

KLS Vishwanathrao Deshpande Institute of Technology

(Accredited by NAAC with "A" Grade)

(Approved by AICTE, New Delhi, Affiliated to VTU, Belagavi)

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

University / Model Question Paper Scheme & Solution

Faculty Name	:	Prof. Vijayalaxmi C Kalal
Course Name	:	Satellite and Optical Communication
Course Code	:	BEC515D
Year of Question Paper	:	Dec - Jan 2025
Date of Submission	:	07/07/2025

Kalal

Faculty Member

MA
HoD
07-07-2025

[Signature]

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Dean Academics
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Dept. of Electronic & Communication Engg.
KLS V.D.I.T., HALIYAL (U.K.)

CBCS SCHEME

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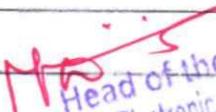
Fifth Semester B.E./B.Tech. Degree Examination, Dec.2024/Jan.2025 Satellite and Optical Communication

Time: 3 hrs.

Max. Marks: 100

*Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M : Marks , L: Bloom's level , C: Course outcomes.*

Module – 1			M	L	C
Q.1	a.	Explain the Kepler laws of planetary motion. Also derive the expression for orbital period.	10	L2	CO1
	b.	A satellite is orbiting earth in a uniform circular orbit at a height of 630 km from the surface of earth. Assuming the radius of earth and its mass to be 6370 km and 5.98×10^{24} kg respectively. Determine the velocity of the satellite. (Take gravitational const $G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$).	10	L3	CO1
OR					
Q.2	a.	The apogee and perigee distance of satellite orbiting in an elliptical orbit are respectively, 45000 km and 7000 km. Determine the followings: i) Semi-major axis of the elliptical orbit. ii) Orbit eccentricity iii) Distance between the center of earth and the center of elliptical orbit.	10	L3	CO1
	b.	Explain briefly any six orbital parameters required to determine a satellite orbit.	10	L2	CO1
Module – 2					
Q.3	a.	Explain the satellite subsystems.	10	L2	CO2
	b.	Explain the solar energy driven power supply system of a satellite.	10	L2	CO2
OR					
Q.4	a.	Describe the telemetry, telecommand and tracking control monitoring system of a communication satellite.	10	L2	CO2
	b.	Explain with block schematic arrangement of a generalized earth's station.	10	L2	CO2
Module – 3					
Q.5	a.	What is transponder? Explain the various types of transponders.	10	L2	CO3
	b.	List the advantages and disadvantages of satellites with respect to terrestrial networks.	10	L1	CO3
OR					
Q.6	a.	Explain with a neat diagram satellite point-to-point telephonic network.	10	L2	CO3
	b.	Explain with a neat diagram satellite – cable TV.	10	L2	CO3


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Module – 4

Q.7	a.	Explain the mode theory as applied to circular wavelength (wave guides) in optical fibers.	10	L2	CO4
	b.	Describe the operational difference between single-mode and multimode fibers in terms of bandwidth and attenuation.	10	L2	CO4

OR

Q.8	a.	What is modal delay and how does it contribute to modal dispersion in multimode fibers?	10	L2	CO4
	b.	Define material dispersion and explain how it arises in optical fibers.	10	L2	CO4

Module – 5

Q.9	a.	Explain the principle operation of LED's.	10	L2	CO5
	b.	Discuss the characteristics of the optical detectors.	10	L2	CO5

OR

Q.10	a.	Explain the principle operation of WDM standards.	12	L2	CO5
	b.	Explain the isolators and circulators.	8	L2	CO5

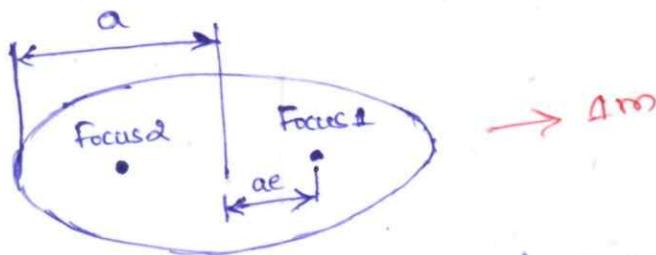
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Q.1a Explain the Kepler laws of planetary motion. Also derive the expression for orbital period $\rightarrow 10m$

Ans: There are three laws of planetary motion by Kepler, they are:

Kepler's First Law:

Statement- "The orbit of a satellite around Earth is elliptical with the centre of the Earth lying at one of the foci of the ellipse." $\rightarrow 2m$



- For any elliptical motion, the law of conservation of energy is valid at all points on the orbit.
- For satellites, it means that the sum of the kinetic & the potential energy of a satellite always remain constant. The value of this constant is equal to $-\frac{Gm_1m_2}{2a}$, where

m_1 : mass of Earth

m_2 : mass of the satellite

a : semi-major axis of the orbit

- The kinetic & potential energies of a satellite at any point at a distance 'r' from the centre of the Earth are given by -

$$\text{Kinetic Energy} = \frac{1}{2} m_2 v^2$$



Potential energy = $-\frac{Gm_1m_2}{r}$

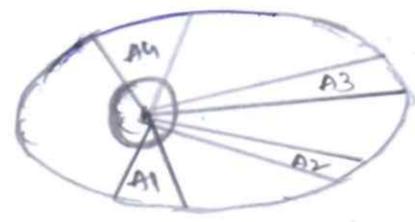
$\therefore \frac{1}{2}m_2v^2 - \frac{Gm_1m_2}{r} = -\frac{Gm_1m_2}{2a}$

$v^2 = Gm_1 \left(\frac{2}{r} - \frac{1}{a} \right)$

$\therefore v = \sqrt{Gm_1 \left(\frac{2}{r} - \frac{1}{a} \right)} = \sqrt{\mu \left(\frac{2}{r} - \frac{1}{a} \right)}$ → 1m

Kepler's Second Law:

Statement: "The line joining the satellite & the centre of the Earth sweeps out equal areas in the plane of the orbit in equal time intervals; i.e. the rate (dA/dt) at which it sweeps area A is constant." → 2m



$\frac{dA}{dt} = \frac{\text{angular momentum of the satellite}}{2m}$ → 1m

m: mass of the satellite.

Kepler's Third Law:

Statement: "The square of the time period of any satellite is proportional to the cube of the semi-major axis of its elliptical orbit." → 2m

Expression for time period:

A circular orbit with radius 'r'. A circular orbit is a special case of an elliptical orbit with the semi-major axis & semi-minor axis equal to the radius.

Equating the gravitational force with the centrifugal force gives

$$\frac{Gm_1m_2}{r^2} = \frac{m_2v^2}{r}$$

Replacing v by ωr in the above eqⁿ gives

$$\frac{Gm_1m_2}{r^2} = \frac{m_2\omega^2r^2}{r} = m_2\omega^2r$$

$$\therefore \omega^2 = Gm_1/r^3$$

Substituting $\omega = 2\pi/T$ gives

$$T^2 = \left(\frac{4\pi^2}{Gm_1}\right)r^3 \Rightarrow T = \sqrt{\left(\frac{4\pi^2}{Gm_1}\right)r^3} = \frac{2\pi}{\sqrt{\mu}} r^{3/2} \rightarrow 1m$$

For elliptical orbits 'r' is replaced by semi-major axis 'a'. $\therefore T = \frac{2\pi}{\sqrt{\mu}} a^{3/2}$



Q1b.

A satellite is orbiting earth in a uniform circular orbit at a height of 630 KM from the surface of earth. Assuming the radius of earth & its mass to be 6370 KM & 5.98×10^{24} Kg respectively. Determine the velocity of the satellite. (Take gravitational const $G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{Kg}^2$). $\rightarrow 10m$

Ans: Orbit radius, $R = 6370 + 630 = 7000 \text{ km} = 7000000 \text{ m}$. $\rightarrow 2\text{m}$

Also constant, $\mu = GM \rightarrow 2\text{m}$

$$= 6.67 \times 10^{-11} \times 5.98 \times 10^{24}$$

$$= 39.8 \times 10^{13} \text{ Nm}^2/\text{kg}$$

$$= 39.8 \times 10^{13} \text{ m}^3/\text{s}^2 \rightarrow 2\text{m}$$

\therefore The velocity of the satellite can be computed from, $\rightarrow 2\text{m}$

$$V = \sqrt{\frac{\mu}{R}} = \sqrt{\frac{(39.8 \times 10^{13})}{7000000}} = 7.54 \text{ km/s} \rightarrow 2\text{m}$$

Q2a. The apogee & perigee distance of satellite orbiting in an elliptical orbit are respectively, 45000 km & 7000 km. Determine the followings:

- i). Semi-major axis of the elliptical orbit
- ii). Orbit eccentricity
- iii). Distance between the center of earth & the center of earth elliptical orbit. $\rightarrow 10\text{m}$

Ans: i). Semi-major axis of the elliptical orbit,

$$a = \frac{\text{apogee} + \text{perigee}}{2}$$

$$= \frac{(45000 + 7000)}{2}$$

$$\therefore a = 26000 \text{ km} \rightarrow 2\text{m}$$

ii). Eccentricity, $e = \frac{\text{apogee} - \text{perigee}}{2a} \rightarrow 2\text{m}$

$$= \frac{45000 - 7000}{2 \times 26000}$$

$$= \frac{38000}{52000}$$

$$\therefore e = 0.73 \rightarrow 2\text{m}$$



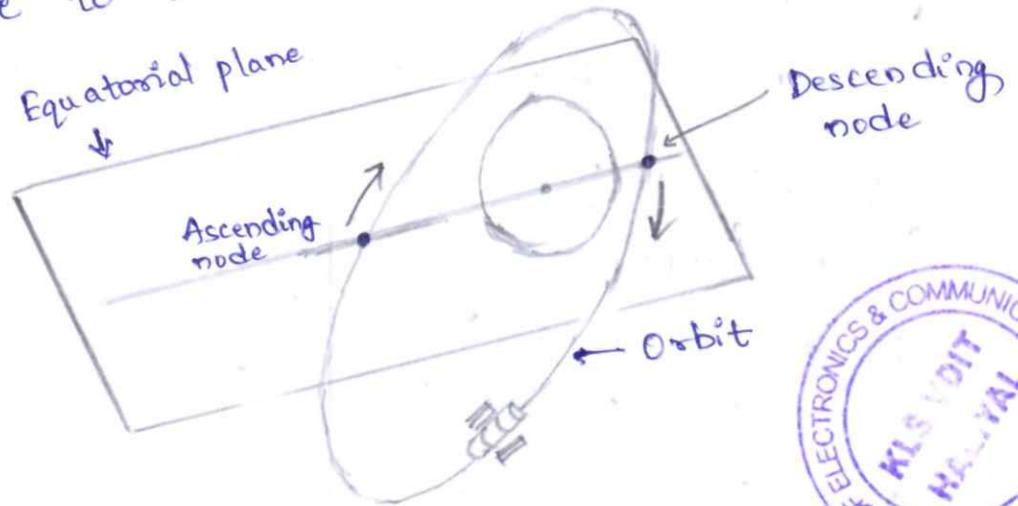
iii) Distance between the centre of the Earth & the centre of ellipse = $ae \rightarrow 2m$
 $\therefore = 26000 \times 0.73$
 $= 18,980 \text{ Km} \rightarrow 2m$

Q2b. Explain briefly any six orbital parameters required to determine a satellite orbit? $\rightarrow 10m$

Ans: Orbital parameters are-

1. Ascending & descending nodes:

The satellite orbit cuts the equatorial plane at two points: the first, called the descending node (N1), where the satellite passes from the northern hemisphere to the southern hemisphere, & the second, called the ascending node (N2), where the satellite passes from the southern hemisphere to the northern hemisphere. $\rightarrow 1.5m$ (1.5m)



2. Solstices:

They are the times when the inclination angle is at its maximum i.e. 23.4° . These also occur twice during a year on 20-21 June, called the summer solstice, & 21-22 December, called winter solstice. $\rightarrow 1.5m$ (1.5m)

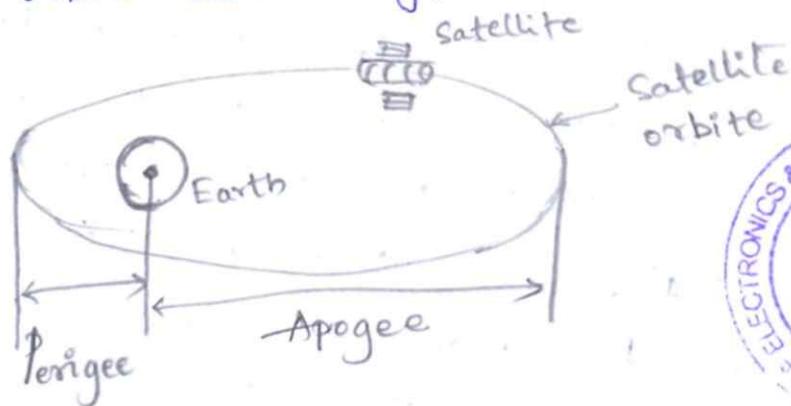
3. Apogee:

Apogee is the point on the satellite orbit that is at the farthest distance from the centre of the Earth. $\rightarrow 1.5m$

$$\text{Apogee distance} = a(1+e)$$

where, a : semi-major axis of orbit

e : orbit eccentricity



4. Perigee:

Perigee is the point on the orbit that is nearest to the centre of the Earth.

$$\text{Perigee distance} = a(1-e) \quad \rightarrow 1.5m$$

5. Eccentricity:

The orbit eccentricity, e is the ratio of the distance between the centre of the ellipse & the centre of the Earth to the semi-major axis of the ellipse.

$$e = \frac{\text{apogee} - \text{perigee}}{\text{apogee} + \text{perigee}} = \frac{\text{apogee} - \text{perigee}}{2a}$$

$e = \sqrt{a^2 - b^2} / a$, where a & b are semi-major & semi-minor axes respectively. $\rightarrow 1.5m$

6. Semi-major axis:

This is a geometrical parameter of an elliptical orbit, a .

$$a = \frac{\text{apogee} + \text{perigee}}{2}$$

→ 1.5m

Note: The listing of orbital parameters any 6 → 1m

Q3a. Explain the satellite subsystems. → 10m

Ans: The different subsystems in satellites are -

1. Mechanical structure
2. Propulsion subsystem
3. Thermal control subsystem
4. Power supply subsystem
5. Telemetry, Tracking & command (TT&C) subsystem
6. Attitude & orbit control ~~sys~~ subsystem.
7. Payload
8. Antennas.

↳ 1m each
(List)

→ Explanation 2m

1. Mechanical Subsystems Structure:

- It provides the framework for mounting other subsystems of the satellite & also an interface between the satellite & launch vehicle.

2. Propulsion subsystem:

- It is used to provide the thrusts required to impart the necessary velocity changes to execute all the maneuvers during the lifetimes of the satellite.



3. Thermal Control Subsystem:

- It will maintain the satellite platform within its operating temperature limits.
- It also ensures reasonable temperature distribution throughout the satellite structure & thus maintains stability & alignment of certain critical equipments

4. Power Supply Subsystem:

- The primary function of this is to collect solar energy, transform it into electrical power with the help of array of solar cells & distribute electric power to other components & subsystems of the satellite.
- In addition, satellite has batteries, provides standby electrical power during eclipse periods, other emergency situations & also during the launch phase of the satellite when the solar arrays are not yet functional.

5. Telemetry, Tracking & Command (TT&C) Subsystem:

- It monitors & controls the satellite right from liftoff stage to the end of its operational life in space.
- The tracking part determines the position of the spacecraft & follows its travel using angle, range & velocity information.
- The telemetry part gathers the information on health of various subsystems of the satellite, encode this



information & then transmits the same.

- The command element receives & executes remote control commands to effect changes to the platform functions, configurations, position & velocity.

6. Attitude & Orbit Control Subsystem:

- It performs two primary functions.
- It controls the orbital path which ensures the satellite in correct location in space.
- It also provides attitude control, which prevents the satellite from tumbling in space & ensures that the antenna remain pointed at a fixed point on the Earth's surface.

7. Payload Subsystem:

- It carries the desired instrumentation required for performing its intended function.
- The nature of payload depends upon its mission.

8. Antennas:

- They are used for receiving the signals from the ground stations as well as for transmitting signals towards them.
- The choice depends on the frequency of operation & required gain.
- Typical antennas include horn antennas, center fed & offset fed parabolic reflectors & lens antennas.



Q3b. Explain the solar energy driven power supply of a satellite. → 10m

Ans: → The major components of a solar power system are the solar panels, rechargeable batteries, battery chargers with in built controllers, regulators & inverters to generate various DC & AC voltages required by various subsystems.

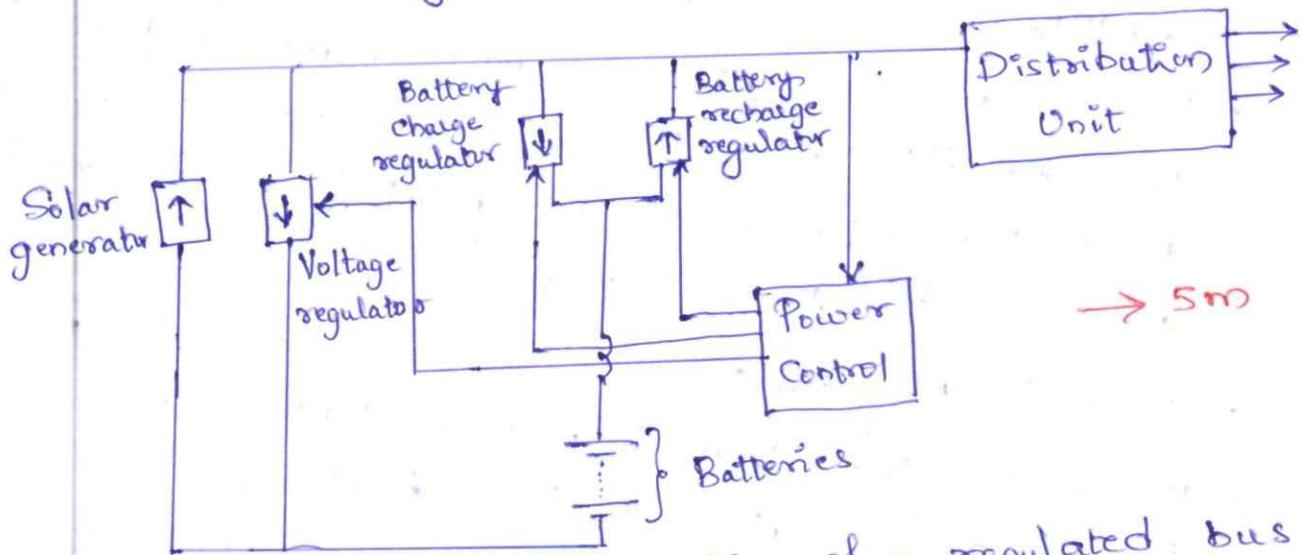


Fig: Basic block schematic of a regulated bus power supply system.

→ During the sunlight condition, the voltage of the solar generator & also the bus is maintained at constant amplitude with the voltage regulator connected across the solar generator.

The battery is decoupled from the bus during this time by means of a battery discharge regulator (BDR) & is also charged using the battery charge regulator (BCR) as shown above.

→ During the eclipse period, the battery provides power to the bus & the voltage is maintained constant by means of the BDR. → 5m



Q4a. Describe the telemetry, telecommand & tracking control monitoring system of a communication satellite. → 10m

- Ans:
- TT&C subsystem monitors & controls the satellite right from the liftoff stage to the end of its operational life from the space.
 - The tracking part of the subsystem determines the position of the spacecraft & follows its travel using angle, range & velocity information.
 - The telemetry part gathers the information on the health of various subsystems of the satellite. It encodes this information & transmits the same towards the Earth Control Center.
 - The command system receives & executes remote control commands from the control center on Earth to effect the changes in configuration, position & velocity.
 - Tracking maintains the satellite in the desired orbit & provides look angle information to the Earth stations. Angle tracking be used to determine the azimuth and elevation angles from the Earth station.
 - Time interval measurement techniques can be used for the purpose of ranging by sending a signal via command link & getting via telemetry link.
 - The rate of change of range can be determined

either by measuring the phase shift of the return signal w.r.t the transmitted signal or by using a pseudorandom code modulation & the correlation between the transmitted & the received signals.

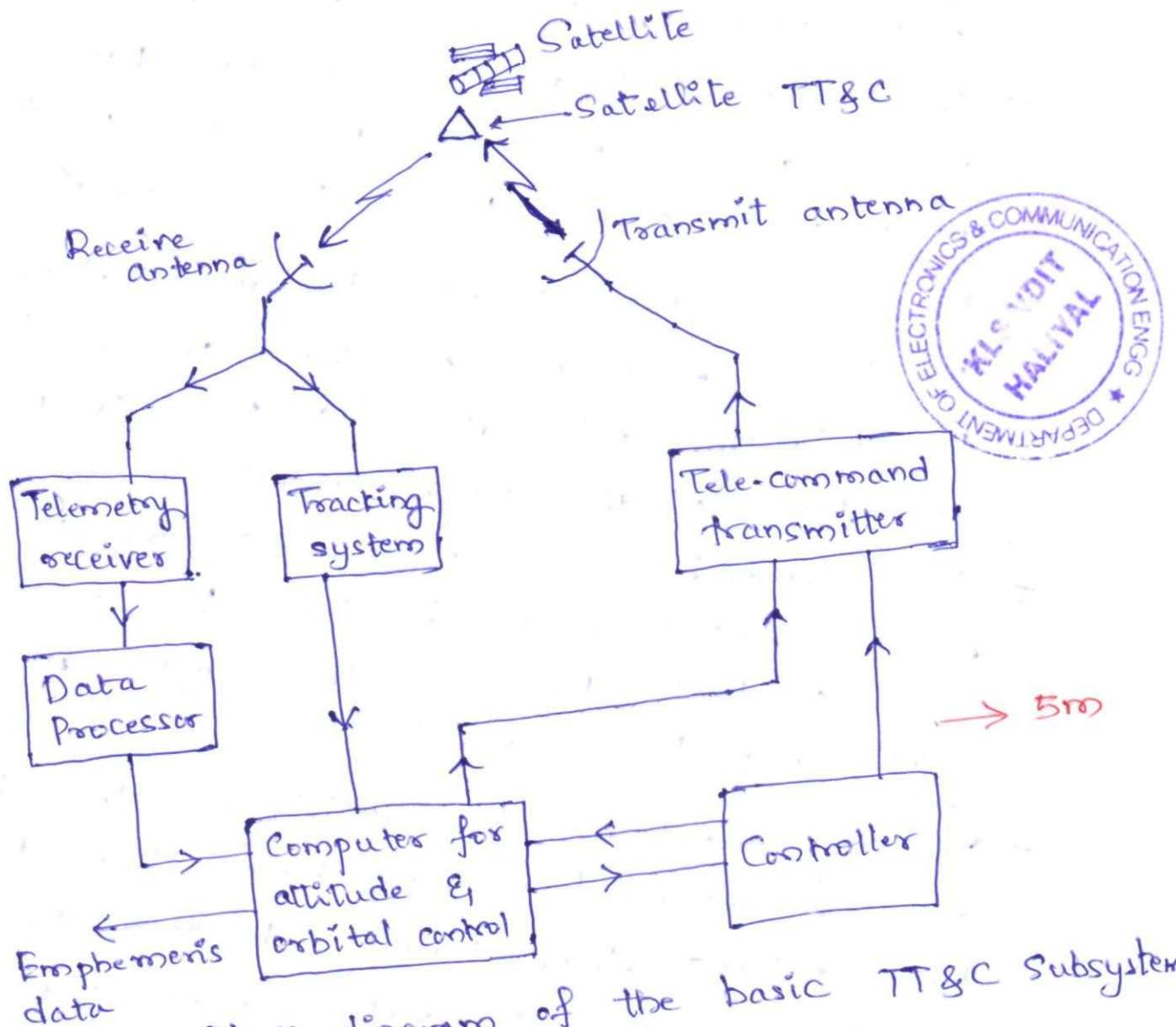


Fig.: Block diagram of the basic TT&C subsystems.

→ During the orbital injection and positioning phase, telemetry link is used by the tracking system to establish a satellite to Earth control center communication channel.

→ 5m

Q4b. Explain with block schematic arrangements of a generalized earth's station. → 10m

Ans: The major components of an Earth station include the RF section, baseband equipment & terrestrial interface.

→ Every earth station has additional facilities such as power supply unit, monitoring & control equipment and thermal & environmental conditioning unit.

→ The RF section comprises of an antenna subsystem; the upconverter & the high power amplifier (HPA) in the uplink channel and the antenna subsystem, low noise amplifier (LNA) & the down converter in the downlink channel.

→ As the earth station is being a major hub of networks, reliability is of major concern hence equipment redundancy is used.

→ RF section interfaces with the modem subsystem of the baseband section.

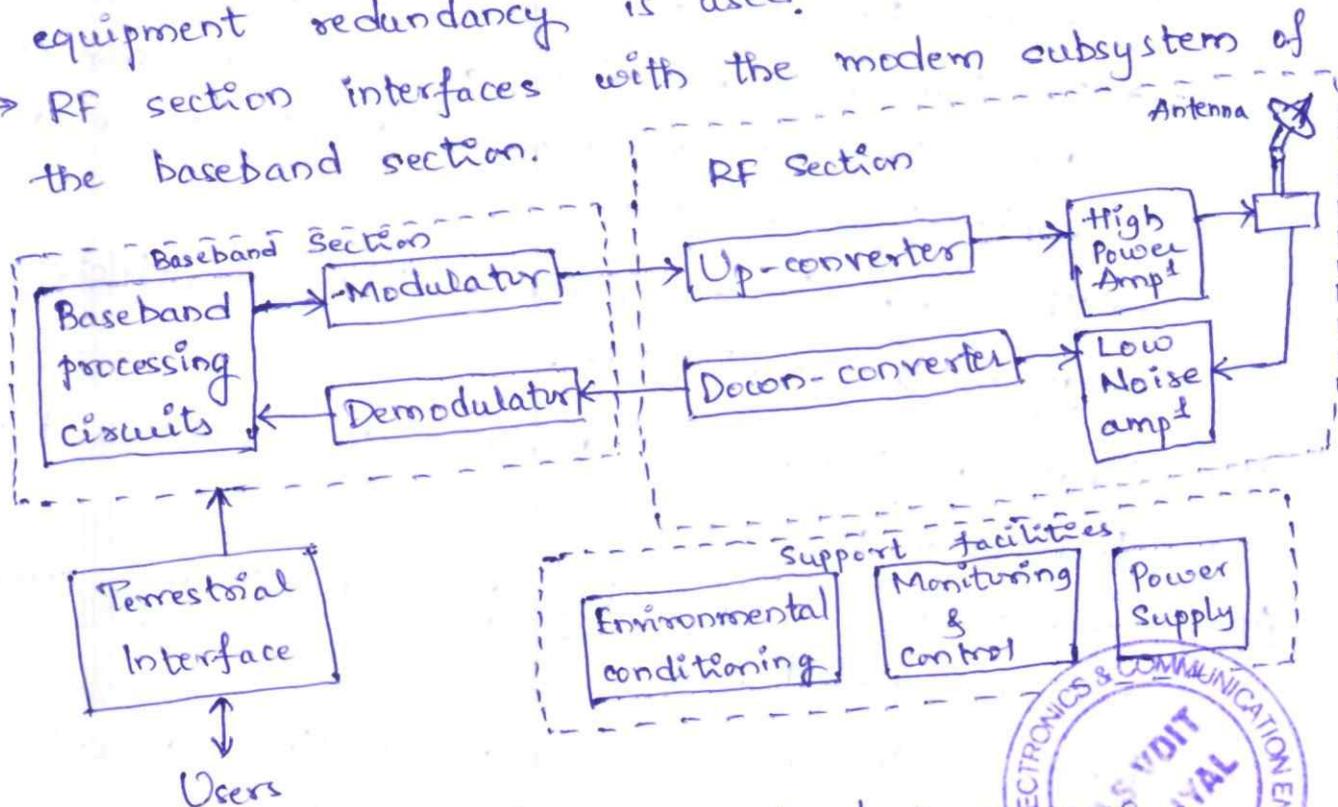


Fig.: Block schematic of a generalized Earth station.



→ The upconverter in the up-link channel is to up-convert the baseband signal to the desired frequency. & this is amplified to the desired level before it is fed to the feed system.

→ LNA amplifies the weak signals and is down converted to the intermediate sign frequency level before it is fed to the modem in baseband section.

→ The antenna feed system introduces desired polarization, isolation between transmitter & receive signals using cross polarization techniques.

→ The baseband section performs modulation/demodulation function along with multiple access method

The baseband section input/output is connected to the terrestrial network through a suitable interface known as terrestrial interface.

The terrestrial network could be a fiber optic cable links or microwave links or even a combination of two.

→ The complexity of earth station architecture depends upon the application. → 5m

Q5a. What is transponder? Explain the various types of transponders? → 10m

Ans: Transponder is the key payload of any communication satellite. → 2m

Based on the manner in which they process signal, transponders are classified into two types—



1. Transparent or bent pipe transponders
2. Regenerative transponders.

Transparent or Bent Pipe Transponders:

- They process the uplink satellite signal in such a way that only their amplitude & the frequency are altered.
- The modulation & the spectral shape of the signal are not affected.
- They simply transmit the information back to Earth so called as bent pipe transponders.
- They comprise an input filter, low noise amplifier (LNA), down converter, input multiplexer, channel amplifiers, high power amplifiers & output demultiplexer.
- The uplink section of transponder comprises of input filter, LNA & down-converter is common to all the channels & is shared by all the transponders.
- Down converter is a mixer which provides a fixed frequency translation corresponding to the exact frequency difference between the center of the uplink & the downlink frequency bands.
- The full bandwidth is separated into individual transponder channels by a bank of RF filters called the input multiplexers (IMUX).
- The output of each IMUX filter is then amplified by separate power amplifiers.



→ The output of all the transponders channels is then combined in an output de-multiplexer & then fed to a common transmitting antenna for down-beaming the signal on to Earth.

→ The transponders always has redundant equipment to ensure its proper performance in the case of failure of any of them.

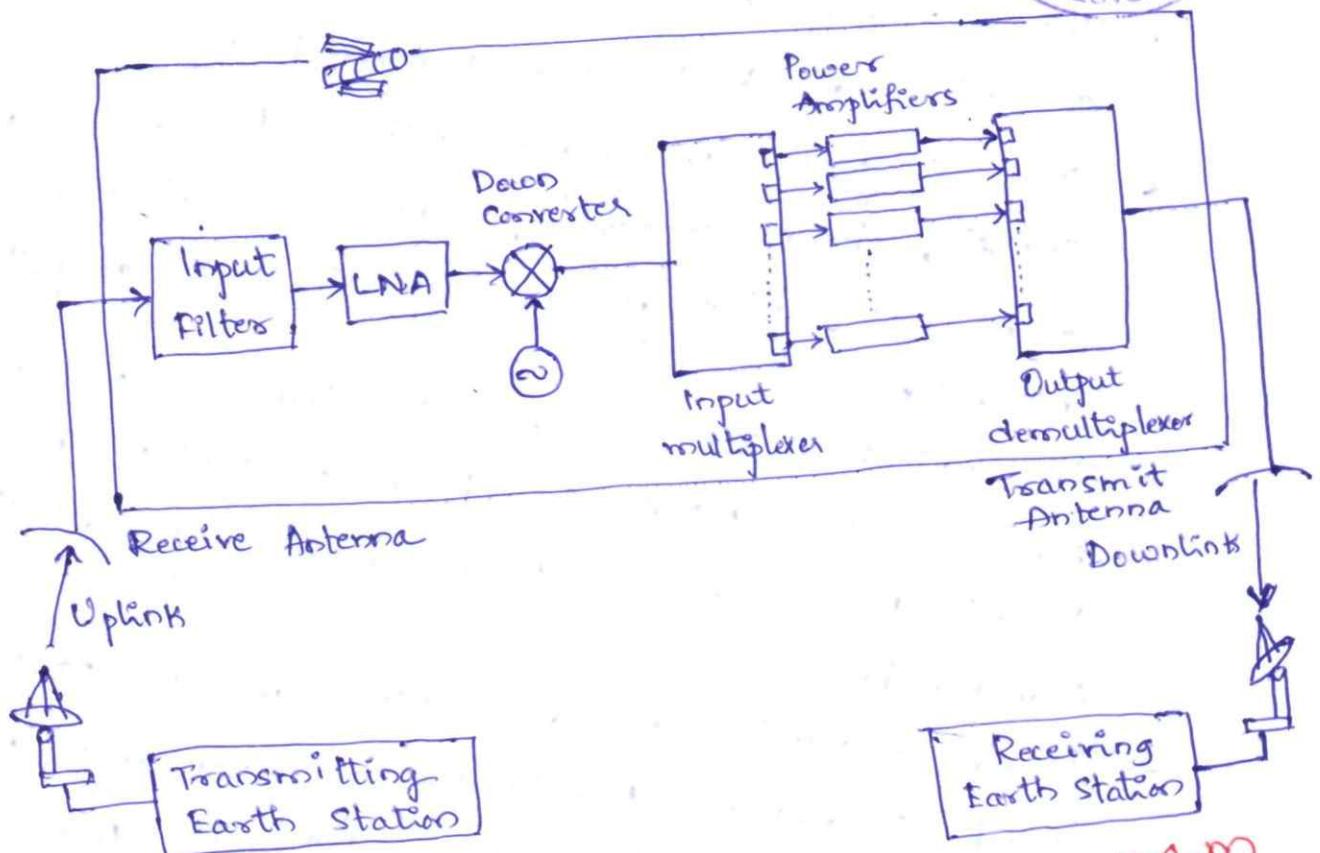
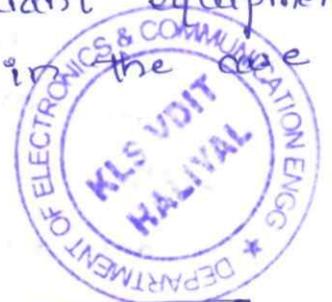


Fig.: Transparent transponders.

Regenerative Transponders:

- Here some onboard processing is done & the received signal is altered before retransmission.
- This onboard processing helps to improve the throughput & error performance by restoring the signal quality prior to retransmission to the Earth.

→ These repeaters are also called digital processing repeaters as they use various digital techniques like narrowband channel selection & routing, demodulation, error correction, reformatting of data, etc, for processing the received signals. → 4m

Q5b. List the advantages & disadvantages of satellites with respect to terrestrial networks.

Ans: Advantages of satellites over terrestrial networks:-

1. Broadcast property - wide coverage area -

Satellites, are an ideal means of transmitting information over vast geographical areas, compared to terrestrial networks, which are not well suited for broadcasting applications. → 1m

2. Wide bandwidth - high transmission speeds & large transmission capacity - → 1m

Satellites provide greater transmission bandwidths & hence more transmission capacity & speeds as compared to terrestrial networks. → 1m

3. Geographical flexibility - independence of location -

Satellites are not restricted to any particular configuration like terrestrial networks. Within their coverage area, satellite networks offer an infinite choices of routes & hence they can reach remote locations having rudimentary, or nonexistent terrestrial networks. → 1m



4. Easy installation of ground stations -

Once the satellite has been launched, installation & maintenance of satellite Earth station is much simpler than establishing a terrestrial infrastructure, which requires an extensive ground construction plan. → 1m

5. Uniform service characteristics -

Satellites provide a more or less uniform service within their coverage area. → 1m

6. Immunity to natural disaster -

Satellites are more immune to natural disasters such as floods, earthquakes, etc., as compared to Earth-based terrestrial networks. → 1m

7. Independence from terrestrial infrastructure -

Satellites can render services directly to the users, without requiring a terrestrial interface. → 1m

8. Cost aspects - low cost per added site & distance intensive costs. -

Satellites do not require a complex infrastructure at the ground level; hence the cost of constructing a receiving station is quite modest. → 1m

Disadvantages of Satellites with respect to

Terrestrial networks:

1. Transmission delay -

Transmission delays of the order of a quarter of a second are involved in transmission of signals from one Earth station to another via a



a geostationary satellite. For satellite-based data communications services, the data communication protocols that require acknowledgement feedback further add to the delay. Hence GEO satellites are in applications which require small transmission delays. → 1m

2. Echo effects -

The echo effect, in which the speaker hears his own voice, is more in satellite-based telephone networks as compared to terrestrial networks. → 1m

3. Launch cost of a satellite -

Though the cost of a satellite ground station is less than that of terrestrial networks & the cost of satellite services are independent of the distances involved, the cost of launching a satellite is huge. → 1m



Q6a. Explain with a neat diagram satellite point-to-point telephonic networks. → 10m

- Ans:
- Satellites provide both long distance point-to-point trunk telephony services as well as mobile telephony services.
 - Satellite telephones either allow the users to access the regular terrestrial telephone networks or place the call through a satellite link.
 - Satellite telephony network employs point-to-point duplex satellite links enabling simultaneous communication in both the directions.

→ Single GEO satellites or a constellation of LEO, MEO and GEO satellites are used for providing telephony services.

→ Telephone satellite links employ circuit-switched systems offering a constant bit rate services, but only for limited duration of the call.

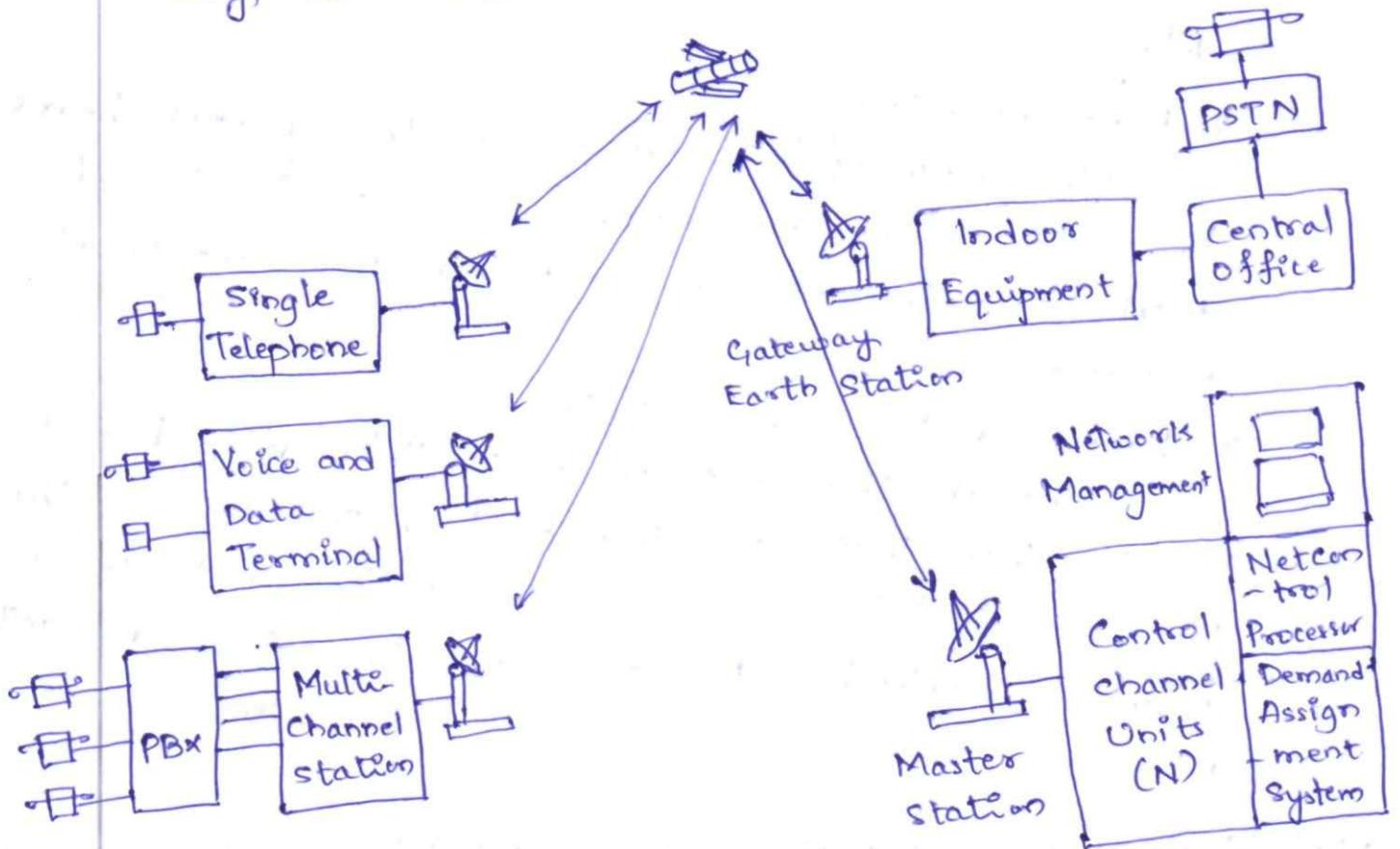


Fig.: Satellite point-to-point telephone networks. → 5m
 Various steps in making a call through a satellite networks are-

1. The user lifts the receiver when he/she wants to make a call. This sends a request to the local Earth station, which in turn sends a service request to the master station.
2. If the master station is able to provide the satellite capacity, it sends a confirmation signal to the local Earth station, resulting in a dial tone in the telephone instrument.

3. The user then dials the destination number, which is transferred to the control station, which determines the destination Earth station and signals it that a connection needs to be established.
4. The destination Earth station then signals the called party of the incoming call by ringing that telephone instrument.
5. The satellite capacity is allocated to the connection & the telephone link is established once the called party lifts the handset.
6. Once the conversation is over, the calling party hangs up the receiver, hence indicating to the local Earth station to terminate the call.

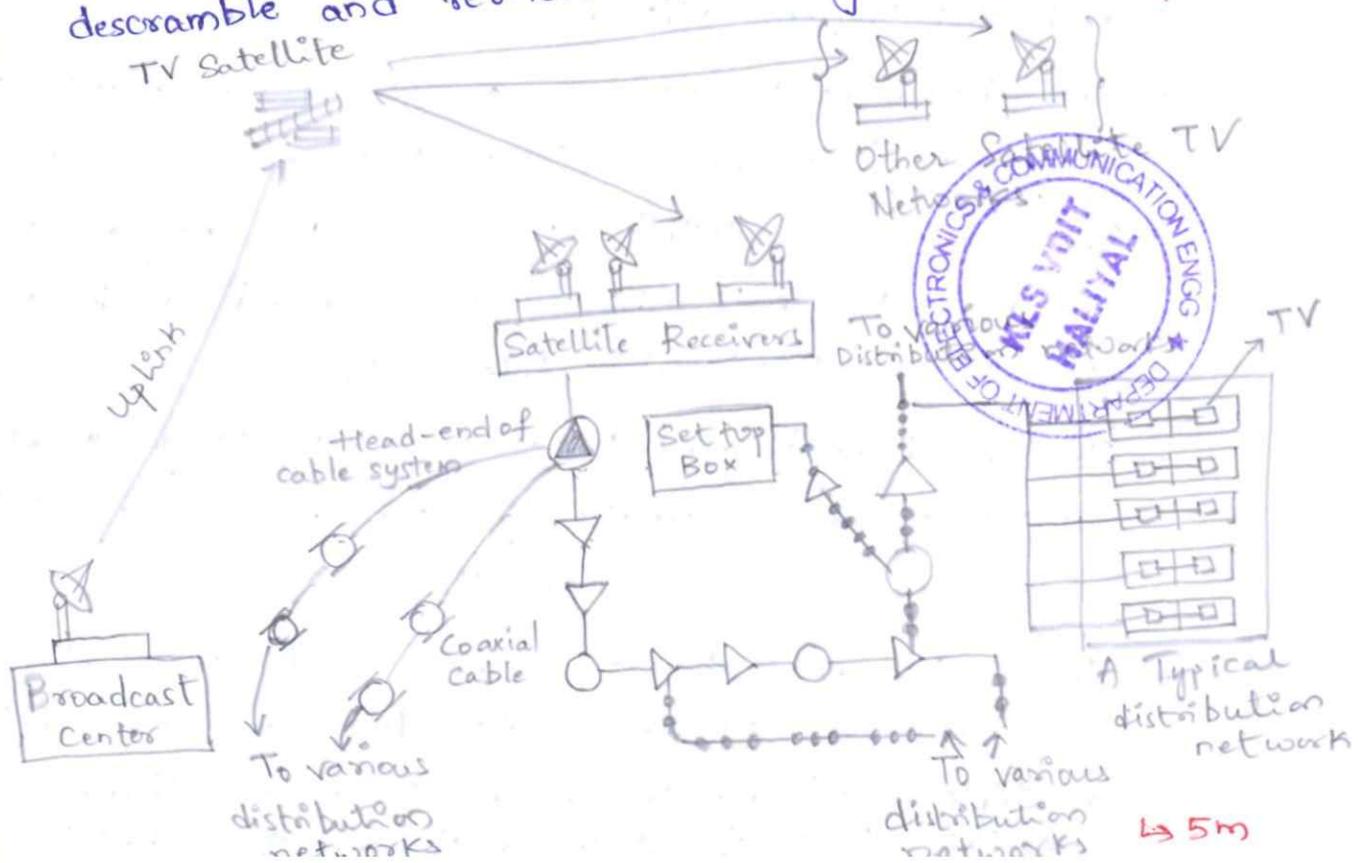
→ 5m

Q6b. Explain with a neat diagram satellite-cable TV. → 10m

- Ans:
- Cable TV refers to the use of coaxial and fiber optic cables to connect each house through a point-to-multipoint distribution network to the head end distribution station.
 - The head ends receive programming channels from either a local broadcasting link or through satellites.
 - The use of satellites to carry the programming channels to the cable systems head ends is referred to as satellite-cable television.
 - The head end consists of receive-only Earth stations with capability of receiving telecast from two to six satellites.
 - These Earth stations either have multiple receiving antennas or, a single dish antenna with multiple feeds, with each feed so aligned as to receive telecast from a different satellite.



- The transmission from the satellite is either in the analogue format or in the digital format.
- In analogue format of transmission, each receiver is tuned to a different transponder channel & the signals from various receivers are multiplexed for transmission to the users.
- The channels received in the digital format can be transmitted either digitally or in the analogue form as mentioned above.
- This processed digital or analogue information is then transmitted over a typical cable distribution networks to a large number of houses known as subscribers, who pay monthly fee for the service.
- The cable operators scramble their programs to prevent unauthorized viewing.
- The receiver end then consists of a set top box to descramble and retrieve the original signal.

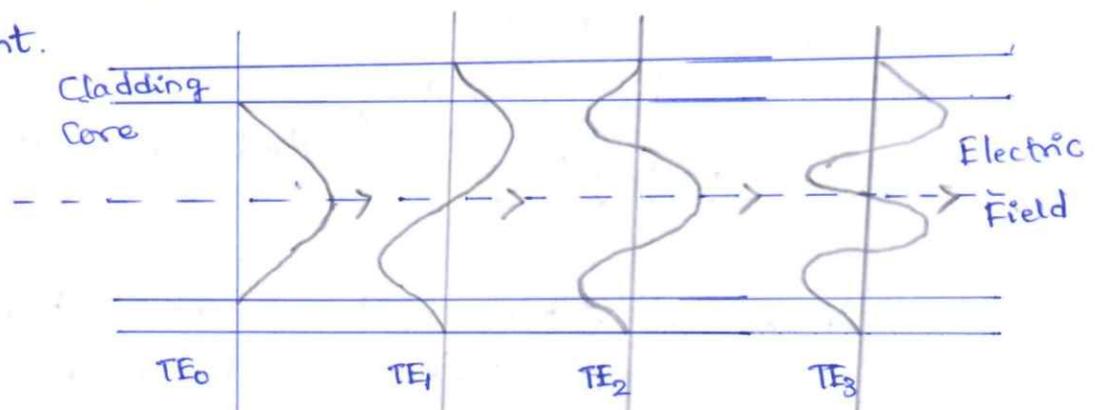


Q7a. Explain the mode theory as applied to circular waveguide (wave guides) in optical fiber? → 10m

- Ans:
- The optical wave guide is the fundamental element that interconnects the various devices of an optical integrated circuit.
 - Optical waves travel in the waveguide in distinct optical modes.
 - A mode, is a spatial distribution of optical energy in one or more dimensions that remains constant in time.
 - The mode theory uses electromagnetic wave behavior to describe the propagation of light along a fiber.
 - A set of guided electromagnetic waves is called the modes of the fiber.
 - For a given mode, a change in wavelength can prevent the mode from propagating along the fiber.
 - If the mode is no longer bound to the fiber, this mode is said to be cutoff.
 - The wavelength at which a mode is cutoff is called the cutoff wavelength for that mode.
 - However, an optical fiber is always able to propagate at least one mode.
 - This mode is referred to as the fundamental mode of the fiber. The fundamental mode can never be cut off.
 - The wavelength that prevents the next higher mode from propagating is called the cutoff wavelength of the fiber.
 - An optical fiber that operates above the cutoff wavelength is called a single mode fiber.



- An optical fiber that operates below the cutoff wavelength is called a multimode fiber.
- In a fiber, the propagation constant of a plane wave is a function of the wave's wavelength and mode.
- Maxwell's equations describe electromagnetic waves or modes as having two components.
- The two components are the electric field, $E(x, y, z)$, and the magnetic field, $H(x, y, z)$.
- The electric field, E , & the magnetic field, H , are at right angles to each other.
- Modes traveling in an optical fiber are said to be transverse.
- The transverse modes, propagate along the axis of the fiber.
- In TE modes, the electric field is perpendicular to the direction of propagation.
- The magnetic field is in the direction of propagation.
- Another type of transverse mode is the transverse magnetic (TM) mode.
- TM modes are opposite to TE modes. The magnetic field is perpendicular to the direction of propagation.
- The electric field is in the direction of propagation of light.



- The TE mode field patterns shown in figure, indicate the order of each mode.
- The order of each mode is indicated by the no. of field maxima within the core of the fiber.
Ex - TE₀ has one field maxima.
- The electric field is maximum at the center of the waveguide and decays toward the core-cladding boundary.
- TE₀ is considered the fundamental mode or the lowest order standing wave.

Q7b. Describe the operational difference between single-mode and multimode fibers in terms of bandwidth and attenuation? → 10m

Ans: Single mode fibers: → 5m

1. Core size is small about 2µm to 15µm.
2. Only one mode can propagate.
3. It is known as fundamental or mono mode fiber.
4. Does not suffer from mode delay.
5. Transmission bandwidth is high.

Multimode fibers: → 5m

1. Core size is small of about 50 to 1000µm.
2. Multimodes can propagate through the cable.
3. Suffer from mode delay.
4. Transmission bandwidth is low.



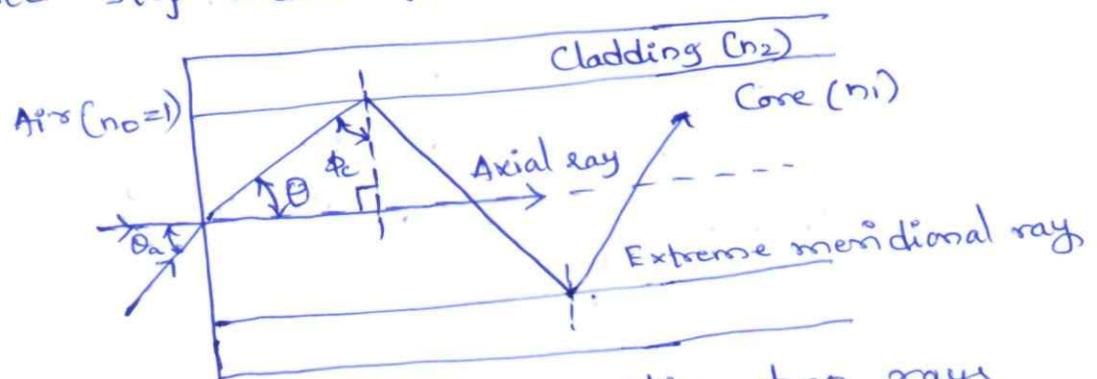
Q8a. What is modal delay and how does it contribute to modal dispersion in multimode fibers? $\rightarrow 10m$

Ans: \rightarrow When an optical pulse is launched into a fiber, the optical power in the pulse is distributed over all of the modes of the fiber. Each of the modes that can propagate in a multimode fiber travels at a slightly different velocity. This means that the modes in a given optical pulse arrive at the fiber end at slightly different times, thus causing the pulse to spread out in times as it travels along the fiber. This effect is known as intermodal dispersion or modal delay.

\rightarrow Intermodal dispersion in multimode step index fibers:-

\rightarrow Using the ray theory model, the fastest and slowest modes propagating in the step index fiber may be represented by the axial ray and the extreme meridional rays.

\rightarrow The paths taken by these two rays in a perfectly structured step index fiber are shown in figure



\rightarrow The delay difference between the two rays when travelling in the fiber core allows estimation of the pulse broadening resulting from intermodal dispersion within the fiber.



→ As the both the rays are travelling at the same velocity within the constant refractive index fiber core, then the delay difference is directly related to their respective path lengths within the fiber.

→ The time taken by the axial ray to travel along a fiber of length L gives the minimum delay time:

$$T_{min} = \frac{\text{distance}}{\text{velocity}} = \frac{L}{c/n_1} = \frac{Ln_1}{c}$$

→ The meridional ray exhibits the maximum delay time

$$T_{max} = \frac{L/\cos\theta}{c/n_1} = \frac{Ln_1}{c\cos\theta}$$

→ Using the Snell's law at core-cladding interface,

$$\sin\phi_c = \frac{n_2}{n_1} = \cos\theta$$

$$T_{max} = \frac{Ln_1^2}{cn_2}$$

→ The delay difference between the extreme meridional ray & the axial ray may be obtained as:

$$\delta T_s = T_{max} - T_{min} = \frac{Ln_1^2}{cn_2} - \frac{Ln_1}{c}$$

$$\therefore \delta T_s = \frac{Ln_1^2}{cn_2} \left(\frac{n_1 - n_2}{n_1} \right) \rightarrow \textcircled{1}$$

$$= \frac{Ln_1^2}{cn_2} \Delta$$

After rearranging eqⁿ $\textcircled{1}$,



$$\tau_s \approx \frac{L n_1 \Delta}{c} \approx \frac{L N A^2}{2 n_1 c}$$

Q8b. Define material dispersion? Explain how it arises in optical fibers? → 10 m

Ans: → Pulse broadening due to material dispersion results from the different group velocities of the various spectral components launched into the fiber from an optical source.

→ It occurs when the phase velocity of a plane wave propagating in the dielectric medium varies non linearly with wavelength.

→ As material is said to exhibit material dispersion when the second differential of the refractive index w.r.t the wavelength is not zero.

Expression for pulse broadening:

→ The group delay is given by

$$\tau_g = \frac{d\beta}{d\omega} = \frac{1}{c} \left(n_1 - \lambda \frac{dn_1}{d\lambda} \right)$$

→ The pulse delay τ_m due to material dispersion in a fiber of length L is

$$\tau_m = \frac{L}{c} \left(n_1 - \lambda \frac{dn_1}{d\lambda} \right)$$

→ For source with rms spectral width $\Delta\lambda$ and a mean wavelength λ , the rms pulse broadening due to material dispersion σ_m may be obtained from the expansion of above equation in a Taylor series about λ where;



$$\sigma_m = \sigma_\lambda \frac{d\tau_m}{d\lambda} + \sigma_\lambda \frac{2d^2\tau_m}{d\lambda^2} + \dots$$

→ As the first term usually dominates, especially for sources operating over the 0.8 to 0.9 μm wavelength range, then:

$$\sigma_m = \sigma_\lambda \frac{d\tau_m}{d\lambda} \rightarrow \textcircled{1}$$

→ Hence the pulse spread may be evaluated by considering the dependence of τ_m on λ .

$$\begin{aligned} \frac{d\tau_m}{d\lambda} &= \frac{L\lambda}{c} \left[\frac{dn_1}{d\lambda} - \frac{d^2n_1}{d\lambda^2} - \frac{dn_1}{d\lambda} \right] \\ &= -\frac{L\lambda}{c} \cdot \frac{d^2n_1}{d\lambda^2} \rightarrow \textcircled{2} \end{aligned}$$

→ Substituting $\textcircled{2}$ in $\textcircled{1}$, the rms pulse broadening due to material dispersion is given by,

$$\sigma_m \approx \frac{\sigma_\lambda L}{c} \left| \lambda \frac{d^2n_1}{d\lambda^2} \right|$$

→ Material dispersion parameter M is defined as,

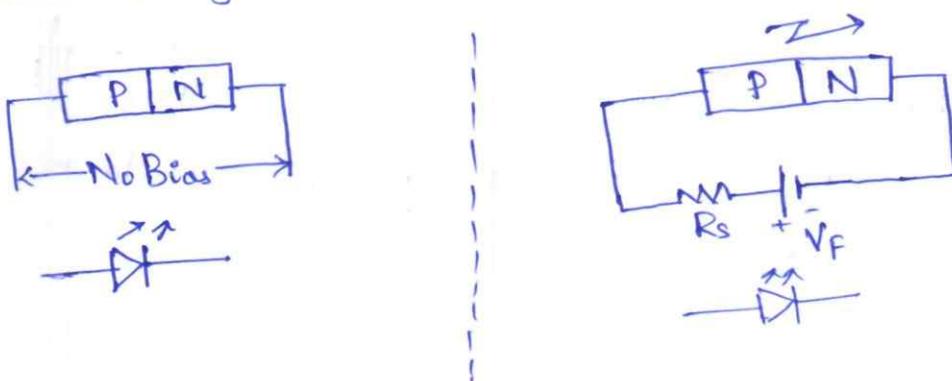
$$M = \frac{1}{L} \frac{d\tau_m}{d\lambda} = \frac{\lambda}{c} \left| \frac{d^2n_1}{d\lambda^2} \right|$$

∴ it is expressed in $\text{ps nm}^{-1} \text{km}^{-1}$.

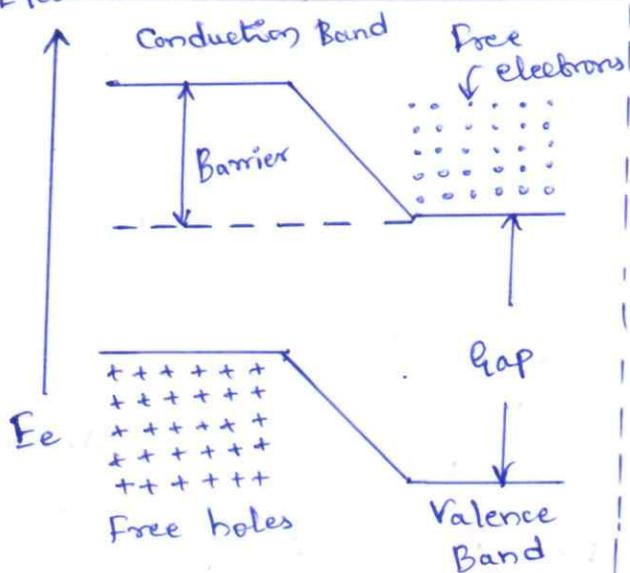


Q9a. Explain the principle operation of LEDs.

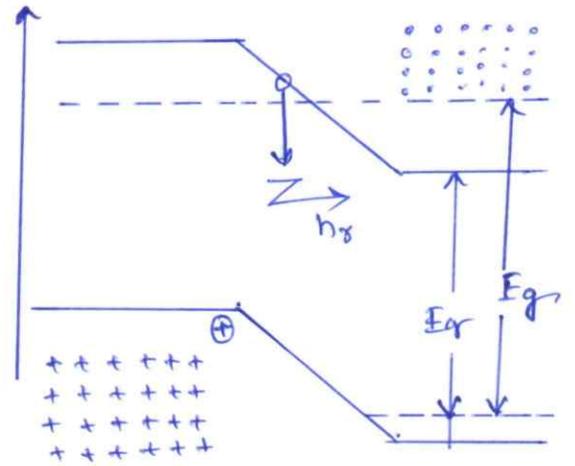
Ans: Light Emitting Diodes (LEDs) is a semiconductor forward biased PN-junction diode as show in figure



Electron Energy



(a) LED with no-bias voltage



(b) LED with forward bias voltage

Working:

Case (a): When a no-bias voltage is present, the energy barrier prevents the movement of the charge carriers as shown in fig (a) with energy level diagram.

Case (b): When a forward voltage is applied, the movement of charge carriers takes place from N → P & P → N regions. As a result, some of the charge carriers recombine in the transition region.

→ The energy lost in the transition is converted to optical energy, which gives rise to a photon.

The wavelength of emission is calculated from the relation:

$$E_g = h\nu = h \frac{c}{\lambda} \quad (\because \nu = \frac{c}{\lambda}) \Rightarrow \lambda = \frac{1.24}{E_g(\text{eV})} \text{ or } (\mu\text{m})$$

$$\lambda = \frac{hc}{E_g} \quad \text{where } h = \text{planck's constant} = 6.626 \times 10^{-34} \text{ J} \\ c = 3 \times 10^8 \text{ m/s.}$$



Q9b. Discuss the characteristics of the optical detectors? → 10m

Ans:

1. Responsivity (R)

→ ratio of current output to light input

$$R = \frac{I_p}{P_o}$$

→ It varies with wavelength

→ Theoretical ^{max.} value is 1.05 A/W at 1300nm

→ Typical responsivity: 0.8 - 0.9 A/W at 1300nm

→ Theoretical max. responsivity (quantum efficiency = 100%)

$$R = \frac{\eta \cdot \lambda}{1240}$$

where, R: theoretical max. responsivity in Amps/Watts

η = quantum efficiency

λ = wavelength in nanometers

$$R = \frac{\eta e \lambda}{hc}$$



2. Quantum Efficiency (η)

→ ratio of primary electron-hole pairs created by incident photons to the photons incident on the diode material.

$$\eta = \frac{\text{numbers of electrons collected}}{\text{numbers of incident photons}} = \frac{\gamma_e}{\gamma_p}$$

where, γ_e : incident photon rate

γ_p : electron rate.

3. Response time:

→ Time needed to respond to optical input and produce an external current

→ It is measured between 10% & 90% of amplitude

4: Cutoff Wavelength, λ_c :

→ It is the maximum wavelength of photon that result to electron-hole

→ Mathematically, wkt, the photon energy

$$E_{\text{photon}} \geq E_g; \quad E_g: \text{Bandgap energy}$$

⇓

$$h\nu \geq E_g$$

$$h \frac{c}{\lambda} \geq E_g$$

∴ The cut-off condition for photon wavelength is $\lambda = \lambda_c$ when $E_g = \frac{hc}{\lambda_c} \Rightarrow \lambda_c = \frac{hc}{E_g}$

5: Dynamic Range:

→ Ratio between the largest and smallest optical signals that can be accurately measured.

→ Wide dynamic range allows for detecting both very weak & very strong signals.



Q10a. Explain the principle operation of WDM standards? → 10m

Ans: Wavelength Division Multiplexing (WDM)

→ The method of combining the number of independent wavelengths that carry information and transmit it on to the same fiber is called as WDM.

→ WDM System

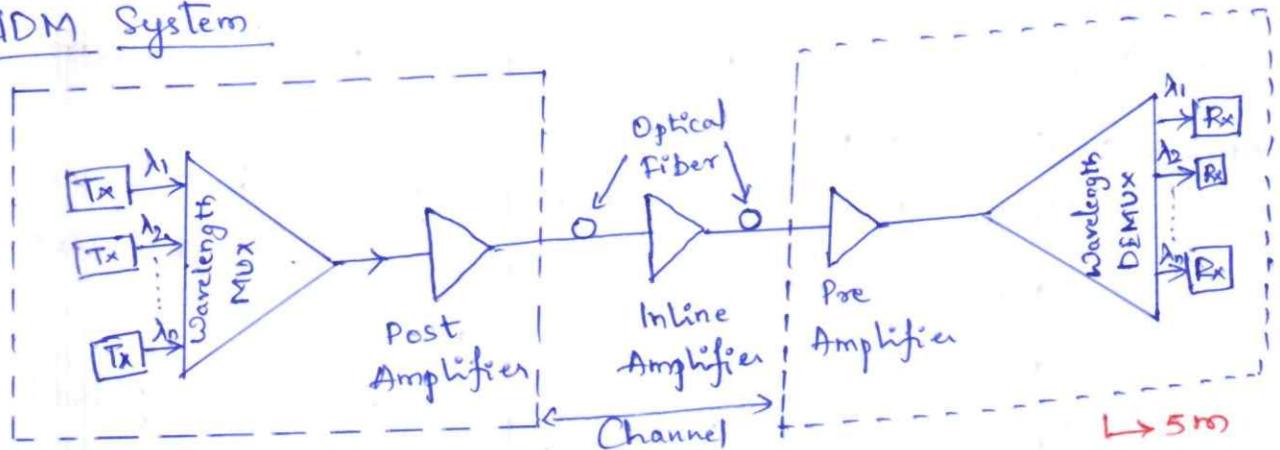


Fig.: Block diagram of WDM System

- 'N' independently modulated light signals each having a unique wavelength ($\lambda_1, \lambda_2, \dots, \lambda_n$) are combined in the wavelength multiplexers. They do not interfere with each other.
- The combined composite signal is amplified & then coupled to a single optical fiber. This amplifier is known as post-amplifier.
- Channel consists of optical fibers. The optical fiber section may include one or more inline-amplifiers.
- At the receiving end the composite signal is amplified & decombed into separate independent signals ($\lambda_1, \lambda_2, \dots, \lambda_n$).
- The amplifiers at the receiver is called pre-amplifier.
- The transmitter usually used is a Tuned LASER diode.
- The receiver can be either PIN or APD.

→ The post amplifier, inline amplifier and pre-amplifier all are optical amplifiers.

→ As per WDM standards, the spacing between two channels is specified by ITU-T G.692 standard is 100 GHz.

→ 5m

Q10b. Explain the isolators & circulators? → 10m

Ans: Isolators and circulators -

→ These devices are non-reciprocal devices i.e., these devices allow light only in one direction & behaves differently in another direction.

→ These are used in optical gratings, optical filters etc

Isolators: → 5m

Isolators allow light to pass through them only in one direction. This is useful in preventing the scattered light passing in reverse direction. A typical arrangement of Isolators is shown in figure

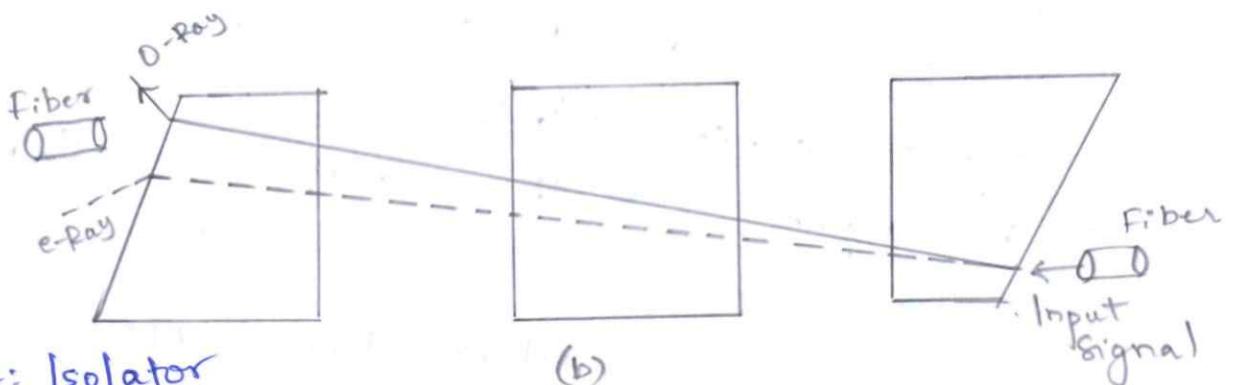
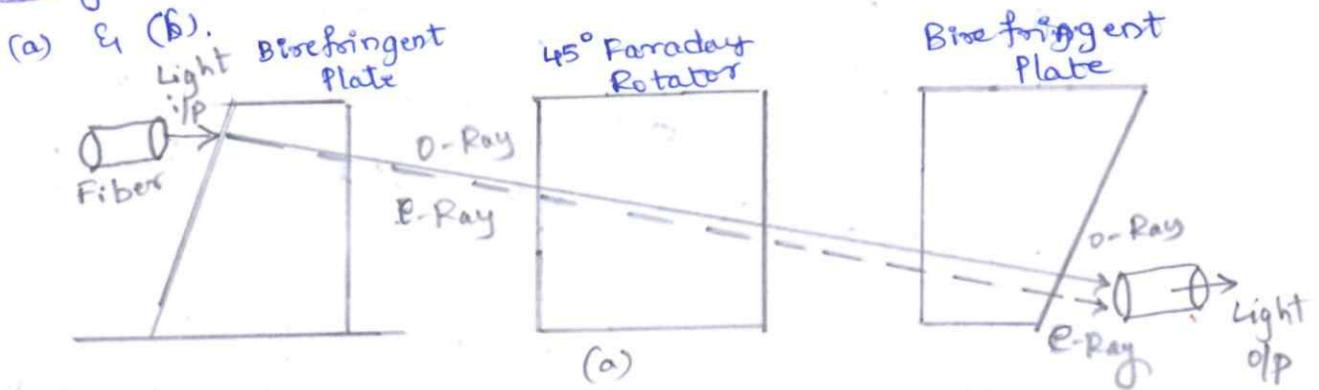


Fig: Isolator

(b)

Figure (a): Left-to-Right: Light is coupled from fiber to fiber

(b): Right-to-Left: Light is diverged from the fibers & no light coupling takes place.

→ Left-to-Right: The birefringent plate 1, splits the optical light input into two rays namely,
• ordinary ray (o-Ray) &
• extraordinary ray (e-Ray)

→ Faraday rotator, rotates the polarization of each plate by 45°. The output is then fed to the birefringent plate 2. It produces two rays (o) & (e) rays that are identical & parallel light is coupled into the fibers as shown in fig (a).

→ In reverse direction (right to left), the two rays while exiting from left hand side birefringent plate diverge. The light rays will not be coupled into the fiber

Optical Circulators: → 5m

→ A circulator is a non-reciprocal multipoint passive device

→ It directs light sequentially from post-to-post in one-direction only

→ A three-input circulator is shown in figure below.

→ The input at post 1 is output at post(2).

→ The input at post 2 (B) is output at post 3 (B) and continued

→ Therefore optical signal is coupled from one post to other post in only clockwise direction.



→ No coupling is possible in anticlockwise direction

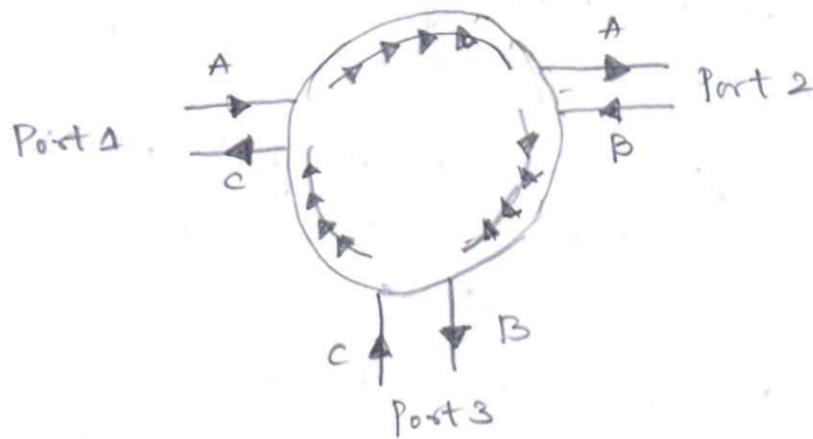


Fig. : Three Input Circulator.

→ Circulators are used in fiber optic communications & sensor applications

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