Internal Assessment Test I

Subject:	**Optical Networking**							Code:	**10TE81**
Date:	**27/ 03/17**	Duration:	**90 mins**	Max Marks:	**50**	Sem:	**VIII**	Branch:	**TCE**

Q1. a) **What is first generation of optical networks? Explain the features and utilities of the first generation optical networks.**

Solution:
First generation of optical networks came in the 1970s, id used TDM as the main multiplexing technique. In the first generation, optics was essentially used for transmission and simply to provide capacity. Optical fiber provided lower bit error rates and higher capacities than copper cables. All the switching and other intelligent network functions were handled by electronics. Examples of first-generation optical networks are SONET (synchronous optical network) and the essentially similar SDH (synchronous digital hierarchy) networks, which form the core of the telecommunications infrastructure in North America and in Europe and Asia, respectively, as well as a variety of enterprise networks such as Fibre Channel.

Several common features of 1st generation of optical networks are:

1. It used TDM for multiplexing. There was no WDM in the 1st generation. So the data rates were quite low in comparison to the WDM systems.
2. It used several electrical to optical conversions. OEO, OE and EO conversions used to be very common in 1st generation networks.
3. It used 3R processing along the links. All these processing used to be done in the electrical domain.
4. Due to the 3R processing all the networks used to be opaque. Transparency came only after the arrival of EDFA.

The main utilities of 1st generation optical networks used to be the high speed. The optical systems used to be much faster than other wired media. It served the role of both core and metro networks.

Q1. b) **What was/were the main multiplexing techniques for first generation optical networks? Explain your answer with justification. How did it change in the second generation?**

Solution:
For 1st generation optical networks, TDM was the only multiplexing technique available. There was no equivalent of frequency division multiplexing in the optical domain. WDM came much later in the 1990s.

Due to the use of only TDM, the capacities of the optical fibers used to be quite small in comparison to the 2nd generation. In the 2nd generation WDM was developed. The simultaneous uses of WDM and TDM increased the data rates by 100s of folds over the 1st generation networks.

Q2. a) **Why nonlinear effects are found in optical fiber communications? Explain the reasons in terms of the physical parameters of communication.**

Solution:

At higher bit rates such as 10 Gb/s and above and/or at higher transmitted powers, it is important to consider the effect of nonlinearities. In the case ofWDM systems, nonlinear effects can become important even at moderate powers and bit rates.

There are two types of origins of nonlinear effects. The first one arises due to the interaction of light waves with phonons (molecular vibrations) in the silica medium. The two main effects in this category are stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS).

The second set of nonlinear effects arises due to the dependence of the refractive index on the intensity of the applied electric field, which in turn is proportional to the square of the field amplitude. The most important nonlinear effects in this category are self-phase modulation (SPM) and four-wave mixing (FWM).

In scattering effects, energy gets transferred from one light wave to another wave at a longer wavelength (or lower energy). The lost energy is absorbed by the molecular vibrations, or phonons, in the medium. (The type of phonon involved is different for SBS and SRS.) This second wave is called the Stokes wave. The first wave can be thought of as being a “pump” wave that causes amplification of the Stokes wave. As the pump propagates in the fiber, it loses power and the Stokes wave gains power. In the case of SBS, the pump wave is the signal wave, and the Stokes wave is the unwanted wave that is generated due to the scattering process. In the case of SRS, the pump wave is a high-power wave, and the Stokes wave is the signal wave that gets amplified at the expense of the pump wave.

In a WDM system with multiple channels, the induced chirp in one channel depends on the variation of the refractive index with the intensity on the other channels. This effect is called cross-phase modulation (CPM). When we discuss the induced chirp in a channel due to the variation of the refractive index with the intensity on the same channel, we call the effect SPM.

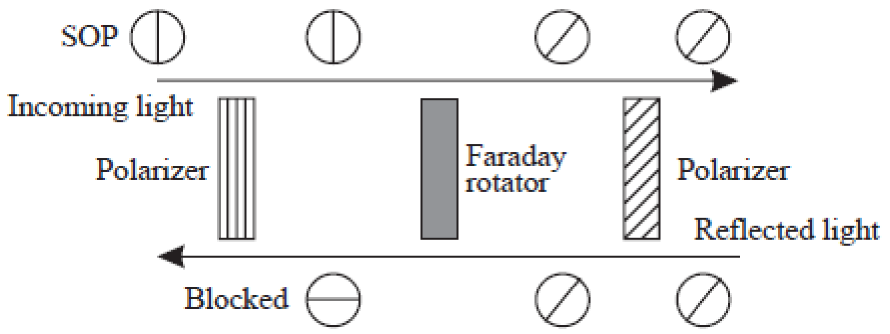
Q2. b) **What are the main nonlinear effects found in optical fiber communications? Briefly explain all the nonlinear effects observed in optical networks.**

Solution:
The main nonlinear effects are:
SBS,
SRS,
FWM,
CPM,
SPM,
and solitons.
Explain each of the above concepts in brief.

Q3. a) **Explain the principle of operation of an isolator using appropriate diagram. Does an isolator depend on polarization? Explain with proper reasons.**

Solution:
An isolator is a non-reciprocal device. Its main function is to allow transmission in one direction through it but block all transmission in the other direction. Isolators are used in systems at the output of optical amplifiers and lasers primarily to prevent reflections from entering these devices, which would otherwise degrade their performance. The two key parameters of an isolator are its insertion

loss, which is the loss in the forward direction and which should be as small as possible, and its isolation, which is the loss in the reverse direction and which should be as large as possible. The typical insertion loss is around 1 dB, and the isolation is around 40–50 dB.

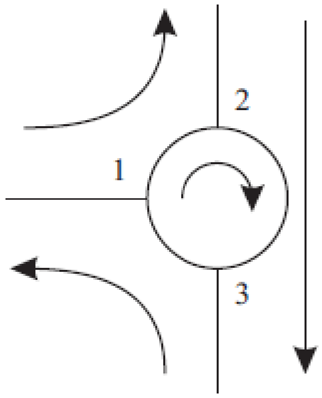


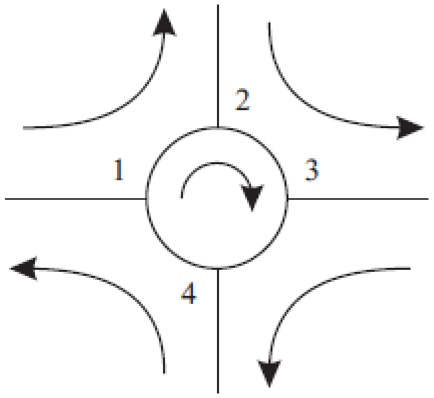
Let us assume that the input light signal has the vertical state of polarization (SOP) shown in the figure. It is passed through a polarizer, which passes only light energy in the vertical SOP and blocks light energy in the horizontal SOP. Such polarizers can be realized using crystals, known as dichroics, which have the property of selectively absorbing light with one SOP. The polarizer is followed by a Faraday rotator. A Faraday rotator is a nonreciprocal device, made of a crystal that rotates the SOP, say, clockwise, by 45◦, regardless of the direction of propagation. The Faraday rotator is followed by another polarizer that passes only SOPs with this 45◦ orientation. Thus the light signal from left to right is passed through the device without any loss. On the other hand, light entering the device from the right due to a reflection, with the same 45◦ SOP orientation, is rotated another 45◦ by the Faraday rotator, and thus blocked by the first polarizer.

Q3. b) **What is a circulator? What are its utilities in optical communication networks? How the circulators and multiplexers are different from each other?**

Solution:

A circulator is a nonreciprocal device. It is similar to an isolator, except that it has multiple ports, typically three or four. As shown below, in a three-port circulator, an input signal on port 1 is sent out on port 2, an input signal on port 2 is sent out on port 3, and an input signal on port 3 is sent out on port 1. Circulators are useful to construct optical add/drop elements. Circulators operate on the same principles as isolators.





Q4. a) Describe the principles of operation of semiconductor optical amplifiers using appropriate diagrams. Are the semiconductor optical amplifiers suitable for long term continuous operation as amplifiers in optical networks?

Solution:
Refer to the lecture notes of the class and the lecture slides. All the figures and the relevant information are presented there.

Q4. b) Using appropriate diagrams explain the principle of operation of EDFAs. Show the emission and absorption characteristics of EDFA.

Solution:
Refer to the lecture notes and the lecture slides. All the figures and the relevant information are presented there.

Q5. a) What are the different types of transmitters used in optical communication? Briefly, explain their application domains. Compare the characteristics of the transmitters with each other.

Solution:
Refer to the lecture notes and the lecture slides. All the figures and the relevant information are presented there.

Q5. b) What are the different types of detectors used in optical communication? Briefly, explain their application domains. Compare the characteristics of the detectors with each other.

Solution:
Refer to the lecture notes and the lecture slides. All the figures and the relevant information are presented there.

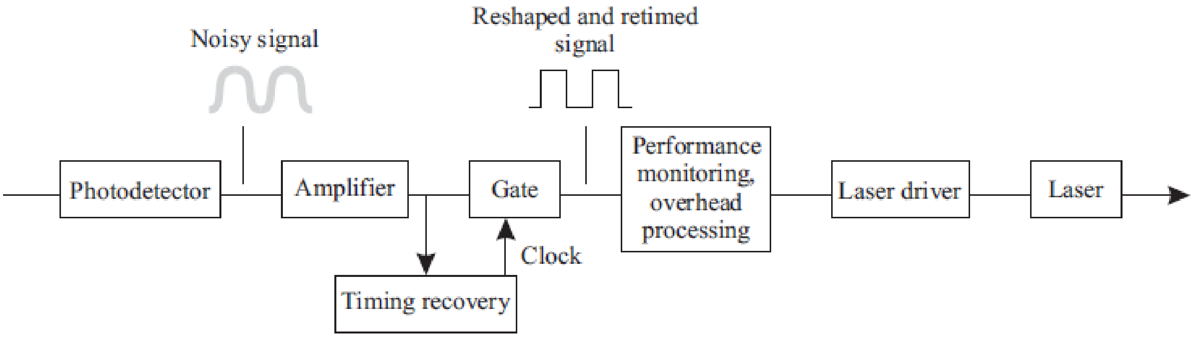
Q6. **What is wavelength converter? Why wavelength converters are needed in optical networks? What are the different principles being used for wavelength conversion. Describe each of them using appropriate physical principles and diagrams if needed.**

Solution:
A wavelength converter is a device that converts data from one incoming wavelength to another outgoing wavelength. Wavelength converters are useful components in WDM networks for three major reasons.

First of all, data may enter the network at a wavelength that is not suitable for use within the network. For example, the first-generation networks commonly transmit data in the 1310 nm wavelength window, using LEDs or Fabry-Perot lasers. Neither the wavelength nor the type of laser is compatible with WDM networks. So at the inputs and outputs of the network, data must be converted from these wavelengths to narrow-band WDM signals in the 1550 nm wavelength range. A wavelength converter used to perform this function is sometimes called a transponder. Second, wavelength converters may be needed within the network to improve the utilization of the available wavelengths on the network links. Finally, wavelength converters may be needed at boundaries between different networks if the different networks are managed by different entities and these entities do not coordinate the allocation of wavelengths in their networks.

There are two broad principles available for the wavelength conversion. The first one is the optoelectronic method and the second one is the all-optical method. In the first method, the wavelength conversion happens in the electrical domain. However, in the second, it is done completely in the optical domain.

Optoelectronic method is the simplest, most obvious, and most practical method today to realize wavelength conversion. As shown in figure below, the input signal is first converted to electronic form, regenerated, and then retransmitted using a laser at a different wavelength. This is usually a variable-input, fixed-output converter. The receiver does not usually care about the input wavelength, as long as it is in the 1310 or 1550 nm window. The laser is usually a fixed-wavelength laser. A variable output can be obtained by using a tunable laser.



Optoelectronic method of wavelength conversion

In the optical domain, optical gating, optical interference and optical mixing principles can be used for the design of wavelength converters. Optical gating makes use of an optical device whose characteristics change with the intensity of an input signal. This change can be transferred to another unmodulated probe signal at a different wavelength going through the device. At the output, the probe signal contains the information that is on the input signal. Like the optoelectronic approach, these devices are variable-input and either fixed-output or variable-output devices, depending on whether the probes signal are fixed or tunable. In all these three methods, SOA are required for the new wavelength generation.

Q7. **Write short notes on <u>any four</u> of the following topics (in 6 to 8 sentences).**

a) Stimulated Brillouin Scattering (SBS)

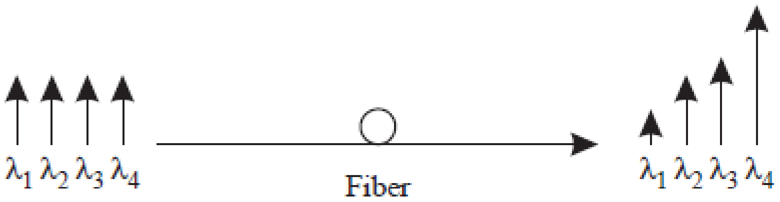
Solution:

SBS is a form of nonlinear scattering phenomena that normally happens due to high intensity of power in the optical fibers. In the case of SBS, the phonons involved in the scattering interaction are acoustic phonons, and the interaction occurs over a very narrow line width, that varies from 20 to 100 MHz at 1.55 μm, depending ob fiber geometry and composition. Also the Stokes and pump waves propagate in opposite directions. Thus SBS does not cause any interaction between different wavelengths, as long as the wavelength spacing is much greater than 100 MHz, which is typically the case. SBS can, however, create significant distortion within a single channel. SBS produces gain in the direction opposite to the direction of propagation of the signal, in other words, back toward the source. Thus it depletes the transmitted signal as well as generates a potentially strong signal back toward the transmitter, which must be shielded by an isolator.

b) Stimulated Raman Scattering (SRS)

Solution:

SRS is a form of nonlinear scattering phenomena that normally happens due to high intensity of power in the optical fibers. In this scattering, power is transferred from lower wavelengths to higher wavelengths as shown below. This coupling of energy from a lower wavelength signal to a higher-wavelength signal is a fundamental effect that is also the basis of optical amplification and lasers. Thus, a photon of lower wavelength has a higher energy. The transfer of energy from a signal of lower wavelength to a signal of higher wavelength corresponds to emission of photons of lower energy caused by photons of higher energy.



Effect of SRS in transferring energy from lower wavelengths to the higher ones

c) SPM

Solution:

SPM is a nonlinear effect which arises because the refractive index of the fiber has an intensity-dependent component. This nonlinear refractive index causes an induced phase shift that is proportional to the intensity of the pulse. Thus different parts of the pulse undergo a different phase shift, which gives rise to chirping of the pulses. Pulse chirping in turn enhances the pulse-broadening effects of chromatic dispersion. This chirping effect is proportional to the transmitted signal power so that SPM effects are more pronounced in systems using high transmitted powers. The SPM-induced chirp affects the pulse broadening effects of chromatic dispersion and thus is important to consider for high-bit-rate systems that already have significant chromatic dispersion limitations. For systems operating at 10 Gb/s and above, or for lower-bit-rate systems that use high transmitted powers, SPM can significantly increase the pulse-broadening effects of chromatic dispersion.

d) **FBG**

Solution:

FBGs are the gratings formed in optical fibers by passing high power high intensity radiations in through the fiber. These are very regular gratings which depend on the wavelengths. So, these gratings can be used for filtration and other wavelength selection purposes. These properties of fiber Bragg gratings make them very useful devices for system applications. Fiber Bragg gratings are finding a variety of uses in WDM systems, ranging from filters and optical add/drop elements to dispersion compensators. Many variations of this simple add/drop element can be realized by using gratings in combination with couplers and circulators. A major concern in these designs is that the reflection of these gratings is not perfect, and as a result, some power at the selected wavelength leaks through the grating. This can cause undesirable crosstalk. Fiber Bragg gratings can also be used to compensate for dispersion accumulated along the link.

d) FWM

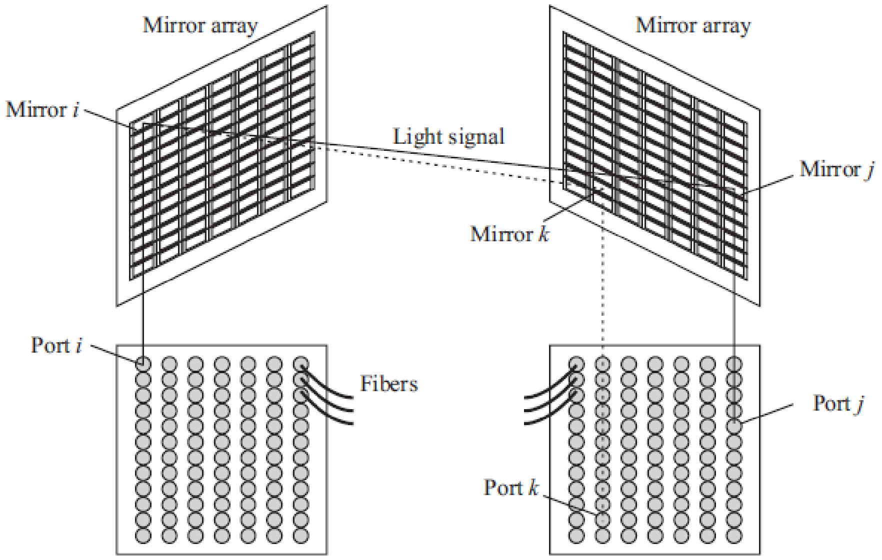
Solution:

FWM is a nonlinear effect found in optical fiber communication systems. In this effect, at least four different waves are generated in the fiber due to nonlinear effects. Four-wave mixing effect is independent of the bit rate but is critically dependent on the channel spacing and fiber chromatic dispersion. Decreasing the channel spacing increases the four-wave mixing effect, and so does decreasing the chromatic dispersion. Thus the effects of FWM must be considered even for moderate-bit-rate systems when the channels are closely spaced and/or dispersion-shifted fibers are used.

f) **MEMS Switches**

Solution:

Micro-electro-mechanical systems are miniature mechanical devices typically fabricated using silicon substrates. In the context of optical switches, MEMS usually refers to miniature movable mirrors fabricated in silicon, with dimensions ranging from a few hundred micrometers to a few millimetres. A single silicon wafer yields a large number of mirrors, which means that these mirrors can be manufactured and packaged as arrays. Moreover, the mirrors can be fabricated using fairly standard semiconductor manufacturing processes. These mirrors are deflected from one position to another using a variety of electronic actuation techniques, such as electromagnetic, electrostatic, or piezoelectric methods, hence the name MEMS. Of these methods, electrostatic deflection is particularly power efficient but is relatively hard to control over a wide deflection range. A MEMS switching system has been shown below.

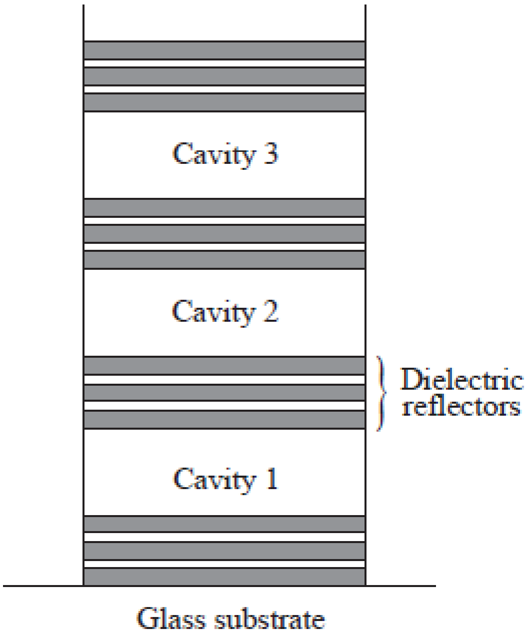


MEMS Switches

g) **Thin-film filters**

Solution:

Thin film filters are the semiconductor filters designed for several wavelength selection or rejection purpose. It uses the principles of reflection and transmission for its operations. A thin-film resonant multicavity filter (TFMF) consists of two or more cavities separated by reflective dielectric thin-film layers, as shown in the figure shown below. The effect of having multiple cavities of glass and semiconductors has been shown in the figure. As more cavities are added, the top of the passband becomes flatter and the skirts become sharper, both very desirable filter features.



This film filters made from glass and semiconductors