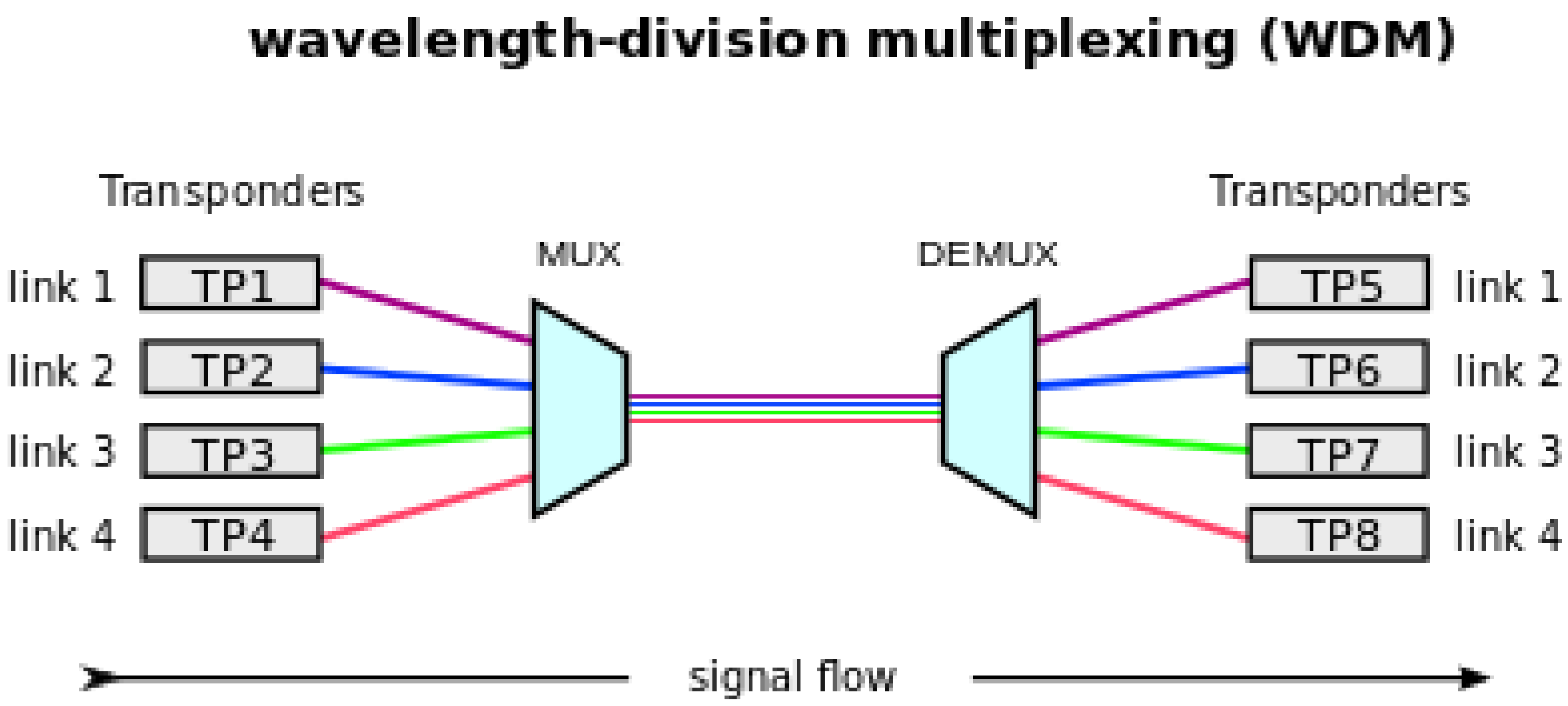


Module – 6
WDM Concepts and Components

Passive components

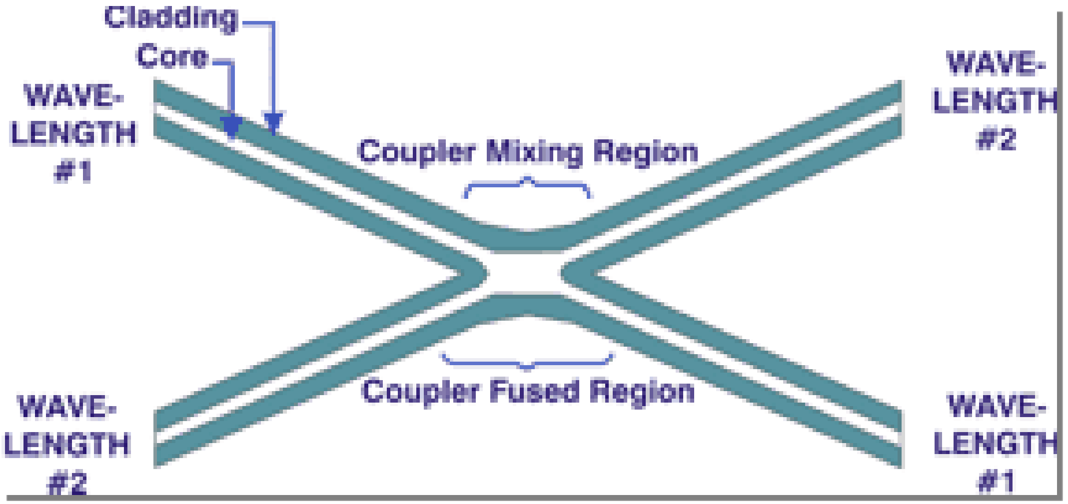
- Operates completely in optical domain
- Split and combine light signals
- N X N coupler, splitter, taps and star coupler
- Fabricated from optical fiber, integrated optical waveguides and bulk micro optics

Passive components and its functions

- Transfer energy: optical fibers
- Attenuate light signals: optical attenuators, isolators
- Influence the spatial distribution of a light wave: directional coupler, star coupler, beam expander
- Modify the state of polarization: polarizer, half-wave plates, Faraday rotator
- Redirect light: circulator, mirror, grating
- Reflect light: Fiber Bragg gratings, mirror
- Select a narrow spectrum of light: optical filter, grating
- Convert light wave modes: fiber gratings, Mach-Zehnder interferometer
- Combine or separate independent signals at different wavelengths: WDM device

Optical Couplers

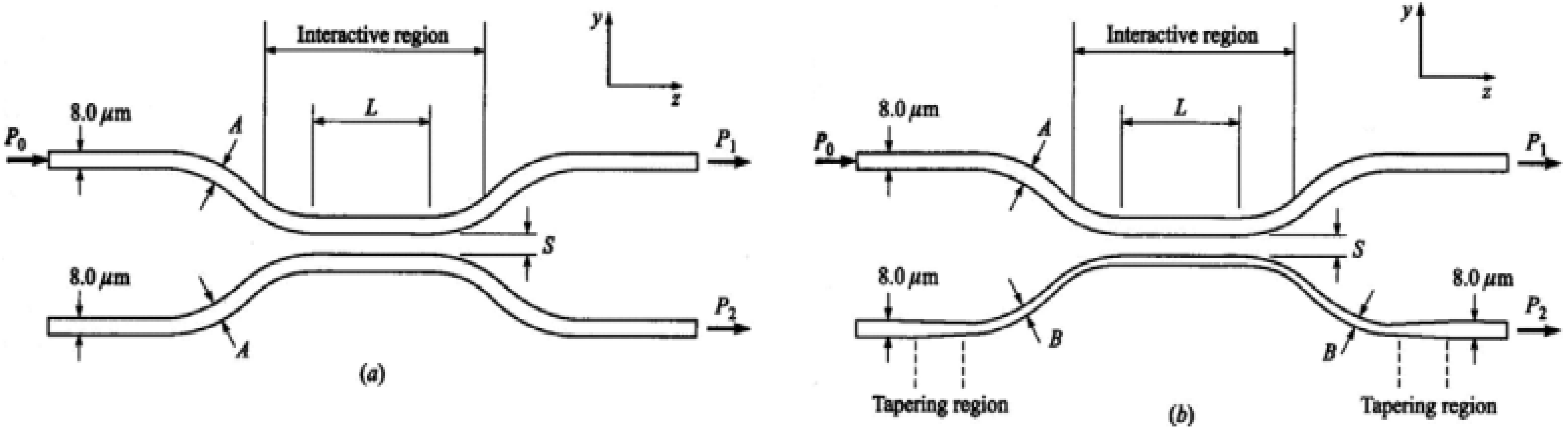
- Optic couplers either split optical signals into multiple paths or combine multiple signals on one path.
- The number of input (N)/ output (M) ports, (i.e.s N x M size) characterizes a coupler.
- Fused couplers can be made in any configuration, but they commonly use multiples of two (2 x 2, 4 x 4,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



Applications of couplers

- Uses
  - Splitter: (50:50)
  - Taps: (90:10) or (95:05)
  - Combiners
- An important issue:
  - two output differ $\pi/2$ in phase
- Applications:
  - Optical Switches
  - Mach Zehnder Interferometers
  - Optical amplifiers
  - Passive star couplers

2 X 2 Waveguide coupler



(a) uniformly symmetric directional waveguide coupler, (b) uniformly asymmetric directional coupler

- Analogues to fused fiber couplers, waveguide devices have an intrinsic wavelength dependence in the coupling region and the degree of interaction between the guides can be varied through the guide width w, the gap s between the guides and the refractive index n_1 between the guides.

2 X 2 Waveguide coupler

- In real waveguides, with absorption and scattering losses, the propagation constant β_z is the complex number given by

$$\beta_z = \beta_r + j\frac{\alpha}{2}$$

- The total power contained in both guides decreases by the factor of exp($-\alpha z$) along its length.
- The transmission characteristics of the symmetric coupler can be expressed through the coupled mode theory approach to yield

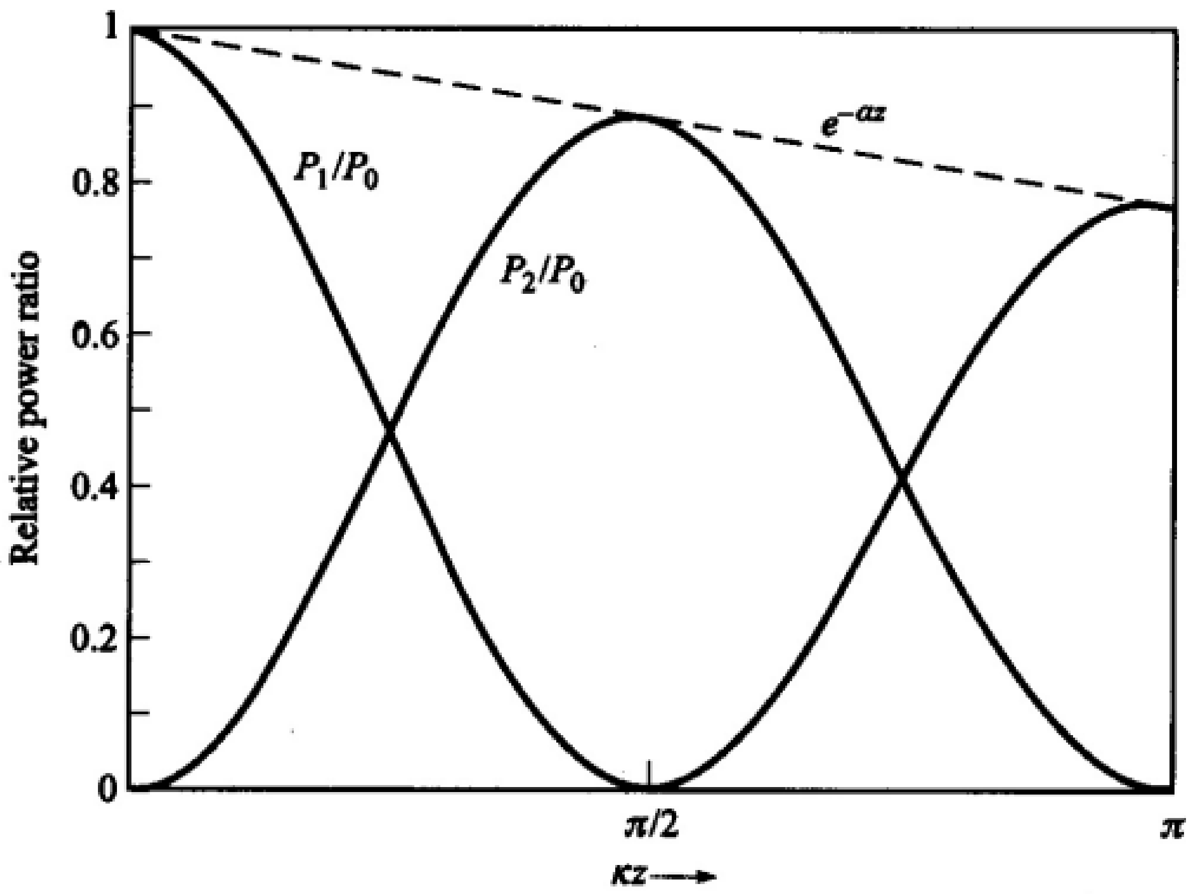
$$P_2 = P_0 \sin^2(kz)e^{-\alpha z}$$

- where k is the coupling coefficient and q is the extinction coefficient

$$k = \frac{2\beta_y^2 q e^{-qs}}{\beta_z w\left(q^2 + \beta_y^2\right)} \qquad q^2 = \beta_y^2 - k_1^2$$

2 X 2 Waveguide coupler

- The theoretical power distribution as a function of the guide length is shown below.

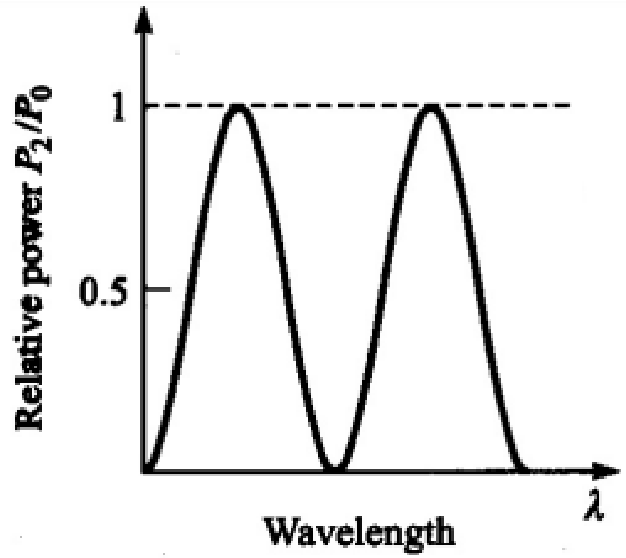


2 X 2 Waveguide coupler

- The complete power transfer to the second guide occurs when the guide length L is

$$L = \frac{\pi}{2k}(m+1) \qquad \text{with } m = 0,1,2,\ldots$$

- The coupling ratio P_2/P_0 raises and falls sinusoidally from 0 to 100 percent as a function of wavelength is given below.



Splitting ratio/ Coupling ratio

- The percentage division of optical power between the output ports

$$SplittingRatio = \left(\frac{P_2}{P_1 + P_2} \right) \times 100\%$$

- 3 dB coupler – Power equally splitted into each of the output

- 1550 nm to one port and 1310 nm to other port

Excess loss

- It is defined as the ratio of the input power to the total output power

$$ExcessLoss = 10\log\left(\frac{P_0}{P_1 + P_2}\right)$$

Insertion loss

- It refers to the loss for a particular port to port path.
- For the path from input port i to output port j,

$$InsertionLoss = 10\log\left(\frac{P_i}{P_j}\right)$$

Crosstalk

- Crosstalk is a measure of degree of isolation between the input at one port and the optical power scattered or reflected back into the other port

$$Crosstalk = 10\log\left(\frac{P_3}{P_0}\right)$$

Numerical Problem

- A symmetric waveguide coupler has a coupling coefficient of 0.6 /mm. Calculate the coupling length at m=1.

Numerical Problem

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$$L = \frac{\Pi}{2k}(m+1) = 5.24mm$$

Numerical Problem

- A 2X2 biconical tapered fiber coupler has an input power of $P0=200\mu W$. The output powers at the three ports are $P1=90\mu W$ (Throughput), $P2=85\mu W$ (coupled) and $P3=6.3nW$ (crosstalk). Calculate the coupling ratio, excess loss, insertion loss (port 0 to port 1 and port 0 to port 2) and the crosstalk.

Numerical Problem

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$$SplittingRatio = \left(\frac{P_2}{P_1 + P_2}\right) \times 100\% = \left(\frac{85}{90+85}\right) = 48.6\%$$

$$ExcessLoss = 10\log\left(\frac{P_0}{P_1 + P_2}\right)$$

$$= 0.58 dB$$

$$InsertionLoss = 10\log\left(\frac{P_i}{P_j}\right)$$

Insertion loss (port 0 to port 1) = 3.47 dB

Insertion loss (port 0 to port 2) = 3.72 dB

$$Crosstalk = 10\log\left(\frac{P_3}{P_0}\right) = -45 dB$$

Numerical Problem

- A bi-conical tapered coupler with 36/64 splitting ratio states that the insertion losses are 3.2 dB for the 64% channel and 5.6 dB for the 36% channel.
- If the input power is 300 μW, find the output power levels P1 and P2.
- Find the excess loss of the coupler
- From the calculated values of P1 and P2, verify that the splitting ratio is 36/64.

Numerical Problem

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$$InsertionLoss = 10\log\left(\frac{P_i}{P_j}\right)$$

$$3.2dB = 10\log\left(\frac{300}{P_1}\right)$$

$$P_1 = 10^{(\log 300 - \frac{3.2}{10})} = 144\mu W$$

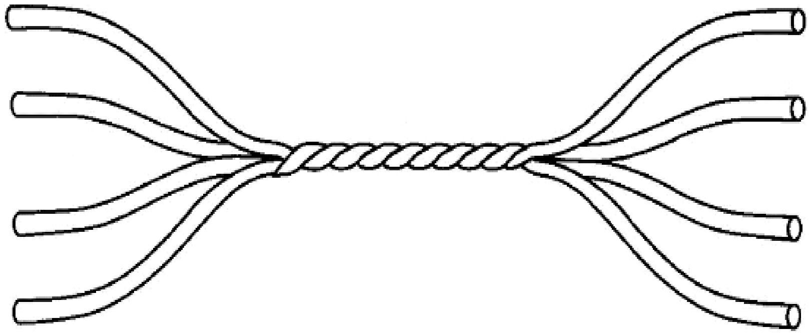
$$P_2 = 10^{(\log 300 - \frac{5.6}{10})} = 82.6\mu W$$

$$ExcessLoss = 10\log\left(\frac{P_0}{P_1 + P_2}\right) = 1.2dB$$

$$\left(\frac{P_1}{P_1 + P_2}\right) = 64\% \qquad \left(\frac{P_2}{P_1 + P_2}\right) = 36\%$$

Star coupler

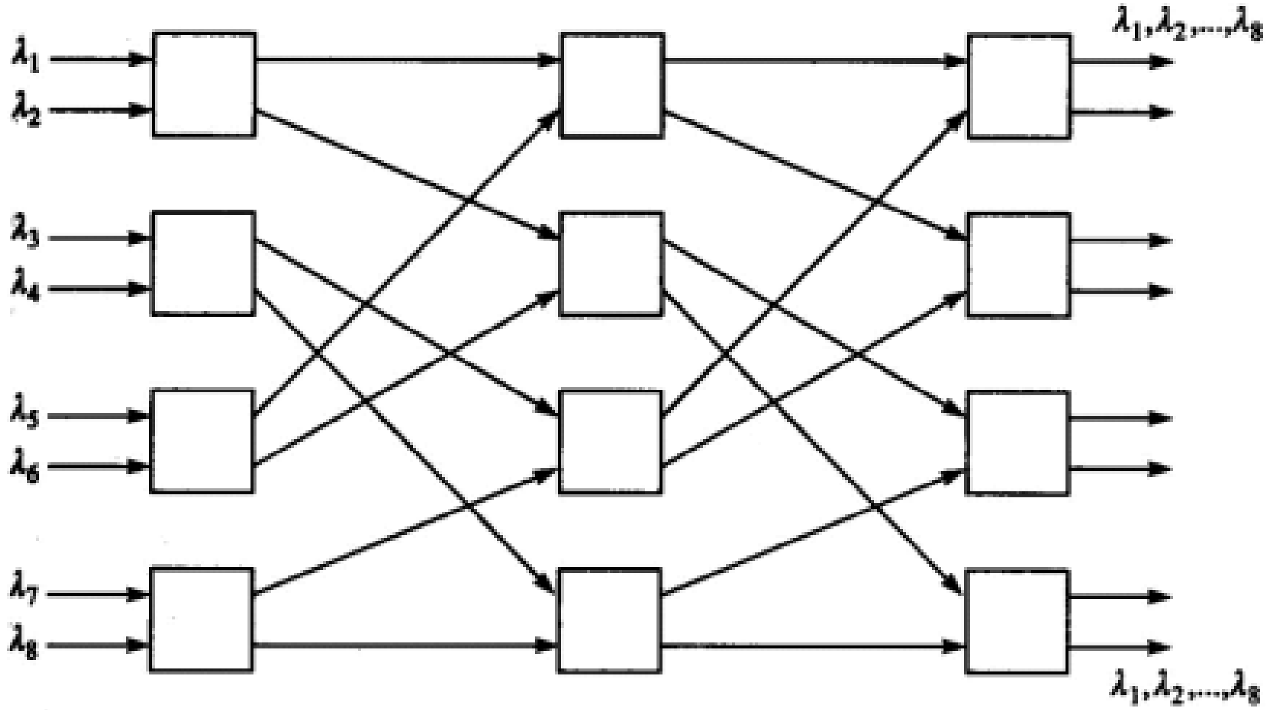
- Combines power from N input ports and divide equally among M output ports
- Techniques for creating star couplers
  - Fused fibers
  - Gratings
  - Micro optic technologies
  - Integrated optics
- Difficulty in controlling the coupling response between numerous fibers



4 x 4 fused star coupler

Star coupler

- An alternative way to construct a star coupler is by cascading 3 dB couplers .
- A 8 x 8 star coupler formed by using twelve 2 x 2 couplers is shown below.



- The number of 3 dB couplers needed to construct a N x N star coupler is $N = \frac{N}{2}\log_2(N)$

Total loss

- The total loss of the device is splitting loss plus excess loss

$$SplittingLoss = 10\log(N)$$

$$ExcessLoss = -10\log\left(F_T^{\log_2 N}\right)$$

- N is the coupler size and F_T is fraction of power traversing each 3 dB coupler element.

Numerical Problem

- Consider a 64 x 64 single-mode coupler made from a cascade of 3-dB fused-fiber 2 x 2 couplers, where 10 percent of the power is lost in each element. Calculate the number of 3 dB coupler required to construct the 64 x 64 star coupler and also determine the total loss for this coupler.

Numerical Problem

- Consider a 64 x 64 single-mode coupler made from a cascade of 3-dB fused-fiber 2 x 2 couplers, where 10 percent of the power is lost in each element. Calculate the number of 3 dB coupler required to construct the 64 x 64 star coupler and also determine the total loss for this coupler.

$$N = \frac{N}{2}\log_2(N) = 192$$

$$SplittingLoss = 10\log\left(N\right) = 18.06dB$$

$$ExcessLoss = -10\log\left(F_T^{\ \log_2 N}\right) = 2.75dB$$

$$TotalLoss = 20.81dB$$

Facts about polarization and polarization-sensitive components

- Light can be represented as a combination of a parallel vibration and a perpendicular vibration, which are called the two orthogonal plane polarization states of a light wave.

- A polarizer is a material or device that transmits only one polarization component and blocks the other.

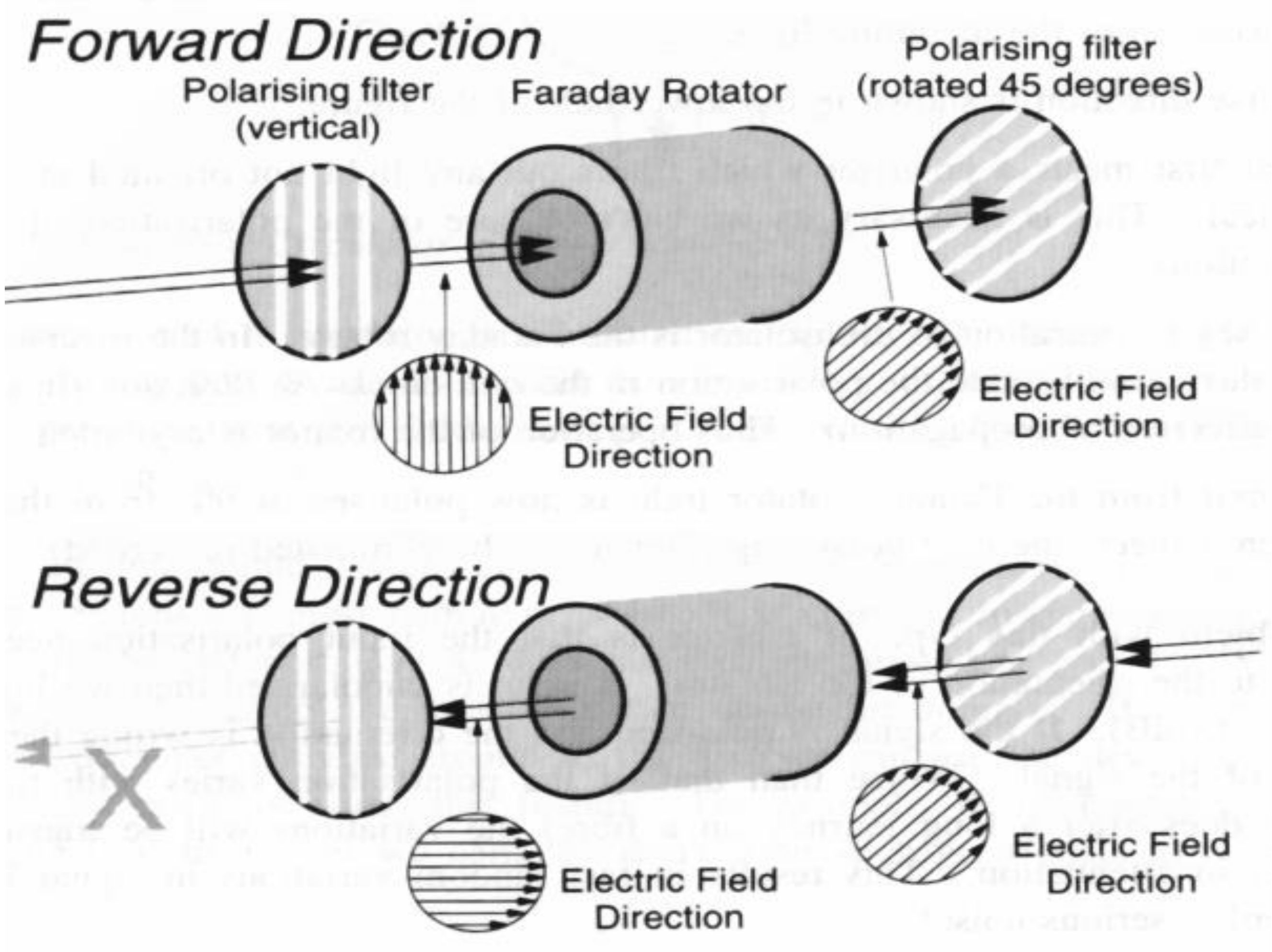
- A Faraday rotator is a device that rotates the state of polarization (SOP) of light passing through it by a specific angular amount.

- A half-wave plate rotates the SOP of a lightwave by 90°; for example, it converts right circularly polarized light to left circularly polarized light.

Isolators

- Optical isolators are devices that allow light to pass through them in only one direction
- One way valves for light
  - Optical analogue of diode
  - Needed to prevent reflections
  - Not so easy to make as electrical diodes
- Isolator using Faraday effect
  - Requires material to be put into strong magnetic field
  - Asymmetric rotation of polarization depending on
    - Incidence
    - Magnetic field strength
    - Length

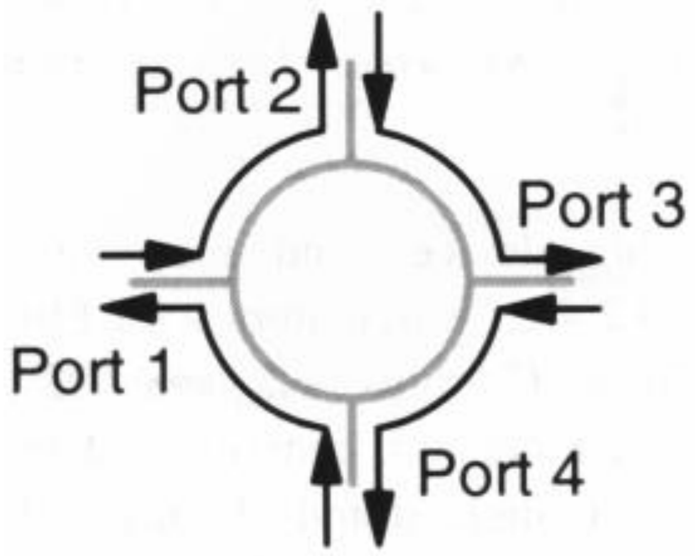
Isolators



Forward Direction
Polarising filter (vertical)
Faraday Rotator
Polarising filter (rotated 45 degrees)
Electric Field Direction
Electric Field Direction
Reverse Direction
X
Electric Field Direction
Electric Field Direction

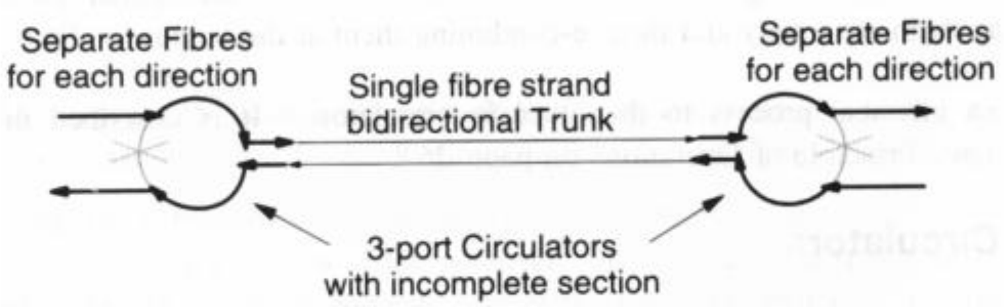
Circulators

- An optical circulator is a nonreciprocal multiport passive device that directs light sequentially from port to port in only one direction.
- The operation of a circulator is similar to that of an isolator except that its construction is more complex.
- Typically it consists of a number of polarizers, half-wave plates, and Faraday rotators and has three or four ports
- Designed to control flow of light
- Have many different applications

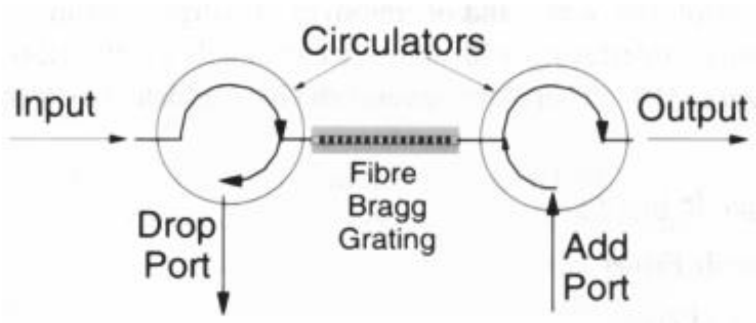


Circulators

Example: multiplexing traffic



Example: Add-Drop Multiplexer



Fiber Bragg Grating (FBG)

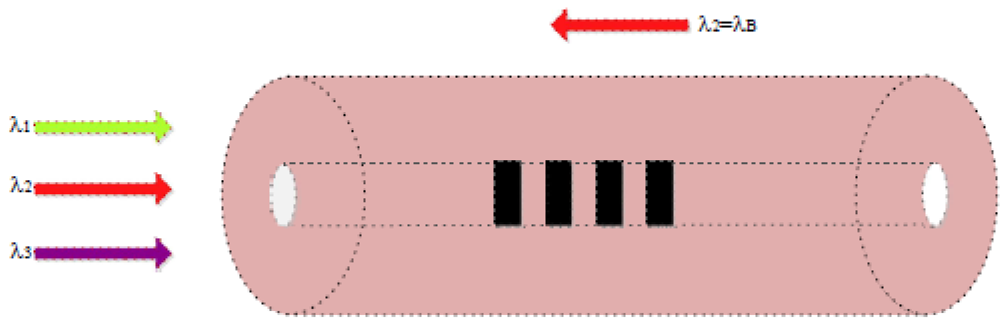
- It is a reflective device composed of an optical fiber that contains a modulation of its core refractive index over a certain length.
- Fiber grating is made by periodically changing the refraction index in the glass core of the fiber.
- The grating reflects light propagation through fiber, when its wavelength corresponds to modulation periodicity
- The reflected wavelength is called Bragg wavelength (λ_B)

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

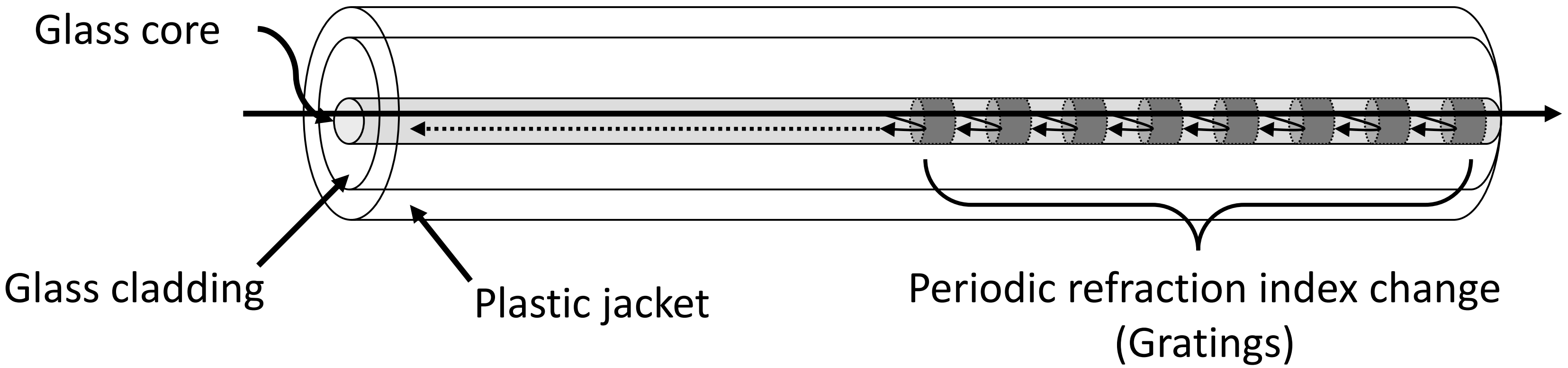
$$n_{eff} - EffectiveRI$$

$$\Lambda - GratingPeriod$$

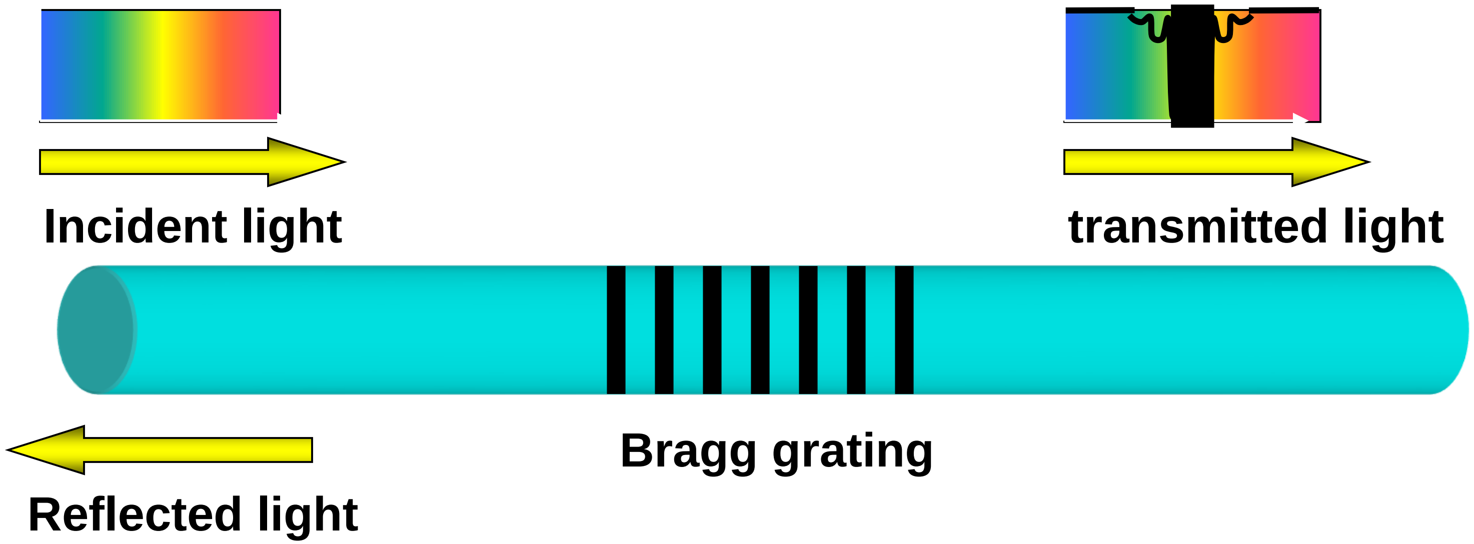
Fiber Bragg Grating (FBG)



Working principle of FBG



Fiber Bragg Grating (FBG)



$\lambda_{bragg} = 2\, n_{eff}\, \Lambda$

$\Lambda \rightarrow$ grating period

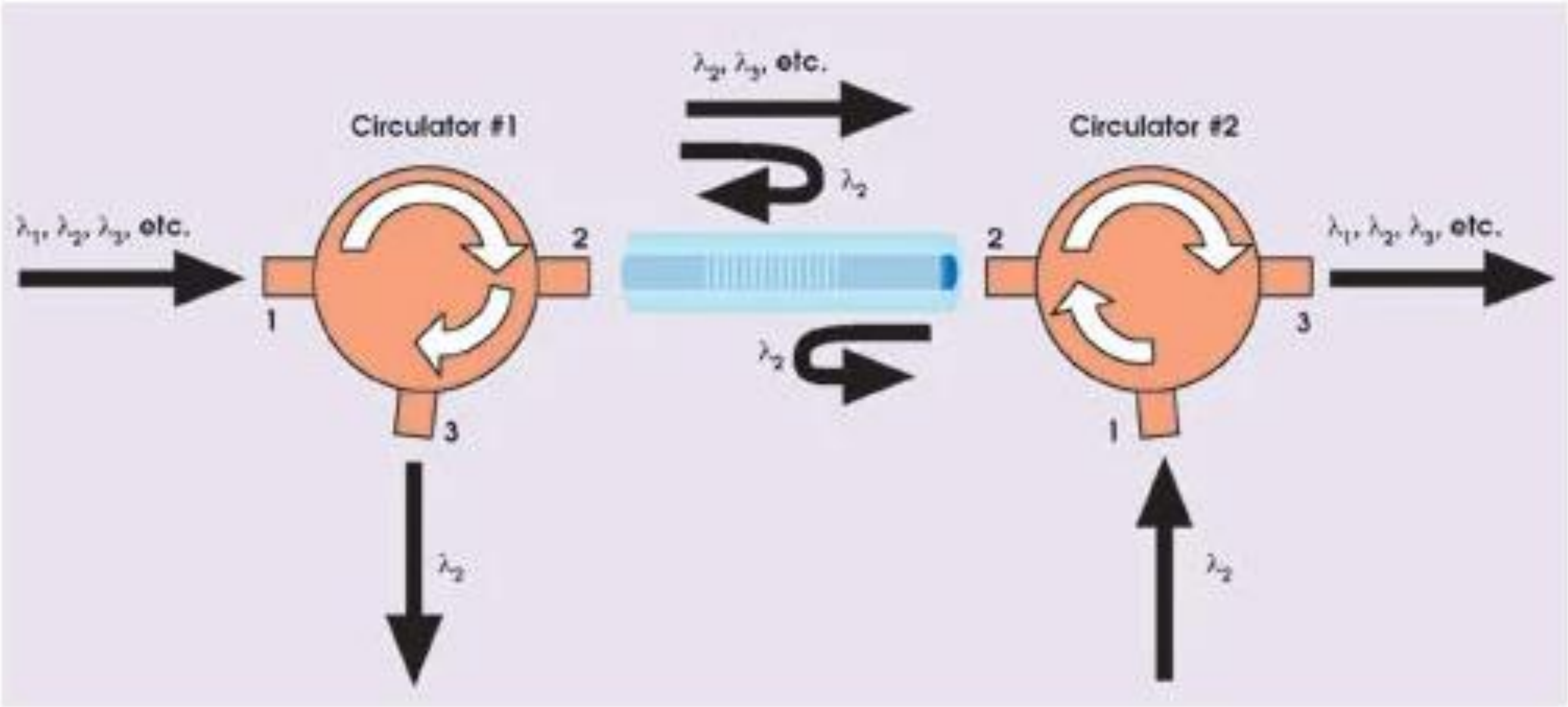
Characteristics of FBG

- It is a reflective type filter
  - Not like to other types of filters, the demanded wavelength is reflected instead of transmitted

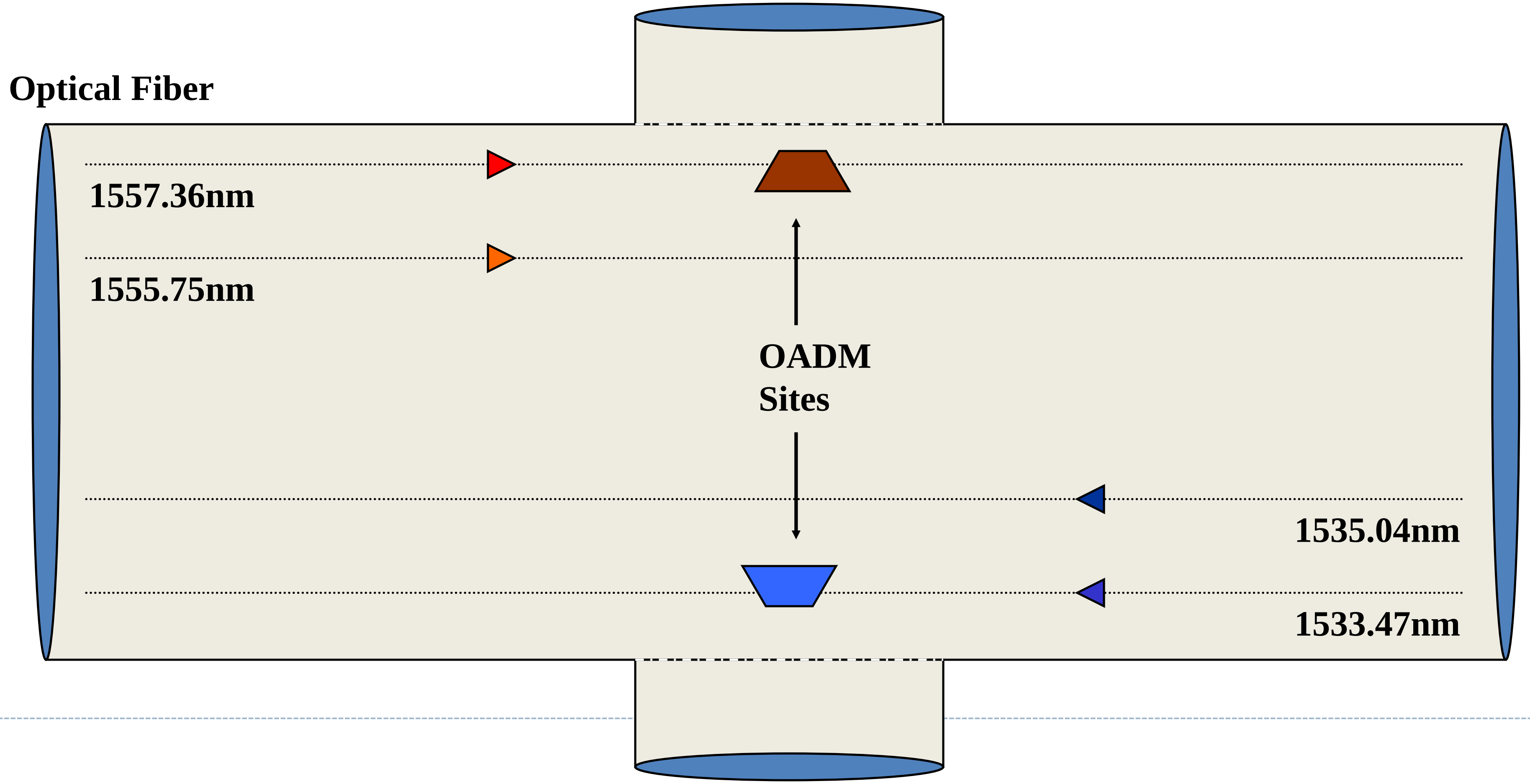
- It is very stable after annealing
  - The gratings are permanent on the fiber after proper annealing process
  - The reflective spectrum is very stable over the time

- It is an in-fiber component and easily integrates to other optical devices

Combining/Separating wavelengths



OADM Illustrated



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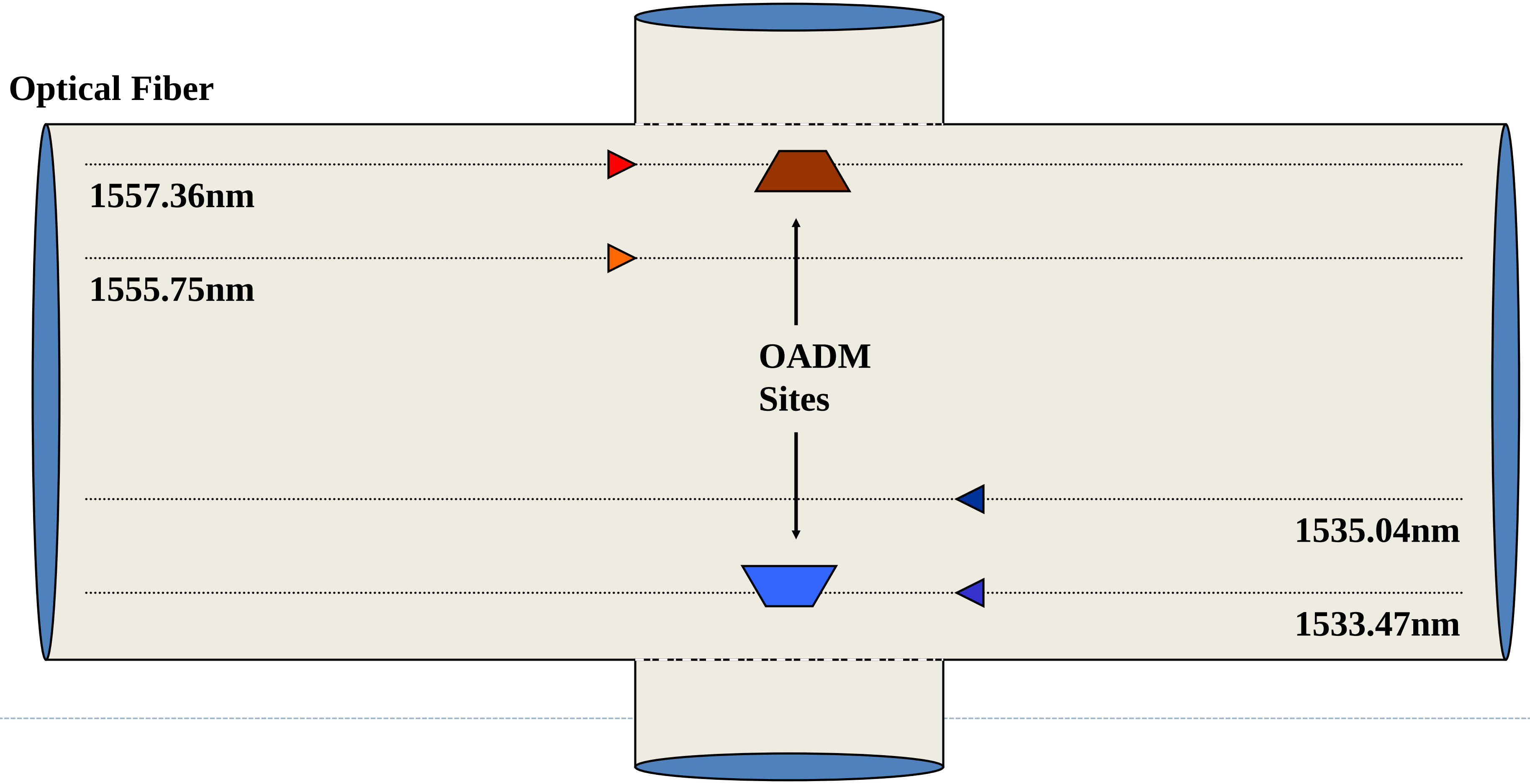

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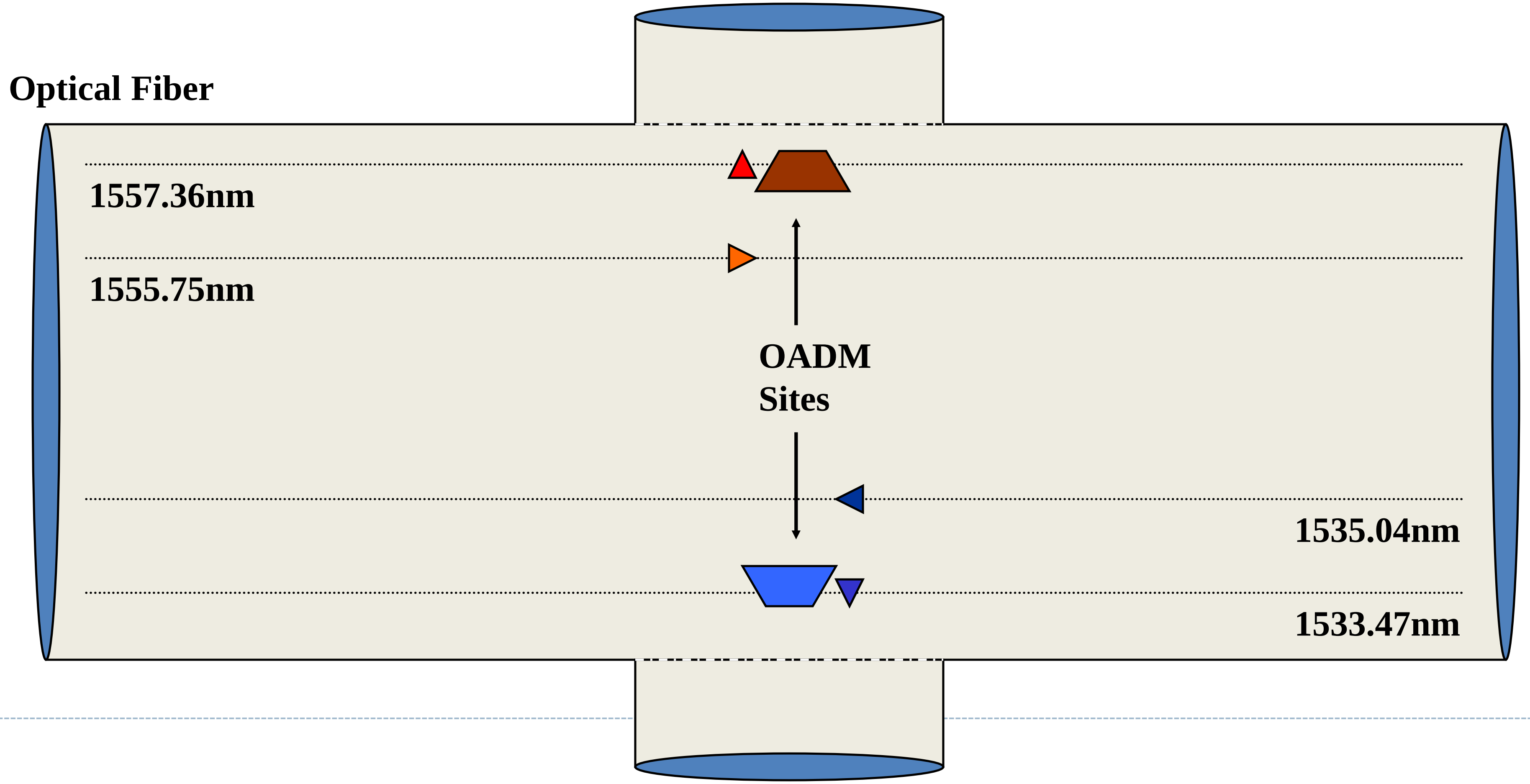

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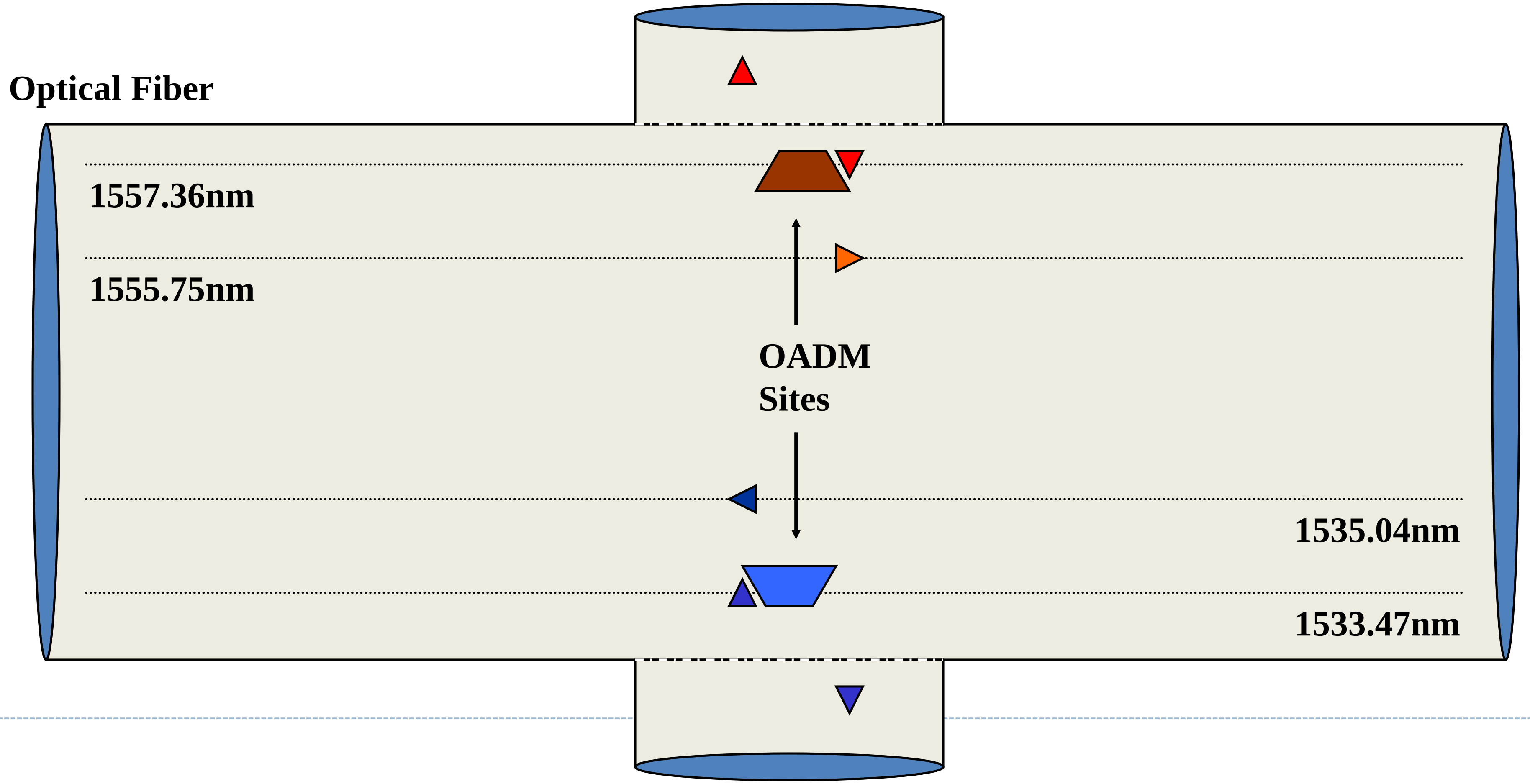

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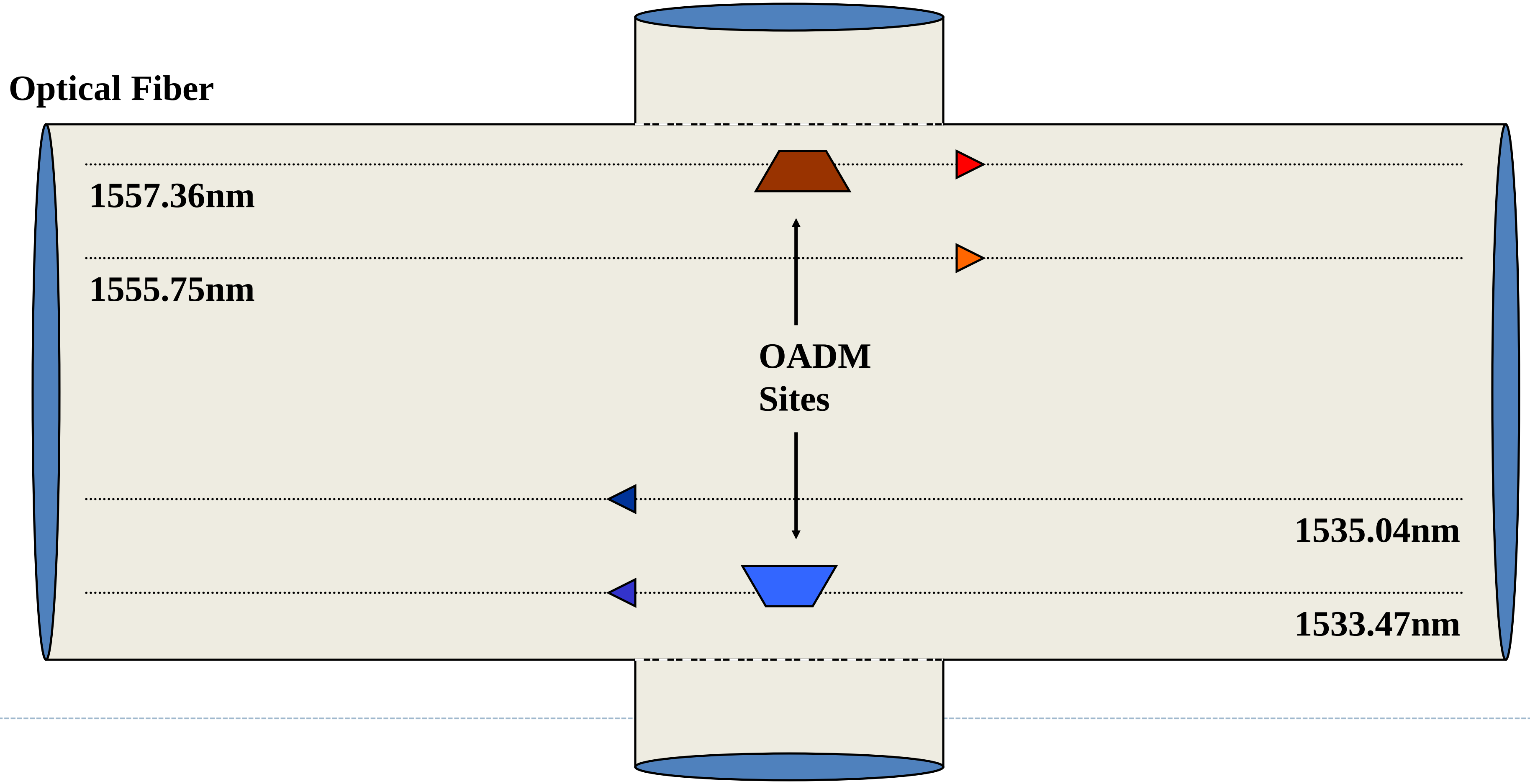

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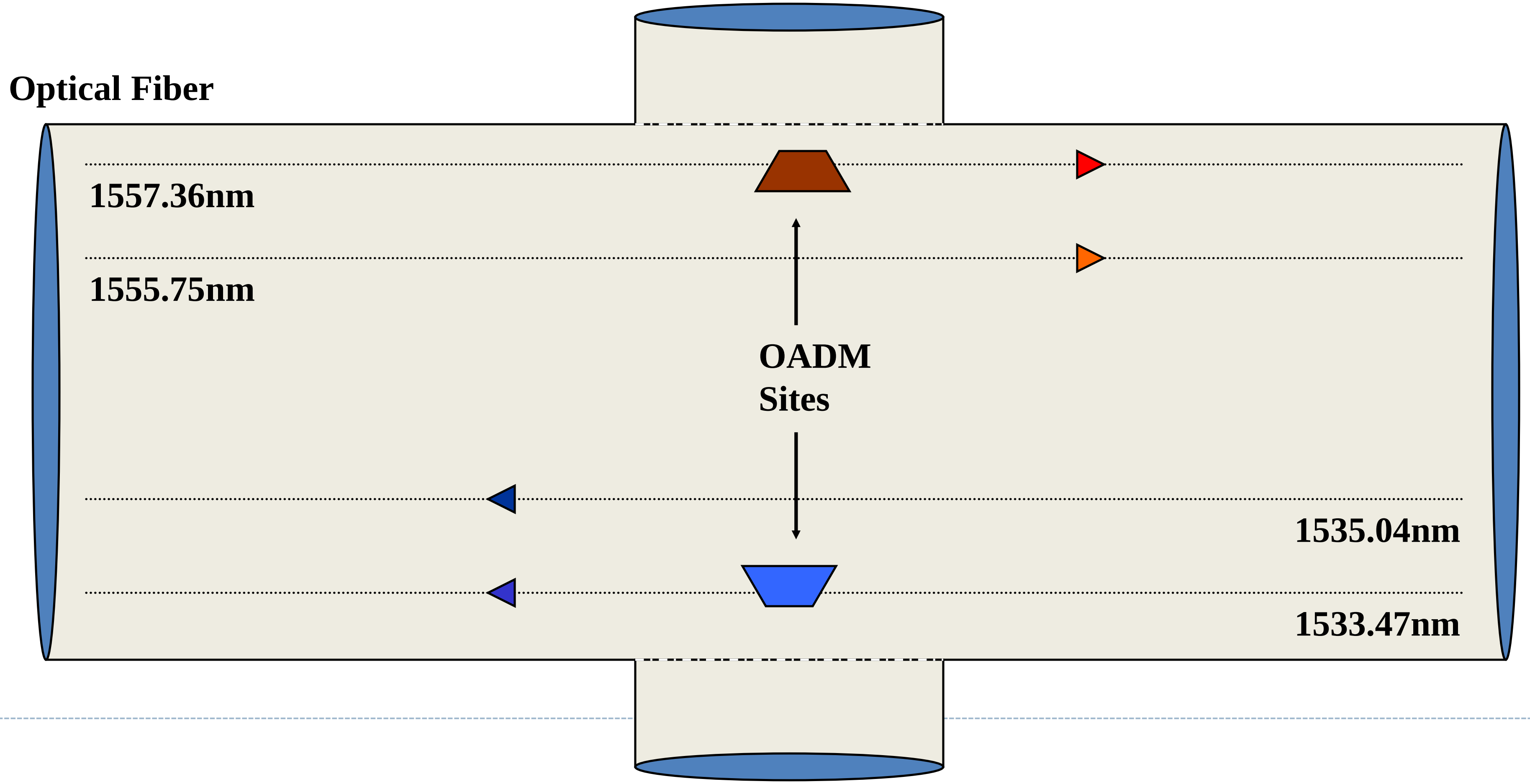
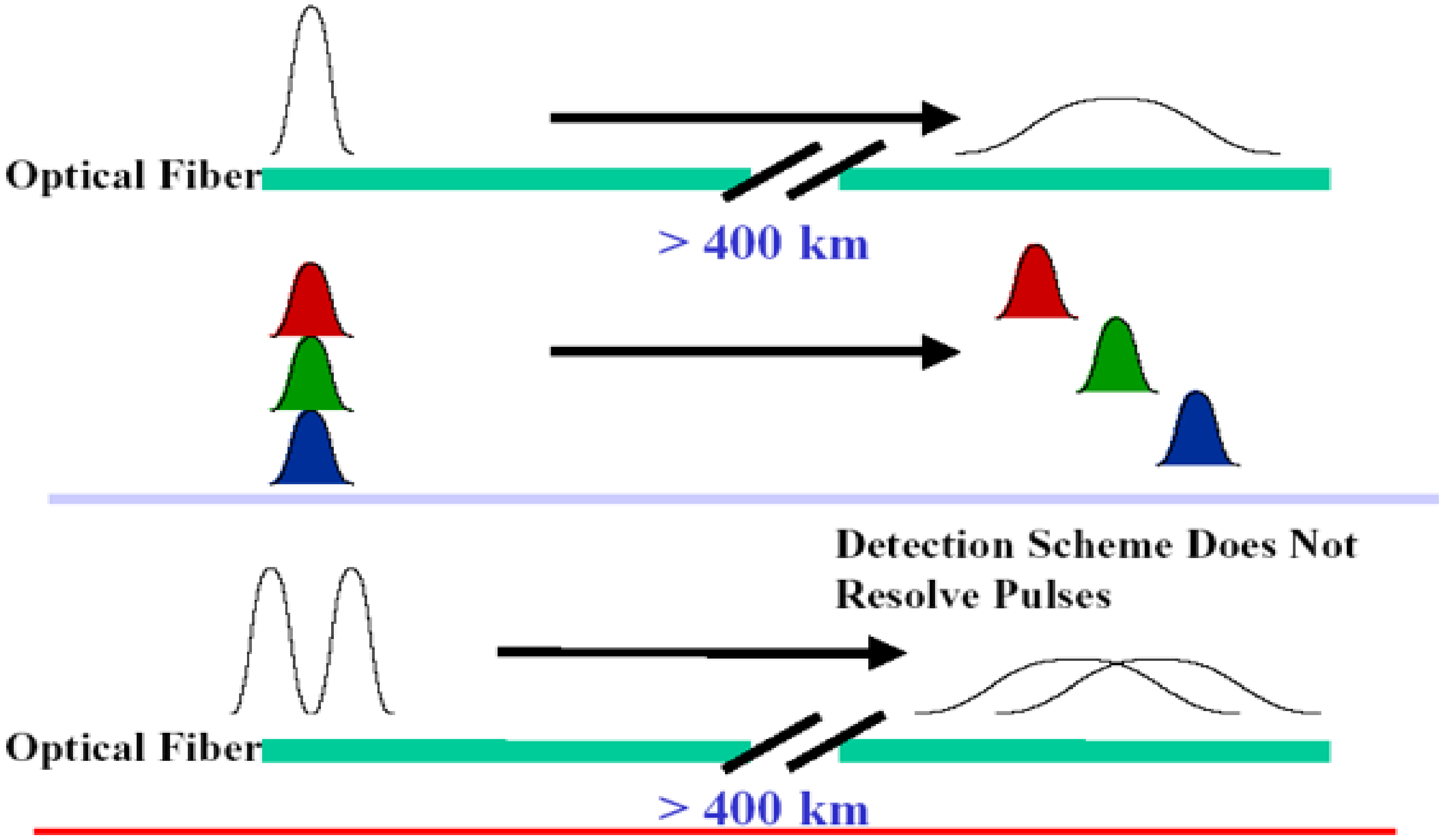
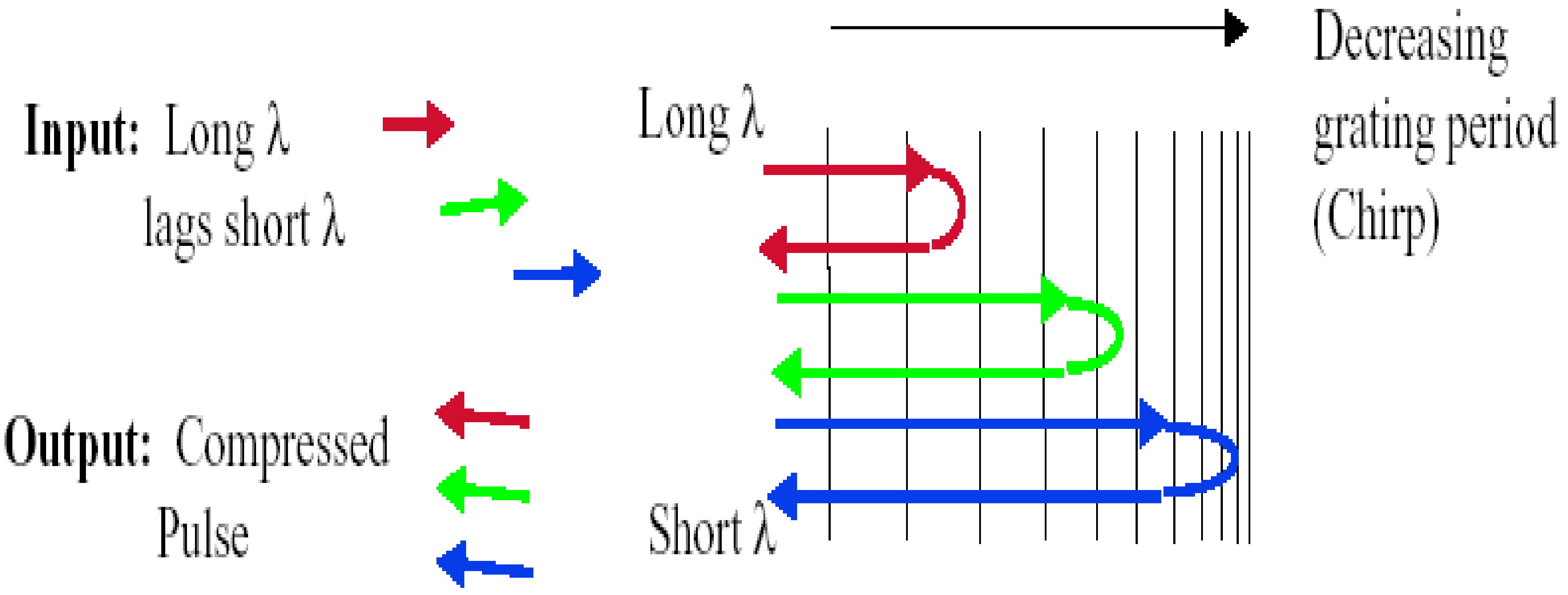


Chromatic dispersion problem



Dispersion Compensation using FBG

Solution: Recompress the optical pulses using a chirped grating



Dispersion Compensation using FBG