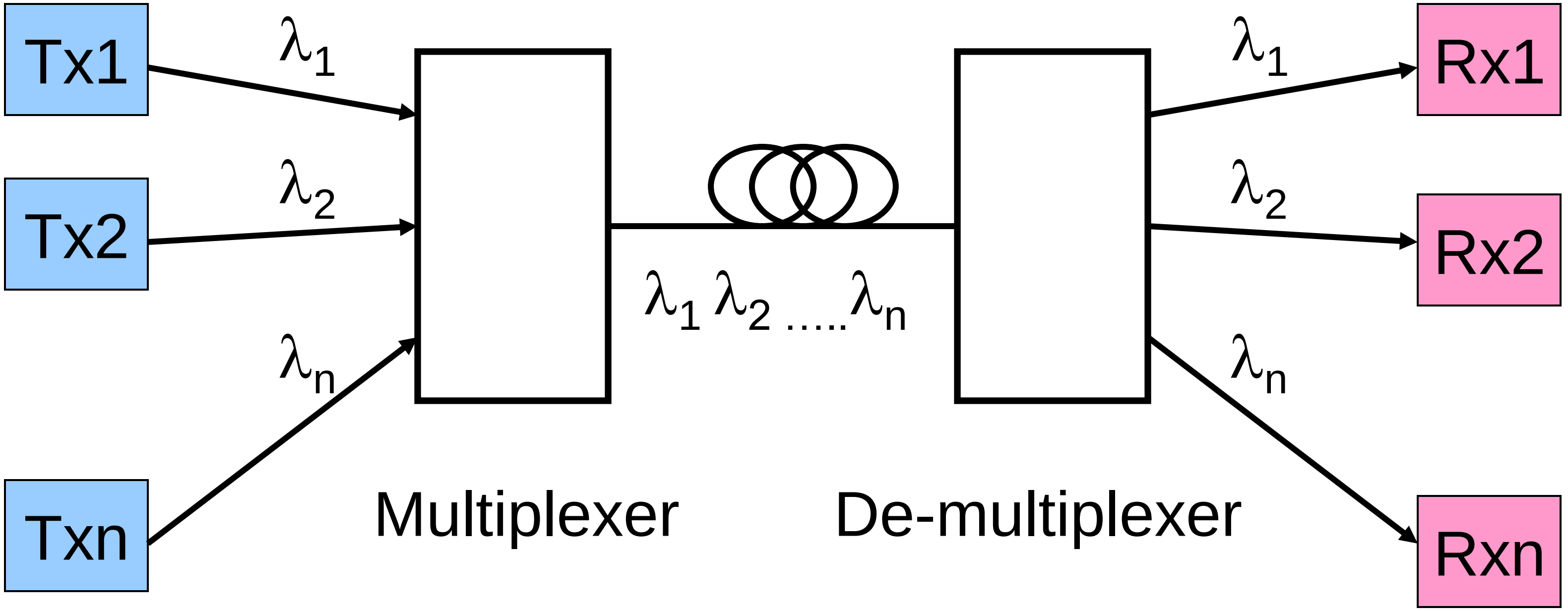
It would be nice to use one cable for many channels!

This is old hat for copper cables – frequency and time division multiplexing



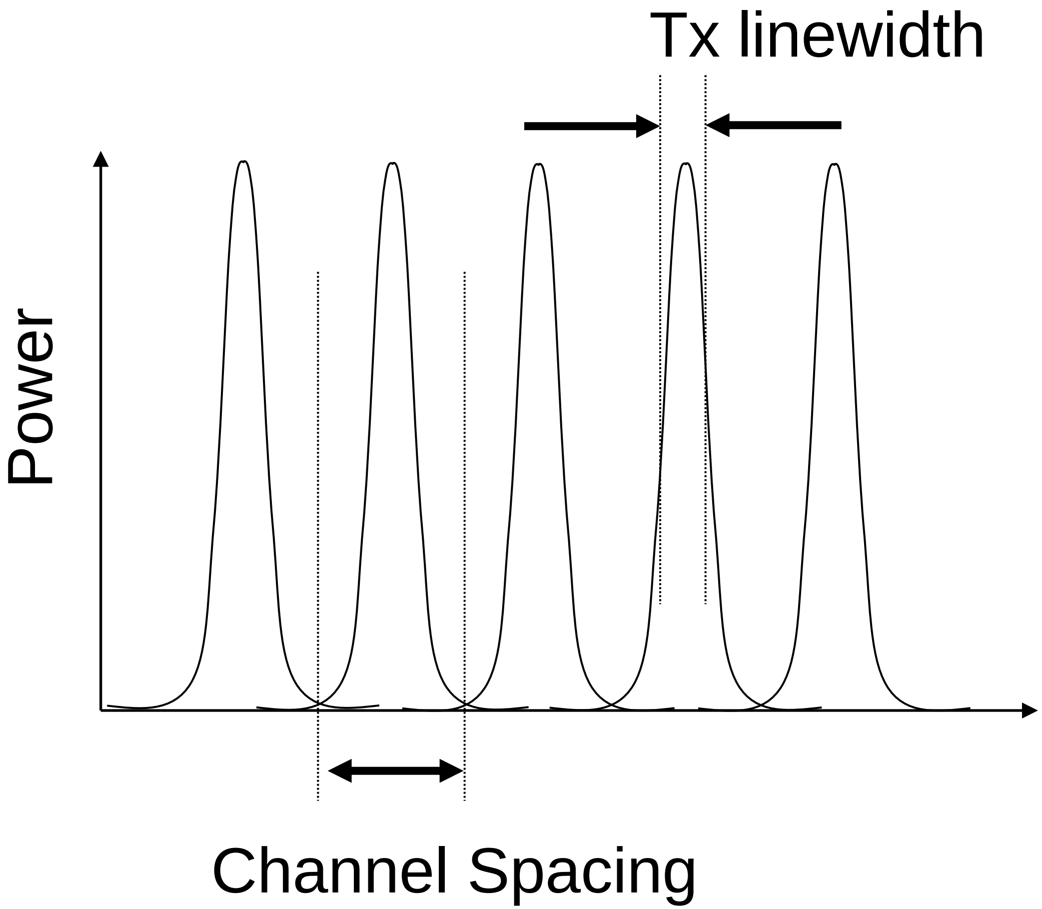
Wavelength Division Multiplexing

WDM – 2 photons of different wavelength can occupy the same space



Wavelength Division Multiplexing

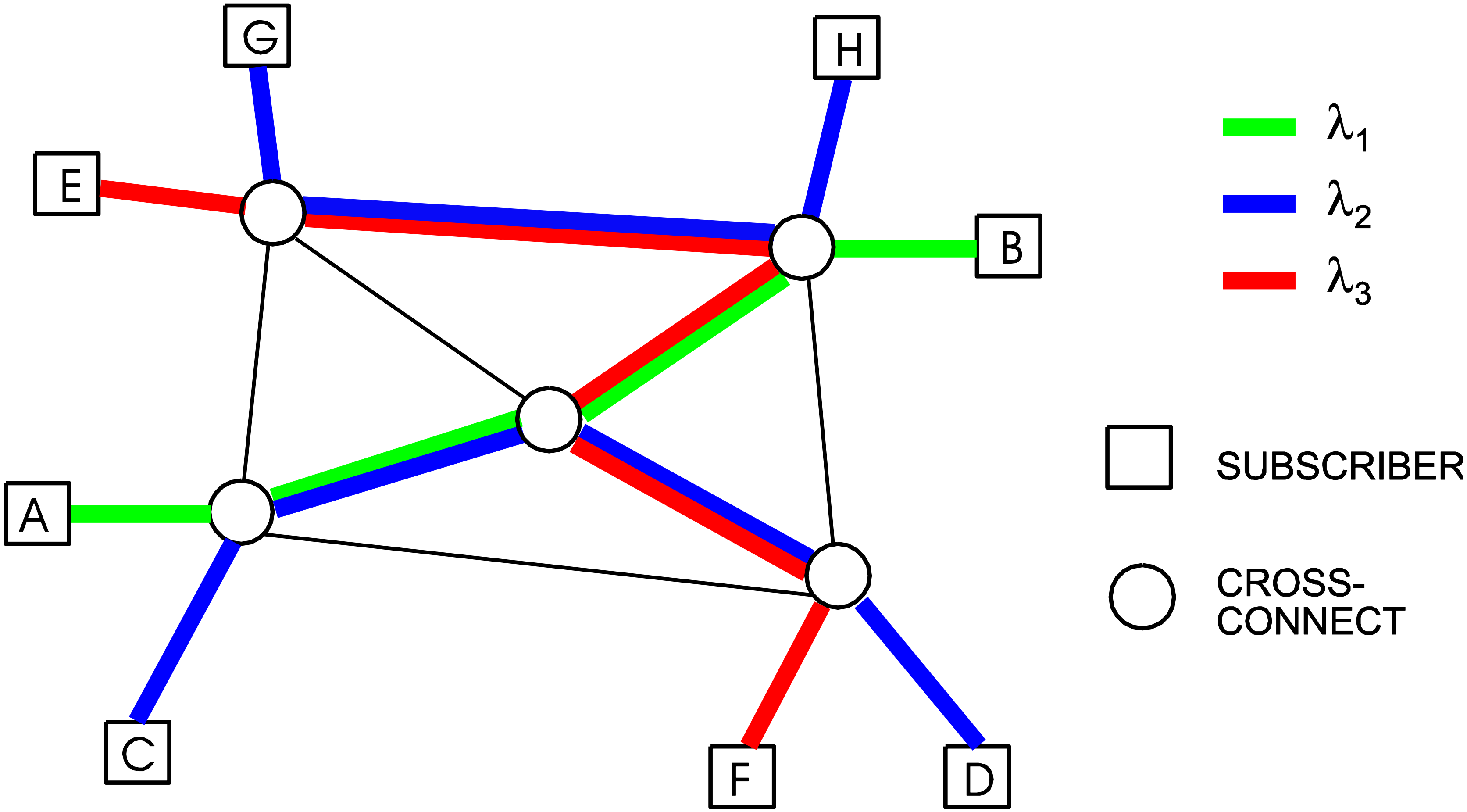
Many channels can be deployed massively increasing available bandwidth of one fibre



Coarse – CWDM – large spacing between channels compared to laser linewidth (~10nm)

Dense – DWDM – small spacing between channels (~<1nm)
High capacity 256 channels
λ

WDM Mesh-based Network



e.g. Subscribers E and F communicating

Wavelength Selective Devices

These perform their operation on the incoming optical signal as a function of the wavelength

Examples:

- Wavelength add/drop multiplexers
- Wavelength selective optical combiners/splitters
- Wavelength selective switches and routers

Multiplexers & de-multiplexers are often same device reversed

WDM Components

Narrow emission linewidth transmitters

Tuneable wavelength transmitters?

Multiplexers – light combiners – easy e.g. coupler

De-multiplexers – (high finesse wavelength filters)

The last two are sometimes the same device in reverse!

(De)multiplexer Components

- Couplers (see previous lecture)
- Fabry-Perot Filter
- Optical interference (Thin Film Filters)
- Diffraction Gratings (Bulk)
- Fiber Bragg grating
- Arrayed Waveguide Grating
- Mach-Zehnder Interferometer
- Acousto-Optic Filter

Interferometer

An interferometer uses 2 interfering paths of different lengths to resolve wavelengths

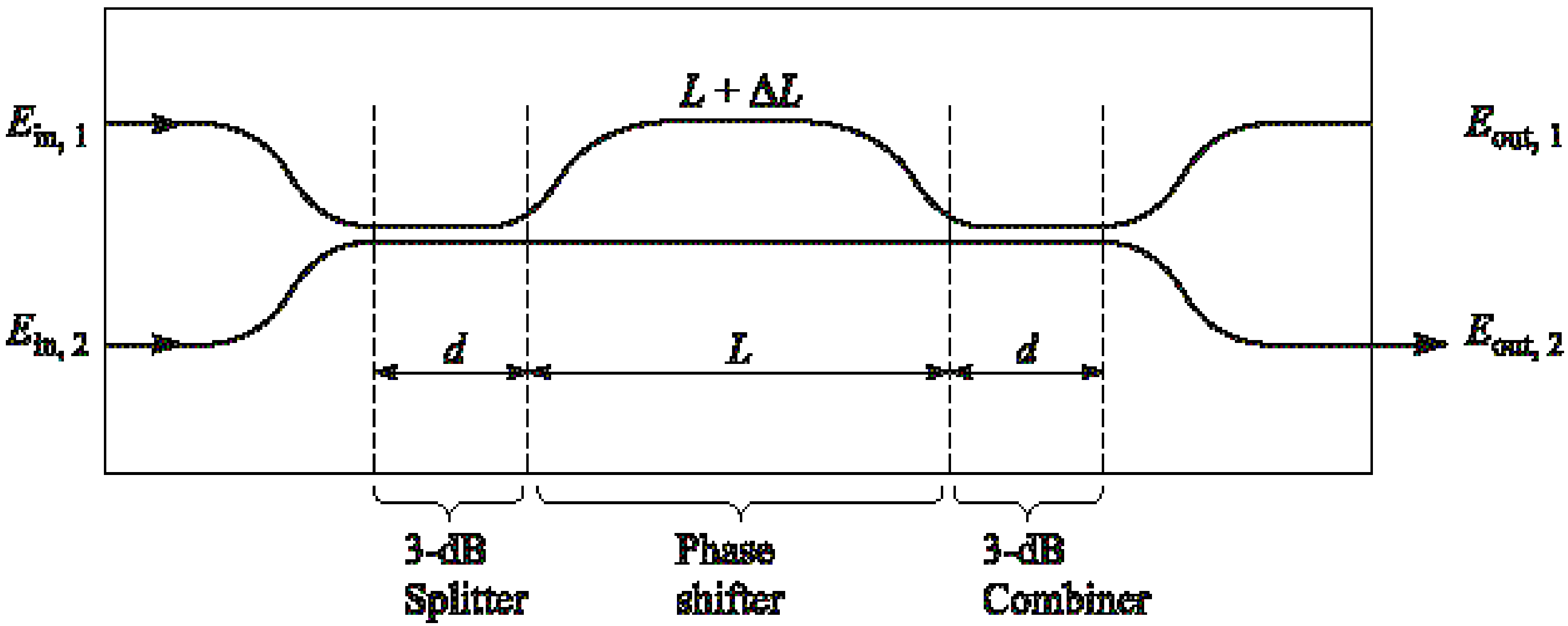
Typical configuration: two 3-dB directional couplers connected with 2 paths having different lengths

Applications:

— wideband filters (coarse WDM) that separate signals at1300 nm from those at 1550 nm

— narrowband filters: filter bandwidth depends on the number of cascades (i.e. the number of 3-dB couplers connected)

Basic Mach-Zehnder Interferometer



Phase shift of the propagating wave increases with ΔL,
Constructive or destructive interference depending on ΔL

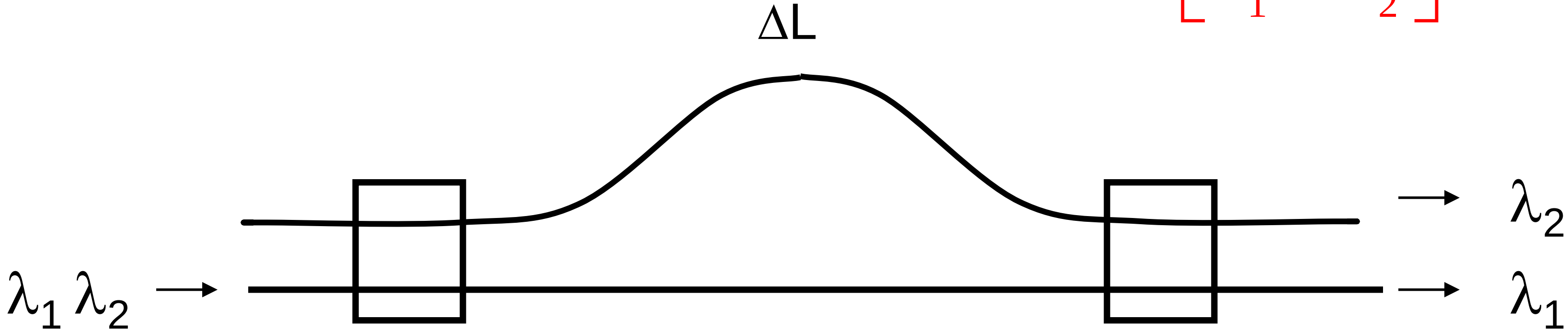
e.g. (De) Multiplexer

Phase shift at the output due to the propagation path length difference:

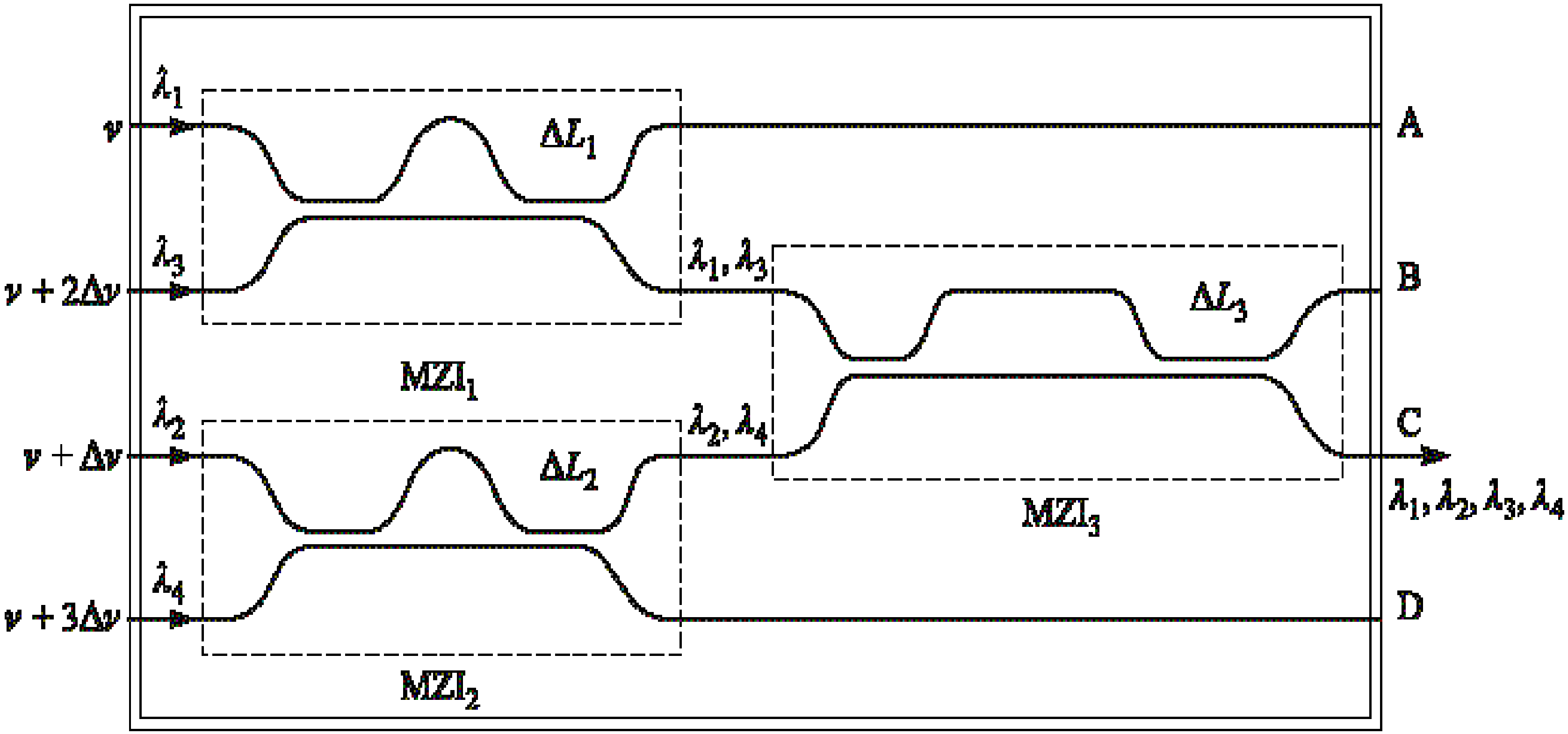
$$\Delta\phi = \frac{2\pi n_{eff}}{\lambda}\Delta L$$

If the power from both inputs (at different wavelengths) to be added at output port 2, then,

$$\pi = 2\pi n_{eff}\left[\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right]\Delta L$$

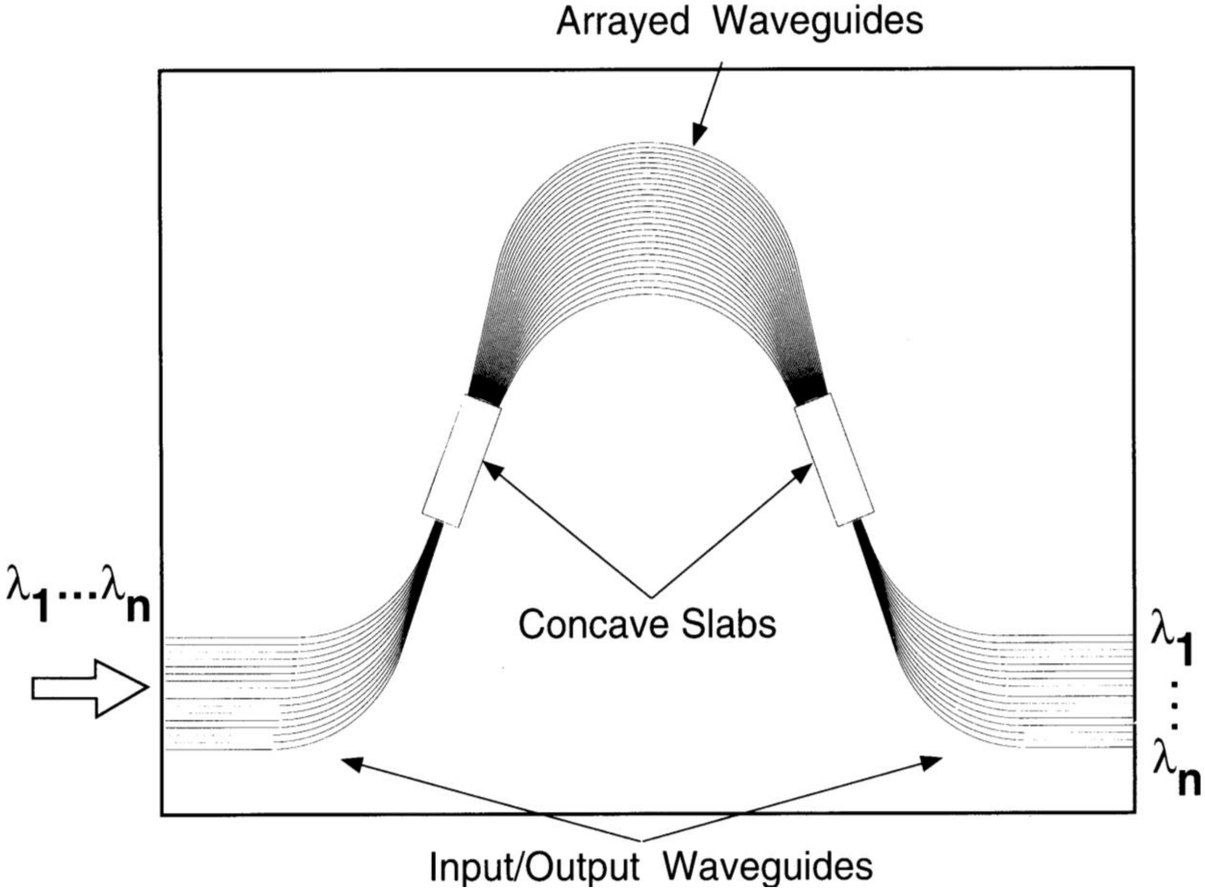


Four-Channel Wavelength Multiplexer



- By appropriately selecting *ΔL*, wavelength multiplexing/de-multiplexing can be achieved

Arrayed-waveguide Grating

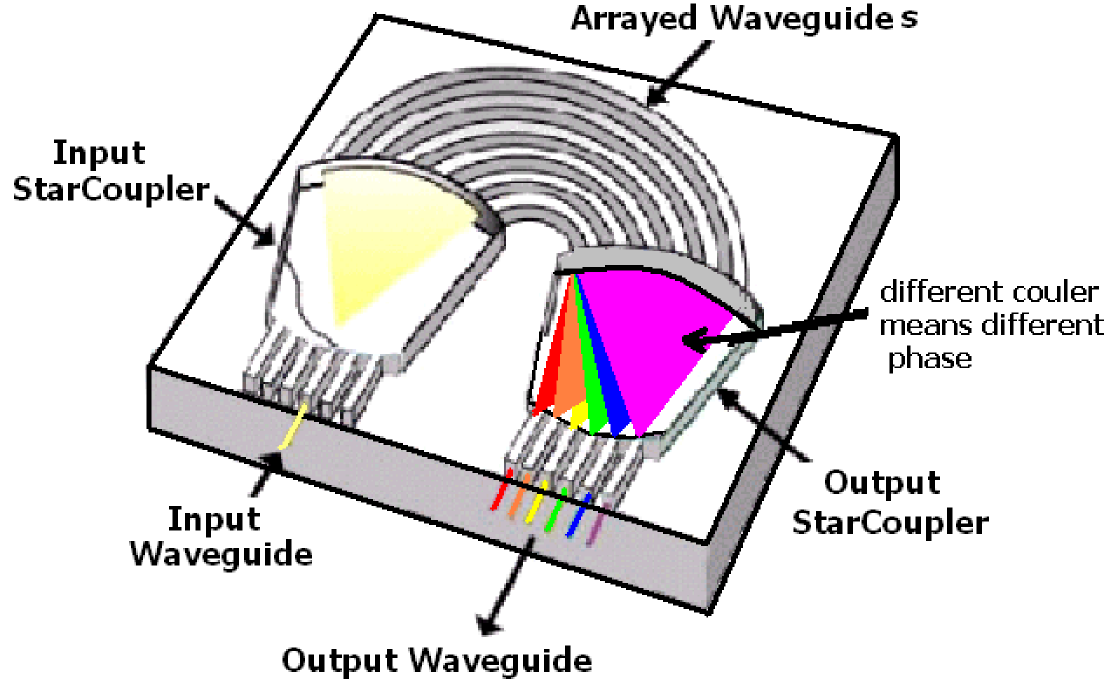


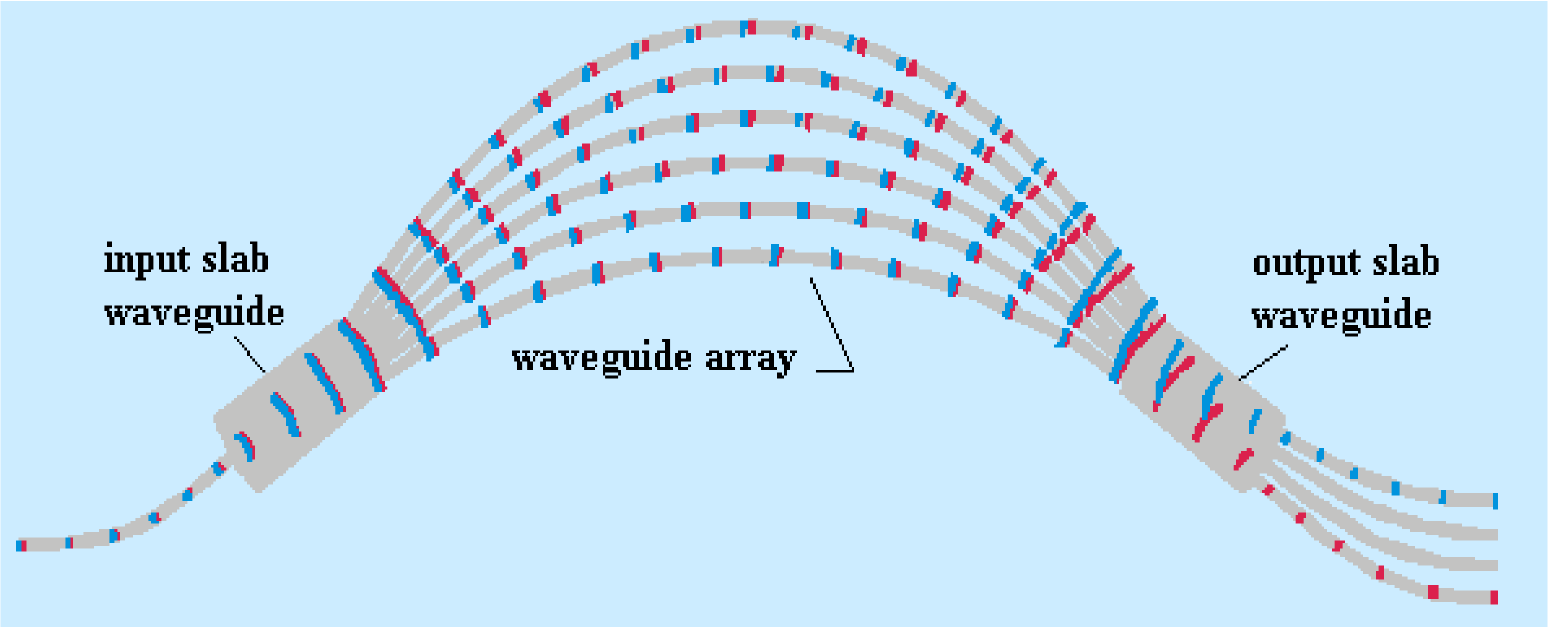
Input signals split equally between arrayed waveguides

Adjacent arrayed waveguides different in length by ΔL – different phase for all wavelengths on each waveguide

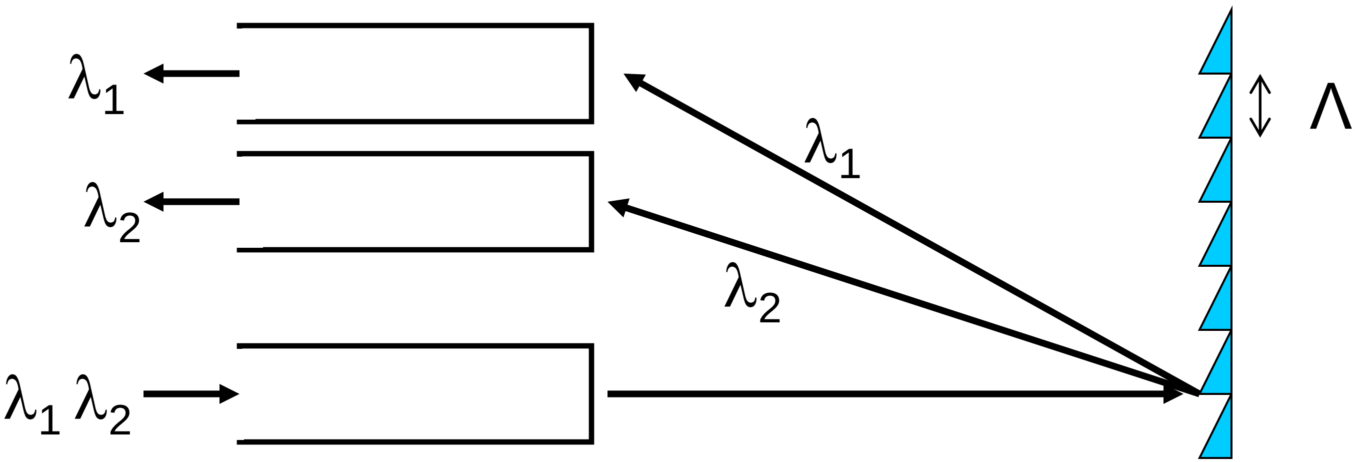
At output interference gives set of maximum light intensities as a function of wavelength

AWG


Arrayed Waveguide s
Input
StarCoupler
different couler
means different
phase
Output
StarCoupler
Input
Waveguide
Output Waveguide

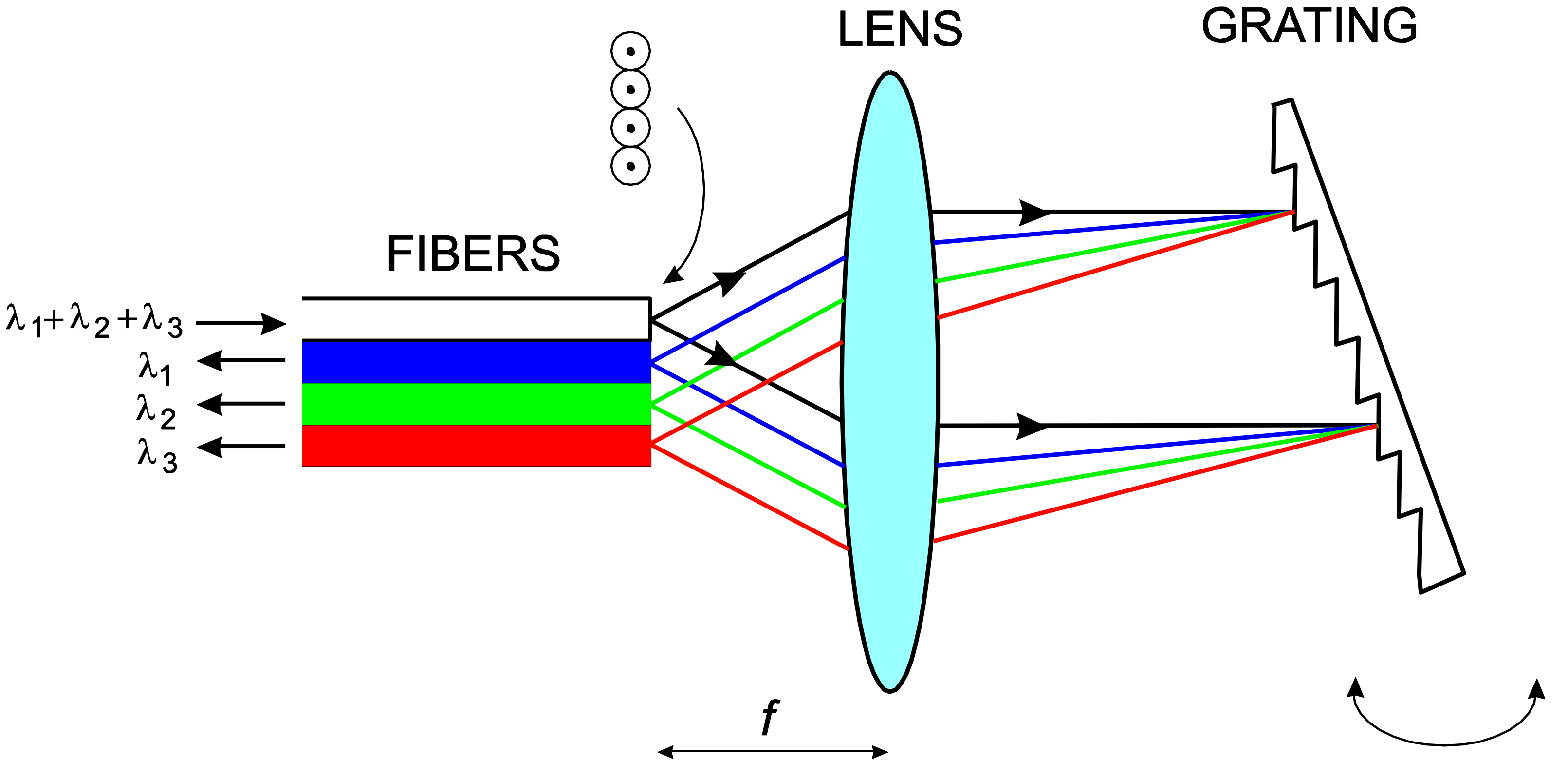

input slab
waveguide
waveguide array
output slab
waveguide

Diffraction Gratings



Light diffracts at a grating
– diffraction angle depends on wavelength
Also transmission grating

Grating demultiplexer

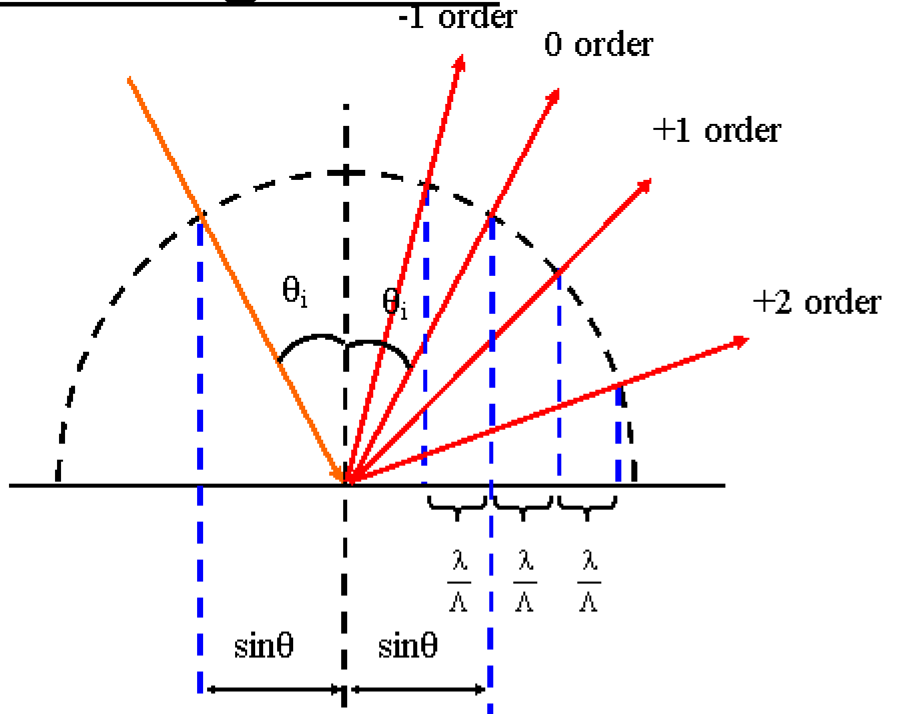


- Simultaneous diffraction of all wavelengths, thus possible to construct simple device with large number of channels
- Bandpass characteristics depend on dimension of input and output fibers

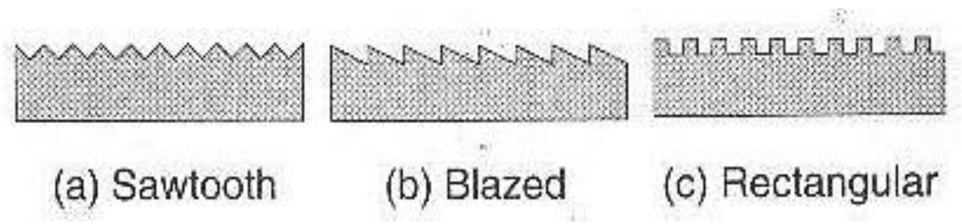
Diffraction Grating Filter

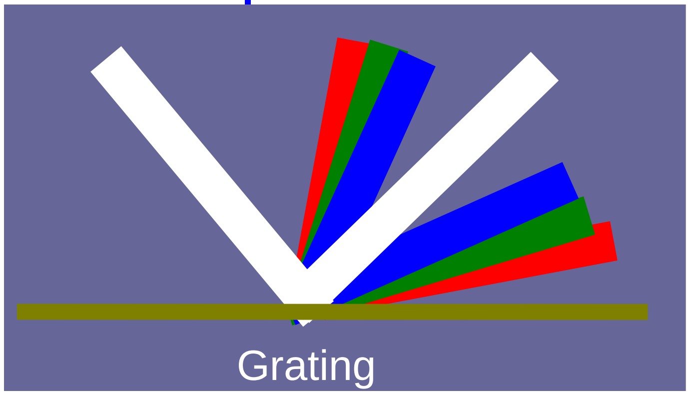
- Grating Equation

$$\sin\theta_r = \sin\theta_i + m\frac{\lambda}{\Lambda}$$

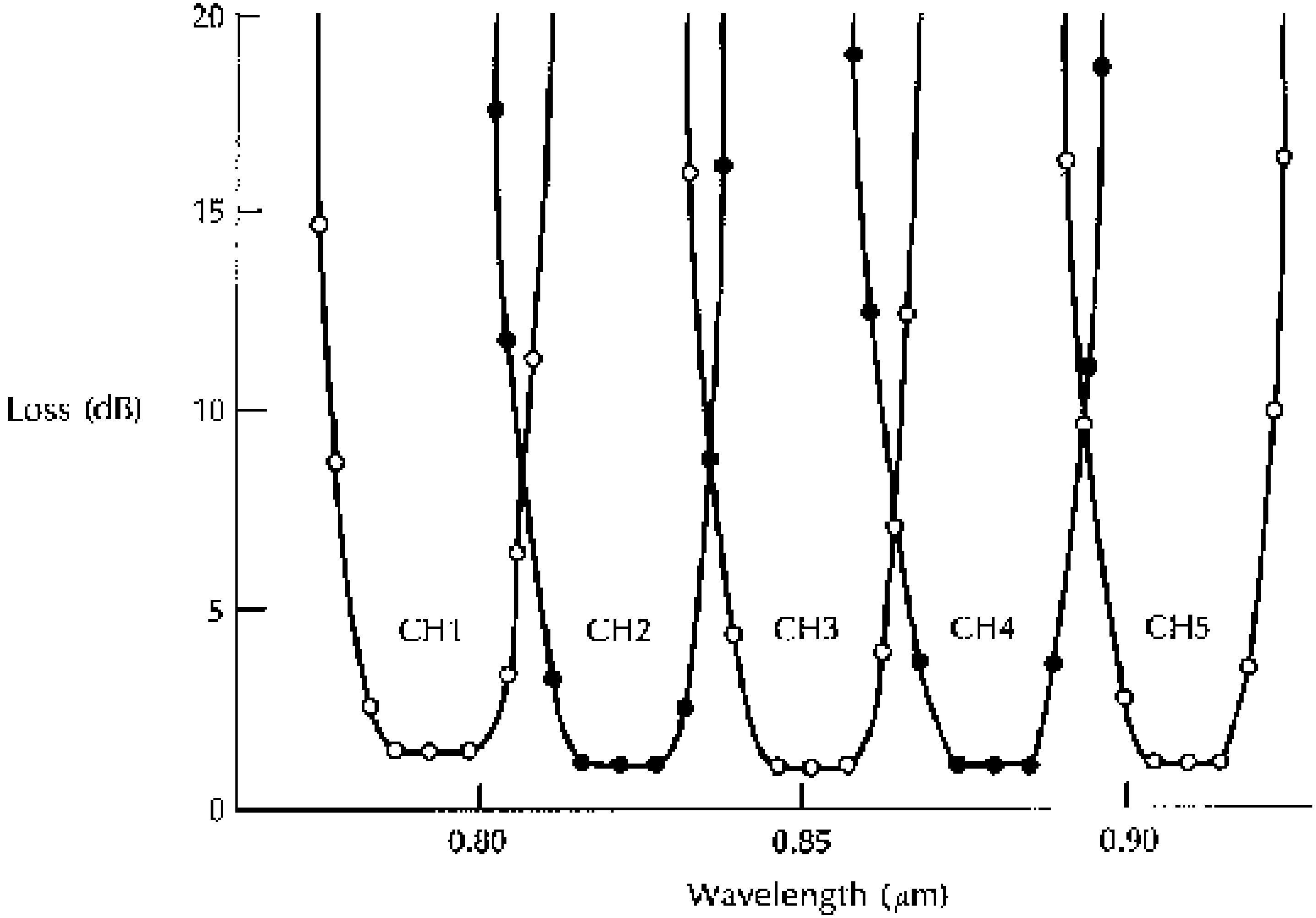


- Λ = spacing of teeth
- Grating Profiles

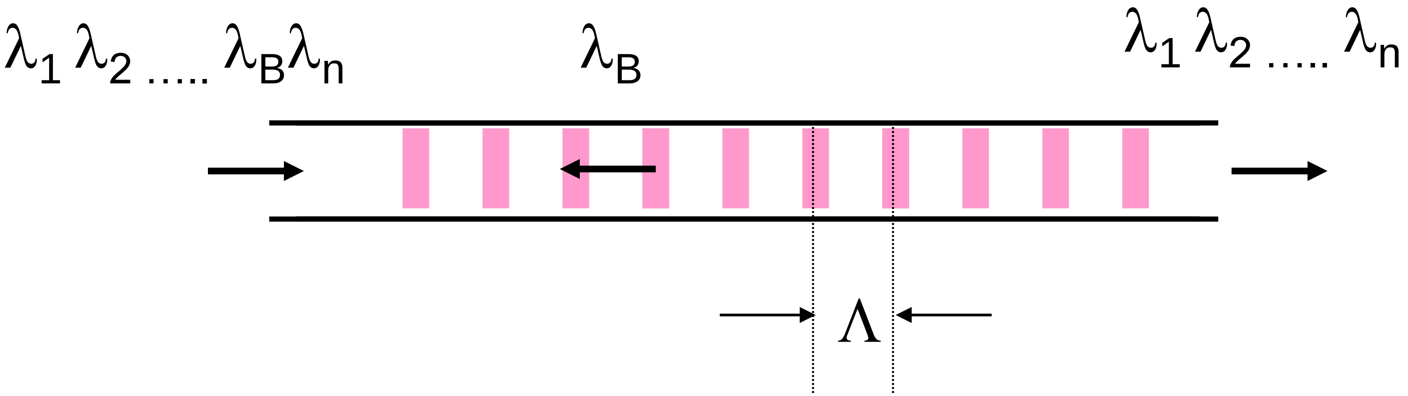




Filter Characteristic of a Grating Demux



Fibre Bragg Gratings

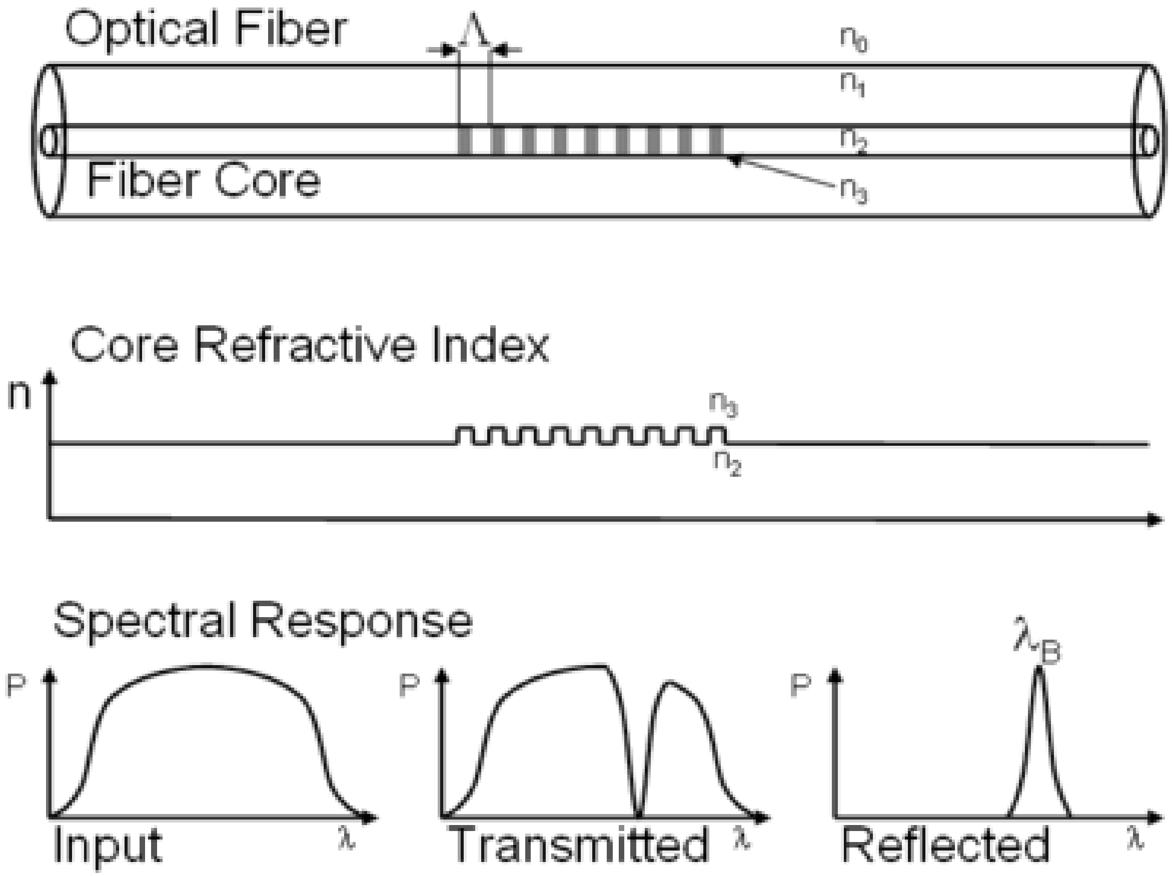


Bragg wavelength = $2\ \Lambda n_{eff} = \lambda_B$

Reflects light of Bragg wavelength

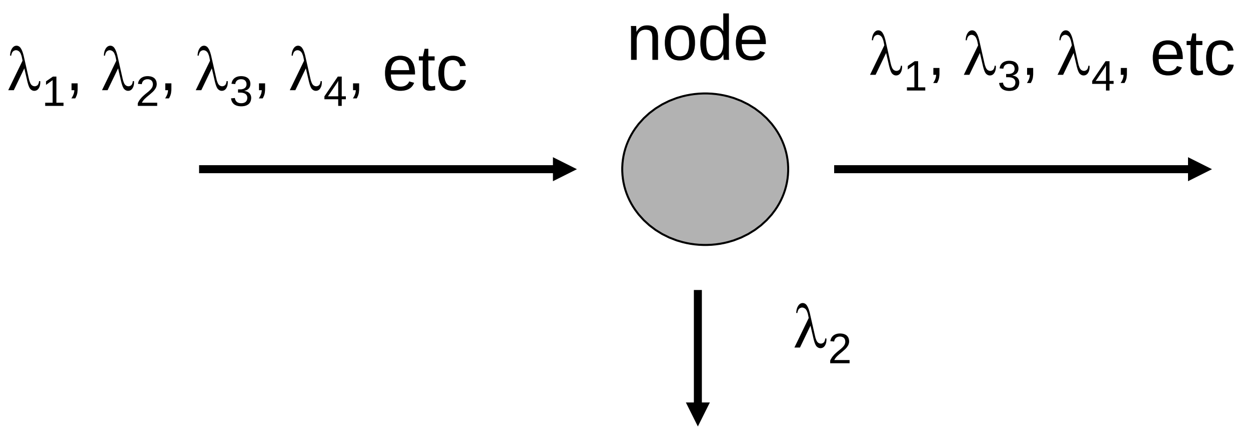
Acts as notch type filter

Fibre Bragg Grating



Source: Wikipedia.org

WDM System

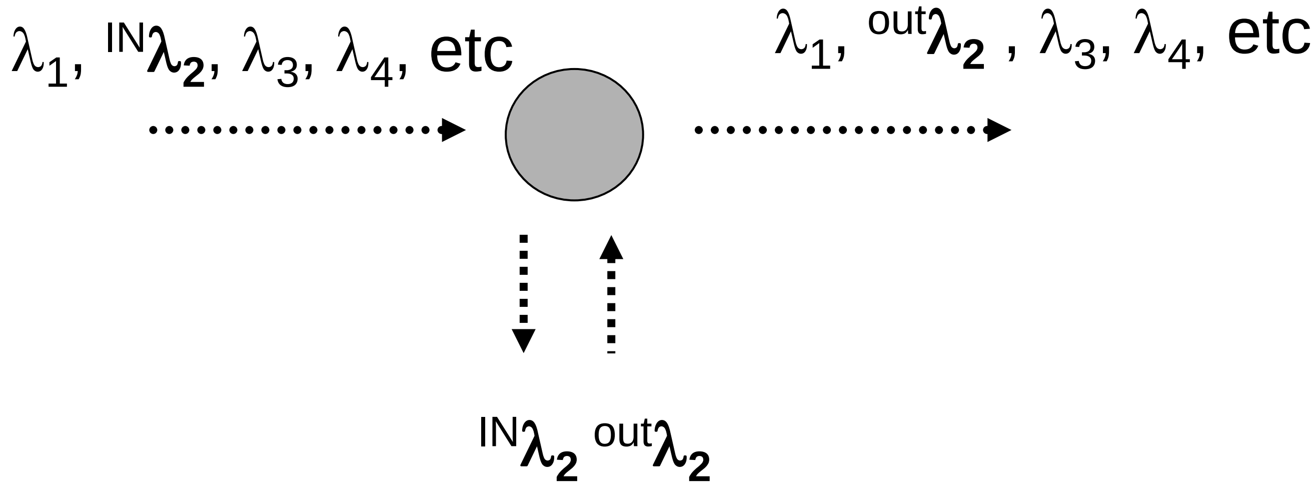


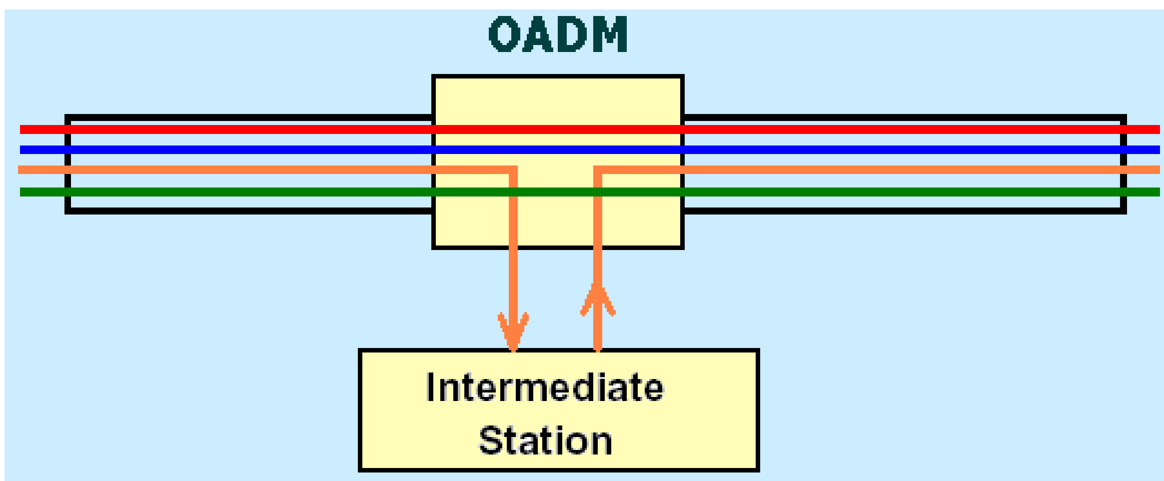
Wavelength routing at a node for WDM systems

-Would like to be entirely in the optical domain (transparent)
(not optical – electrical – optical (opaque))

Electronics is expensive and a bottleneck

Add / Drop Demultiplexer

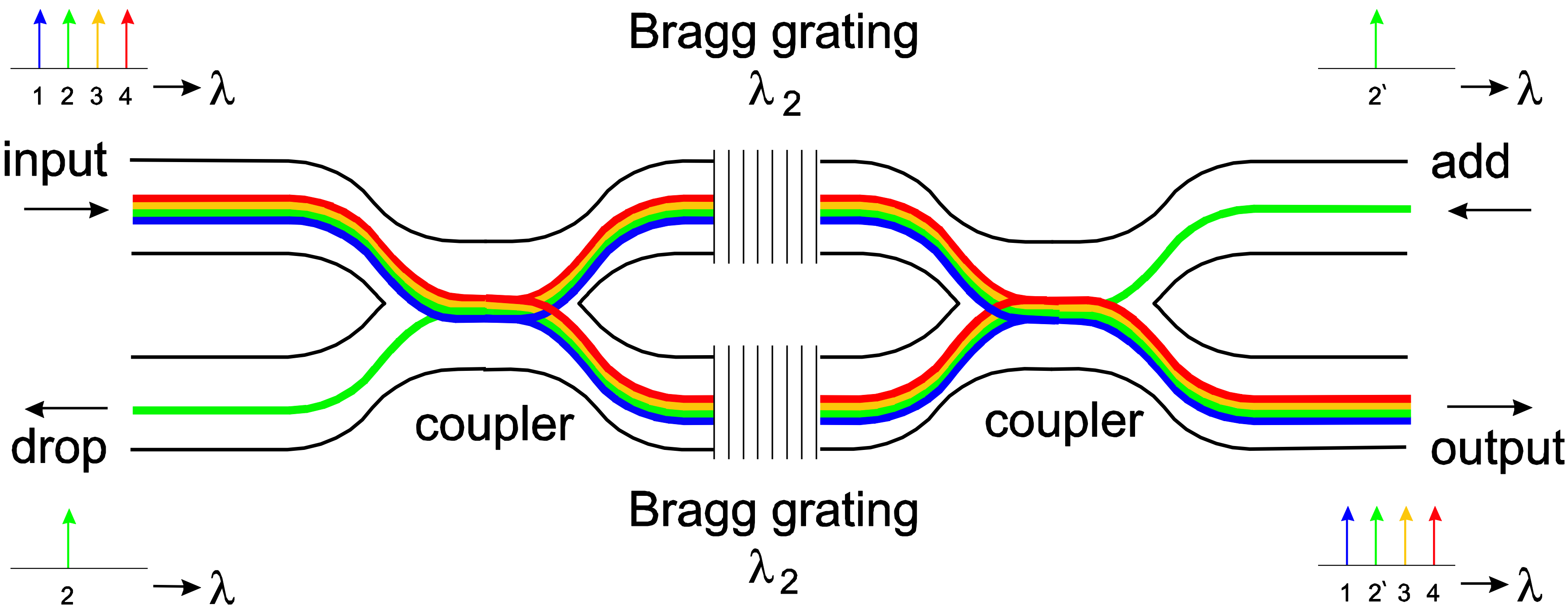




a wavelength is assigned to a specific node – for it’s use alone

Add/Drop filter (ADM)

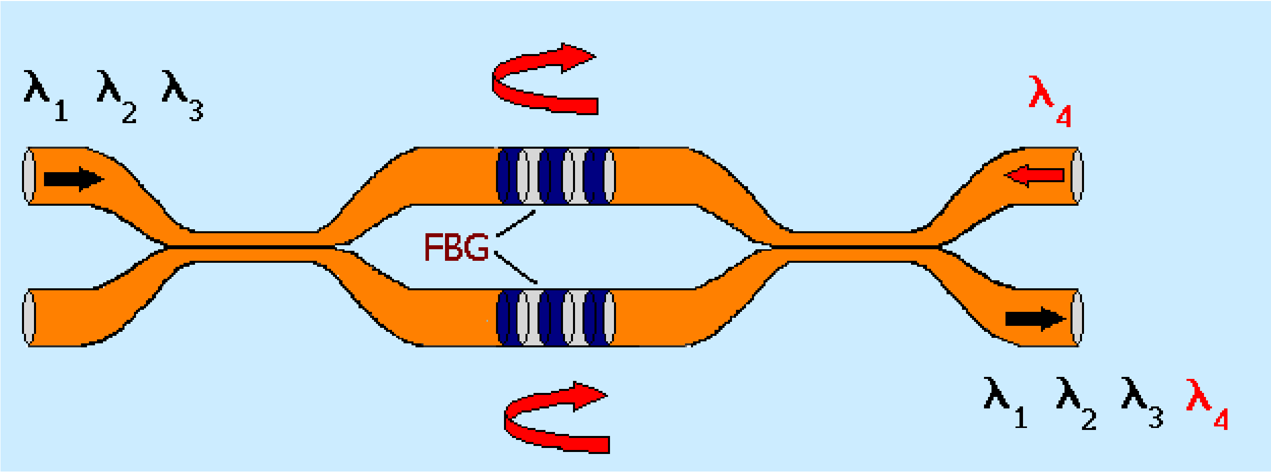
Combination of Mach Zender Interferometer and Bragg Filters



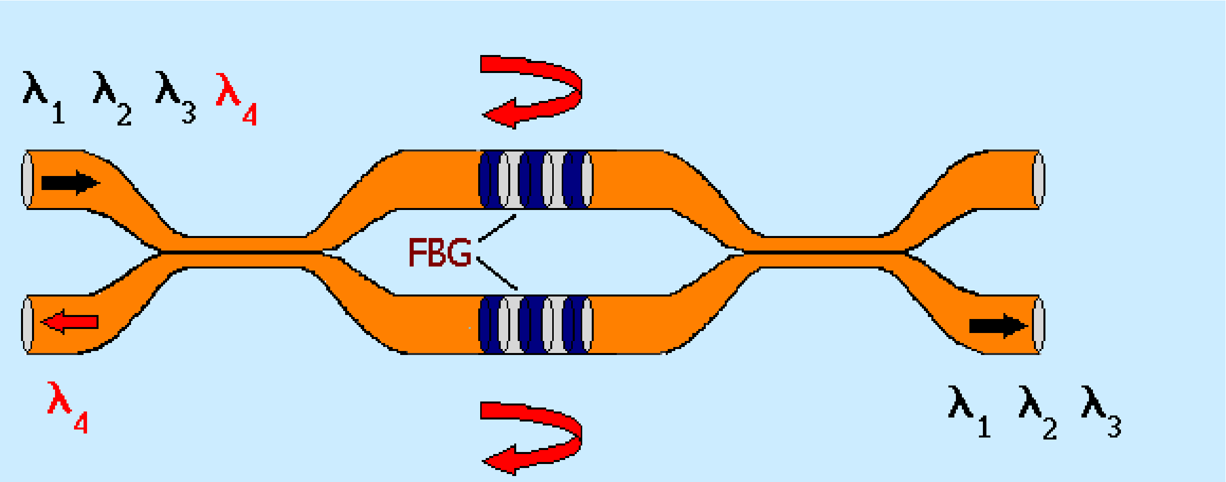
Only one wavelength is dropped and added

FBG

MZI with FBG Multiplexer



MZI with FBG DeMultiplexer



Maximum Link Capacity

What is data capacity of a WDM Link?

DWDM –

Channel spacing 0.4nm (50GHz)

40GBit/s per channel

Use 1250 – 1650nm (may need dry fibre)

Gives ~30TBit/s

Using amplifiers etc – can transmit this over 1000km……..

Practical Limiting Factors

Amplifiers don't cover all this spectral range – EDFAs only cover ~40nm

Number of channels limited by

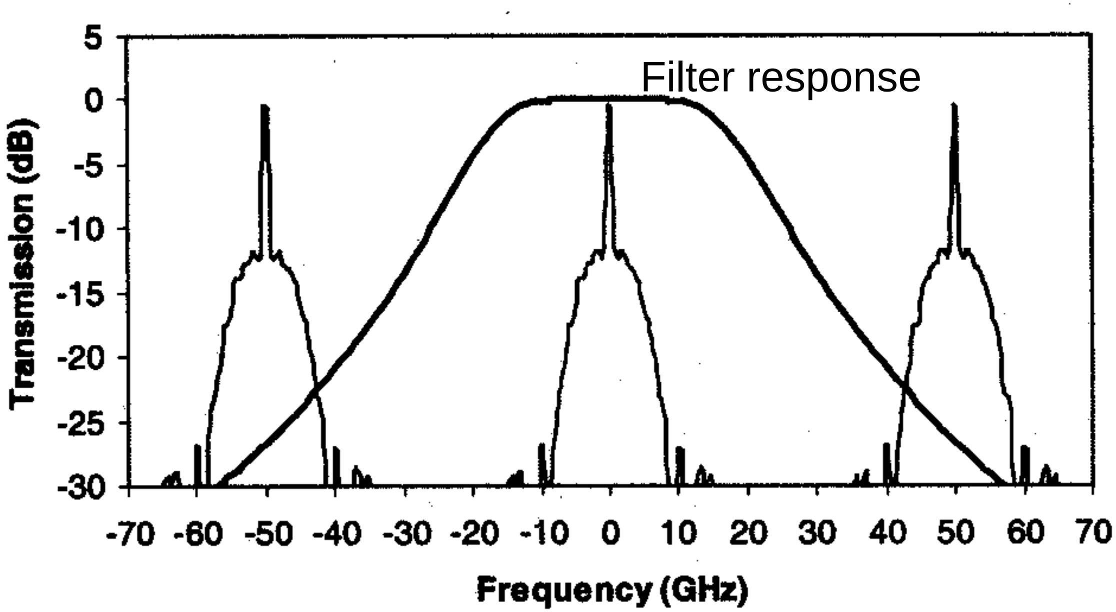
(1) Wavelength stability of laser (DFB)
(2) Signal degradation – non-linear effects (not discussed)
(3) Interchannel crosstalk at DEMUX

Research Groups have demonstrated

~6 Tbit/s over 3000km
~4 Tbit/s over 11000km

Commercially available
160 channels each at 10Gbit/s

Inter-channel Crosstalk



Optical filters, Demultiplexers often let a fraction of the signal power from neighbouring channels “leak” into the desired channel – termed **out-of-band crosstalk**

Gives rise to additional optical power and noise for the “0” level on an eye diagram – in turn gives rise to a power penalty

DWDM – Demands on Components

DWDM Channel spacings ~200GHz = 1.3nm and 100GHz = 0.7nm
50 GHz =0.4nm
Plan to go to 25GHz = 0.175nm

Requirement for narrower DWDM channel spacing drives control over laser linewidth tuning and stability

Filters, Routers, need to be "perfect" – or pay power penalty

Amplifiers – want high saturated gain, broadband (1250-1650) amplifier

Would like wavelength converters

Want all the above very fast so as to dynamically route data

Summary WDM

- Photons do not easily interact with other photons – we can transmit many optical channels (different wavelengths) down one physical channel
- The optical spectrum may be sliced into a number of channels, and we require the transmitter wavelength to sit centrally in this band, and any demultiplexing components to have a high rejection of neighbouring wavelengths
- There are many forms of filters, demux, routers, allowing many possible functions within a network – additional noise (crosstalk) in a WDM system may be from within the same optical channel or from neighbouring channels. A power penalty is paid to achieve required BER if these noise sources are present

Summary WDM - Components

In addition to loss, dispersion effects on components discussed previously….

Channel spacing getting narrower in wavelength

Transmitters

– need wavelength selectable, wavelength tuneable

Filters, Routers,

-need to have high finesse/Qfactor (or pay power penalty)

Amplifiers

Need high saturated gain, broadband

EDFA good but 40nm wide band and limited gain