Module 19 : WDM Components

Lecture : WDM Components - I

Part - I

Objectives

In this lecture you will learn the following

- WDM Components
- Optical Couplers
- Optical Amplifiers
- Multiplexers (MUX)
- Insertion Loss, Cross Talk and Optical Isolation
- Arrayed Waveguide Grating

WAVELENGTH DIVISION MULTIPLEXING (WDM)

Introduction:

We have seen that it is possible to pack many channels into a SONET/SDH network, using the principle of time division multiplexing (TDM). However, available technology puts an upper limit to the realizable band width. OC-48/STM-16 with a speed of 2.488 Mbit/sec is most popular today. More expensive OC-192/STM-64 with a 10 Gigabit/sec is available. A practical upper limit using developing technology is 40 Gbps.

An alternative is to assign different frequencies to different channels, multiplex them for carrying information over fibers and finally demultiplex at the receiver end. The **wavelength division multiplexing (WDM)** is the same as frequency division, excepting that the terminology is used for optical frequencies.

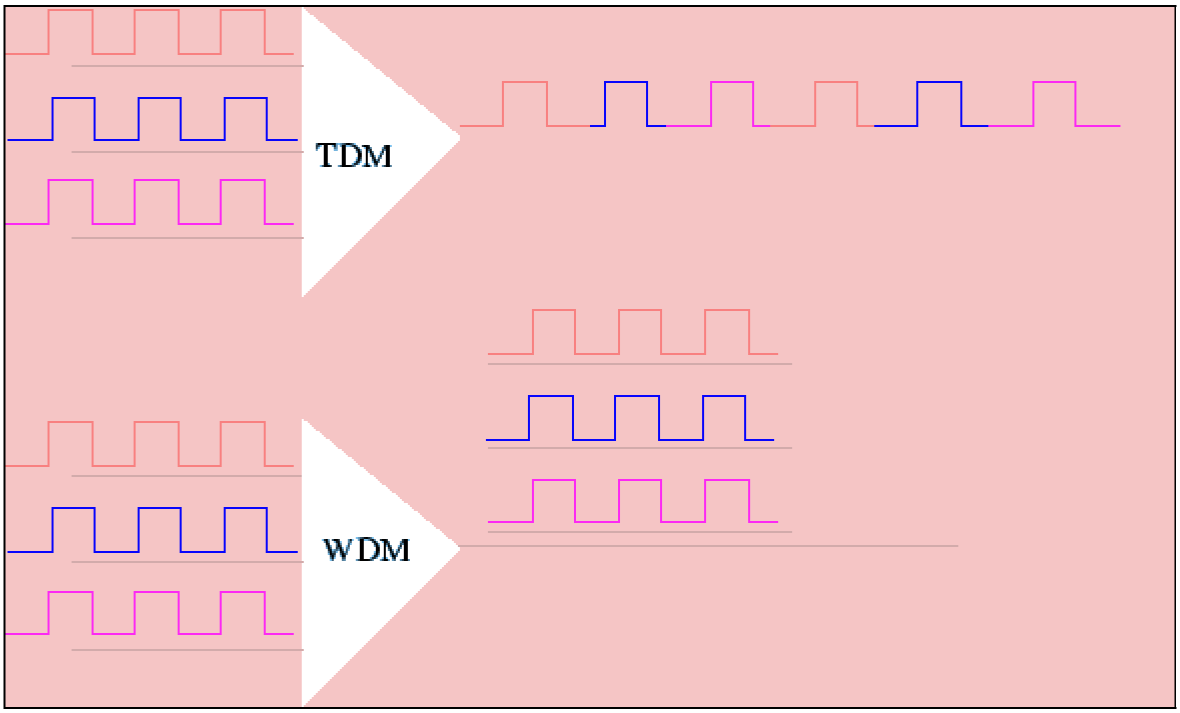
Features of WDM:

1. **Bandwidth:** The fact that one can use different wavelengths over the same channel increases bandwidth capacity
enormously. Most WDM systems work in the C-band around 1550 nm. ITU has specified a standard channel separation grid from 191.1 THz to 196.5 THz separated by 100 GHz. In practice, channels separated by 50 GHz are used. (In terms of wavelengths, it corresponds to the range 1526 nm to 1570 nm with a separation of about 0.8 nm. However, in WDM, the channels are equispaced in frequency and not in wavelengths.) Older systems which were spaced at 200 GHz are known as WDM whereas systems with denser packing such as give above are called **Dense WDM (DWDM)** . Still older ITU specification, referred to now

a days as CWDM (Coarse- WDM) specified a 20 nm spacing in the wavelength range 1270 to 1610 nm.

The number of channels (alls called λs) could be reaching up to 128 so that a single fiber supporting, say OC-48, can give a bandwidth of over 300 Mbit/sec. Modern systems (for instance 40λat OC-192) can easily pack channels to give a bandwidth of 400 Gbps. A similar calculation for 40λat OC-768 can reach up to 1.6 Terrabits/sec.

2. Since WDM carries each signal independently of other signal, each channel has a dedicated bandwidth. Signals arrive at
the destination at the same time and not in different time slots as is the case with TDM.



1. **Independent of bit-rates and formats:** WDM can support multiple protocols. Each signal can be carried at different
bit rates. For instance, one signal can be carried a OC-12 while another at OC-48. Similarly, signals can be carried over different formats like SONET, ATM etc.

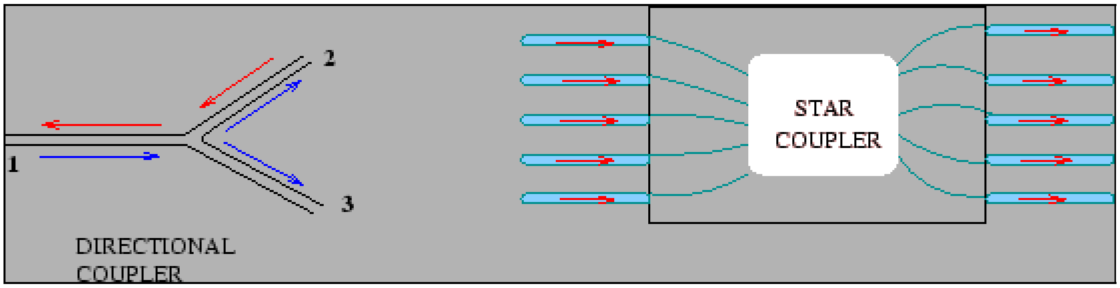
2. Channel capacity can be increased incrementally by adding more wavelengths. Thus a 10 wavelength OC-12 with
a bit rate of 24 Mbps can be upgraded to a 40 wavelength one with a bandwidth of 99.52 Mbps.

WDM Components:

The essential components of a WDM system are primarily those of any network, viz., transmitters, link and receivers. In addition, the system would require other components such as switches, modulators, amplifiers etc. In case of WDM technology, the transmitters are laser sources with stable tunable wavelengths. Before sending the signal through the link, multiplexers mix the wavelengths. Link is low loss optical fiber while at the receiver end there are photo detectors and wavelength demultiplexers. As we have earlier discussed sources and detectors in detail, in this module we will concentrate on components which are specific to the WDM core technology.

Optical Couplers:

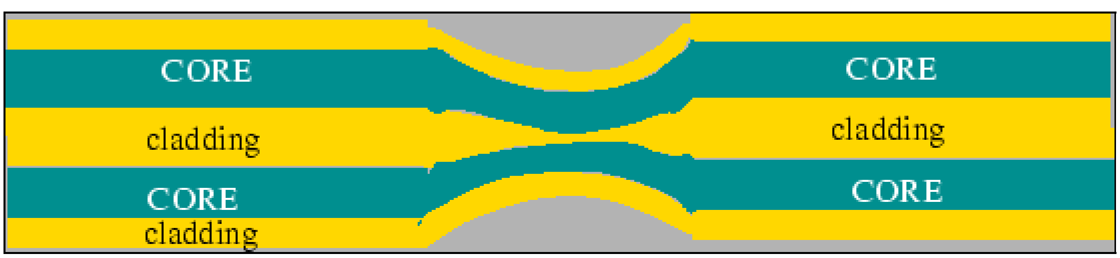
Optical couplers are devices which split light to divert them into multiple paths or combine light from multiple paths to channel them into a single path. Light signal propagates differently from electric signal. An electric signal passes through a receiver to the ground. However, a light signal is absorbed by a receiver so that if one puts a series of optical receivers at the output end almost no signal will get past the first receiver. Thus it is necessary to split the beam and put the receivers in a parallel fashion.



In **Directional couplers** , light energy generally flows in one direction though they are capable of allowing flow in the other direction as well. For instance, in the Y-shaped 1×2 coupler shown here, a signal arriving at port 1 would be distributed to port 2 and 3 and would travel from left to right. However, if a signal arrives at port 2 (or 3), it would only go to port 1 because of geometry. Directional couplers can be designed such that a predetermined percentage of optical power is output into a particular port.

Star couplers are passive devices which connect multiple inputs with i multiple outputs. Star couplers can be both directional and non-directional. Couplers may be designed to be wavelength selective which channel different wavelengths in different directions. These are used in making wavelength division multiplexers and demultiplexers.

Couplers are made by fusing and tapering two fibers together so that the cores of the two fibers are close enough so that the evanescent wave from one fiber can be picked by the providing necessary coupling. The property of coupling depends on whether the fibers are multi-mode fibers or single mode fibers.



Optical Amplifiers:

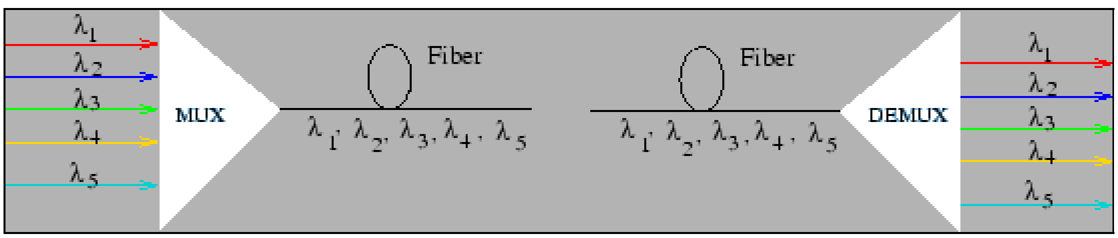
Inline signal amplification is done by placing optical amplifiers along the fiber span. Erbium doped fiber amplifiers (EDFA) are generally used in WDM applications. Key performance parameters of amplifiers are gain, gain-flatness, noise level and power output.

Gains greater than 30 dB over a wide spectral width (nm) with low noise are characteristics of EDFAs which are available in both L-band and C-band. Signal gain provided by EDFAs has reasonably flat wavelength response. However, the flatness can be improved by gain flattening optical filters. Signal can travel over 100 km between amplifiers. If longer haul is required, it will be necessary to regenerate signal. **Regenerators** , in addition to amplifying signals, perform what is known as **3R- operations** , viz., reshaping, retiming and retransmitting.

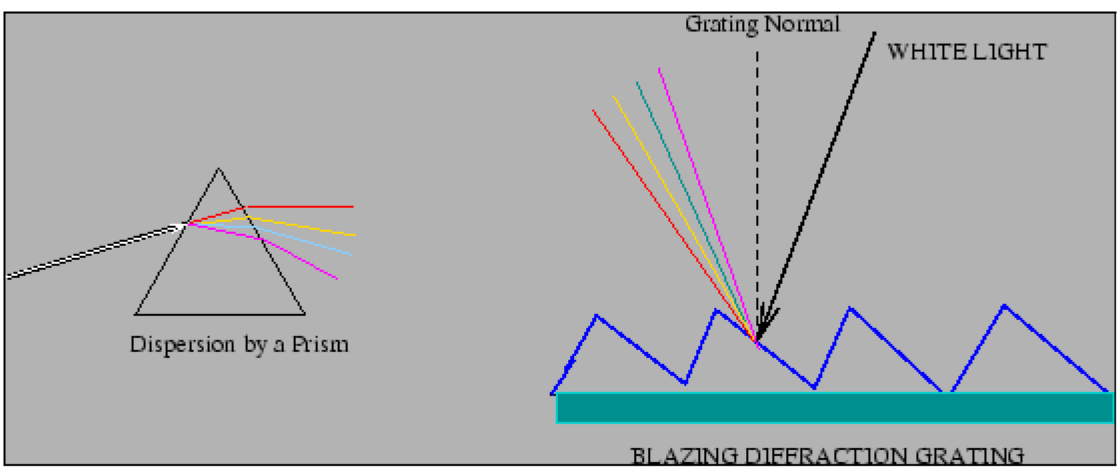
As the total gain in EDFA is shared between different wavelength channels, the gain per channel decreases. As there are OADMs in the network, this would result in different channels being received with different power at the receiver end. The problem is addressed by **equalizing filters** which attenuate wavelengths that are strongly amplified.

Multiplexers (MUX)

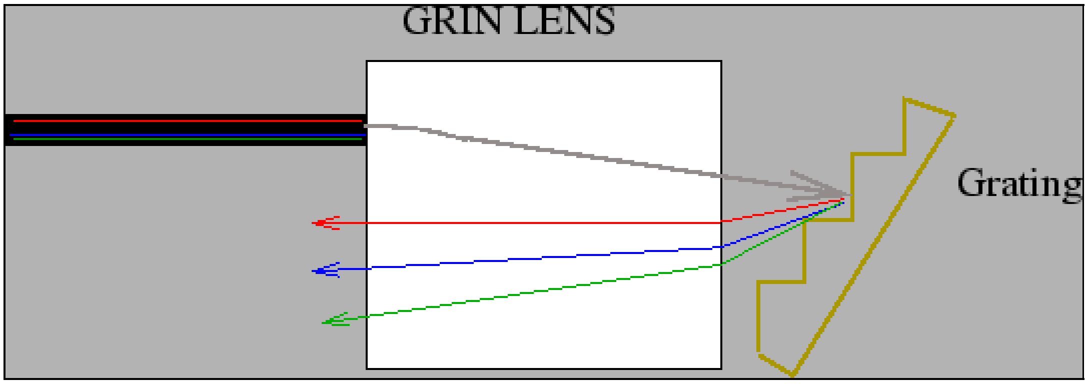
At first sight it would seem that multiplexing different wavelengths would be a relatively simple job of simply allowing different wavelength signals to fall on an opical fiber within th latter's angle of acceptance. However, one has to take care to see that the noise associated with each channel is kept to a minimum. Channels must be isolated to ensure that noise at a different wavelength does not interfere with the signal that is being carried.



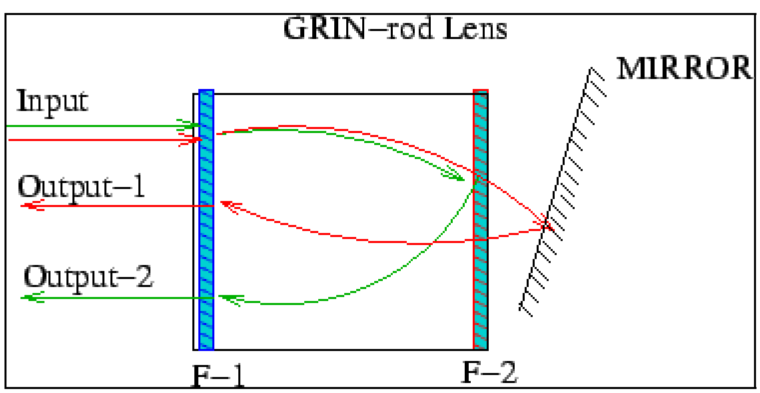
A wavelength multiplexer (MUX) combines incident wavelengths and launches the output to the fiber. At the receiving end a demultiplexer (DEMUX) reverses the above and separates the signal into the components. Multiplexers are generally based on one of two principles, viz., angular dispersion and optical filtering. Prism and reflection gratings are used for separating wavelengths. The same elements can combine wavelengths on reversing the direction of the beams.



Reflection gratings can also be used to separate wavelengths. By choosing a suitable periodic structure for the grating, it is possible to coincide the directions of constructive interference and specular reflection from the grating for a given order and wavelength. The technique is known as **blazing** .



The figure shows a demultiplexer using a blazed reflection grating. Light consisting of a mixture of different wavelengths enters a GRIN lens which collimates the beam to fall on the grating. After reflection, the components are spatially separated and focussed by the lens as outputs to fibers carrying different wavelengths.
Multiplexers may also be made using **interference filters** . Optical filters can be designed using various techniques, the cheapest being deposition of thin films of varying refractive indices on a substrate. When incident light falls on such a material, it encounters ***stacks of boundaries*** which produces constructive interference for some wavelengths and destructive interference for some others. As the number of sacks increases, the resolution becomes better and the band of selected wavelengths becomes narrower. The essential difference between filters based on reflection gratings and interference filters is that gratings selectively reflect a narrow range of wavelengths while the interference filters ***transmit*** a narrow range of wavelengths.
In the figure, a demultiplexer using two optical filters F_1 and F_2 and a GRIN-lens-mirror assembly is shown. The Filter F_2 is attached at the end of the lens. The input fiber and the output fibers (shown only as light path) are at the focal plane of the lens. Filter F_1 is between the fibers and the lens.

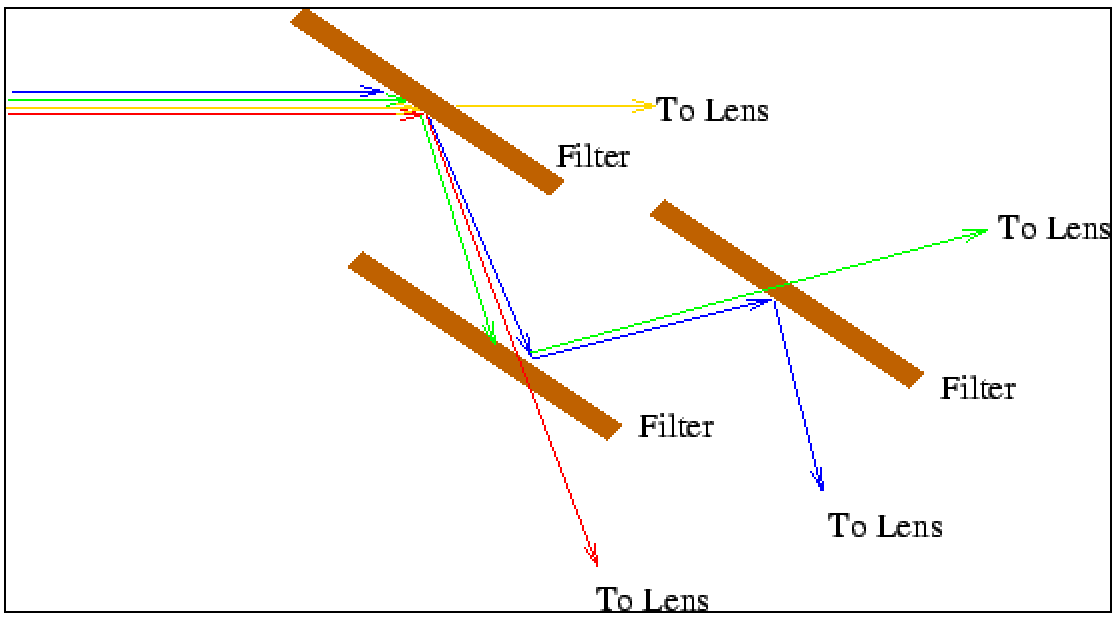


The filter F_1 is a short wavelength pass filter while F_2 is a long wavelength pass filter. Light from the input port becomes parallel at the end of the lens. The shorter wavelength is reflected by F_2 and enters through to the lower ouput fiber. The longer wavelength

F_1

enters through F_2 and is reflected by the plane mirror. It is focussed on to the second output port through the filter F_1. The same principle can be used to design a multiplexer.

A sequence of interference filters, each of which is designed to transmit a single wavelength can be used to design a DEMUX, as shown in the figure. To demultiplex n wavelengths, we would need $n-1$ such filters. The transmitted signal at each port is collected by a lens and fed to the output fiber of the DEMUX.

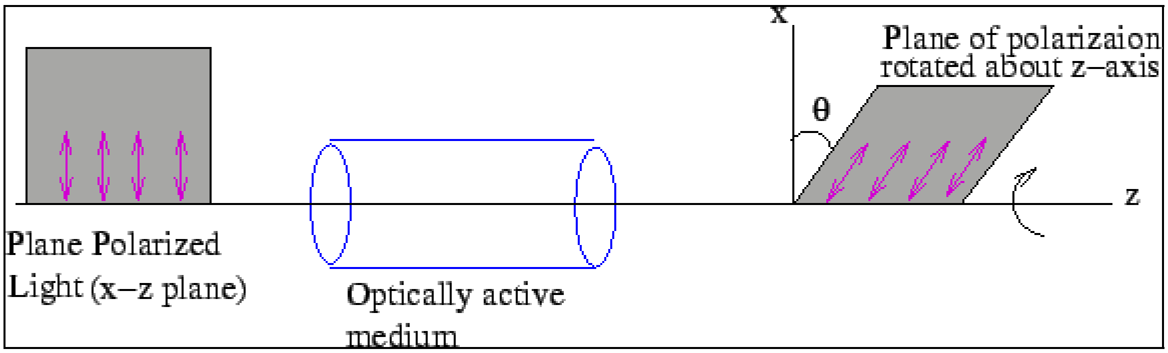


The problem of using so many filters is that at each reflection there is some power loss which adds up to a substantial fraction of signal power. The way to minimize losses is to pass the signal through high and low pass filters which helps in splitting the signal into wavelength groups. If the incoming signal has n wavelengths and we use, say, 4 pass filters of decreasing bandwidth for transmission, it would divide the signal into 5 groups each of which could then be demultiplexed using interference filters. If the groups contain $n/5$ wavelengths each, each wavelength would have been subjected to a maximum $n/5$ reflections (one reflection at the pass-filter and $n/5-1$ at the interference filter). It may be noted that the process does not reduce the number of filters.

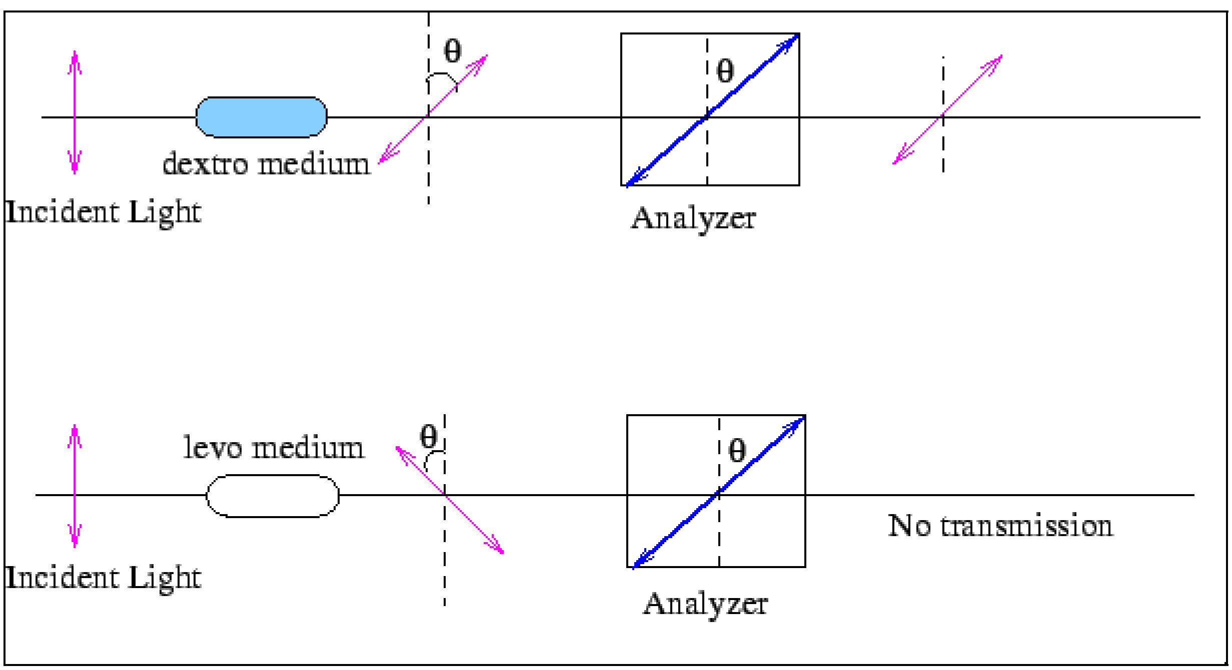
Insertion Loss, Cross Talk and Optical Isolation:

A multiplexer should have low insertion loss and should not allow back scattering of light to any of the input ports. Insertion loss is the attenuation in the signal in travelling from the input port to the output port. It is defined as $L=-10\log(P_{in}/T_{out})$.

Back reflection can be avoided by use of **optical isolators** , which allow light to propagate only in one direction, similar to a diode in an electronic circuit which allow current in one direction. A typical optical isolator has an insertion loss less than 1 dB and high return loss greater than 40 dB. This is achieved by using the property of **optical activity.** When a beam of linearly polarized light is passed through an optically active medium, the transmitted light is also plane polarized. However, the plane of polarization is rotated about the direction of propagation. If an observer looks towards the source parallel to the direction of propagation, the plane of polarization would rotate either clockwise (towards observer's right) or anticlockwise (towards left). The optically active substance is known respectively as dextrorotatory or as levorotatory.

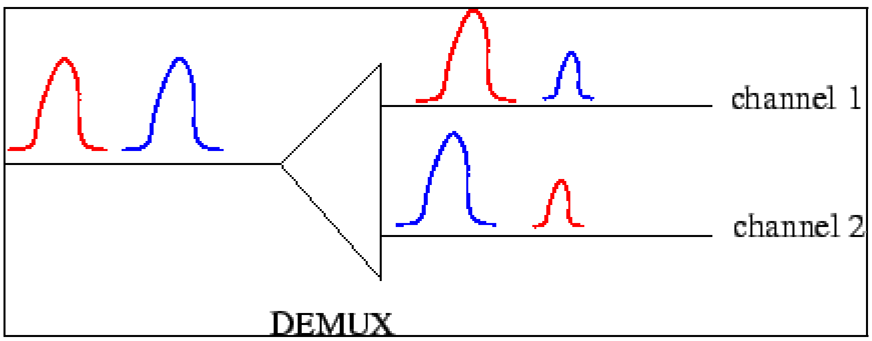


By suitably adjusting the length of the optically active substance through which light travels, one can control the angle of rotation θ.
Consider the incident light to be plane polarized in the x-z plane (z is the direction of propagation, x the direction of electric vector $\vec{E}$).



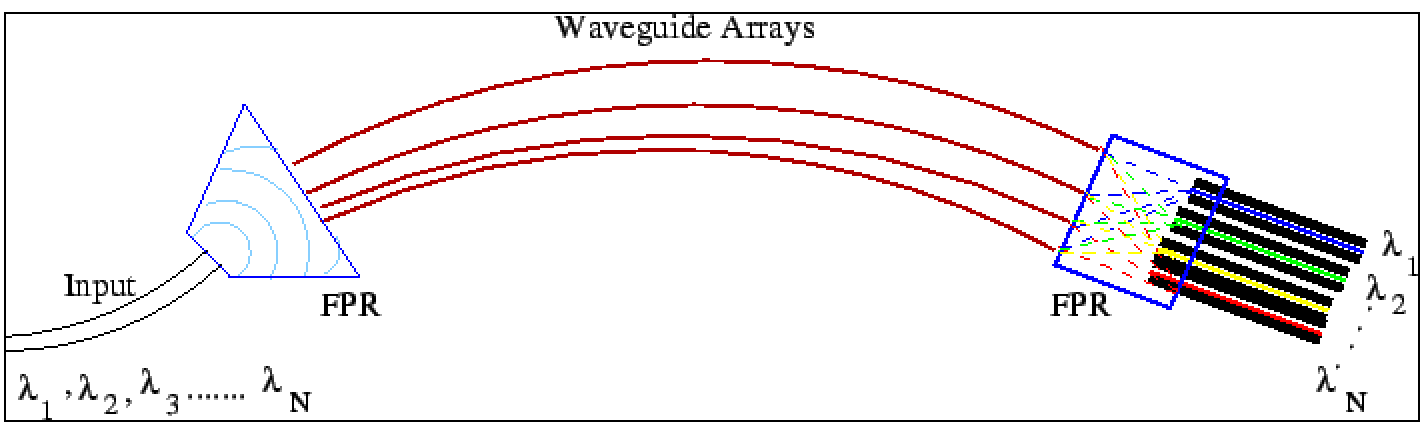
After passing through the polarizer, suppose the electric vector is in the x-y plane, making an angle 45° with the x-axis. If now, the transmitted light is made to pass through an analyzer whose axis is parallel to the direction of the rotated electric vector, the polarized light would pass through such an analyzer. However, if the light were to enter the optically active medium from the opposite direction, the optical rotation will be -45°. If the transmitted light enters the analyzer with axis same as before, no light would pass through as the direction of polarization and the axis of analyzer are at right angles to each other. Thus, using a combination of an optically active substance and analyzer (and in some cases, by application of a magnetic field), one can design such that light travels primarily in one direction, cutting off light travelling in the opposite direction by as much as 40 dB. A primary disadvantage associated with this is that since the incident light is not polarized to begin with, the polarizer reduces the incident intensity by a factor of two, causing a 3 dB loss. This loss can be eliminated by a complicated wich uses a beam splitter and an acousto-optic filter. Optical isolation is the ratio of the transmitted power in the desired direction to that in other directions. In ideal situation, the insertion loss should be zero while the optical isolation should be infinite. Isolators are designed using polarizers, acousto-optic filters and beam splitters.

A demultiplexer should give rise to minimum **cross talk** , i.e., the amount of input power associated with a particular wavelength (say, λ_1) which reaches a channel for a different wavelength (λ_2) should be minimum.



Arrayed Waveguide Grating:

Arrayed waveguide gratings (AWG) are used for demultiplexing. These are based on diffraction principle. The input consists of several channels carrying different wavelengths.



Light propagating in the input waveguides are coupled to the arrayed waveguides after propagating through a free space region (FPR). The AWG consists of an array of curved waveguides. Each curved waveguide has a length which is $\Delta L = m\lambda_c/n$ more than the array element immediately below it, where λ_c is the central operating wavelength, n is the effective refractive index and m is an integer. Thus at the central wavelength, the light will focus at the centre of the image plane. Different wavelengths have different phase differences and the focal point for each will be shifted. A second coupler will deliver different wavelengths to different waveguides.

Recap

In this lecture you have learnt the following

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- Arrayed Waveguide Grating