

# Module 19 : WDM Components

## Lecture : WDM Components - II

### Objectives

In this lecture you will learn the following

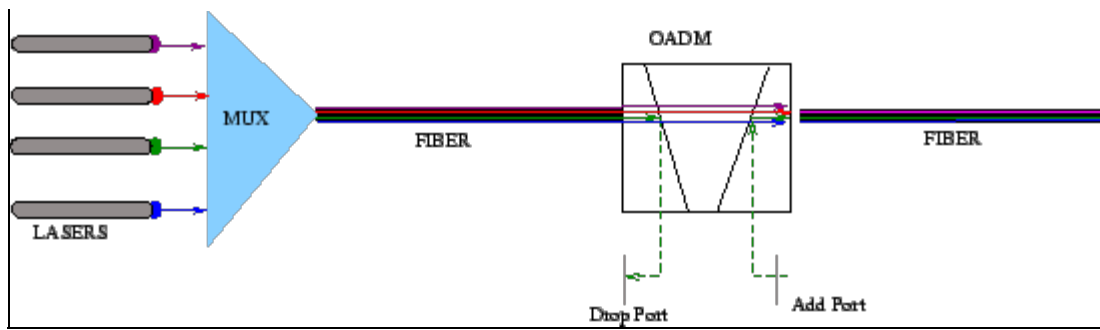
- OADM
- Optical Circulators
- Bidirectional OADM using Optical Circulators and FBG
- Optical Cross Connects (OXC)
- Wavelength Converters
- Modulation (XGM)
- Four Wave Mixing (FWM)
- DWDM Network Topology

### OADM

In its passage from the MUX to DEMUX, the signal passes through one or more **Optical Add-Drop Multiplexer (OADM)** . The function of an OADM is to selectively drop one or more wavelengths by rerouting its data content to another fiber. The OADM may just allow the remaining traffic to pass or add a different data set at a wavelength equal to that of a dropped data. This helps to create a virtual point-to-point circuit.

An OADM is generally a device such as a Bragg grating which could be used to selectively reflect a wavelength that is to be dropped while allowing the others to be transmitted.

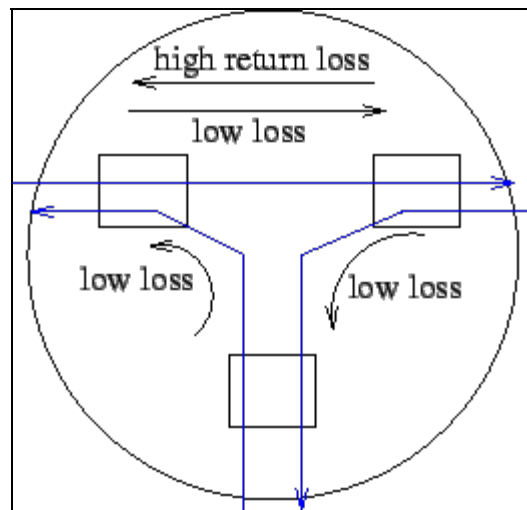
OADM's are passive components of the network. They are manufactured to operate either at fixed wavelengths or at dynamically selectable wavelengths. In case of fixed wavelengths, the wavelengths to be dropped or added are pre-selected.



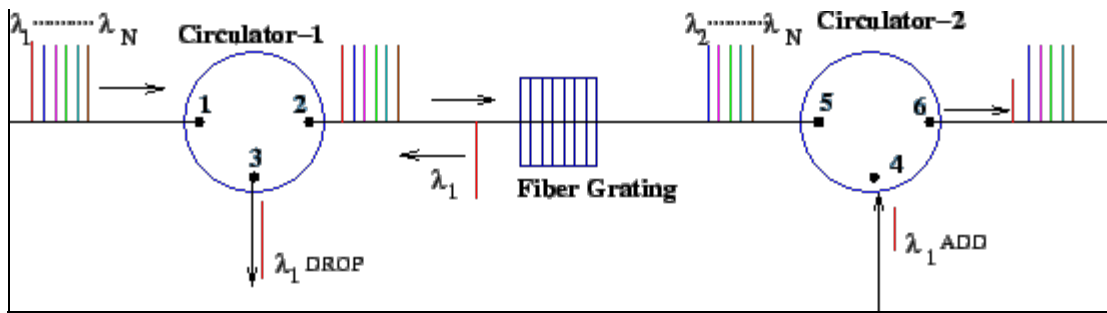
## Optical Circulators

An optical circulator is a 3 or 4 port device which allows flow of light energy in a circular fashion.

For instance in a three port circulator, an input into port 1 appears in port 2 as output with low forward loss and high return loss. Similarly, an input in port 2 goes to port 3 and an input into port 3 appears as output in port 1. Circulators are characterised by low insertion loss (  $< 1$  dB) and high isolation (  $> 50$  dB). Circulators in conjunction with wavelength selective Fiber Bragg Grating (FBG) are used in design of optical add-drop multiplexers.



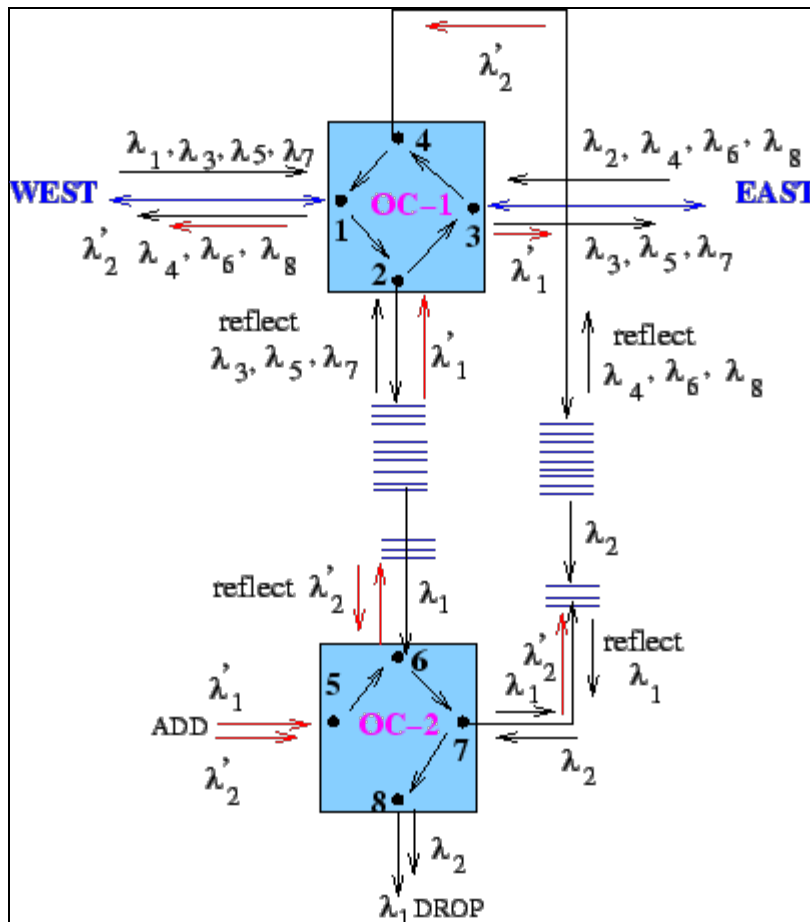
The following figure illustrates the design of an OADM. Several wavelengths from a multiplexer are fed into port 1 of the first optical circulator. The signal passes to port 2 and then on to a fiber grating which selectively reflects  $\lambda_1$ , which, in turn, becomes input to port 2.



The signal of wavelength  $\lambda_1$  then outputs to port 3, where it is dropped. A second signal with wavelength  $\lambda_1$  arrives at the port 4 of the second circulator (whose ports are numbered 4,5, 6 to avoid confusion). This added signal proceeds to port 5, reflected by Bragg grating and re-enters port 5 as an input. The signal, along with  $\lambda_2, \lambda_3, \dots$  is output at port 6.

### Bidirectional OADM using Optical Circulators and FBG

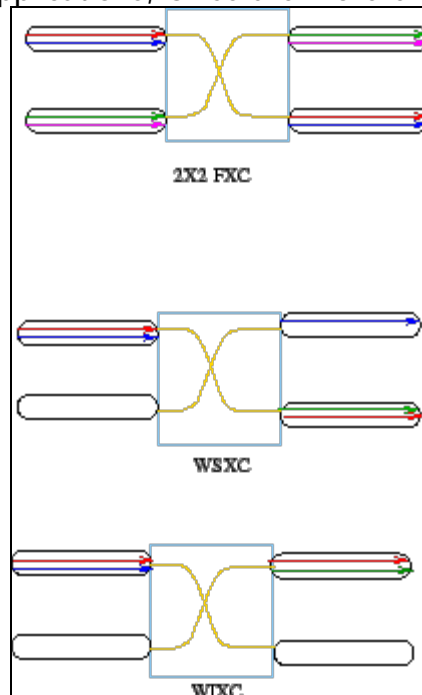
We can design a bidirectional OADM using two four port circulators and wavelength selective fiber gratings.



In the figure, the circulator OC-1 whose ports are numbered from 1 to 4 is used to transform the wavelengths  $\lambda_1, \lambda_3, \lambda_5, \lambda_7$  from west to east and the circulator OC-2 to transform  $\lambda_2, \lambda_4, \lambda_6, \lambda_8$  from east to west. The second circulator OC-2 is used to drop  $\lambda_1$  and  $\lambda_2$  at port 8 and add  $\lambda'_1$  and  $\lambda'_2$  at port 5. Signals  $\lambda_1, \lambda_3, \lambda_5, \lambda_7$  enter port 1 of OC-1 and leave from port 2. All wavelengths other than  $\lambda_1$  are reflected by FBG, re-enter port 2 and leave OC-1 through port 3 travelling east.  $\lambda_1$  enters port 6 of OC-2, travels to port-7, reflected by FBG to re-enter port 7, travels to port 8 and is dropped there. In a similar way  $\lambda_2$  is dropped at port 8 while  $\lambda_4, \lambda_6, \lambda_8$  travelling towards west leave OC-1 through port 1. Wavelengths  $\lambda'_1$  and  $\lambda'_2$ , added at port 5, respectively leave OC-1 through ports 3 and 1.

### Optical Cross Connects (OXC)

Cross connects are essential components of any communication system. Optical cross connects (OXC) are essentially switches which connect any of the input ports to any of the output ports. In the hybrid version of optical switches, switching was done by first converting optical signal to electrical signals, do switching electronically and then reconvert the electrical signals to optical signals. An OXC is an all optical switch which work entirely at photonic level. Because of the high cost of OXCs, hybrid switches are still used today. However, in large bandwidth applications, OXCs are more effective.



Various types of OXCs are made depending on the type of function. **Fiber Cross Connects (FXC)** s are those which connect one fiber channel to another. For wavelength switching **Wavelength Switching Cross Connects (WSXC)** switch wavelength from one port to a port which might be carrying a different wavelength without having to resort to wavelength conversion. WIXCs are switches which provide for wavelength conversion in switching from one fiber to another.

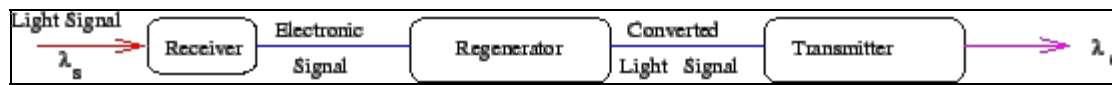
## Wavelength Converters

Wavelength converters are devices which changes the wavelength of an input signal. There are several ways in which a wavelength conversion can occur. Usually, wavelength conversion takes place from a shorter wavelength to a longer wavelength. For instance, certain material can absorb radiation and re-radiate at a lower frequency.

In WDM network, frequency converters are used in conjunction with OXCs for better utilization of available wavelengths. The most commonly used techniques of wavelength conversion are

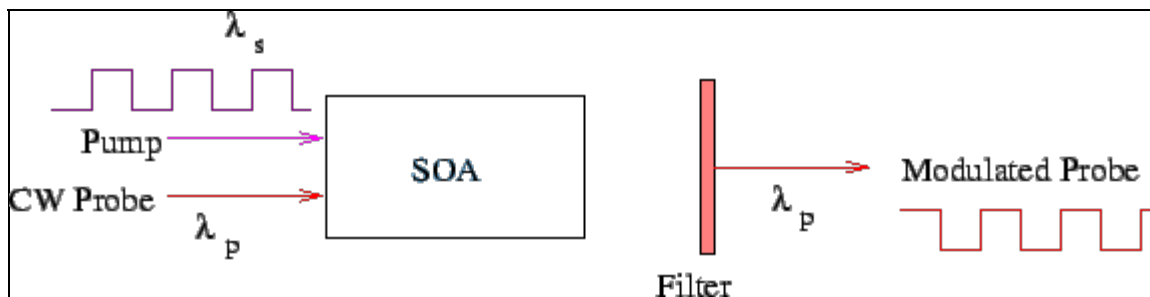
- Electro-optic conversion
- Cross - Gain Modulators (XGM)
- Cross-Phase Modulation (XPM)
- Four-wave mixing

**Electro-optic conversion** In electro-optic conversion an input light signal is converted into an electrical signal, regenerated and re-transmitted at a different wavelength using a tunable laser.



## Cross-Gain Modulation (XGM)

Semiconductor Optical Amplifiers (SOA) are used in WDM systems for switching and wavelength conversion. The active medium in SOAs have homogeneously broadened gain, i.e., change in carrier density in the medium affects all input signals. Thus a strong signal at a wavelength  $\lambda_1$  will affect a weak signal at a different wavelength.



Consider a strong signal at a wavelength  $\lambda_s$  and a weak continuous probe at a wavelength  $\lambda_p$  incident on an SOA. When the signal is in logic state 1, the power is high, carrier

depletion occurs and the probe is blocked. However, when the signal goes to logic zero, there is no depletion and the probe signal passes at full power so that probe is in logic 1 state. Thus the probe signal has been modulated same way as the signal, implying that a wavelength conversion of the signal has taken place. It may be noted that the output signal is inverted in the sense that when the signal should have been in logic state 1, the output is in logic state zero and vice versa. This may be easily set right. **Cross-Phase Modulation (XPM)**

Non-linear properties of some semi conducting material can be used to convert wavelength. As the refractive index of the active medium depends on the carrier density, an incoming signal which depletes carrier density will modulate the refractive index. The change in refractive index, in turn, will phase modulate the continuous wave probe signal. The signal itself is filtered out at the output state, passing the modulated probe signal at a wavelength of  $\lambda_p$  carrying the same information as the original signal with wavelength  $\lambda_p$  was carrying.

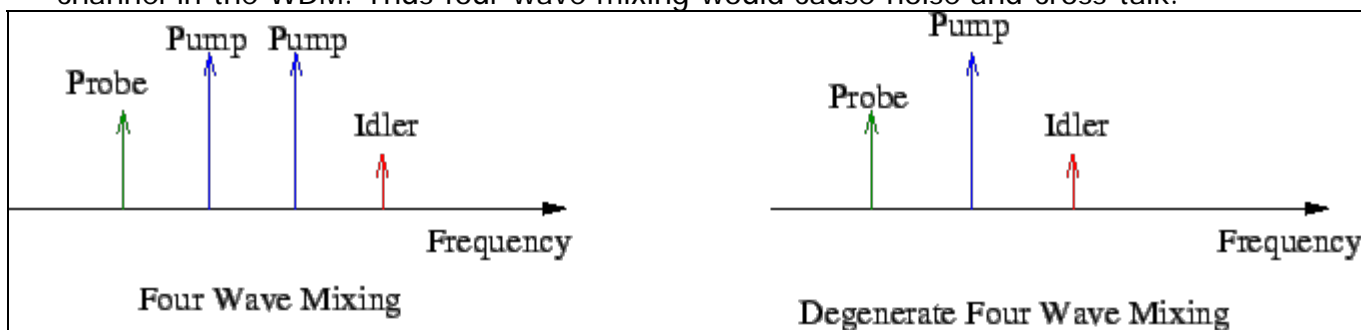
### Four Wave Mixing (FWM)

Four wave mixing, which is an undesirable feature in fiber propagation can be exploited to convert wavelength. When a high powered optical signal is launched into a fiber, the linearity of the medium for optical response is lost. Four wave mixing occurs due to a third order nonlinearity in silica fibers, known as optical **Kerr effect**. When three frequencies  $f_1, f_2$  and  $f_3 (\neq f_1, f_2)$  are launched into the fiber, it results in a fourth wave of frequency

$f = f_1 + f_2 - f_3$ . The new wave is known as the *idler*. Four wave mixing causes

undesirable effect in optical transmission when the probe wavelength is close to the signal wavelength as the resulting wave has the frequency of the input signal. For instance, in DWDM channels which are separated by 100 GHz, three waves of frequencies  $f, f + 100$

GHz and  $f + 200$ GHz will give rise to a wave of frequency  $f - 100$ GHz, which is another channel in the WDM. Thus four wave mixing would cause noise and cross talk.



When the frequencies of the pumping waves are equal ( $f_1 = f_2 = f_p$ ), one gets what is known as Degenerate Four Wave Mixing (DFWM) for which the idler frequency is

$$f = 2f_p - f_s$$

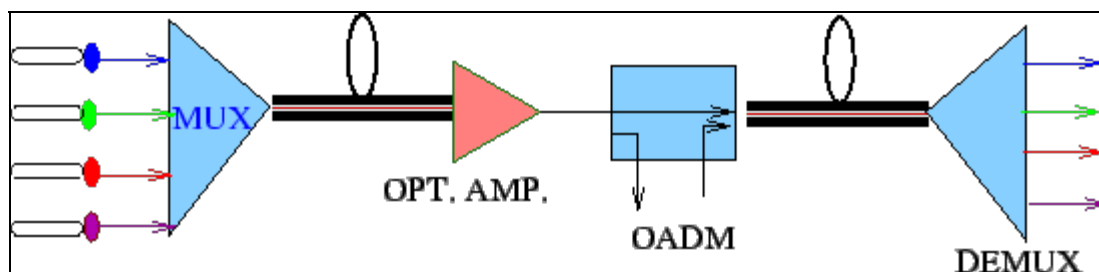
, where  $f_s$  is the frequency of the probe signal. Thus if we take two continuous pumping

waves of same wavelength and a signal of a different wavelength, the output would be modulated the same way as the signal, though with a converted frequency.

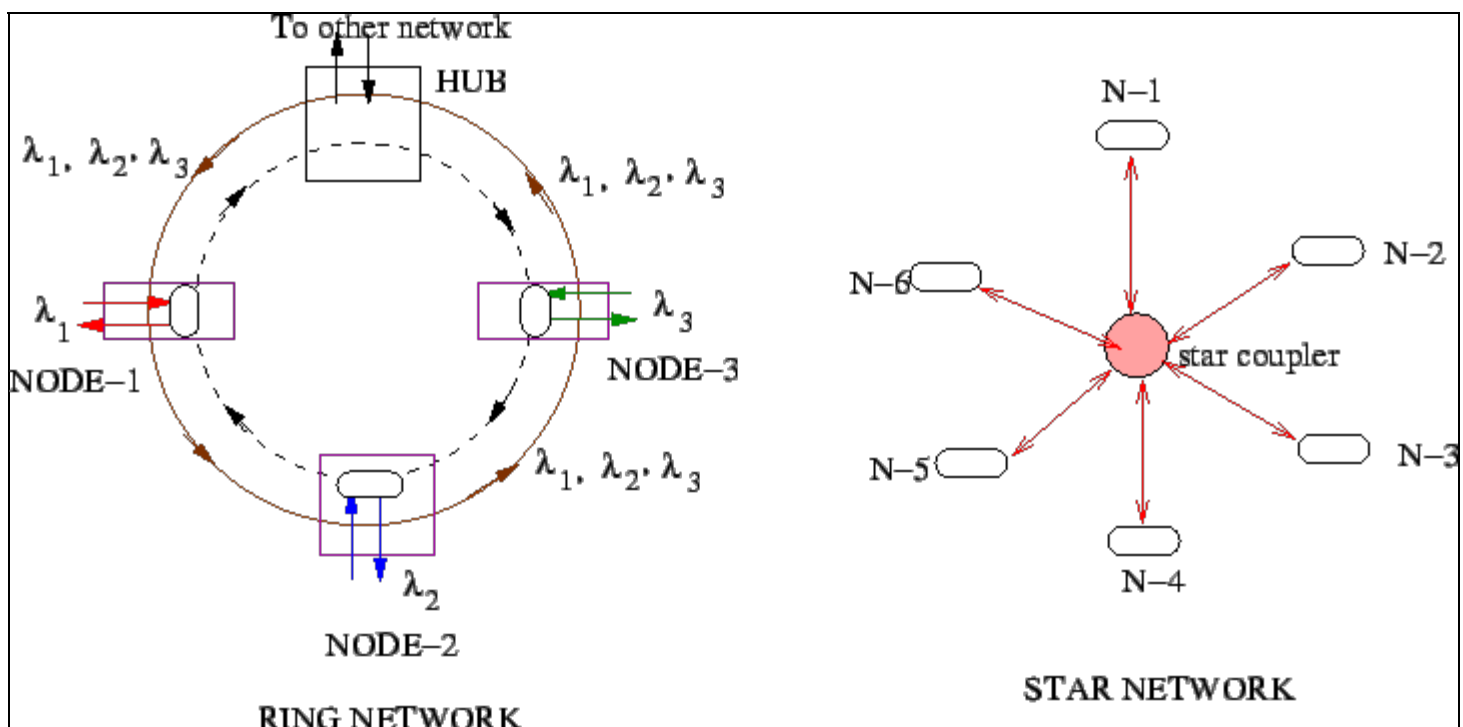
## DWDM Network Topology

DWDM was originally meant to be supported by a point-to-point network topology. Point-to-point topology in its most elementary form, consists of a transmitter and a receiver with a fiber link between them. The first generation WDM

network supported only a few wavelengths at low bit rates over a single fiber. Because of insertion loss and signal degradation, OADM's were not added in the circuit. These days, however, a point to point network can be used over very long hauls (thousands of kilometers) with many components, including amplifiers, wavelength converters, OXCs etc.



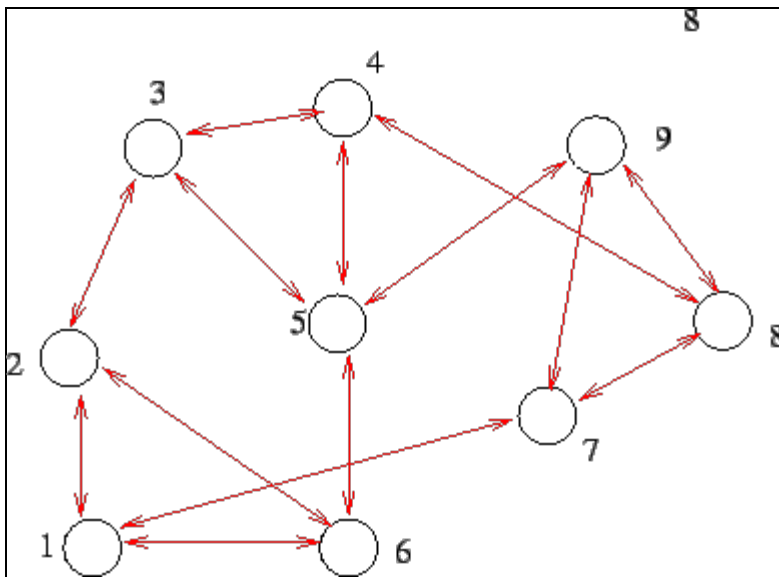
**Ring topology**, modeled after the **Fiber Distributed Data Interface (FDDI)** used in early optical networks which consisted of two rings (called the primary and the secondary rings) running in opposite directions with the nodes placed along the circular paths. In case of a fault at any of the nodes, it was automatically passed by the adjacent node by optically connecting the primary and the secondary rings. SONET rings with nodes having OADM's are quite popular.



One of the nodes, called a hub, is used to manage wavelengths. A hub may assign a set of wavelengths to a particular light path. Wavelengths may be added or dropped at a node while the remaining wavelength passes transparently through it. In some cases, the hub may receive a wavelength from a node and convert it to another wavelength. Such a network is called **Broadcast and Select Network**.

In a **Star topology**, signal to and from every node passes through a central node, which is either an active or a passive optical coupler.

In a **Mesh topology**, the interconnections are from any node to any other node in the network. The topology uses optical cross connects which have the ability to connect any input port with any output port. Fault tolerance is inherently built into this topology as there are several paths between a pair of nodes. For instance, in the adjoining figure, the nodes 1 and 9 are connected by the paths  $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 8 \rightarrow 9$  or  $1 \rightarrow 6 \rightarrow 5 \rightarrow 9$  or  $1 \rightarrow 7 \rightarrow 8 \rightarrow 9$  etc.



## Recap

In this lecture you have learnt the following

- OADM
- Optical Circulators
- Bidirectional OADM using Optical Circulators and FBG
- Optical Cross Connects (OXC)
- Wavelength Converters



## Modulation (XGM)

- Four Wave Mixing (FWM)
- DWDM Network Topology

Congratulations, you have finished Module 19. To view the next lecture select it from the left hand side menu of the page