Optical Fiber Commonication OFC

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Module 4

WDM Concepts & components

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WDM Concepts

* Technology of combining a number of independent information-carrying wavelengths onto the same fiber is known as Wavelength Division Multiplexing.

* Applications of WDM techniques are found in all levels of communication links including long-distance terrestrial & undersea transmission systems, metro networks etc.

* Complex wavelength division multiplexed links design require optical sources with narrow spectral emission bands. optical sources can be a series of individual lasers or variety of wavelength-tunable components which will be discussed in further topics

Overview of WDM

* Use of WDM was to upgrade the capacity of installed point-to-point transmission links : This was achieved with wavelengths that were separated from several tens upto 200nm.

* With the advent of highquality light sources with extremely narrow spectral emission widths, many independent wavelength channels spaced less than a nanometer apart could be placed on same fiber.

Advantages of WDM

* With light sources, the use of WDM allows a dramatic increase in capacity of an optical fiber compared to original simple point-to-point link ~~th~~ carried only a single wavelength.

* Various optical channels support different transmission formats. By using separate wavelengths, different formatted signals at any data rate can be sent simultaneously & independently over same fiber.

Overview of WDM operation principle

* Characteristic of WDM is that discrete wavelengt form an orthogonal set of carriers that can be separated, routed & switched without interfering with each other.

* Implementation of WDM network require passive & active devices to combine, distribute, isolate & amplify optical power at different wavelength

- Passive devices : Do not require external control for their operation & limited in application flexibility Ex: Splitter, combiner etc.
- Active Devices : Require control through electrically or Optically, providing large degree of network flexibility. Ex : Tunable optical filters, Amplifier etc

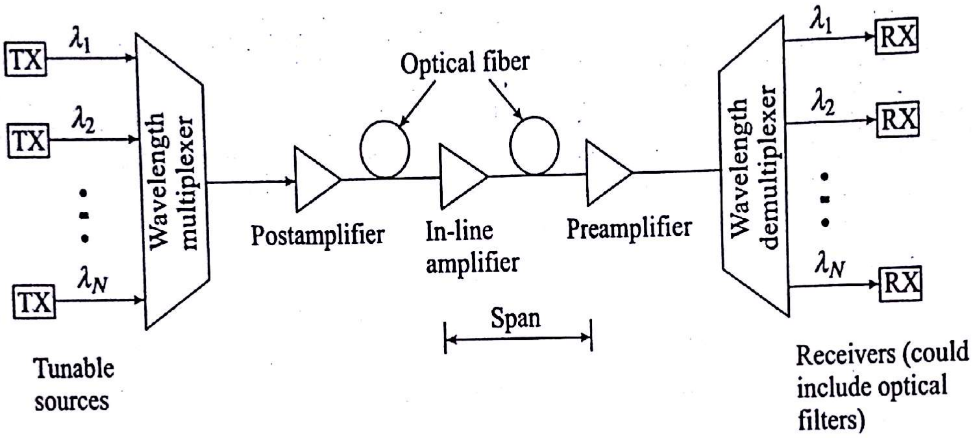
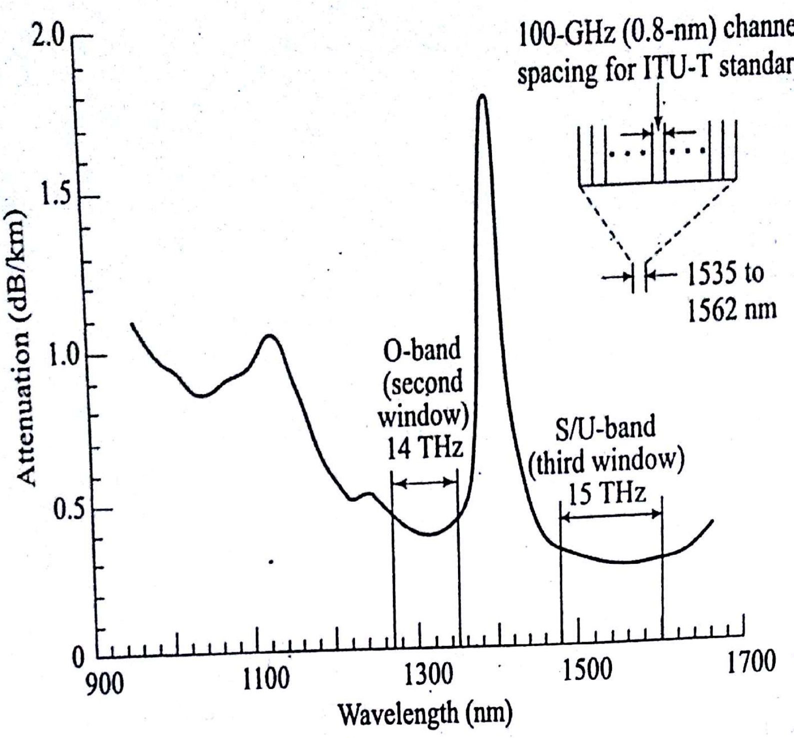


Fig. 10.1 *Implementation of a typical WDM network containing various types of optical*

- Above figure shows Implementation of passive & active components in a WDM link containing various types of optical Amplifiers.
- Multiplexer is needed to combine these optical outputs into a continuous spectrum of signals & couple them onto a single fiber.
- At receiving end a demultiplexer is required to separate the optical signals into appropriate detection channels for signal processing



The transmission-band widths in the O- and C-bands (the 1310-nm and 1550-nm windows) allow the use of many simultaneous channels for sources with narrow spectral widths. The ITU-T G.692 standard for WDM specifies channels with 100-GHz spacings

Above figure shows many independent operating
regions across the spectrum ranging from the
O-band through L-band in which narrow-linewidth
optical sources can be used simutaneously.

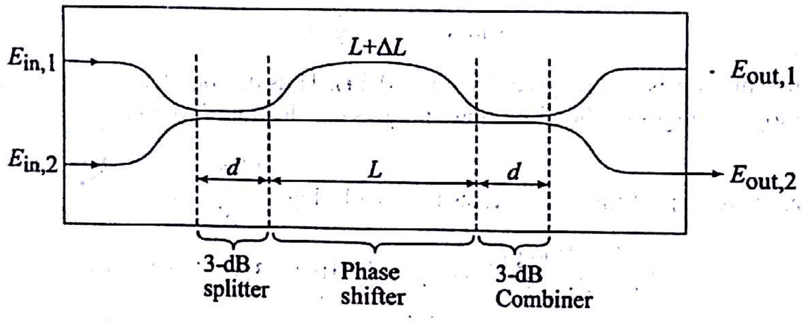
WDM standards

Table 10.1 *Portion of the ITU-T G.694.1 dense WDM grid for 100- and 50-GHz spacings in the L- and C-bands*

L-band				*C-band*			
100-GHz		*50-GHz offset*		*100-GHz*		*50-GHz offset*	
THz	*nm*	*THz*	*nm*	*THz*	*nm*	*THz*	*nm*
186.00	1611.79	186.05	1611.35	191.00	1569.59	191.05	1569.18
186.10	1610.92	186.15	1610.49	191.10	1568.77	191.15	1568.36
186.20	1610.06	186.25	1609.62	191.20	1576.95	191.25	1567.54
186.30	1609.19	186.35	1608.76	191.30	1567.13	191.35	1566.72
186.40	1608.33	186.45	1607.90	191.40	1566.31	191.45	1565.90
186.50	1607.47	186.55	1607.04	191.50	1565.50	191.55	1565.09
186.60	1606.60	186.65	1606.17	191.60	1564.68	191.65	1564.27
186.70	1605.74	186.75	1605.31	191.70	1563.86	191.75	1563.45
186.80	1604.88	186.85	1604.46	191.80	1563.05	191.85	1562.64
186.90	1604.03	186.95	1603.60	191.90	1562.23	191.95	1561.83

Mac- Zehnder Interferometer Multiplexer

- Wavelength-dependent multiplexers are designed using Mach-Zender interferometry techniques.
- Devices can be either passive or active.
- Figure shows the 2x2 passive Mac-Zehnder Interferometer (MZI)



Layout of a basic 2 × 2 Mach-Zehnder interferometer

- Above 2x2 MZI Consists 3 stages :

→ Initial 3-dB directional Coupler/Splitter that splits the input signals

→ Central section is phase shifter, where one of the waveguide is longer by ΔL to give a wavelength-dependent phase shift between two arms.

→ 3-dB coupler that recombines the signal at the output.

* In the following derivation, the function of MZI Interferometer Multiplexer is, by splitting the input beam & introducing a phase shift in one of the paths. the recombined signals will interfere constructively at one output & destructively at the other. Signals finally emerge from only one output port.

The propagation matrix $M_{coupler}$ for a coupler of length d is

$$M_{coupler} = \begin{bmatrix} \cos kd & j\sin kd \\ j\sin kd & \cos kd \end{bmatrix}$$

where k is coupling coefficient. Since we are considering 3-dB couplers that divide the power equally, then $2kd = \pi/2$, so that

$$M_{coupler} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix}$$

In the central region, when signals in the two arms come from same light source, outputs from two guides have a phase difference $\Delta\phi$ given by

$$\Delta\phi = \frac{2\pi n_1}{\lambda} L - \frac{2\pi n_2}{\lambda}(L+\Delta L) \rightarrow ①$$

when $n_1 = n_2 = n_{eff}$ = effective refractive index in waveguide, eq^n 1 becomes,

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

$$= k\Delta L \rightarrow ③$$

where $k = 2\pi n_{eff}/\lambda$.

* Note that the phase difference can arise either from a different path length (ΔL) or through a relative index difference if $n_1 \neq n_2$. We take both arms to have same index & let $n_1 = n_2 = n_{eff}$ (the effective refractive index in the waveguide).

For a given phase difference $\Delta\phi$, propagation matrix $M_{\Delta\phi}$ for phase shifter is

$$M_{\Delta\phi} = \begin{bmatrix} \exp(jk\Delta L/2) & 0 \\ 0 & \exp(-jk\Delta L/2) \end{bmatrix} \rightarrow ④$$

optical output fields $E_{out,1}$ & $E_{out,2}$ from two central arms are Related to input fields $E_{in,1}$ & $E_{in,2}$ by

$$\begin{bmatrix} E_{out,1} \\ E_{out,2} \end{bmatrix} = M \begin{bmatrix} E_{in,1} \\ E_{in,2} \end{bmatrix} \rightarrow ⑤$$

where $M = M_{coupler} \cdot M_{\Delta\phi} \cdot M_{coupler} = \begin{bmatrix} M_{11} & M_{21} \\ M_{12} & M_{22} \end{bmatrix}$

$$= j \begin{bmatrix} \sin(k\Delta L/2) & \cos(k\Delta L/2) \\ \cos(k\Delta L/2) & -\sin(k\Delta L/2) \end{bmatrix} \rightarrow ⑥$$

For MZI multiplexer, a different wavelengths are required at inputs. Let E_{in1} is at λ_1 & $E_{in,2}$ is at λ_2. Then from eq^n ⑤, the output field $E_{out,1}$ & $E_{out,2}$ are each the sum of individual contributions from two input fields.

$$E_{out,1} = j\left[E_{in,1}(\lambda_1)\sin(K_1\Delta L/2) + E_{in,2}(\lambda_2)\cos(K_2\Delta L/2)\right] \rightarrow ⑦$$

$$E_{out,2} = j\left[E_{in,1}(\lambda_1)\cos(K_1\Delta L/2) - E_{in,2}(\lambda_2)\sin(K_2\Delta L/2)\right] ⑧$$

where $K_j = 2\pi n_{eff}/\lambda_j$. output power is found from light intensity, which is square of field strength,

$$P_{out,1} = E_{out,1} E^{*}_{out,1} = \sin^2(K_1\Delta L/2) P_{in,1} + \cos^2(K_2\Delta L/2) P_{in,2}$$

$$P_{out,2} = E_{out,2} \cdot E^{*}_{out,2} = \cos^2(K_1\Delta L/2) P_{in,1} + \sin^2(K_2\Delta L/2) P_{in,2}$$

where $P_{inj} = |E_{in,j}|^2 = E_{in,j} \cdot E^{2}_{in,j}$

From eq^n 7 & 8, cross terms are dropped because their frequency, which is twice optical carrier frequency is beyond response capability of photodetector.

From eq^n 7 & 8, if all power from both inputs have to leave same output port, we need to have

$$k_1 \Delta L/2 = \pi \quad \& \quad k_2 \Delta L/2 = \pi/2$$

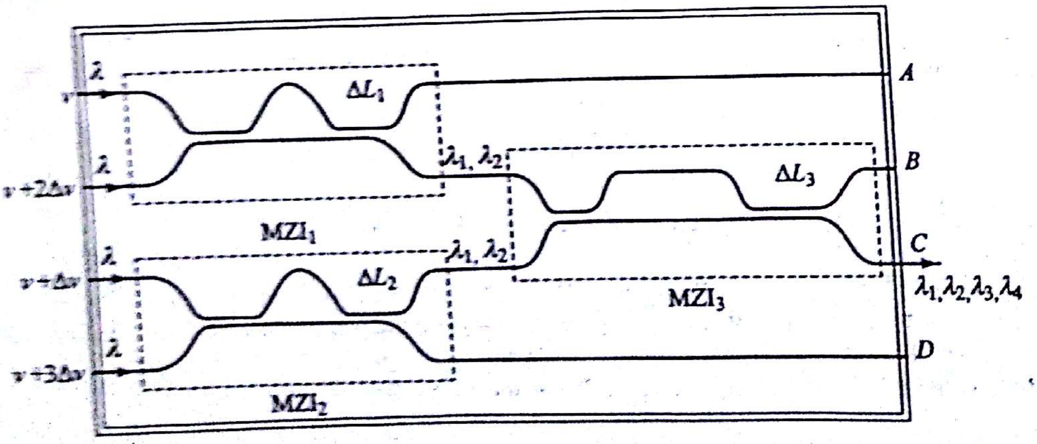
$$(k_1 - k_2)\Delta L = 2\pi n_{eff}\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)\Delta L = \pi \quad \rightarrow 9$$

The length difference in interferometer arms should be

$$\Delta L = \left[2n_{eff}\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)\right]^{-1} = \frac{c}{2n_{eff}\Delta\nu}$$

where $\Delta\nu$ is frequency separation of two wavelength

Using 2×2 MZI, Any size N×N multiplexer can be contructed. As shown in below figure, 4×4 multiplexer is designed.



Example of a 4 channel wavelength multiplexer using three 2 × 2 MZI elements

Isolators & circulators.

- passive optical devices used in number of applications may be nonreciprocal, that is, it works differently when its inputs & outputs are reversed.

- Examples: Isolators & Circulators.

Some facts about polarization & polarization-sensitive components:

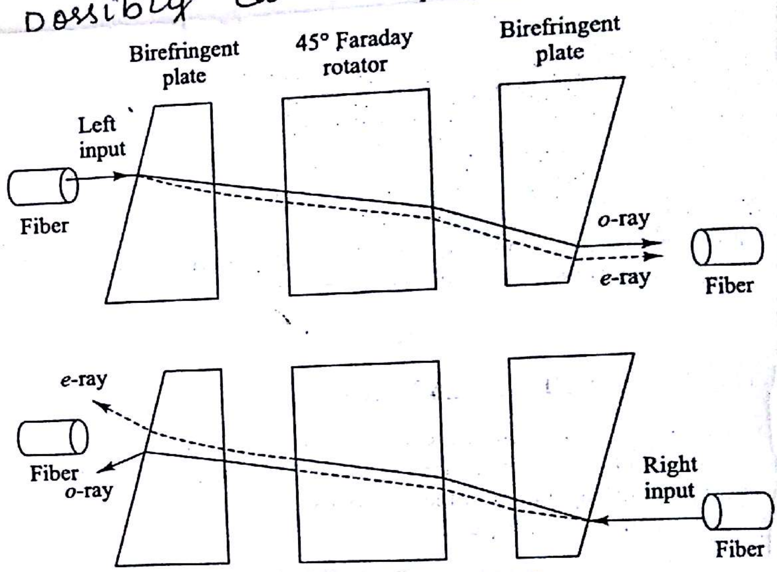
- Light can be represented as a combination of a parallel & perpendicular vibrations, which are called two orthogonal plane polarization states of a lightwave.
- A Polarizer is a material or a device that transmits only one polarization component & blocks other.
- A Faraday rotator is a device that rotates state of polarization (SOP) of light passing through it by a specific angular amount.
- A device made from birefringent material splits light signal entering it into two orthogonally polarized beams, which then follow different paths through material.
- A Half-wave plate rotates the SOP clockwise by 45° for signals going from left to right & counterclockwise by 45° for signals propagating in other direction

* Fa

optical Isolator

* optical isolators are devices that allow light to pass through them in only one direction, & hence prevent scattered or reflected light from travelling in reverse direction.

* Application: Laser diode - prevents backward-travelling light entering a laser diode & possibly causing instabilities in optical output



* Above figure shows a design for polarization-independent isolator made

* core of the device consists of 45° Faraday rotator that is placed between two wedge-shaped birefringent plates or walk-off polarizers.

* plates are made of material YVO_4 or TiO_2.

* light travelling in forward direction is separated into ordinary & extraordinary rays by first birefringent plate

* Faraday rotator then rotates polarization plane of each ray by 45°.

* After exiting the rotator, two rays pass through second birefringent plate, the axis of this plate is oriented in such a way that relationship between the two types of rays is maintained.

* When rays exit the polarizer, they both are refracted in identical parallel direction.

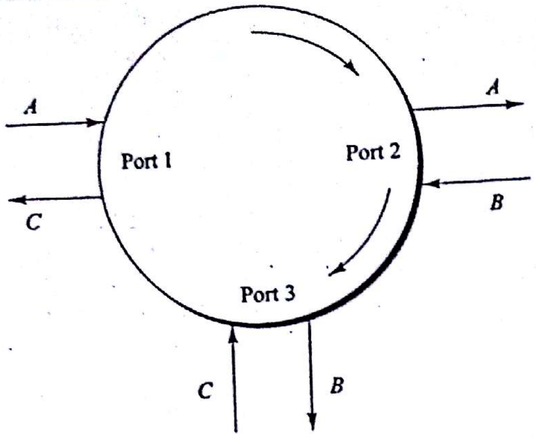
* In reverse direction (right to left), the relationship of ordinary & extraordinary is reversed due to nonreciprocity of faraday rotation & rays diverge when they exit from left-hand birefringent plate & are not coupled to fiber anymore.

optical circulator

* An optical circulator is a nonreciprocal multiport passive device that directs light sequential from port to port in only one direction.

* Applications: optical Amplifiers, add/drop multiplexers, dispersion compensation modules.

* ~~Construction~~ operation same as isolator except that is construction is more complex



Operational concept of a three-port circulator

* As shown in above fig, it consists of number of walk-off polarizers, half wave plates & faradays rotators.

* Consider three port circulator. Here input on port 1 is sent out on port 2, an input on port 2 is sent out on port 3 & input on port 3 is sent out on port 1.

* In a four-port device ideally one could have four inputs & four outputs, but in actual application four port circulator have three inputs & three output ports, making port 1 be an input port only, 2 & 3 being input & output ports, port 4 be an output-port only.

* Advantages:

→ Low insertion loss

→ High isolation over wide wavelength range

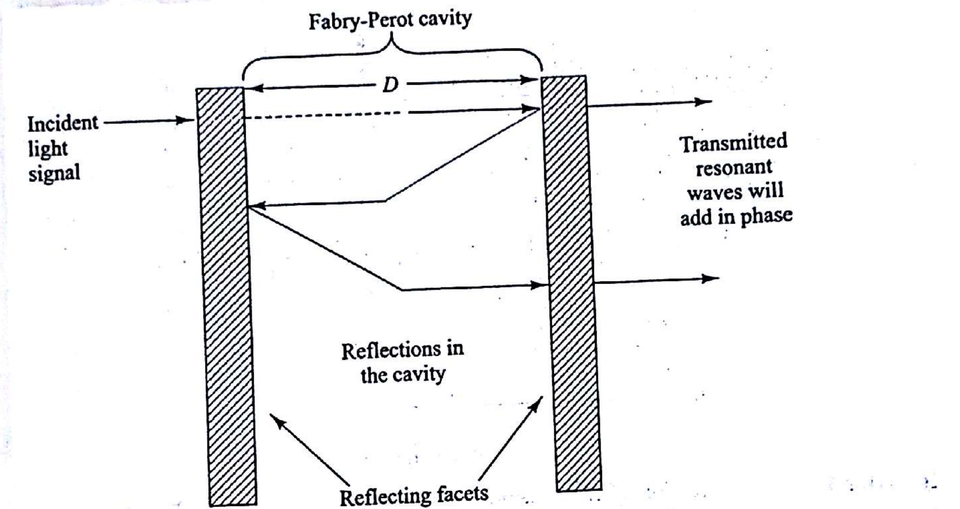
→ Minimal polarization-dependent loss

→ Low plarization-mode dispersion

Dielectric Thin-Film Filters (TFF)

* TFF is used as an optical bandpass filter which allows particular narrow wavelength band to pass straight through it & reflects all other.

* Basis of TFF is classical Fabry perot filter structure, which is formed by two parallel highly reflective mirror surfaces shown below,



Two parallel light-reflecting mirrored surfaces define a Fabry-Perot resonator cavity or an etalon

* Structure is called Fabry-perot interferometer or an etalon or thin film resonant cavity filter.

* Working :
→ consider a light signal incident on left surface of etalon. After light passes through the cavity & hits inside surface on right, some of light leaves cavity & some reflected

* Amount of light reflected depends on Reflectivity R of surface.

* ~~of~~ Roundtrip distance between two mirrors is an integral ~~part~~ multiple of wavelength λ then all light at those wavelength add in phase & interfere constructively & adds to intensity. These wavelengths are resonant wavelengths of cavity. Etalon rejects all other wavelengths.

* Etalon Theory.

The Transmission T of an ideal Etalon in which there is no light absorption by mirrors is an Airy function given by

$$T = \left[1 + \frac{4R}{(1-R)^2}\sin^2\left(\frac{\phi}{2}\right)\right]^{-1}$$

Where R is reflectivity of mirrors & ϕ is roundtrip phase change of light beam.

Active optical Components

* Active components require some type of external energy either to perform their functions or to be used over a wider operating range than a passive devices, thereby offering greater application flexibility. Ex: Variable optical Attenuator, tunable optical filter. etc

MEMS Technology

* Micro Electro-mechanical systems (MEMS) are miniature devices than can combine mechanical, electrical & optical components to provide sensing & actuating functions.

* MEMS are fabricated using integrated circuit & range in size from micrometers to millimeters

* Applications : Air-bag deployment systems, ink-jet printer heads, biomedical applications, Variable optical attenuators, tunable lasers, optical add-drop multiplexers etc.

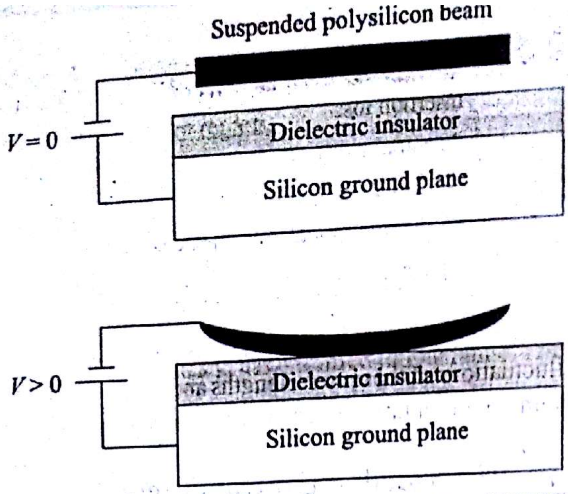


Fig. 10.33 *A simple example of a MEMS actuation method. The top shows an "off" position and the bottom shows an "on" position*

- Above figure shows example of MEMS actuation method.
- At top of device there is a thin suspended polysilicon beam that has typical length, width & thickness dimensions of 80um, 10um & 0.5um respectively.
- At the bottom there is a silicon ground plane that is covered by an insulator material.
- There is a gap of 0.6um between the beam & insulator. When a voltage is applied between silicon ground plane & polysilicon beam, electric force pulls the beam down so that it makes contact with lower structure.

* Initially MEMS devices were based on standard silicon technology, which is stiff material.

* Since some type of electric force typically is used to bend or deflect one of MEMS layer to produce desired mechanical motion, stiffer materials require higher voltage to achieve deflection. To reduce required forces, polymeric materials are used which are six orders of magnitude less stiff than silicon. component is compliant MEMS or CMEMS & the elastometric material can be stretched as much as 300 percent, as opposed to less than 1 percent for silicon.

Variable optical Attenuator

* precise active signal-level control is essential for proper operation of DWDM networks.

* A variable optical attenuator (VOA) offers dynamic signal control.

* This device attenuates optical power by various means to control signal levels precisely without disturbing other properties of light signal.

* They are polarization independent, attenuate light independent of wavelength & Have low insertion loss.

* control methods include :

→ Mechanical methods which are reliable but have a low dynamic range & slow response time.

→ Thermo-optic methods that have a high dynamic range, but slow & require thermoelectric cooler (TEC)

→ MEMS technique : An electrostatic actuation method which is most commonly used, since IC processes offer a wider selection of conductive & insulating ~~[illegible]~~ materials. A voltge change across a pair of electrodes provides an electrostatic actuation force & Require lower power levels tha other methods & is fastest.

Below table shows some Representative ~~optical~~ operational parameter values for VOA.

Parameter	Specification
Insertion loss	<1.8dB
Attenuation Range	>15dB
PDL @25dB attenuation	<0.3dB
Maximum optical power per channel	>150mW
Optical return loss	>42dB

Table 10.9 *Representative operational parameter values for a typical VOA*

Parameter	*Specification*
Insertion loss	< 1.8 dB
Attenuation range	> 15 dB (up to 60 dB possible)
PDL @ 25 dB attenuation	< 0.3 dB
Maximum optical power per channel	> 150 mW (up to 500 mW possible)
Optical return loss	> 42 dB

When wavelengths are added, dropped, or routed in a WDM system, a VOA can manage the optical power fluctuations of these wavelengths and other simultaneously propagating wavelength signals. Table 10.9 shows some representative operational parameter values for a VOA.

10.8.3 Tunable Optical Filters

Tunable optical filters are key components for dense WDM optical networks. Two main technologies to make a tunable filter are MEMS-based and Bragg-grating-based devices. MEMS actuated filters have the advantageous characteristics of a wide tuning range and design flexibility. One such filter is a tunable variation on the classical structure that has been used widely for interferometer applications. The MEMS-based device consists of two sets of epitaxially grown semiconductor layers that form a single Fabry-Perot cavity. The device operation is based on allowing one of the two mirrors to be moved precisely by an actuator. This enables a change in the distance between the two cavity mirrors, thereby resulting in the selection of different wavelengths to be filtered (see Sec. 10.5).

Fiber Bragg gratings are wavelength-selective reflective filters with steep spectral profiles, as shown in Fig. 10.34. Tunable optical filters based on fiber Bragg gratings involve a stretching and relaxation process of the spacing in the fiber grating, that is, in the periodic variation in the refractive index along the core. Since glass is a slightly stretchable medium, as an optical fiber is stretched with the grating inside of it, the spacing of the index perturbations and the refractive index will change. This process induces a change in the Bragg wavelength thereby changing the center wavelength of the filter. Before it is stretched, the center wavelength

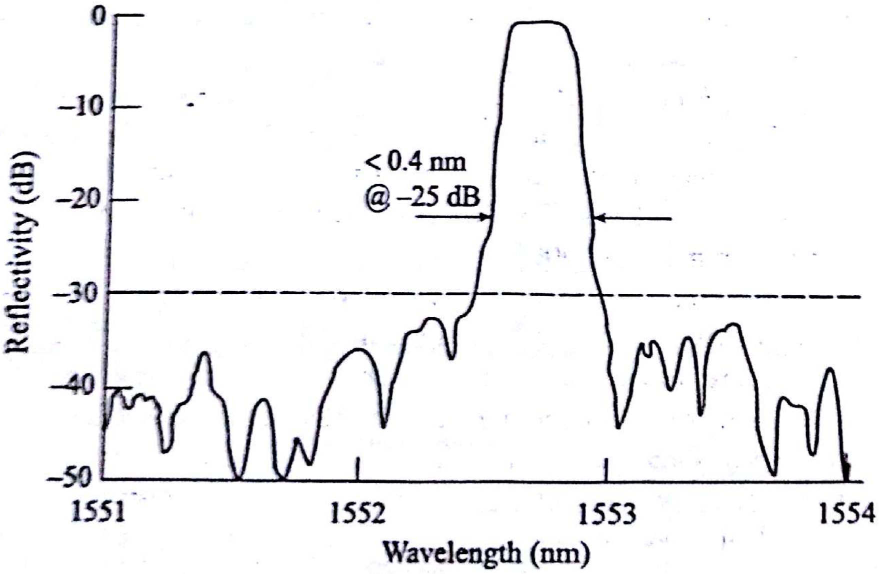


Fig. 10.34 *Example of the reflection band and steep spectral profiles for a 50-GHz fiber Bragg grating filter*

λ_c of a fiber Bragg grating filter is given by $\lambda_c = 2n_{\text{eff}}\Lambda$, where n_{eff} is the effective index of the fiber containing the grating and Λ (*lambda*) is the period of the index variation of the grating. When elongating the fiber grating by a distance $\Delta\Lambda$, the corresponding change in the center wavelength is $\Delta\lambda_c = 2n_{\text{eff}}\Delta\Lambda$. Such optical filters can be made for the S-, C-, and L-bands and for operation in the 1310-nm region.

The stretching can be done by thermo-mechanical, piezoelectric, or stepper-motor means, as shown in Fig. 10.35. The thermo-mechanical methods might use a bimetal differential-expansion element that changes its shape as its temperature varies. In the figure the high-expansion bar changes its length more with temperature than the low-expansion frame, thereby leading to temperature-induced length variations in the fiber grating. This method is inexpensive but it is slow, takes time to stabilize, and has a limited tuning range. The *piezoelectric technique* uses a material that changes its length when a voltage is applied. Although this method provides precise wavelength resolution, it is more expensive, complex to implement, and has a limited tuning range. The stepper-motor method changes the length of the fiber grating by pulling or relaxing one end of the structure. It has a moderate cost, is reliable, and has a reasonable tuning speed.

Table 10.10 lists representative performance parameters of a tunable optical filter. Applications of these devices include gain-tilt monitoring in optical fiber amplifiers, optical performance monitoring in central offices, channel selection at the receive side of a WDM link, and suppression of amplified spontaneous emission (ASE) noise in optical amplifiers (see Chapter 11).

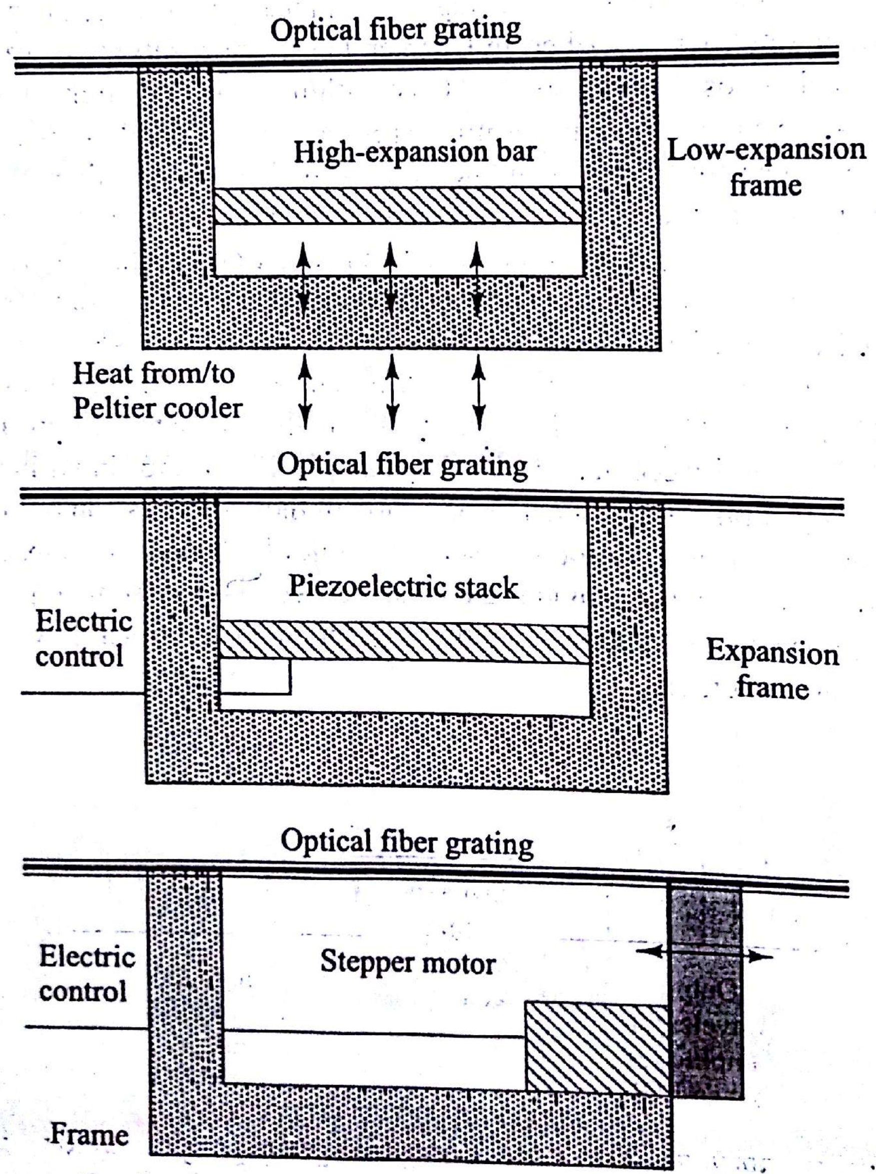


Fig. 10.35 *Three methods for adjusting the wavelength of a tunable Bragg grating*

Table 10.10 *Typical performance parameters of a tunable optical filter*

Parameter	*Specification*
Tuning range	40 nm typical
Channel selectivity	100, 50, and 25 GHz
Bandwidth	< 0.2 nm
Insertion loss	< 3 dB across tuning range
Polarization dependent loss (PDL)	< 0.2 dB across tuning range
Tuning speed	Technology dependent
Tuning voltage	12 to 40 V

10.8.4 Dynamic Gain Equalizers

A *dynamic gain equalizer* (DGE) is used to reduce the attenuation of the individual wavelengths within a spectral band. These devices also are called *dynamic channel equalizers* (DCE) or *dynamic spectral equalizers.* The function of a DGE is equivalent to filtering out individual wavelengths and equalizing them on a channel-by-channel basis. Their applications include flattening the nonlinear gain profile of an optical amplifier (such as an EDFA or the Raman amplifier described in Chapter 11), compensation for variation in transmission losses on individual channels across a given spectral band within a link, and attenuating, adding, or dropping selective wavelengths. For example, the gain profile across a spectral band containing many wavelengths usually changes and needs to be equalized when one of the wavelengths is suddenly added or dropped on a WDM link. Note that component vendors sometimes distinguish between a DGE for flattening the output of an optical amplifier and a DCE, which is used for channel equalization or add/drop functions. Depending on the application, certain operational parameters such as the channel attenuation range may be different.

These devices operate by having individually tunable attenuators, such as a series of VOAs, control the gain of a small spectral segment across a wide spectral band, such as the C- or L-band. For example, within a 4-THz spectral range (around 32 nm in the C-band) a DGE can individually attenuate the optical power of 40 channels spaced at 100 GHz or 80 channels spaced at 50 GHz. For example, Fig. 10.36 shows how a DGE equalizes the gain profile of an erbium-doped fiber amplifier. The operation of these devices can be controlled electronically and configured by software residing in a microprocessor. This control is based on feedback information received from a performance-monitoring card that provides the parameter values needed to adjust and adapt to required link specifications. This allows a high degree of agility in responding to optical power fluctuations that may result from changing network conditions.

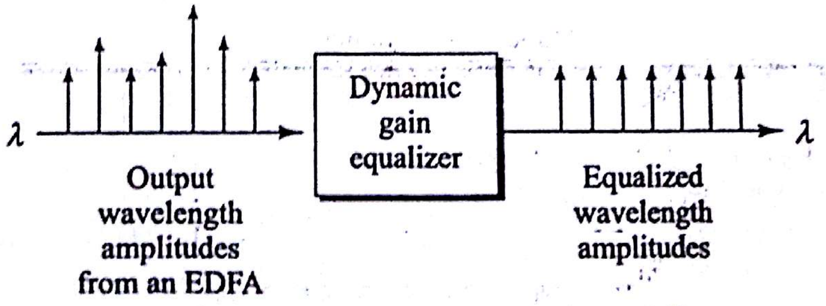


Fig. 10.36 *Example of how a DGE equalizes the gain profile of an erbium-doped fiber amplifier (EDFA)*

Optical Add/Drop Multiplexer (OADM)

- Function of OADM is to insert (add) or extract (drop) one or more selected wavelengths at a designated point in an optical network

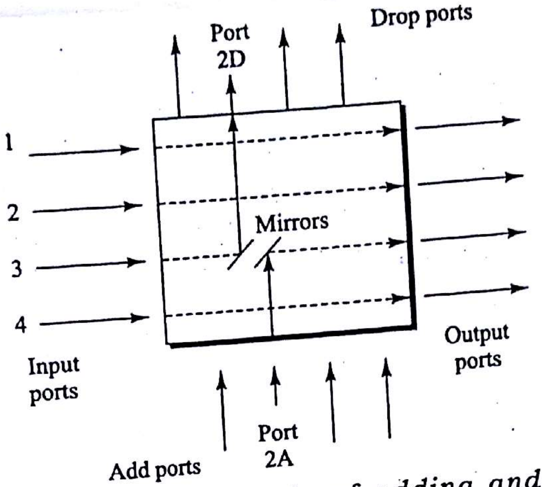


Fig. 10.37 *Example of adding and dropping wavelengths with a 4 × 4 OADM device that uses miniature switching mirrors*

- Above figure shows a simple OADM which has four input & four output ports.
- In this case, add & drop functions are controlled by MEMS based miniature mirrors that are activated separately & selectively to connect the desired fiber paths
- When no mirrors are activated, each incoming channel passes through switch to output port.
- Incoming signals can be dropped from traffic flow by activating appropriate mirror pair.
- Example : To have signal carried on wavelength λ_3 entering port 3 be dropped to port 2D, mirrors are

are activated as shown in figure. When an optical signal is dropped, another path is established simultaneously allowing a new signal to be added from port 2A to traffic flow. OADM is independent of wavelength, data rate & signal format.

Polarization controller

- * Polarization controller offer high-speed real-time polarization control in a closed-loop system that includes a polarization sensor & control logic
- * These devices dynamically adjust any incoming state of polarization to an arbitrary output state of polarization.
- * Applications : polarization mode dispersion (PMD) compensation, polarization scrambling & multiplexing
- * For Example, the output could be a fixed, linearly polarized state. Nominally this is done through electronic control voltages that are applied independently to adjustable polarization - retardation plates

Chromatic Dispersion Compensators

- A critical factor in optical links operating above 2.5 Gb/s is compensating for chromatic dispersion effects.

- This phenomenon causes pulse broadening, which leads to increased bit-error rates.

- An effective means of meeting the strict narrow dispersion tolerances for such high-speed network is to start with a first order dispersion management method, such as dispersion compensating fiber. Then fine tuning is carried by means of tunable dispersion compensator that works over a narrow spectral band to correct for any residual & variable dispersion

- Device for fine tuning is dispersion compensating module (DCM) which is tuned manually, remotely or dynamically.

→ Manual tuning is done by a network technician prior to or after installation of module in telecommunication rack

→ By using network management software it can be adjusted remotely from central management by network operator if this feature is included in its designs

→ Dynamic tuning is done by module itself without any human intervention

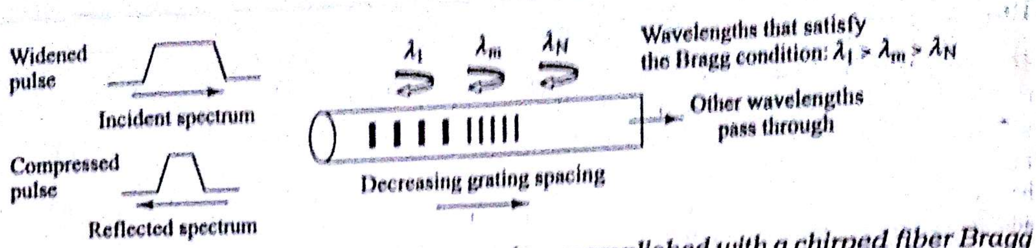


Fig. 10.38 *Dynamic chromatic dispersion may be accomplished with a chirped fiber Bragg grating*

* As shown in above figure, dynamic chromatic dispersion is achieved through use of chirped fiber bragg grating.

* Here grating spacing varies linearly over length of grating, which creates chirped grating.

* This results in a range of wavelengths that satisfy Bragg condition for reflection.

* In configuration shown, the spacing decreases along fiber, Bragg wavelength decreases with distance along the grating length.

* Consequently, shorter-wavelength components of a pulse travel farther into fiber before being reflected & experience more delay than longer-wavelength components.

* The relative delays induced by grating on different frequency components of pulse are opposite of delays caused by fiber.

* This results in dispersion compensation because it compresses pulse.

Tunable Light Sources

* Light sources must be carefully controlled & monitored to ensure that their wavelengths do not drift with time & temperature into spectral region of adjacent sources.

* A more flexible implementation is to have tunable laser.

* The fundamental concept to making such a laser is to change the cavity length in which the lasing occurs in order to have device emit at different wavelengths. Basing tuning options are :

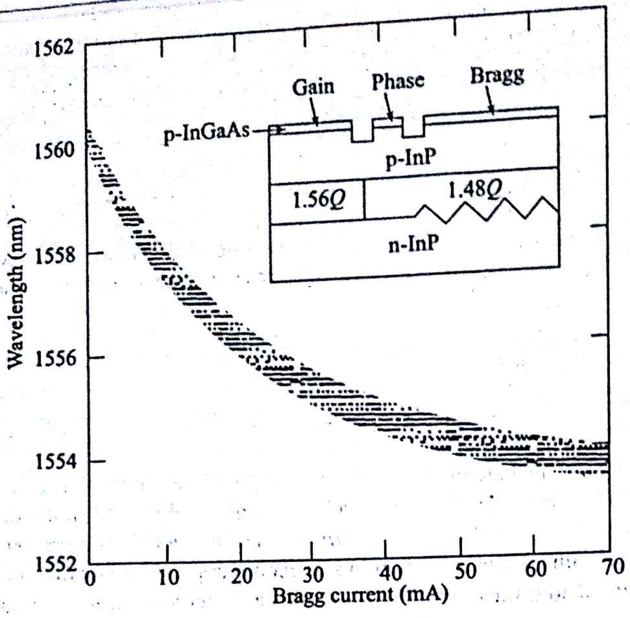
→ Wavelength tuning of a laser by means of temperature or current variations

→ Use of a specially designed wavelength tunable laser

→ Frequency locking to a particular lasing mode in a Fabry-Perot laser.

→ Spectral slicing by means of a fixed or tunable narrow-band optical filter & a broadband LED.

* With frequency tunable laser, one needs only one source. These devices are based on DFB or DBR structure



Tuning range of an injection-tunable three-section DBR laser. (Reproduced with permission from Staring et al.,[75] © 1994, IEEE)

* Above figure shows the tuning range of an injection-tunable three-section DBR laser.

* Frequency tuning is achieved either by changing temperature of device or by altering injection current into the active section or passive section.

* In above, latter method is used which result in a change in the effective refractive index, which causes a shift in peak output wavelength.

* The maximum tuning range depends on the optical output power, with larger output level resulting in a narrower tuning range.

* The tuning range $\Delta\lambda_{tune}$ can be estimated by

$$\frac{\Delta\lambda_{tune}}{\lambda} = \frac{\Delta n_{eff}}{n_{eff}}$$

where Δn_{eff} = change in the effective refractive index

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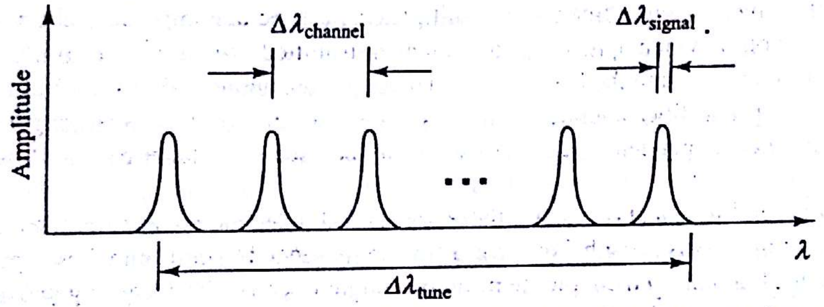
* practically the maximum index change is around 1 %, resulting in a tuning range of 10 - 15 nm.

* Below figure depicts relationship between tuning range, channel spacing & source spectral width.



Relationship between tuning range, channel spacing, and source spectral width

* To avoid crosstalk between adjacent channels, a channel spacing of 10 times the source spectral width $\Delta\lambda_{signal}$ is specified.

That is, $\Delta\lambda_{channel} \simeq 10\Delta\lambda_{signal}$.

Thus, the maximum number of channels N that can be placed in tuning range $\Delta\lambda_{tune}$ is

$$N = \frac{\Delta\lambda_{tune}}{\Delta\lambda_{channel}}$$

Example 10.15

Suppose that the maximum index change of a particular DBR laser operating at 1550 nm is 0.65 percent. Then, the tuning range is

$$\Delta\lambda_{\text{tune}} = \lambda\frac{\Delta n_{\text{eff}}}{n_{\text{eff}}} = (1550\text{ nm})(0.0065) = 10\text{ nm}$$

If the source spectral width $\Delta\lambda_{\text{signal}}$ is 0.02 nm for a 2.5-Gb/s signal, then using Eqs. 10.68 and 10.69 the number of channels that can operate in this tuning range is

$$N = \frac{\Delta\lambda_{\text{tune}}}{\Delta\lambda_{\text{channel}}} = \frac{10\text{ nm}}{10(0.02\text{ nm})} = 50$$

External-cavity laser designs include the use of Littman and Littrow cavities. The *Littman cavity* scheme uses a grating and a MEMS-based tuning mirror to deliver a high level of side-mode suppression (typically 60 dB) with a narrow linewidth (0.3–5 MHz). The *Littrow cavity* method uses a grating to offer an increase in optical output power but with a slight reduction in side-mode suppression (40 dB). In both devices coarse tuning is achieved by manual adjustment of a high-precision adjuster and further fine tuning is achieved by means of a piezoelectric actuator. Various multiple-section tunable lasers have been examined. These designs can include a distributed Bragg reflector, a gain portion, a passive phase-correction section, and a coarse-tuning section. Modulating the Bragg-grating reflector provides a series, or comb, of wavelength peaks. By using an external control current, the coarse tuner then selects one of these peaks. Such a device can be tuned over a 32-nm range, which covers the entire C-band.

Other designs utilize an integrated combination of an optical source (either a broadband laser diode or LED), a waveguide grating multiplexer, and an optical amplifier.[76–80] In this method, which is known as *spectral slicing*, a broad spectral output (for example, from an amplified LED) is spectrally sliced by the waveguide grating to produce a comb of precisely spaced optical frequencies, which become an array of constant-output sources. These spectral slices are then fed into a sequence of individually addressable wavelength channels that can be externally modulated.

X