Photonic Networks

Lecture 2 - Devices & Components

Professor Z Ghassemlooy

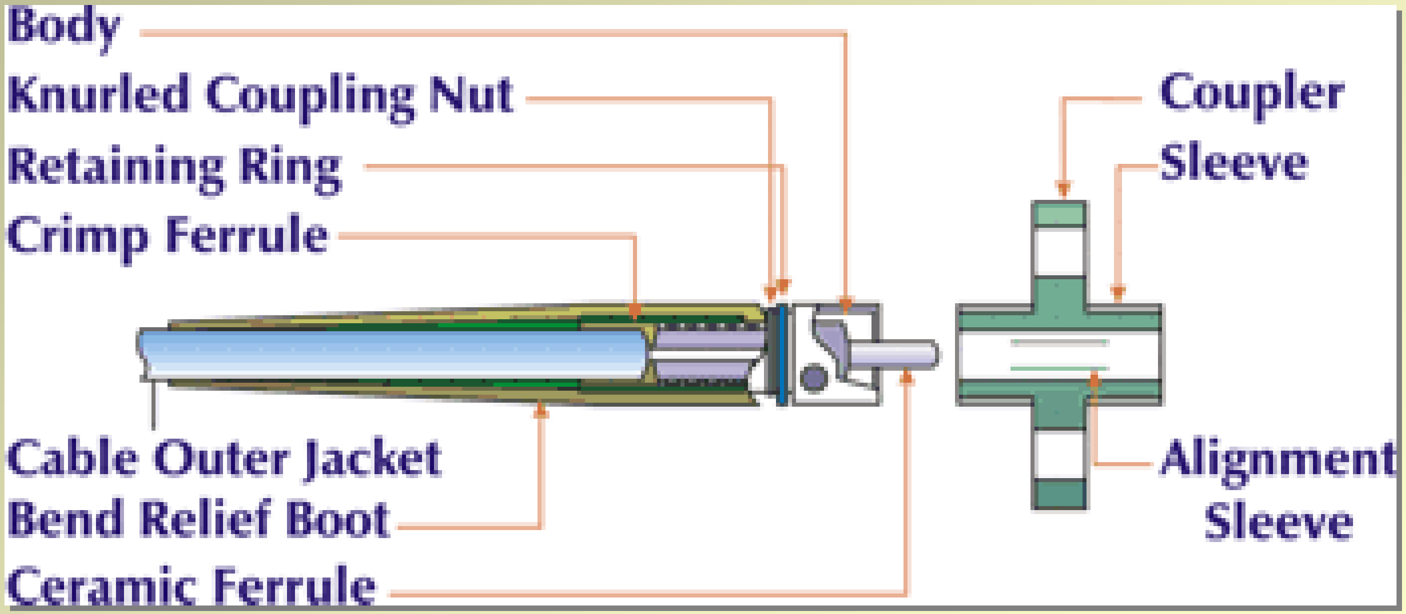
The University of Northumbria
U.K.

Contents

- Connectors + Optical Splice
- Attenuators
- Coupler
- Splitter
- Filters
- Fibre Brag Grating
- Optical Isolator
- Circulators
- Optical Add/Drop
- Multiplexer & Demultiplexer

Connectors

A mechanical or optical device that provides a demountable connection between two fibers or a fiber and a source or detector.

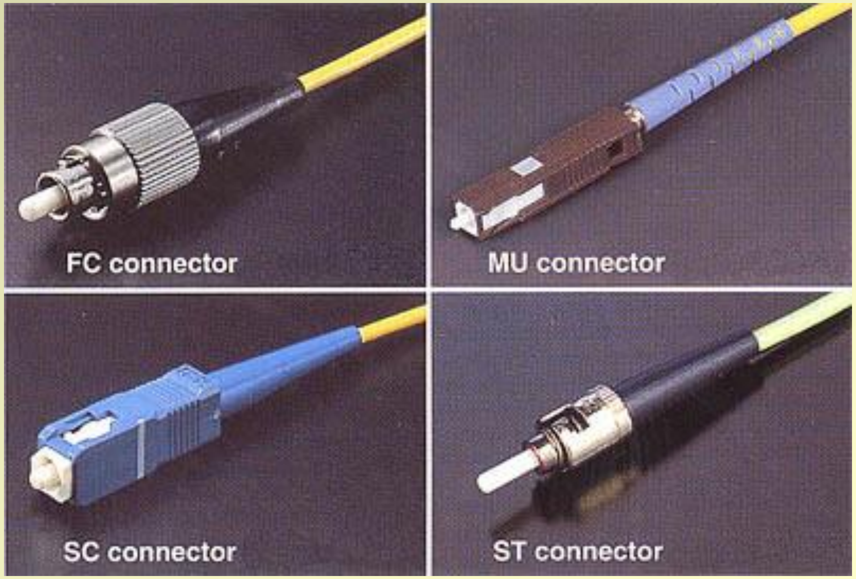


Connectors - *contd.*

Type: SC, FC, ST, MU, SMA

- Favored with single-mode fibre
- Multimode fibre (50/125um) and (62.5/125um)
- Loss 0.15 - 0.3 dB
- Return loss 55 dB (SMF), 25 dB (MMF)

Single fibre connector



Connectors - *contd.*

- Single-mode fiber
- Multi-mode fiber (50/125)
- Multi-mode fiber (62.5/125)
- Low insertion loss & reflection


MT-RJ Patch Cord


MT-RJ Fan-out Cord

Optical Splices

- Mechanical
  - Ends of two pieces of fiber are cleaned and stripped, then carefully butted together and aligned using a mechanical assembly. A gel is used at the point of contact to reduce light reflection and keep the splice loss at a minimum. The ends of the fiber are held together by friction or compression, and the splice assembly features a locking mechanism so that the fibers remained aligned.
- Fusion
  - Involves actually melting (fusing) together the ends of two pieces of fiber. The result is a continuous fiber without a break.

Both are capable of splice losses in the range of 0.15 dB (3%) to 0.1 dB (2%).

Attenuators

Singlemode Variable Attenuator

- Repeatable, variable attenuation from 2 to 40dB
- <-70dB reflectance (unconnectorized)
- Polarization insensitive
- Low modal noise
- Long-term reliability

Attenuators - *contd.*

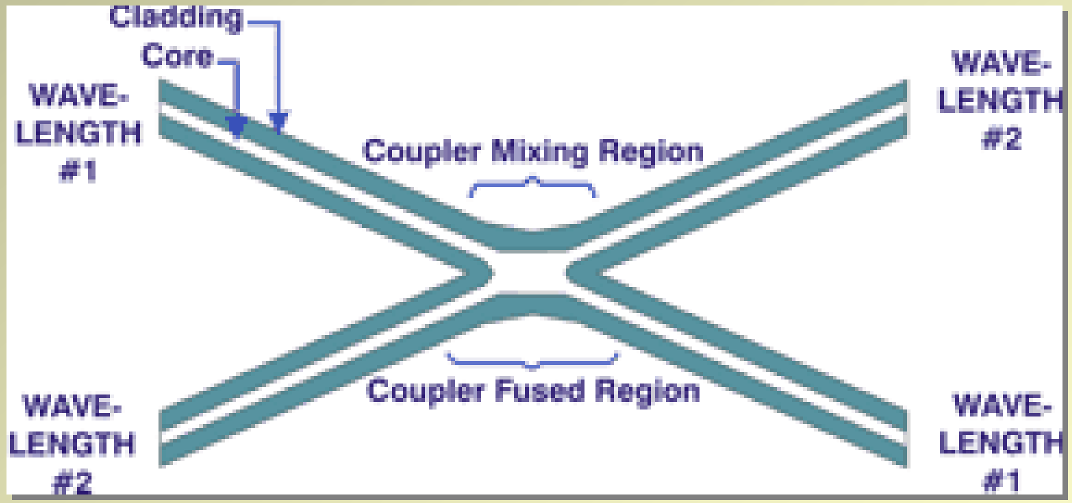
Dual window

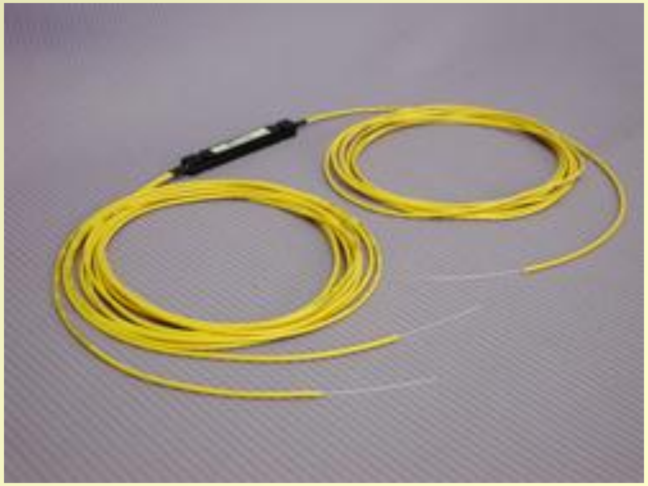
In line attenuator

- Bandpass 1310/1550nm
- FC, SC, ST, and D4 styles
- Wavelength independent
- Polarization insensitive
- Low modal noise

Optical Couplers

- Optic couplers either split optical signals into multiple paths or combine multiple signals on one path.
- The number of input (N)/ output (M) ports, (i.e.s N x M size) characterizes a coupler.
- Fused couplers can be made in any configuration, but they commonly use multiples of two (2 x 2, 4 x 4, 8 x 8, etc.).

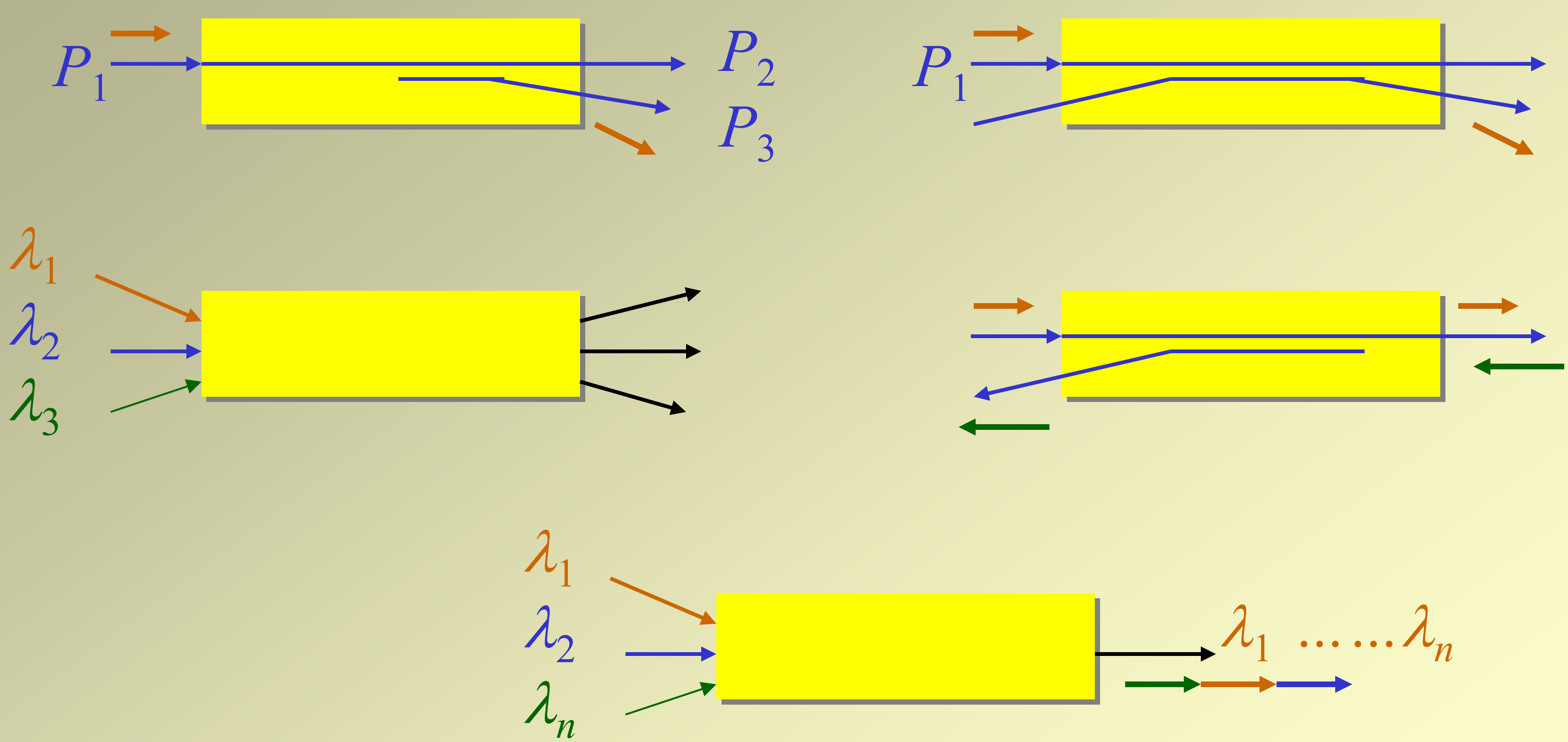




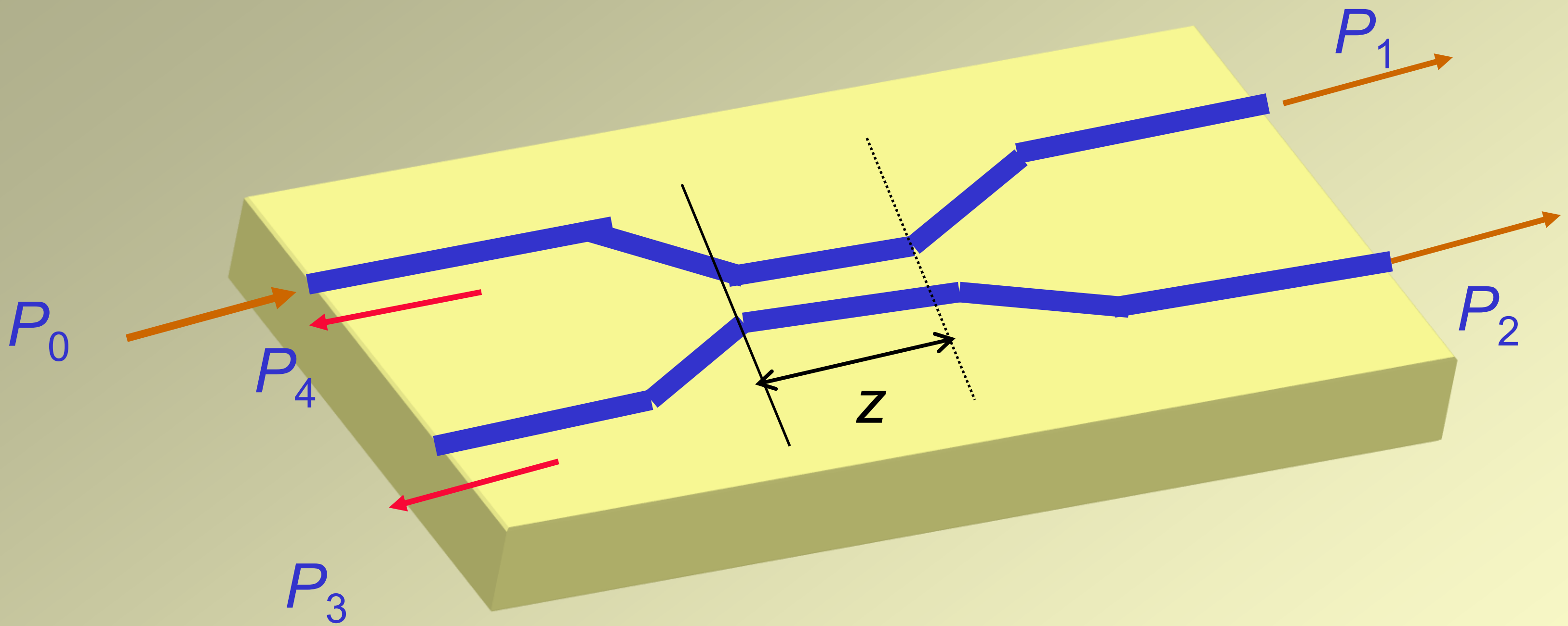
Coupler

- **Uses**
  - Splitter: (50:50)
  - Taps: (90:10) or (95:05)
  - Combiners
- **An important issue:**
  - two output differ by **π/2** in phase
- **Applications:**
  - Optical Switches,
  - Mach Zehnder Interferometers,
  - Optical amplifiers,
  - passive star couplers, ...

Coupler Configuration



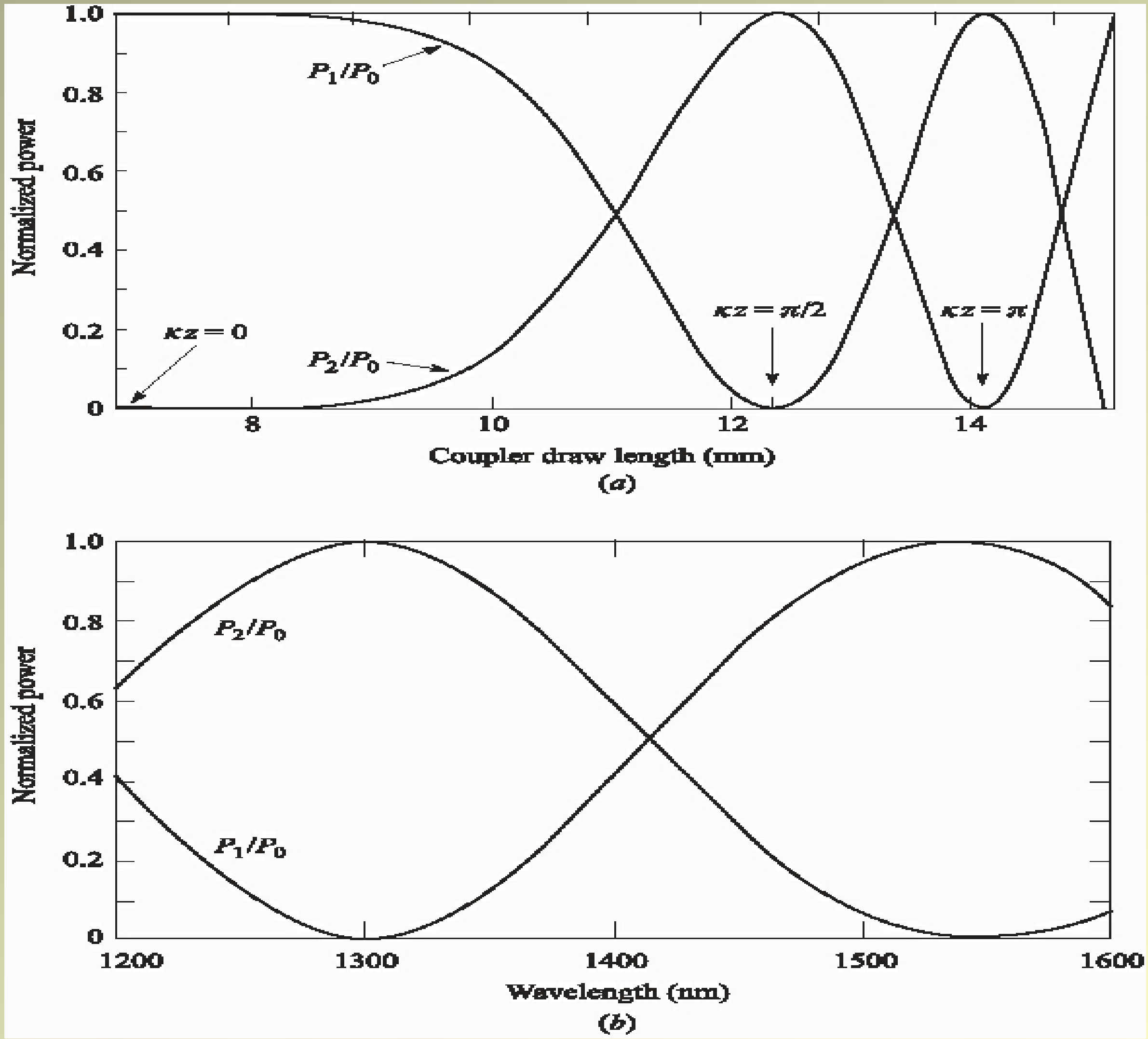
Coupler - Integrated Waveguide Directional Coupler



$P_2 = P_0 \sin^2 kz$ $\quad$ $P_1 = P_0 - P_2 = P_0 \cos^2 kz$

k = coupling coefficient = $(m + 1)\pi/2$

Coupler - Integrated Waveguide Directional Coupler

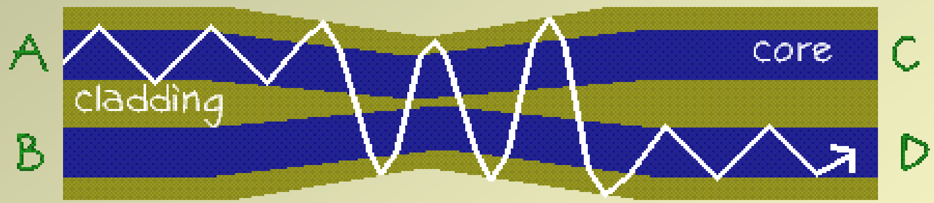


- A directional coupler
- Different performance couplers can be made by varying the length, size for specific wavelength.

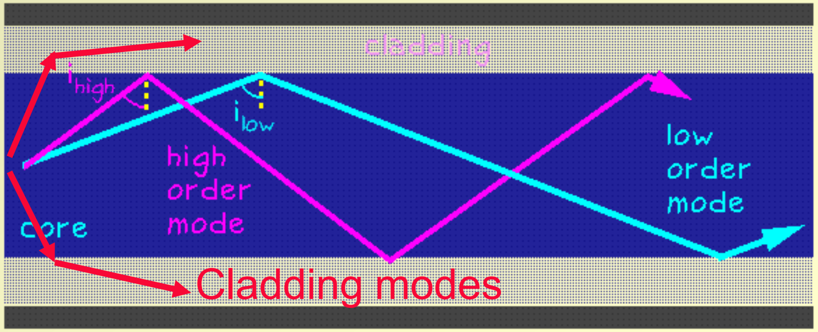
G Keiser

Couplers - Fabrication

- **Multimode Fibres**



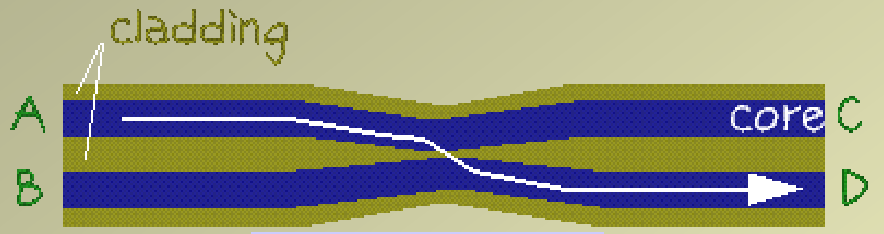
- Wavelength independent, depends on how light is launched
- In the coupling region
  - Higher order modes are trapped at the outer surface of the cladding: thus becoming cladding modes
  - Lower order modes remain in the original fibre (as the incident angles are still > the critical angle)
- Cladding modes are converted back into core modes at the output ports.
- The splitting ratio is determined by the
  - length of the taper
  - thickness of the cladding.



Source: Australian Photonics CRC

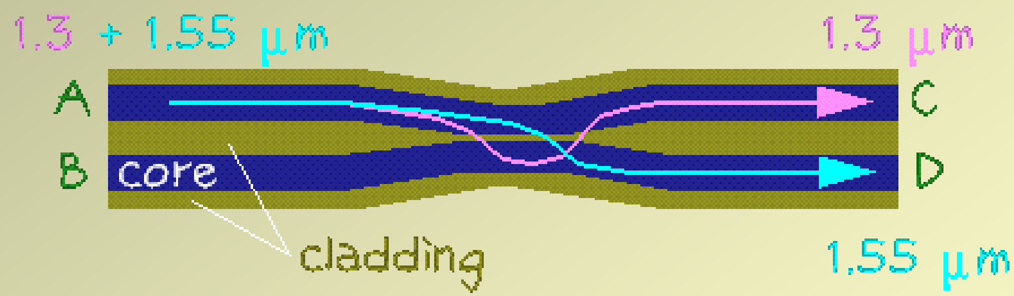
Couplers - Fabrication

- **Single Fibres**



100% coupling

- It is wavelength dependent. Resonance occur when the two fibres are close to each other.



- The coupling length for 1.55 µm > the coupling length for 1.3 µm:
  - 100 % of light coupling for 1.3 µm to the core of fibre B, and to the core of fibre A.
  - 100% of light coupling for 1.55 µm to the core of fibre B

Source: Australian Photonics CRC

Couplers - Fabrication

- The amount of power transmitted into fibres depend on the coupling length
- The coupling length changes with the wavelength.
- The splitting ratio can be tuned choosing the coupling length.
- By choosing carefully the coupler length, it is possible to **combine** or **separate** Two different wavelengths

Coupler - Performance Parameters

- Coupling ratio or splitting ratio

$$CR = \frac{\textbf{Power from any single output}}{\textbf{Total power out to all ports}} \quad \frac{P_t}{P_{T-out}}$$

In dB

$$CR = 10\,\mathbf{log}_{10}\left(\frac{P_2}{P_1 + P_2}\right)$$

For 2 x 2 coupler

- Excess Loss

$$L_e = \frac{\textbf{Input power } P_i}{\textbf{Total output power } P_{T-out}}$$

$$Le = 10\,\mathbf{log}_{10}\left(\frac{P_0}{P_1 + P_2}\right)$$

Coupler - Performance Parameters

- Insertion Loss

$$L_i = \frac{\text{Power from any single output}}{\text{Power input}} = \frac{P_t}{P_i}$$

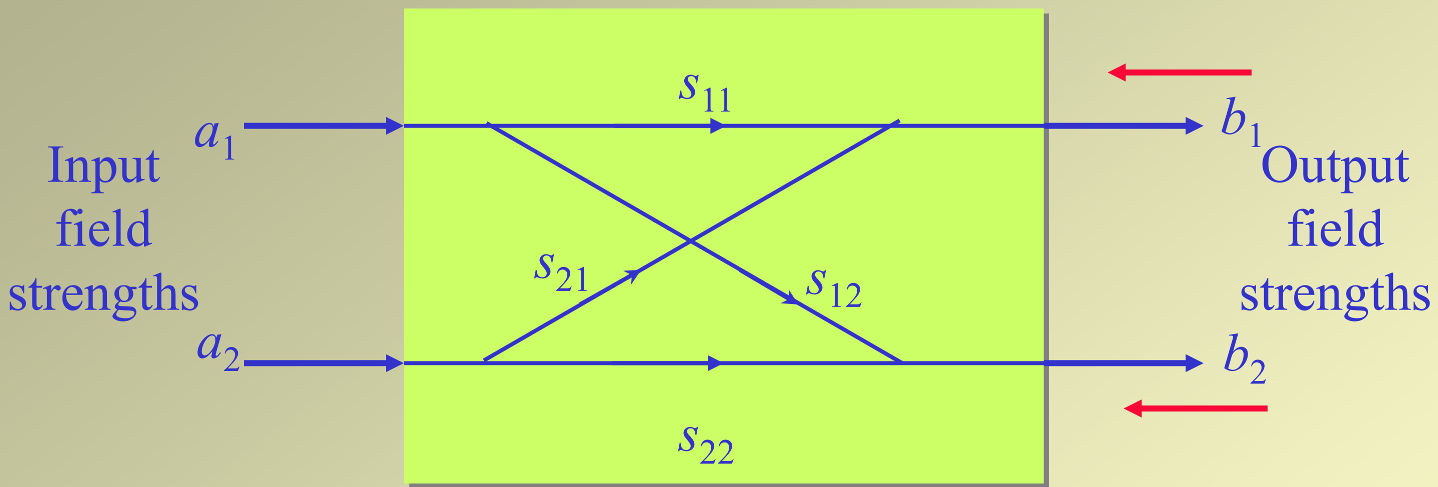
- Isolation Loss or Crosstalk

$$L_{iso} = \frac{\textbf{Input power at one port}}{\textbf{Reflected power back into other input port}}$$

In dB

$$L_{iso} = 10\,\mathbf{log}_{10}\left(\frac{P_0}{P_3}\right)$$

Generic 2X2 Guided-Wave Coupler



$$\mathbf{b} = \mathbf{S}\mathbf{a}$$

where $\mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$, $\mathbf{a} = \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$, *and* $\mathbf{S} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix}$

There are altogether eight possible ways(two ways) for the light to travel.

Generic 2X2 Guided-Wave Coupler

Assume: Fraction (1- ε) of power in the input port 1 appears at output port 1,and the remaining power ε at the output port 2

$$\mathbf{S} = \begin{bmatrix} \sqrt{1-\varepsilon} & j\sqrt{\varepsilon} \\ j\sqrt{\varepsilon} & \sqrt{1-\varepsilon} \end{bmatrix}$$

If ε = 0.5, and input signal defined in terms of filed intensity E_i, then

$$\begin{bmatrix} E_{o,1} \\ E_{o,2} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} E_{i,1} \\ E_{i,2} \end{bmatrix}$$

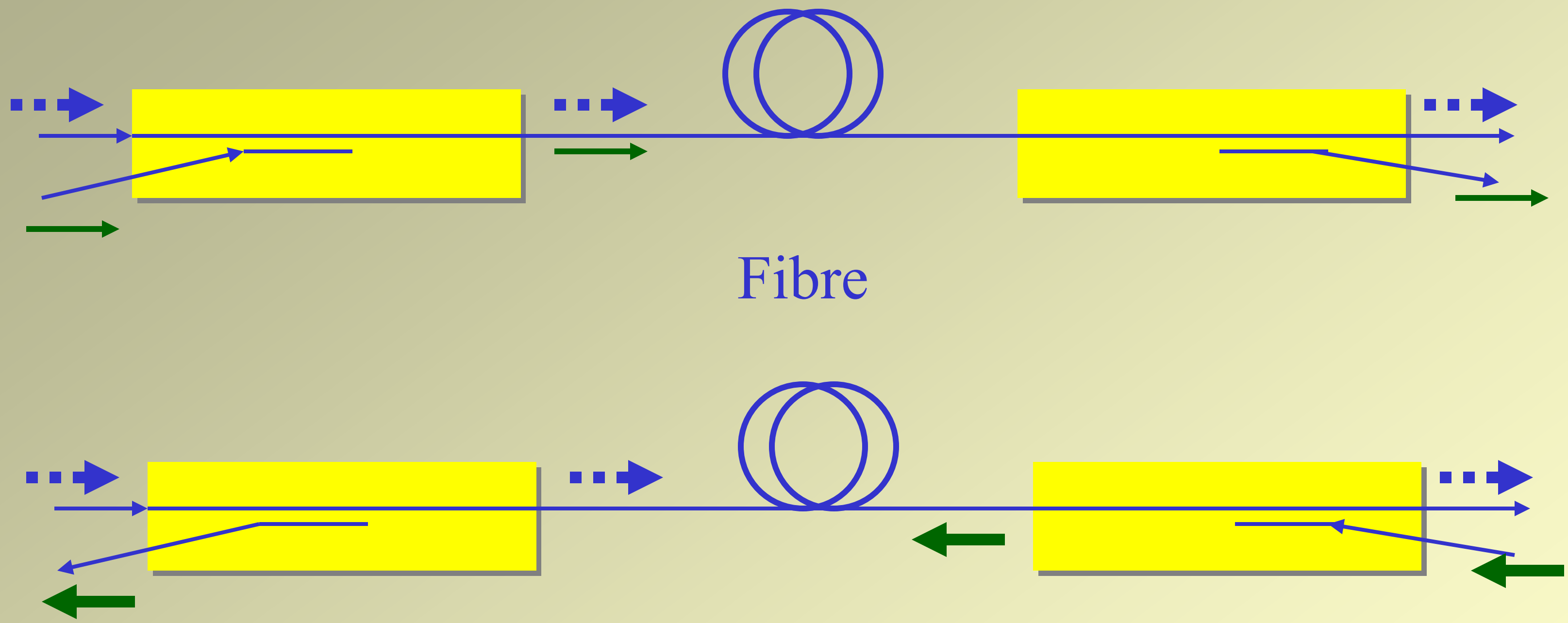
Let $E_{o,2}$ = 0, thus in term of optical power

$$P_{o,1} = E_{o,1} E^{*}{}_{o,1} = \tfrac{1}{2} E^{2}{}_{i,1} = \tfrac{1}{2} P_0$$

$$P_{o,2} = E_{o,2} E^{*}{}_{o,2} = \tfrac{1}{2} E^{2}{}_{i,1} = \tfrac{1}{2} P_0$$

Half the input power appears at each output

Tree and Branch Coupler



Coupling ratio; 1:1 or 1: *n*,
where *n* is some fraction

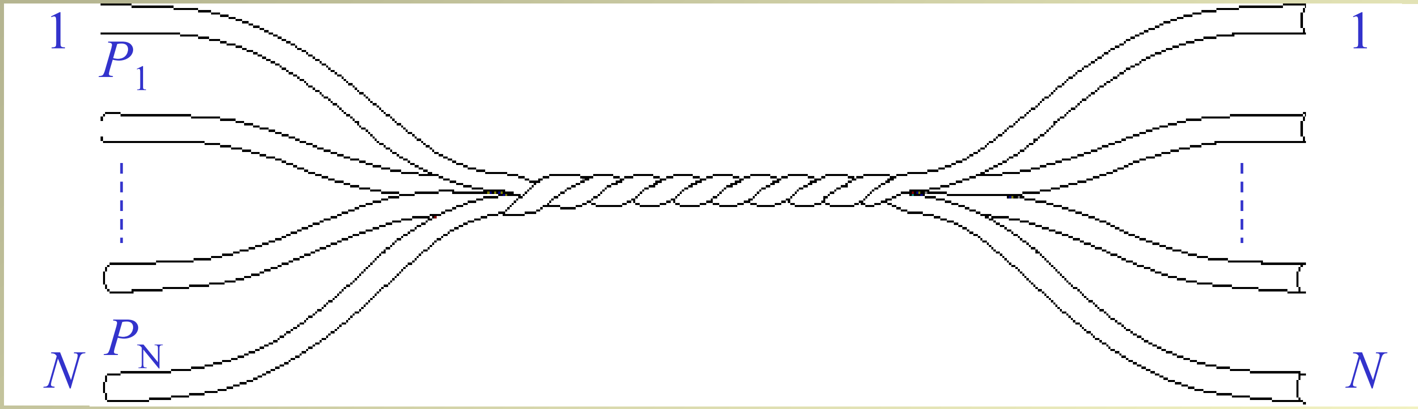
Star Couplers

- Optical couplers with more than four ports.
- Types of star couplers:
  - **transmission star coupler**

    the light at any of the input port is split equally through all output ports.
  - **reflection star coupler**

Fibre Star Coupler

Combines power from *N* inputs and divided them between *M* outputs



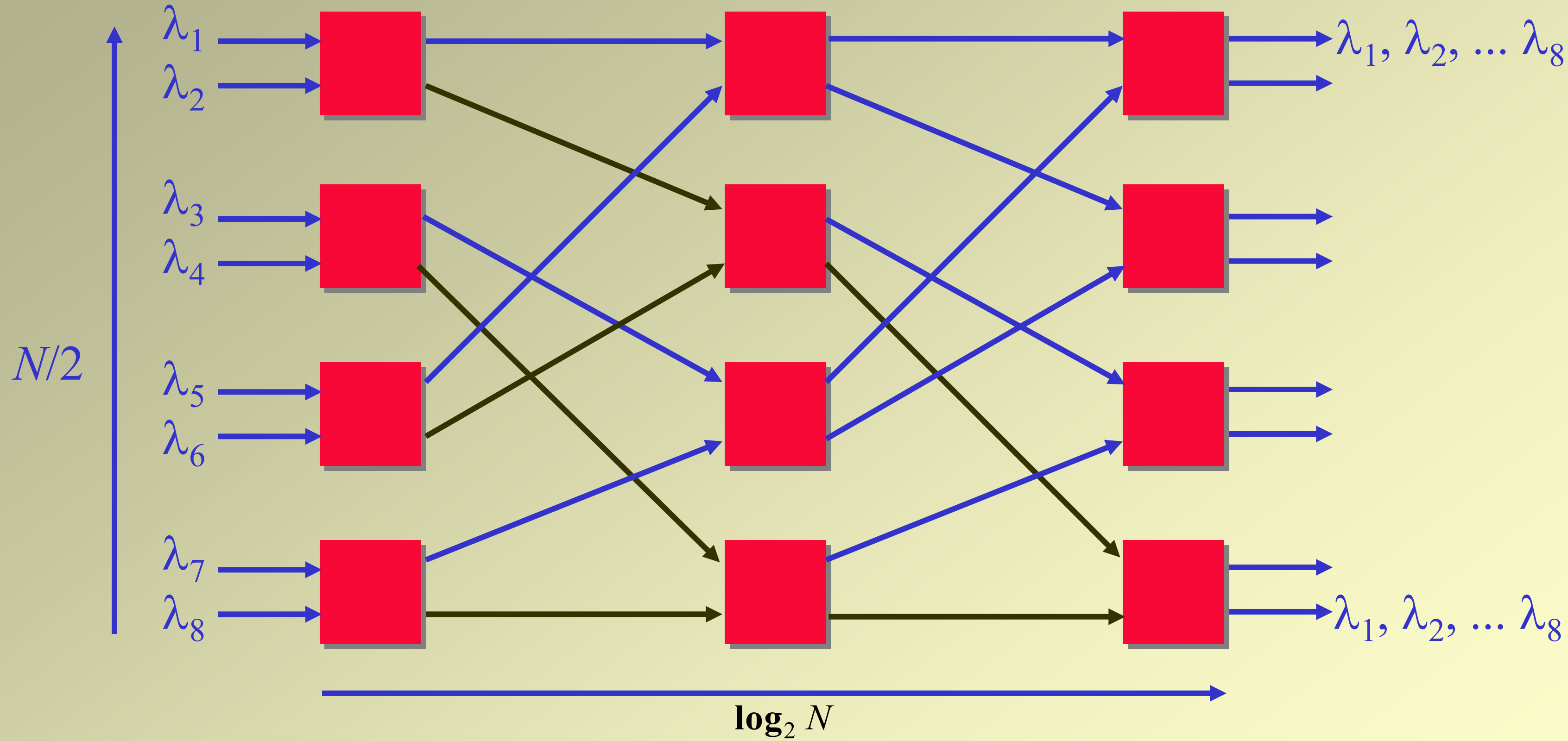
Coupling ratio $$CR = -10\log_{10}\left(\frac{1}{N}\right) = 10\log_{10} N$$

Excess loss $$L_e = 10\log_{10}\left(\frac{P_{in}}{\sum_i^N P_{out,i}}\right)$$

Power at any one output $$P_{o,i} = \frac{1}{n}(P_1 + P_2 + ...P_N)$$

Star Coupler - 8 X 8

Star couplers are optical couplers with more than four ports



No of 3 dB coupler $N_{c-3dB} = \frac{N}{2} \log_2 N$

Star Coupler - 8 X 8 - *contd.*

If a fraction of power traversing each 3 dB coupler = F_p,

where $0 < F_p < 1$.

Then, power lost within the coupler = $1 - F_p$.

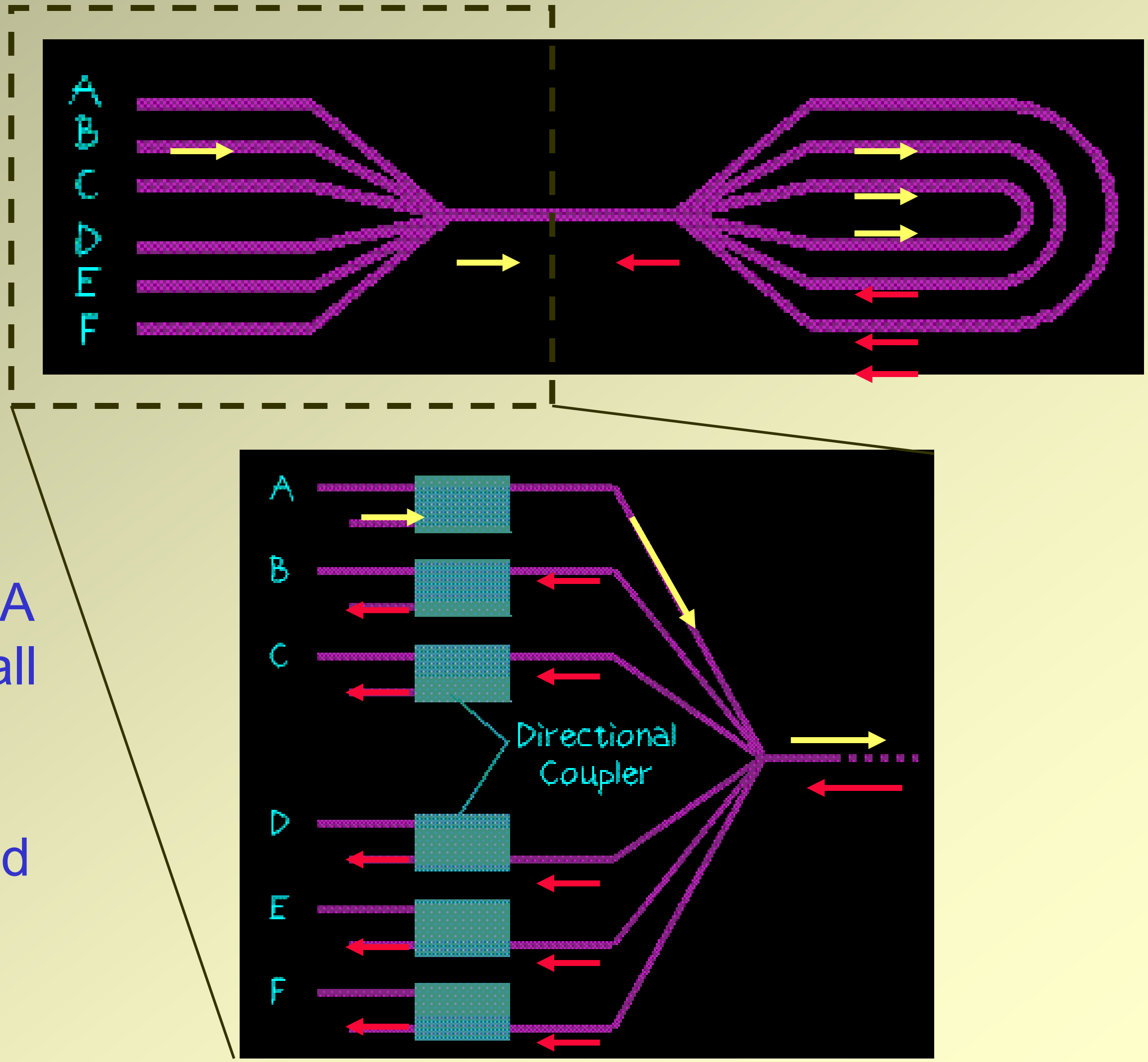
Excess loss $$L_e = -10\log_{10}\left(F_p^{\log_2 N}\right)$$

Coupling ratio (splitting loss) $$CR = -10\log_{10}\left(\frac{1}{N}\right) = 10\log_{10} N$$

Total loss = splitting loss + excess loss

$$L_T = 10(1 - 3.322\log_{10} F)\log_{10} N$$

Reflection Star Couplers

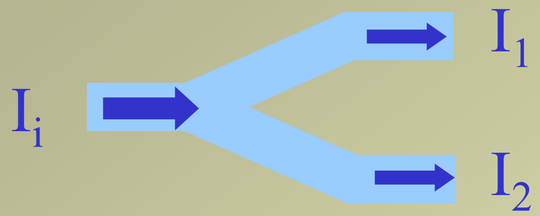


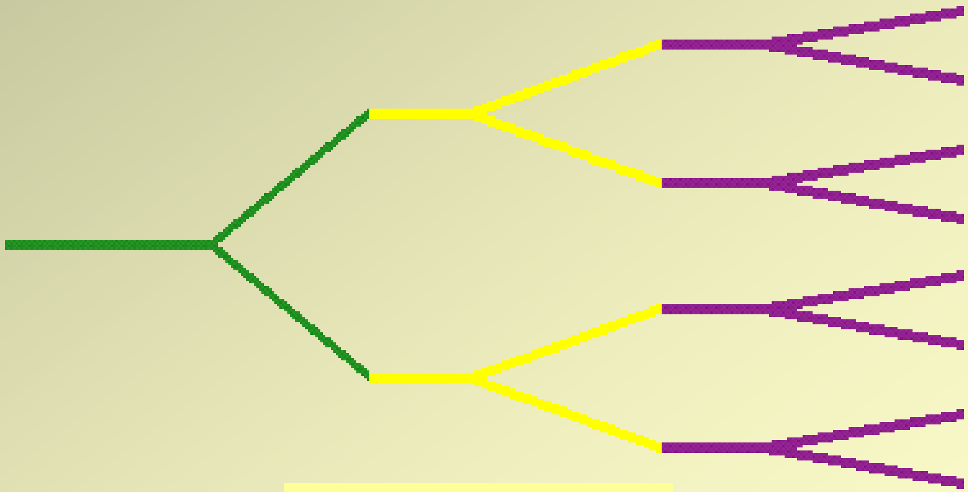
The light arriving at port A and is reflected back to all ports.
A directional coupler separates the transmitted and received signals.

Source: Australian Photonics CRC

Y- Couplers

Are 1 x 2 couplers and are a key element in networking.





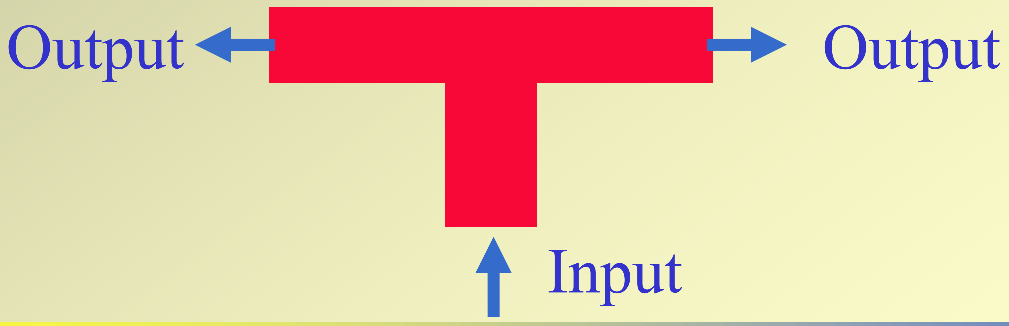
1 X 8 coupler

Coupler - Characteristics

Design class	No. of port	*CR*	*Le* (dB)	Isolation directivity (-dB)
2 x 2 Single mode	2	0.1-0.5	0.07-1.0	40 to 55
2 x 2 Multimode	2	0.5	1-2	35 to 40
N* x *N Star	3-32	0.33-0.03	0.5-8.0	

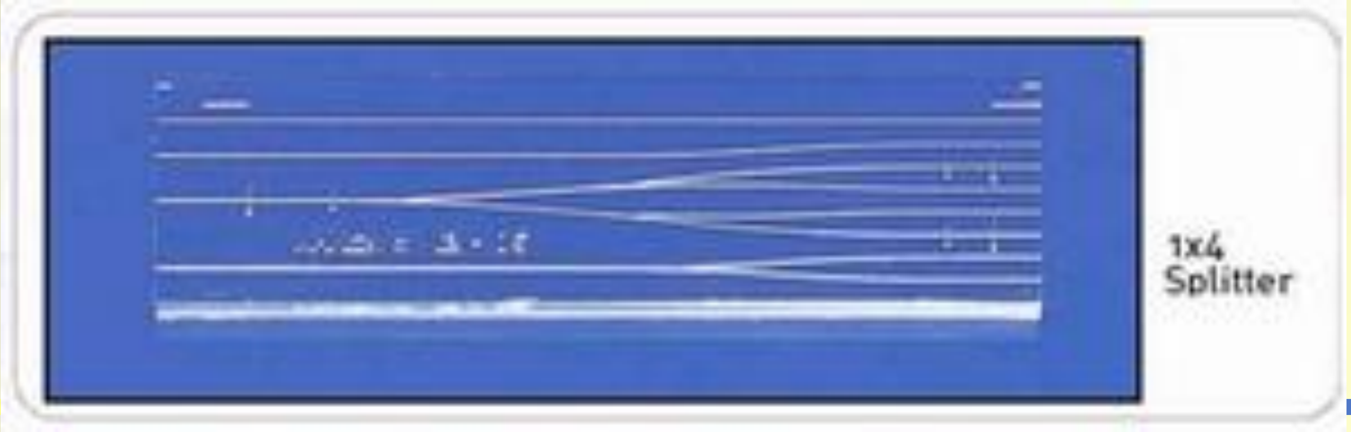
Splitters

- The simplest couplers are fiber optic splitters.
- They possess at least three ports but may have more than 32 for more complex devices.
- Popular splitting ratios include 50%-50%, 90%-10%, 95%-5% and 99%-1%; however, almost any custom value can be achieved.
- Excess loss: assures that the total output is never as high as the input. It hinders the performance. All couplers and splitters share this parameter.
- They are symmetrical. For instance, if the same coupler injected 50 μW into the 10% output leg, only 5 μW would reach the common port.



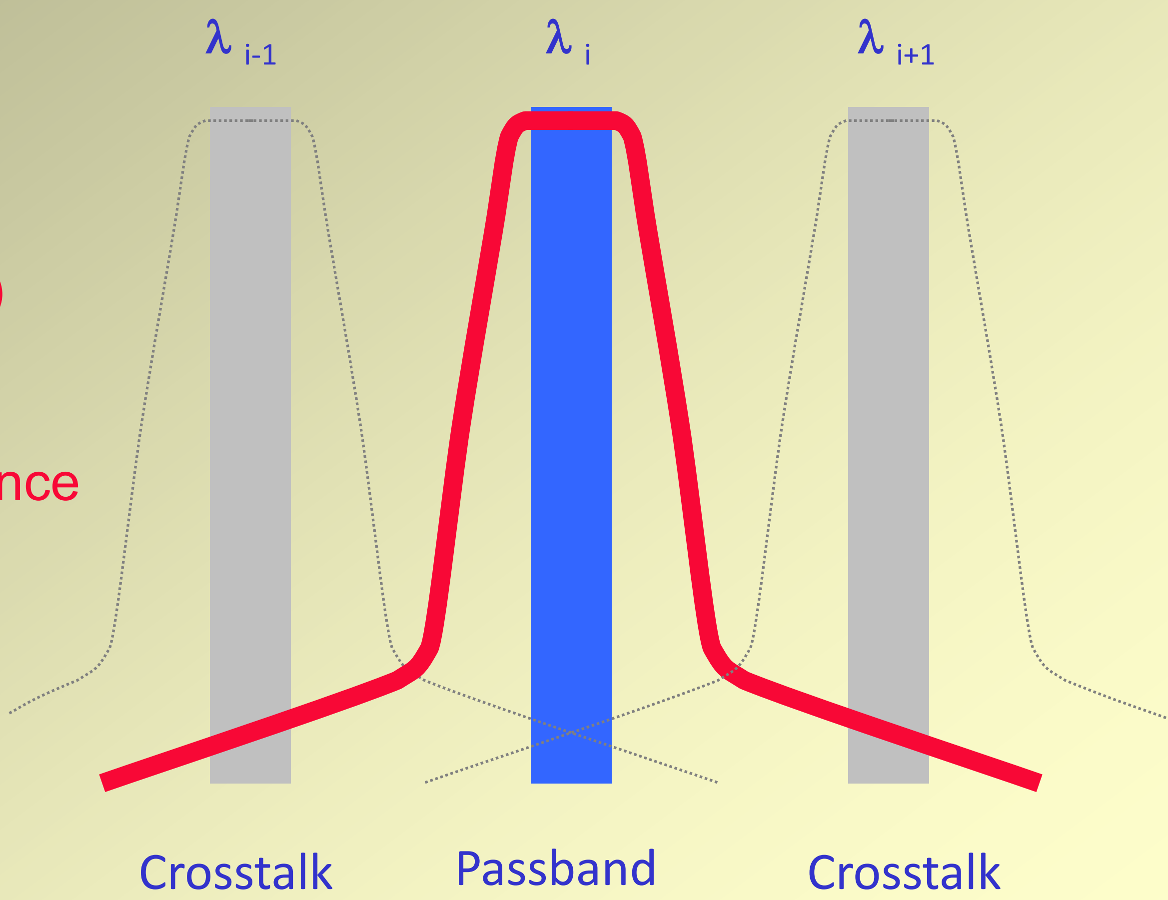
Coupler & Splitter - Applications

- Local monitoring of a light source output (usually for control purposes).
- Distributing a common signal to several locations simultaneously.
- Making a linear, tapped fiber optic bus. Here, each splitter would be a 95%-5% device that allows a small portion of the energy to be tapped while the bulk of the energy continues down the main trunk.



Optical Filters

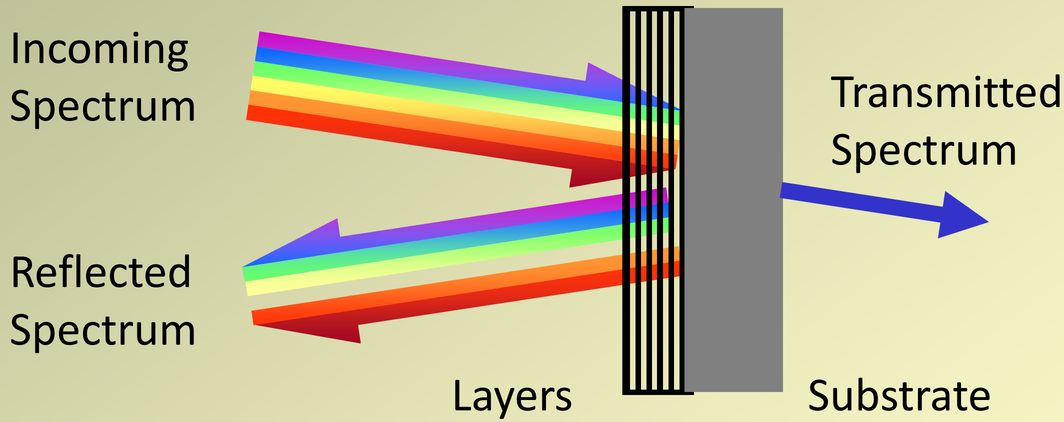
- **Passband**
  - Insertion loss
  - Ripple
  - Wavelengths (peak, center, edges)
  - Bandwidths (0.5 dB, 3 dB, ..)
  - Polarization dependence
- **Stopband**
  - Crosstalk rejection
  - Bandwidths
  - (20 dB, 40 dB, ..)

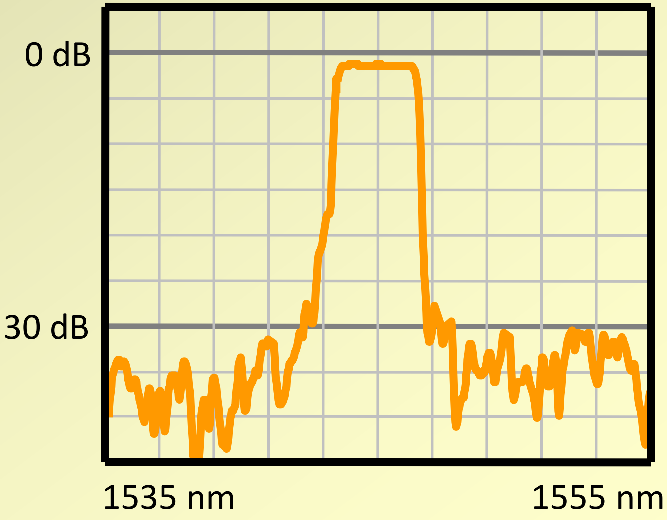


Agilent Tech. LW Div.

Filters - Thin-film Cavities

- Alternating dielectric thin-film layers with different refractive index
- Multiple reflections cause constructive & destructive interference
- Variety of filter shapes and bandwidths (0.1 to 10 nm)
- Insertion loss 0.2 - 2 dB, stopband rejection 30 - 50 dB

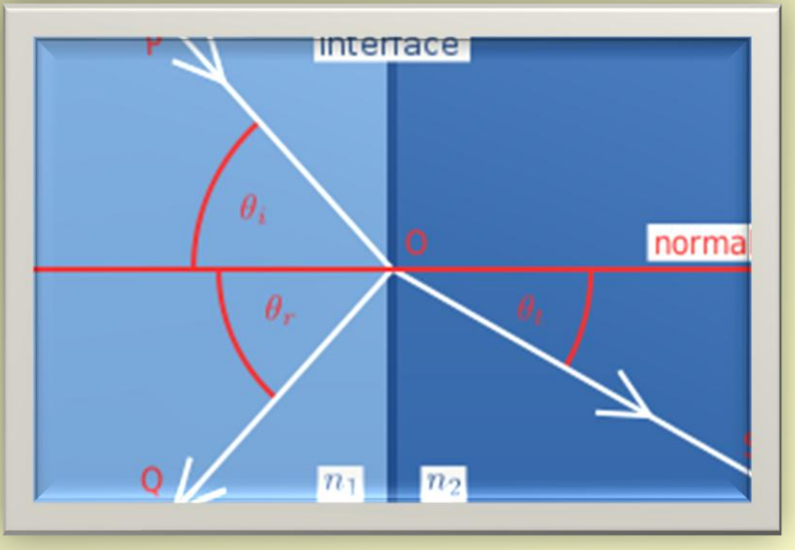




Agilent Tech. LW Div.

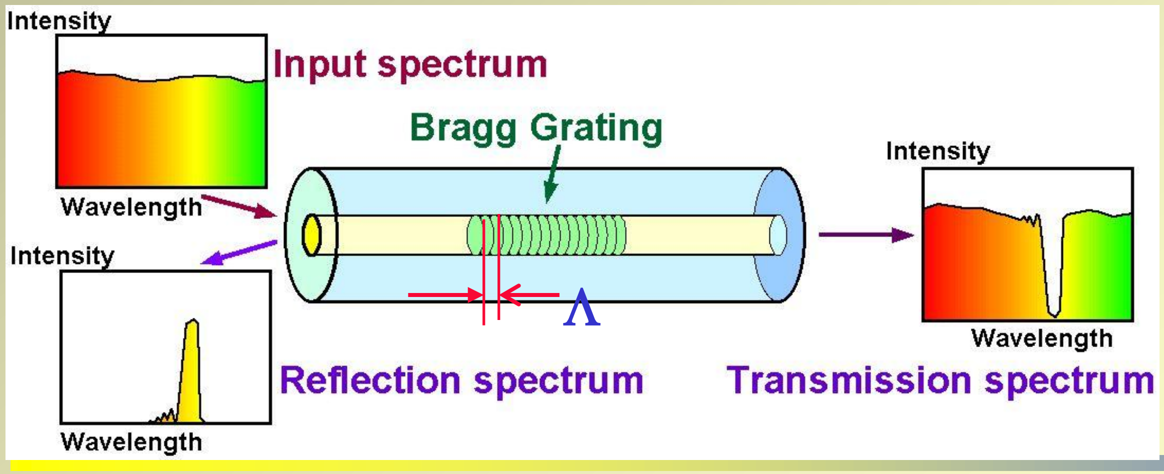
Fiber Bragg Gratings (FBG)

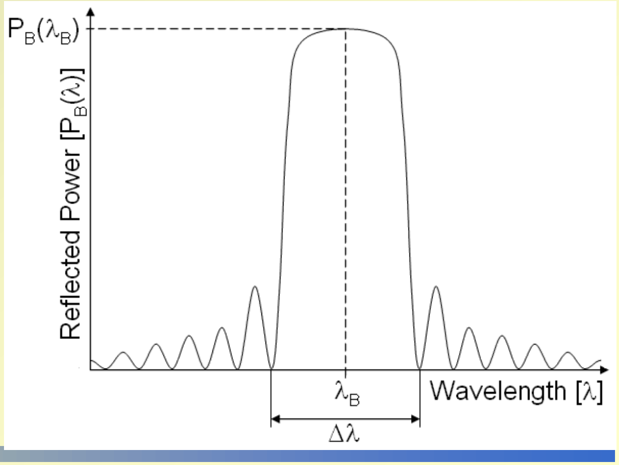
- Fresnel reflection: The main principle behind FBG operation
  - which describe the performance of light moving between media having differing refractive indices.



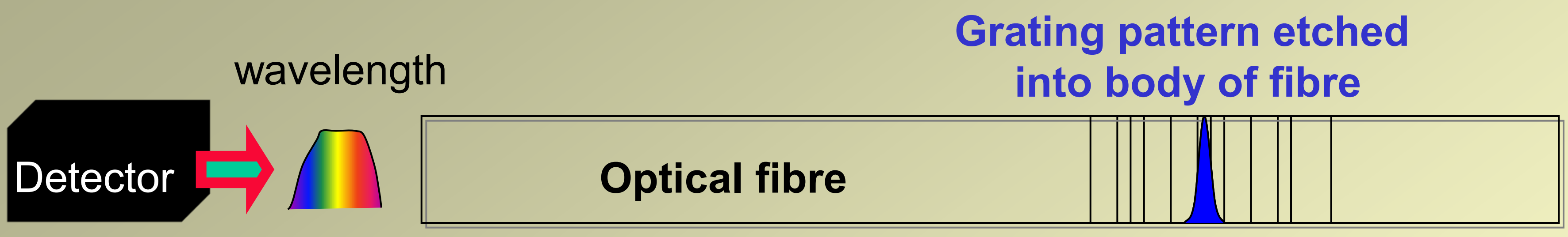
Fiber Bragg Gratings (FBG)

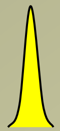
- FBG is a periodic refractive index variation (**Period Λ**) written along the fibre (single-mode) core using high power UV radiation.
- All the wavelengths statisfying the condition $\lambda_0 = 2\,\Lambda\, n_{eff}$ are reflected
- If the optical period is $\lambda_0 / 2$, the grating reflects wavelength λ_0 selectively. Useful in filtering communication channels in or out.



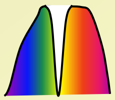


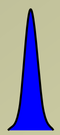
Fiber Bragg Gratings (FBG)



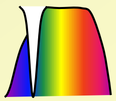


For a given grating period a particular wavelength (frequency) of light is reflected. In this case yellow light will be reflected





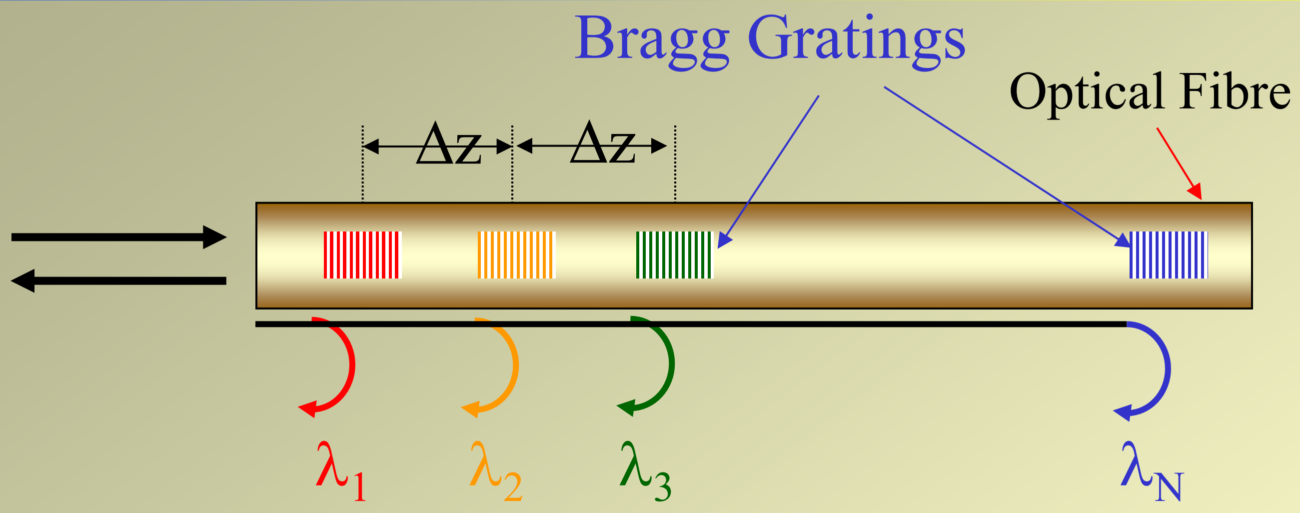
If the grating spacing is changed (e.g. reduced due to compression of the fibre or a drop in temperature} the wavelength of the reflected light changes. In this case it becomes higher and reflects blue light



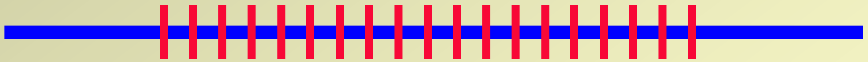
In practice the colour shifts will be much finer than those illustated

http://www.co2sink.org/ppt/fbganimation.ppt

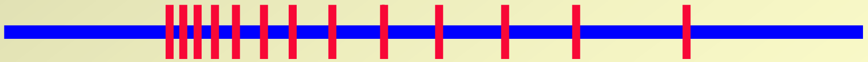
FBG - *contd.*



- **Regular interval pattern:** reflective at *one* wavelength
  - Notch filter, add / drop multiplexer (see later)



- Increasing intervals: “chirped” FBG compensation for chromatic dispersion



FBG - Applications

- Notch filter
- Optical multiplexers
- Optical demultiplexers
- Optical add-drop multiplexers
- Dispersion compensation
- Optical sensor
-

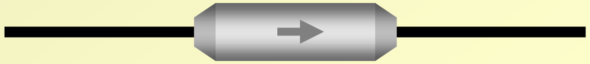
Optical Isolators

Only allows transmission in one direction

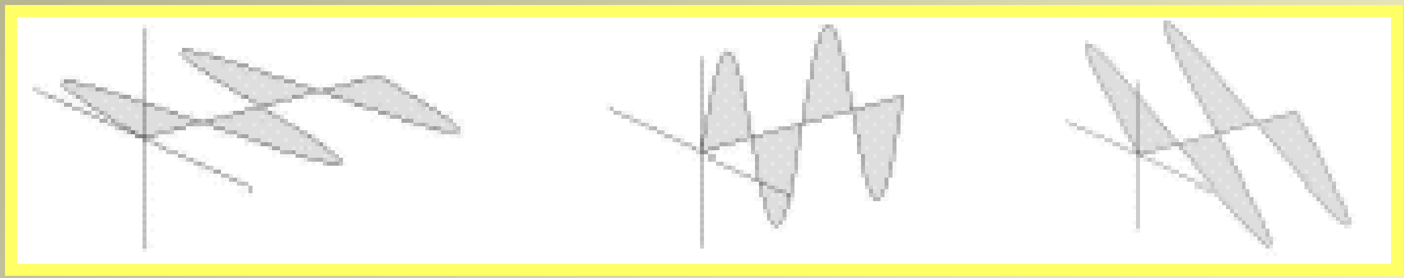
– **Main application:** To protect lasers and optical amplifiers from returning reflected light, which can cause instabilities

- **Insertion loss:**
  – Low loss (0.2 to 2 dB) in forward direction
  – High loss in reverse direction:
  20 to 40 dB single stage, 40 to 80 dB dual stage)

- **Return loss:**
  – More than 60 dB without connectors



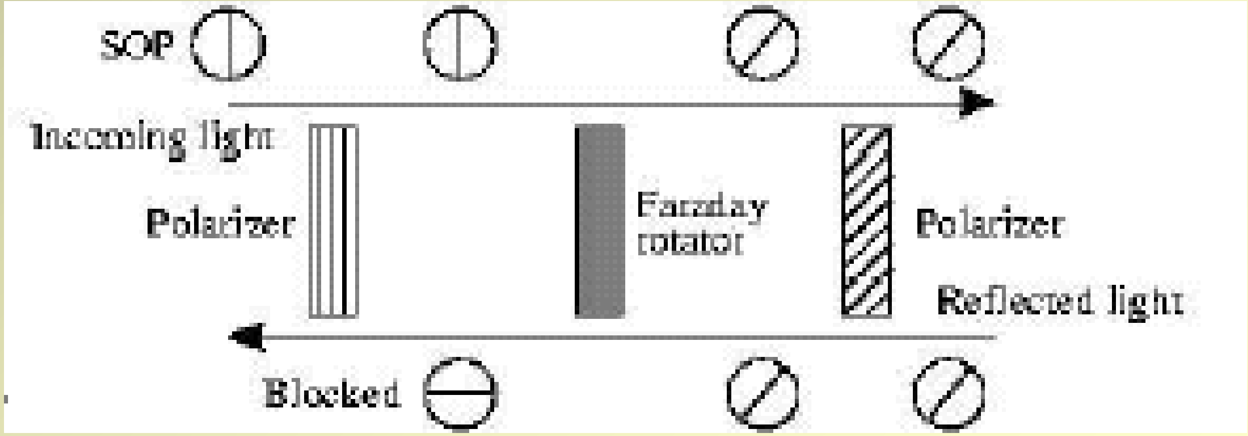
Principle of operation



Horizontal polarisation

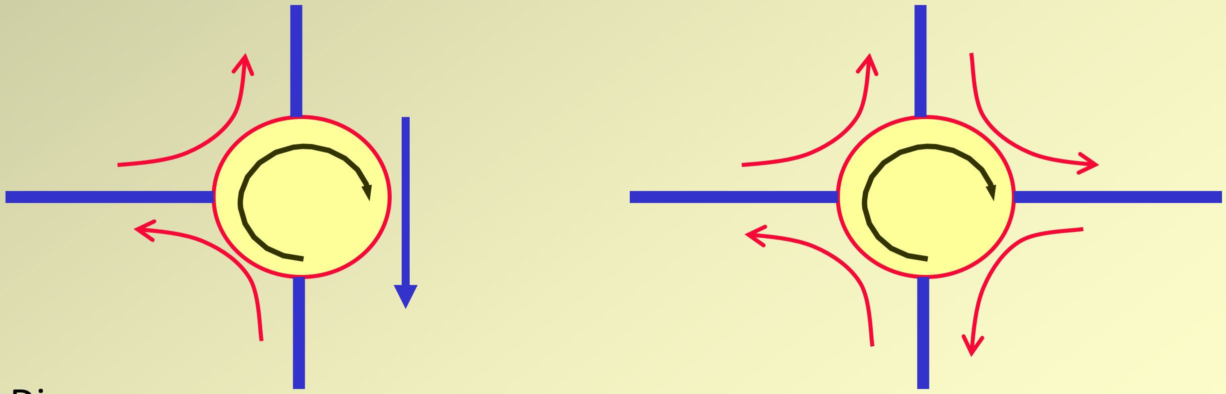
Vertical polarisation

Linear polarisation



Optical Circulators

- Based on optical crystal technology similar to isolators
  - Insertion loss 0.3 to 1.5 dB, isolation 20 to 40 dB
- Typical configuration: 3 port device
  - Port 1 -> Port 2
  - Port 2 -> Port 3
  - Port 3 -> Port 1



Agilent Tech. LW Div.

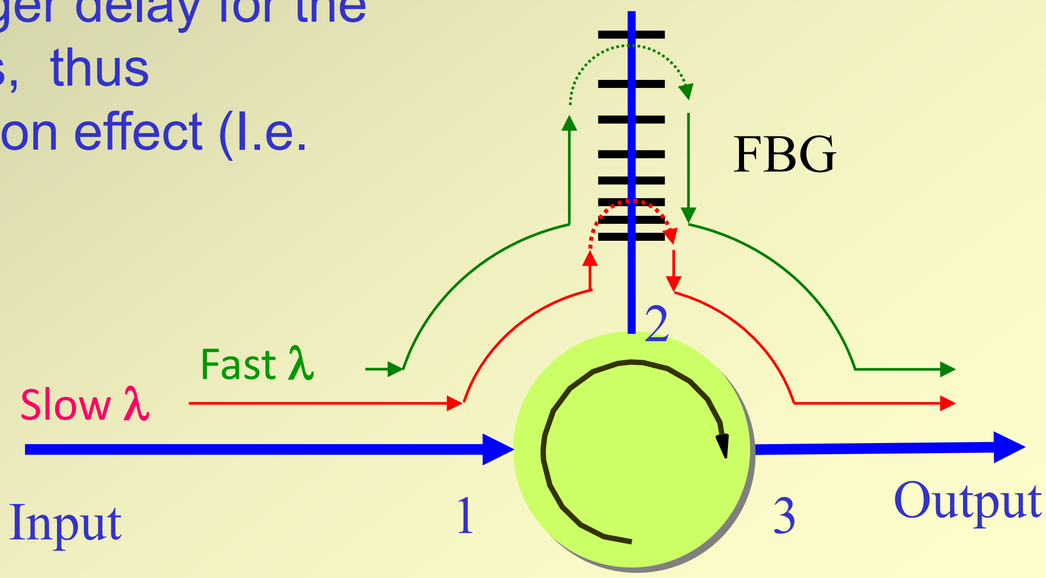
Dispersion Compensation using Chirped FBG and Circulator

- FBG is linearly chirped:

  the grating period varies linearly with position. Thus the grating reflects back different wavelengths at different points along its length. **Therefore, introducing different delay**.

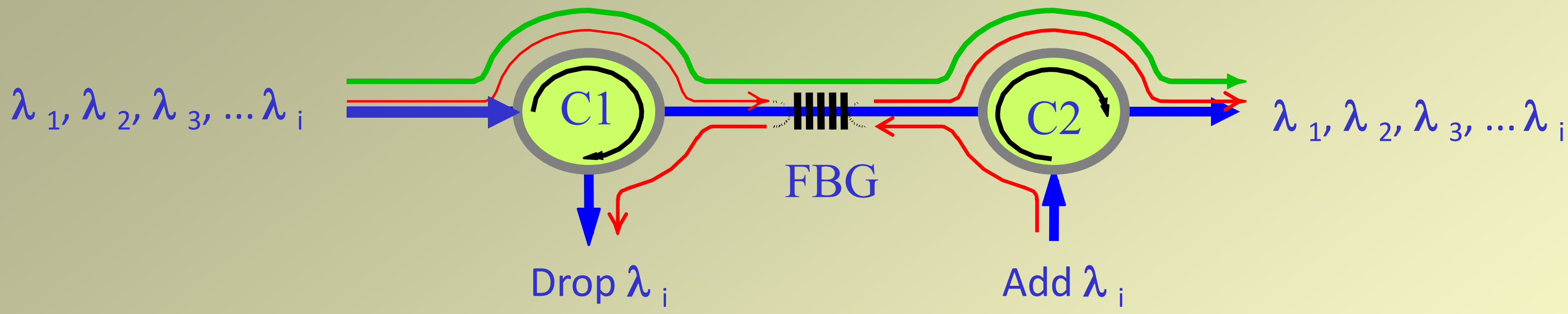
- In a standard fibre chromatic dispersion introduces larger delay for lower frequency (high wavelength) components of a pulse.

- Chirped FBG introduces larger delay for the higher frequency components, thus compensating for the dispersion effect (I.e. compressing the pulse)

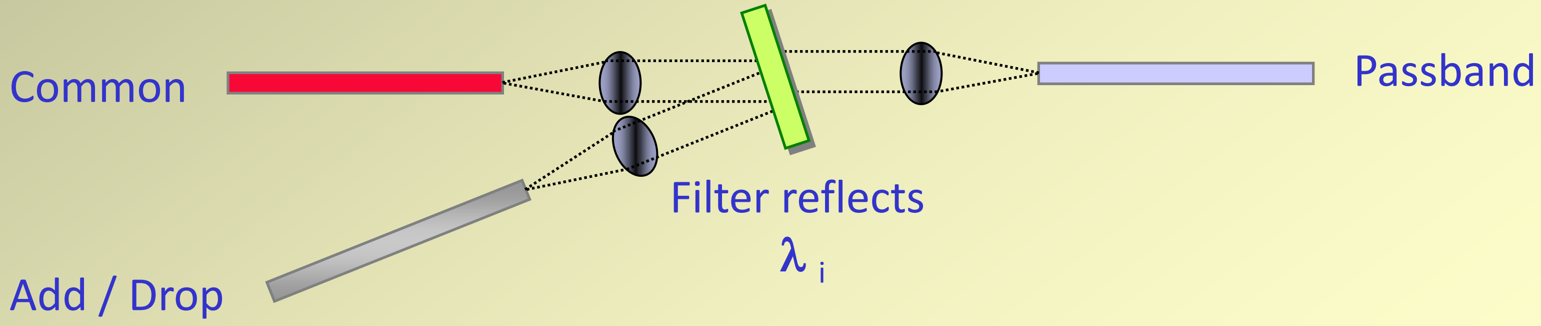


Add - Drop Multiplexers

- **Circulator with FBG**



- **Dielectric thin-film filter design**



Agilent Tech. LW Div.

Optical ADMux

- Utilizes the full spectrum of the C and L band: 160 channels / single fibre pair
- Allows for the direct interface and transport of data rates from 100 Mbps to 10 Gbps
- Transports up to 160 OC-192 signals with a capacity of 1.6 Tb/s

Transmit wavelength adaptor

Error detection and correction

Optical amplifier:
- Gain 25 dB
- Noise figure 5 dB

Receive wavelength adaptor

Wavelength Add/Drop

Network management

Optical supervisory channel

ADMux – System Performance

Capacity:

- 80 channels on ITU 50 GHz spacing:
- Upgradeable to 160 Channels (C and L band)

Bit Rate Compatibility: 100 Mbps to 10 Gbps (OC-192)

Span Performance:

- 13 spans with 25 dB loss per span (OC-48)
- 10 spans with 25 dB loss per span (OC-192)

Bit Error Rate: Better than 10^{-16}

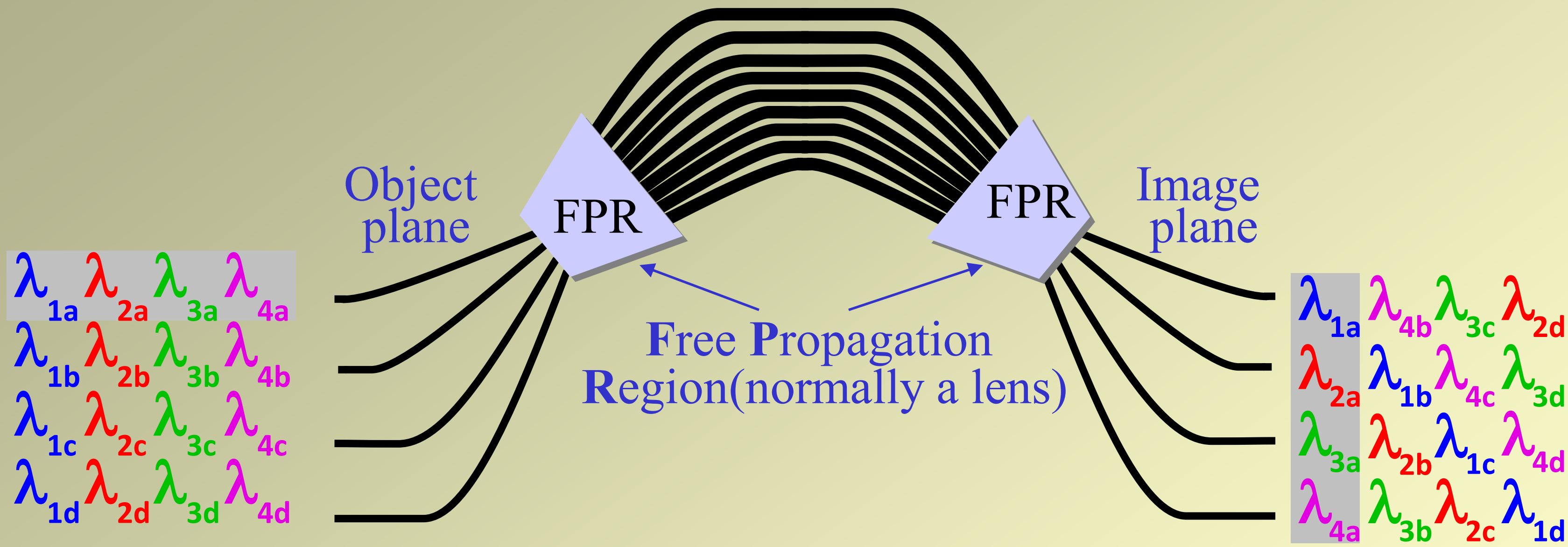
Dispersion Tolerance:

- 600 to 900 ps/nm at 10 Gbps
- > 12,000 ps/nm at 2.5 Gbps

Multiplexers (MUX) / Demultiplexers (DEMUX)

- Key component of wavelength-division multiplexing (WDM) technology
- Types of technologies
  - Cascaded dielectric filters
  - Cascaded FBGs
  - Phased arrays (see later)
- Low crosstalk is essential for demultiplexing

Array Waveguide Grating (AWG)



Rows .. **.. translate into ..** **.. columns**

- N X N demultiplexer
- 1 X N demultiplexer!

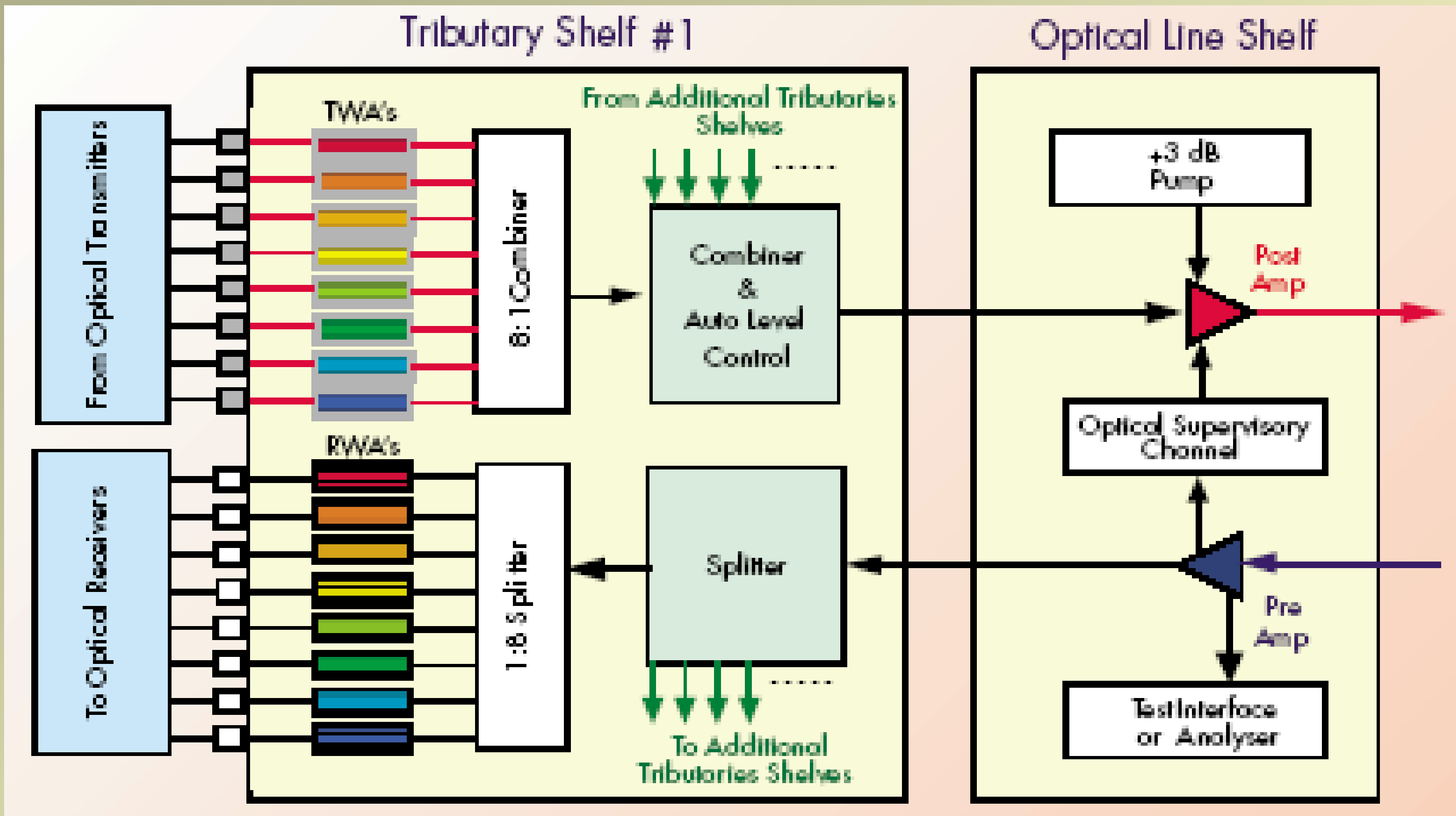
Agilent Tech. LW Div.

AWG - *contd.*

- Each λ experience a different phase shift because of different lengths of waveguide.
- Phase shifts wavelength are dependent.
- Thus, different channels focus to different output WG, on exit.
- N-input and N-output fibres
- Single input: wavelength demultiplexer!

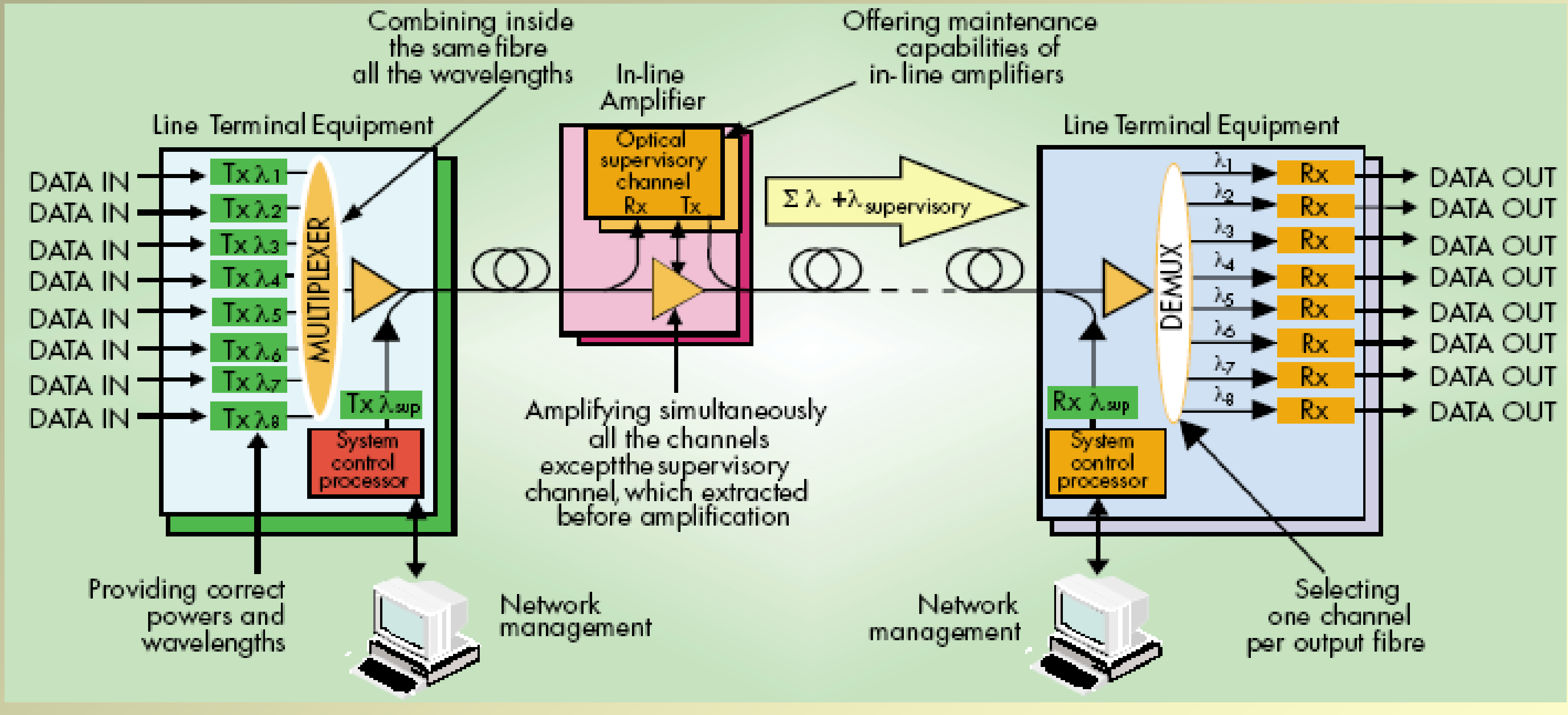
- 1990s - First developed
- 1999 - Commercially available
- No. of channels: 250 to 1000 @ spacing of 10 GHz.

Multiplexers



Alcatel 1640 Line Terminal block diagram

Multiplexers – Supervisory Channel



This extra channel, at 1510 nm, carries all the management information. It also transports Electrical Order Wire (EOW) data channels, service channels, and control commands for house keeping contacts.

Alcatel 1640 Line Terminal block diagram

Multiplexers

- Transmission lengths of more than 900 km can be achieved on a 0.25 dB/km fibre.
- The 240 channels using 3 optical bands:
  - C (1530–1570 nm)
  - L (1570–1610 nm)
  - S (1450–1490 nm)
- Error detection and correction
- Different synchronous bit rate
- Multi bit rae: 2.5 Gbps, 10 Gbps and 40 Gbps
- Judged by the insertion loss/channel

MUX - DeMUX - Performance

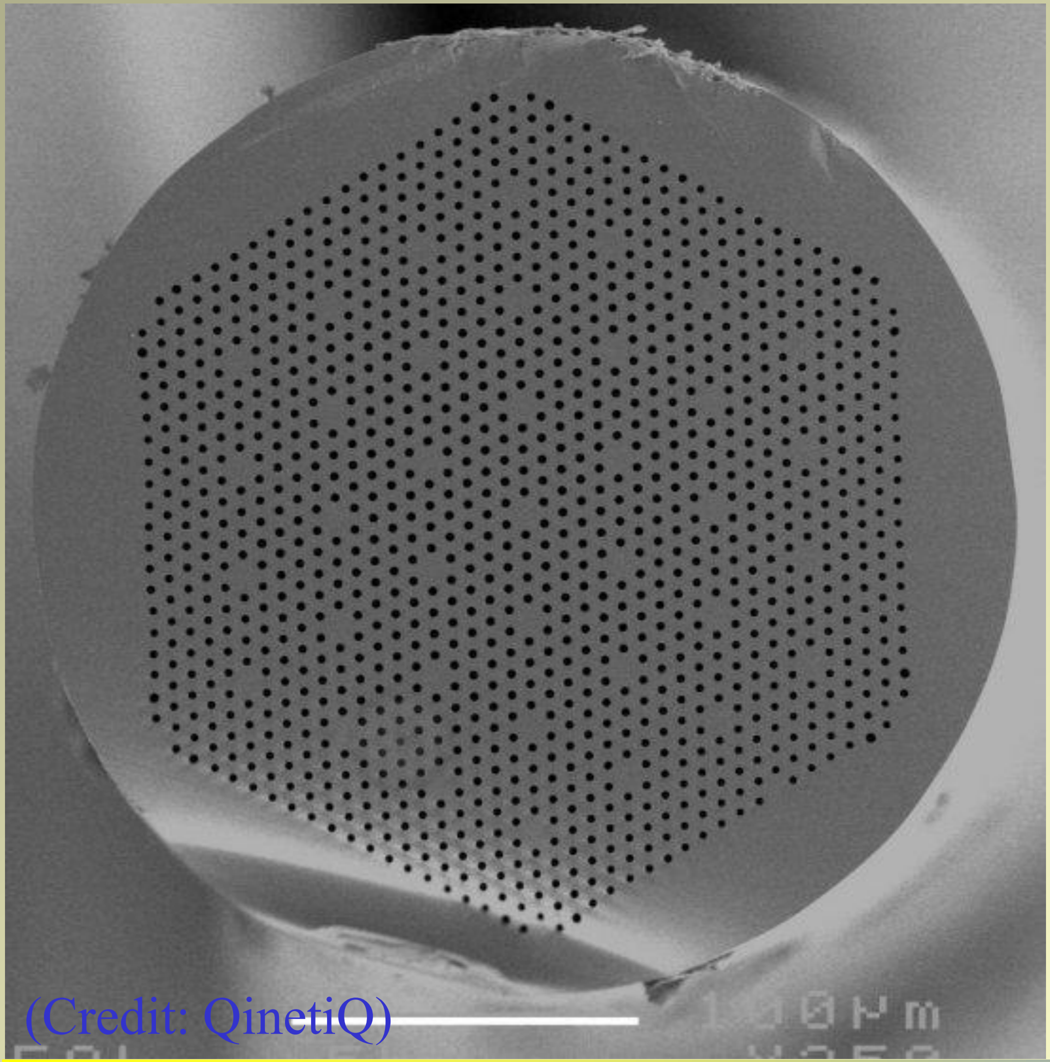
MUX

- Judged by the insertion loss/channel

DeMUX

- Sensitivity to polarisation
- Crosstalk (< -20 dB)

Microstructured Fibre (MsF)



- A MsF with 37 light carrying cores packed into record density of 1150/mm2.
- Applications:
  - LANs
  - Storage area networks
  - Connections to backplanes
  - Connections between electronic processors.

References

- http://oldsite.vislab.usyd.edu.au/photonics/index.html

Next Lectures

- Optical amplifier
- Optical Switches