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| **SCHOOL OF ELECTRICAL AND ELECTRONICS**  **DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING**  **SECA2701 - MICROWAVE AND OPTICAL LAB**  **INDEX**   |  |  | | --- | --- | | **Sl. No.** | **Name of the Experiment** | | 1 | STUDY OF MICROWAVE COMPONENTS | | 2 | REPELLER MODE CHARACTERISTICS OF REFLEX KLYSTRON | | 3 | CHARACTERISTICS OF GUNN DIODE | | 4 | CHARACTERISTICSOF ISOLATOR AND CIRCULATOR | | 5 | CHARACTERISTICS OF E - PLANE TEE, H – PLANE TEE AND MAGIC TEE | | 6 | MEASUREMENT OF RADIATION PATTERN AND GAIN OF HORN ANTENNA | | 7 | CHARACTERISTICS OF DIRECTIONAL COUPLER | | 8 | MEASUREMENT OF VSWR OF AN UNKNOWN LOAD | | 9 | STUDY OF FIBER OPTICS COMMUNICATION | | 10 | ANALOG LINK USING OPTICAL FIBER CABLE (OFC) | | 11 | DIGITAL LINK USING OPTICAL FIBER CABLE | | 12 | MEASUREMENT OF NUMERICAL APERTURE | | 13 | MEASUREMENT OF PROPAGATION LOSS AND BENDING LOSS IN OFC |   **EXPERIMENT NO : 1**  **STUDY OF MICROWAVE COMPONENTS**  **AIM: -**The main objective of this experiment is to get acquainted with all sorts of microwave components and other passive devices and also get familiarized with the microwave components that are available in our laboratory.  **APPARATUS REQUIRED**: - Flanges, Twisted wave guide, wave guide tees, Directional Coupler, Attenuator, Isolators, Circulators, Matched terminator, Slide screw tuner, Slotted Section, Tunable probe, Horn antennas, Movable Short and Detector mount.  **THEORY**: - A pipe with any sort of cross- section that could be used as a wave guide or system of conductors for carrying electromagnetic wave, is called a wave guide in which the waves are truly guided. The microwave region is typically definedas those frequencies between **300 MHz and 300 GHz**. (1 MHz = Hz and 1 GHz = Hz.) These frequencies include free-space wavelengths between 1 m and 1 mm. Here’s a look at a few important regions in the electromagnetic spectrum. Microwaves are used because of its wider bandwidth, smaller component size, better resolution and for many other reasons. Microwave finds application in communication radar, navigation, remote sensing etc. Some of the microwave components and equipments were follows   |  |  |  | | --- | --- | --- | | **REGION** | **FREQUENCY RANGE** | **WAVELENGTH RANGE** | | Microwave | 1GHz – 300 GHz | 3cm – 1 mm | | Millimeter-Wave | 30 GHz – 300 GHz | 1 cm – 1 mm | | Infrared | 1000 GHz – 10000 GHz | 0.3 mm – 30 μm | | Visible light | 430000 GHz – 750000 GHz | 700 nm – 400 nm |   Note: 1000 GHz = 1 THz = = Hz  **KLYSTRON POWER SUPPLY**  Klystron%20Power%20SupplyIt generates voltage required for driving the reflex klystron tubes like 2k25, 2k56, 2k22. It is absolutely stable, regulated and short circuit protected power supply. It has built in facility of squire wave and saw tooth generators, for amplitude and frequency modulation. **Specifications:** Operating Voltage - 230V+/- 10%, 50Hz AC Beam supply - Voltage:200-450V continuously variable; Current: 50mA max.; Regulation: better than 0.5% for +/-10% variation in  mains supply voltage; Ripple: less than 5mV rms Repeller Supply - Voltage: -10V to -270V continuously variable with respect to klystron cathode;   Regulation: better than 0.25% for +/-10% variation in mains supply voltage Heater Supply - 6.3V DC (regulated) Modulation - Square Wave : Frequency 500Hz to 2000Hz; Max. Amplitude +110V peak to peak, Amplitude and frequency continuously variable; Sawtooth: Frequency 50Hz to 150Hz; Max. Amplitude -60V peak to peak, Amplitude and frequency continuously variable;  **GUNN POWER SUPPLY**  It comprises of an electronically regulated power supply and a square wave generator designed to operate the Gunn Oscillator and Pin Modulator.  Voltage range - 0 - 12 Volts variable Heater Supply - 6.3V DC (regulated)  Gunn%20Power%20SupplyModulation - Square Wave : Frequency 500Hz to 2000Hz; Max. Amplitude +110V peak to peak, Amplitude and frequency continuously variable; Sawtooth: Frequency 50Hz to 150Hz; Max. Amplitude -60V peak to peak, Amplitude and frequency continuously variable;  **RECTANGULAR WAVE GUIDE**  Wave guides are manufactured to the highest mechanical and electrical standards and mechanical tolerances. L and S band wave guides are fabricated by precision brazing of brass-plates and all other wave guides are in extrusion quality. W.G. sections of specified length can be supplied with flanges, painted outside and silver or gold plated in side. Flange are used to couple sections of wave guide components. These flanges are designed to have not only mechanical strength but also desirable electric characteristics.    **ISOLATOR AND CIRCULATOR**  The isolators & circulators are matched 2 port/3 port devices which offer low insertion loss and high isolation over 1 GHz band width. The performance of these Isolators optimizes at the specific frequency. A unit can be optimized at any frequency within the wave guide band. An isolator is a [two-port](http://en.wikipedia.org/wiki/Two-port_network) device that transmits [microwave](http://en.wikipedia.org/wiki/Microwave) or [radio frequency](http://en.wikipedia.org/wiki/Radio_frequency) power in one direction only. It offers zero attenuation (minimum attenuation) when a wave passes from port 1 to port 2 and it offers maximum attenuation in the reverse direction. It is used to improve frequency stability of microwave generators such as klystrons and magnetrons. If an isolator is placed between MW generator and load, it offers zero attenuation for the generator output which is coupled to the load and if any reflections from the load is absorbed by isolator. Thus, the generator appears to be matched for all loads.      A **circulator** is a [passive](http://en.wikipedia.org/wiki/Passivity_(engineering)) non-[reciprocal](http://en.wikipedia.org/wiki/Reciprocity_(electromagnetism)) three- or four-[port](http://en.wikipedia.org/wiki/Port_(circuit_theory)) device, in which a [microwave](http://en.wikipedia.org/wiki/Microwave) or [radio frequency](http://en.wikipedia.org/wiki/Radio_frequency) signal entering any port is transmitted to the next port in rotation (only). A *port* in this context is a point where an external [waveguide](http://en.wikipedia.org/wiki/Waveguide_(electromagnetism)) or [transmission line](http://en.wikipedia.org/wiki/Transmission_line) (such as a [micro strip](http://en.wikipedia.org/wiki/Microstrip) line or a [coaxial cable](http://en.wikipedia.org/wiki/Coaxial_cable)), connects to the device. For a three-port circulator, a signal applied to port 1 only comes out of port 2; a signal applied to port 2 only comes out of port 3; a signal applied to port 3 only comes out of port 1  **WAVE GUIDE TEE**: - Tees are junctions which are required to combine or split two signals in a wave guide. Different type of tees are  **H - PLANE TEE**: - All the arm of the H- plane Tee lies in the plane of the magnetic field which divide among the arm. This is thus a current or parallel junction. As the axis of sidearm is parallel to the plane of H field of main arm the tee is called H-plane tee. If the wave enters through the side arm, then that leaving through the main arm are equal in magnitude and phase.  **E- PLANE TEE:** - It lies in the plane of electric field. It is voltage or series junction. In this signal is divided in to two parts having same magnitude but in opposite phase. If the input arm of tee comes broad wall, then the junction is called as an E-Plane tee. The wave entering form sidearm split up and leaves the main arm with equal magnitude but have opposite phase. Similarly, the wave entering the junction from main arm leave the side arm, the resulting field being proportional to the difference between the instantaneous fields.  **MAGIC TEE**: - If another arm is added to either of the T-junction. Then a hybrid T-junction or magic tee is obtained. The arm three or four is connected to arm 1&2 but not to each other. A magic tee is a combination of E-Plane tee and H- Plane tee. It acts as a 4- port circuit. If power enters through arms A and C, then the power is delivered entirely to arms B and D, with no power transmission from port A to port C and vice versa.  **ROTARY PHASE SHIFTER**:  The quarter wave plates convert a linearly polarized TE11 mode into a circularly polarized mode      **MATCHED TERMINATION**: - A termination producing no reflected wave at any transverse section of the wave guide. It absorbs all the incident wave. This is also equivalent to connecting the line with its characteristic impedance.    **BEND AND TWIST :-**In measurements, it is often necessary to bend a waveguide by some angle in E and H plane respectively. Although for special requirement we can provide bending angle of 30 o,45 o,60 o and 120 o in either plane. These bends incorporate a bend waveguide section and two standard flanges. Twists are used to rotate the plane of polarization of a waveguide transmission line. Twists are manufactured from a section of standard waveguide which has been precisely twisted maintaining the internal waveguide dimension. Standard models is 90 o and left-hand twist. Other configurations are available as special order with different angle and overall length.    **DIRECTION COUPLER**: - The power delivered to a load or an antenna can be measured using sampling technique in which a known fraction of the power is measured so that the total may be calculated. A number of coupling units used for such purpose are known as directional coupler.    **ATTENUATOR:** -Attenuators are required to adjust the power flowing in a waveguide. Fixed, variable and rotary vane attenuators are commonly used in waveguide.   1. **Fixed:**Any amount of fixed attenuation can be supplied between 3 to 40 dB. These attenuators are calibrated to a specified frequency band.      1. **Variable:**Variable attenuators provide a convenient means of adjusting power level very accurately. 2. **Rotary:**The rotary vane attenuators are the ideal instrument for use in waveguide systems where broad band direct reading of attenuation is required.     **DIRECT READING FREQUENCY METER**  Direct reading frequency meter is made up of a cylindrical cavity resonator fitted with a variable short circuit termination. It can measure the frequency of microwave signal directly. Very useful for measurement of frequency differences of small changes. Micrometer type frequency meter is used for high accuracy measurements.  It consists of a cavity, plunger fitted with a micrometer and section of standard waveguide  **Frequency%20Meter%20-%20Direct%20Reading%2F%20Micrometer%20type**  **\**  **Direct reading Frequency Meter**  **DETECTOR MOUNT: -**The crystal detector can be used for the demodulation of microwave signal. There are two types of detectors: a. Tuned broad band and b. Tunable waveguide. RF choke is built into the crystal mounting to reduce leakage from BNC connector. A square law characteristic may be used with a high gain selective amplifier having a square law meter calibration. At low level of microwave power, the response of each detector approximates to a square law characteristic and may be used with a high gain selective amplifier having a square law meter calibration.    **HORN ANTENNA :-**A horn antenna is used for the transmission and reception of [microwave](http://searchnetworking.techtarget.com/definition/microwave) signals. It derives its name from the characteristic flared appearance. The flared portion can be square, rectangular, or conical. The maximum radiation and response correspond with the axis of the horn. In this respect, the antenna resembles an acoustic horn. It is usually fed with a wave guide.    **VARIABLE SHORT CIRCUIT: -**It is a termination that reflects all the incident power. The phase of the reflected wave is varied by changing the position of the short circuit and this is equivalent to changing the reactance of termination The simplest form of adjustable short circuit for use in waveguide is a sliding block of copper or some other good conductor that makes a snug fit in the guide. The position of the block is varied by means of a micrometer device.  **SLOTTED SECTION :-** A [section](http://www.dictionaryofengineering.com/definition/section.html) in a [transmission line](http://www.dictionaryofengineering.com/definition/transmission-line.html), such as a waveguide or coaxial [line](http://www.dictionaryofengineering.com/definition/line.html), in which a lengthwise [slot](http://www.dictionaryofengineering.com/definition/slot.html) is cut into the outer conductor, with an adjustable probe placed in said slot. Used, for instance, for the determination of load impedance or wave ratios in [microwave](http://www.dictionaryofengineering.com/definition/microwave.html) systems. Also called slotted section, slot line, or slotted waveguide [section](http://www.dictionaryofengineering.com/definition/section.html) in a [transmission line](http://www.dictionaryofengineering.com/definition/transmission-line.html), such as a [waveguide](http://www.dictionaryofengineering.com/definition/waveguide.html) or coaxial [line](http://www.dictionaryofengineering.com/definition/line.html), in which a lengthwise [slot](http://www.dictionaryofengineering.com/definition/slot.html) is cut into the outer conductor, with an adjustable probe placed in said slot. Used, for instance, for the determination of load impedance or wave ratios in [microwave](http://www.dictionaryofengineering.com/definition/microwave.html) systems. Also called slotted section, slot line, or slotted waveguide  Image result for slotted line section with tunable probe  **GUNN OSCILLATORS:** This is an economical source of microwave power in which Gunn diode is used which work on negative resistance produced by application of DC bias. Precision micrometer fitted with the plungers is used to change the frequency of the oscillations. Gunn Oscillators utilize the bulk negative conductance properties of Gallium Arsenide (GaAs) and Indium Phosphide (InP) Gunn diodes to convert direct current (dc) into power at millimeter wave frequencies. Circuits incorporating the Gunn diodes are designed to provide state-of-the-art performance at frequencies from 18 GHz to above 120 GHz. InP Gunn Oscillators yield higher output power, higher efficiency, and lower AM noise than their GaAs counterparts. Tunable models feature high power-bandwidth products. Gunn Oscillators are solid state microwave energy generators. These consists of waveguide cavity flanged on one end and micrometer driven plunger fitted on the other end. A gunn-diode is mounted inside the Wave guide with BNC (F) connector for DC bias. Each Gunn oscillator is supplied with calibration certificate giving frequency vs micrometer reading.    **PIN MODULATORS: -** PIN modulators are designed to modulate the carrier wave output of Gunn Oscillators. It is operated by the square pulses derived from the UHF(F) connector of the Gunn power supply. These consists of a pin diode mounted inside a section of Wave guide flanged on it’s both ends. A fixed attenuation vane is mounted inside at the input to protect the oscillator through wide range of frequencies.    **PRECAUTIONS:-**  **1. Handle all components with care and do not allow any damage to take place.**  **2. Do not rub/scratch the inner polished surfaces of the components with any sharp edged body.**  **3. If demonstrating any assembly of components, ensure that there is no cross threading and proper tightening.**  **RESULT:**- Thus all the microwave components were studied in detail.  **FAQ**  **1 What is the purpose of wave guide flange?**  It is used to connect two similar types of wave guides or wave guide components.  **2 What is a wave guide?**  It is a metallic structure of any cross-section, highly polished & silver plated from inside. It is used for flow of electromagnetic energy.  **3 Why the wave guide is air filled?**  The wave guide is filled with dry air under pressure to remove any moisture from the wave guide that might cause corrosion. It also increases the power handling capacity of the wave guide.  **4 What is a wave guide bend?**  It is a bend, which is used to change the path of flow of EM energy in the waveguide.  **5 What is isolator?**  It is a device, which allows the flow of EM energy in one direction but does not permit energy to travel in the opposite direction.  **6 What is circulator?**  It is a multi-port device. It has a property that energy entering in one port is permitted to come out from the next port only and not from any other port.  **7 What is Attenuator?**  It is a device that is used to reduce the strength of signal.  **8 What are Tees. How many types of Tees are there?**  Junction of wave guide in different configurations is called Tee. Following type of Tees are there: - E plane Tee, H plane Tee, Magic Tee, Rat Race.  **9 What is slotted line?**  It is a wave guide in which a slot is made on the broader side, in the centre of the side along the axis of the wave guide. It is used to facilitate movement of travelling probe along the wave guide to detect & measure the standing wave ratio.  **10 What is tunable detector?**  It is a device that is used to detect microwave signal. Detector diode can be Point Contact Diode or Schottky Barrier Diode.  **EXPERIMENT NO : 2**  **CHARACTERISTICS OF THE REFLEX KLYSTRON TUBE**  **AIM: -**To study the Repeller mode characteristics of the Reflex Klystron Tube and to determine its modes of operation.  **Apparatus Required:**   * Klystron Power Supply * Klystron tube with Klystron mounts * Isolator * Frequency meter * Variable attenuator * Detector mount, Wave guide stand * CRO with BNC cable   **Theory:**  The reflex klystron is an oscillator tube with built in feedback mechanism. It uses the same cavity for bunching and for the output cavity. If we assume an initial AC field in the cavity the beam will be velocity modulated as it passes through the cavity up on entering the drift space, the beam is decelerated and reversed (reflected) by the large DC field set up by the repeller or reflector electrode at potential –vr. Thus the beam is made to pass through the cavity again, but in opposite direction. By proper choice of the reflector voltage vr the beam can be made to pass through the cavity on its return flight when the AC current phase angle is such that the field excited in the cavity by the returning beam adds in phase with the initial modulating field. The feedback is then positive and oscillations will be building up in amplitude until the system loses and non-linear effects prevent further build up.  **BLOCK DIAGRAM**    **PROCEDURE:**  1. Connect the microwave components as shown in the block diagram.  2. Set the variable attenuator at the minimum attenuation position.  3. Set the mod. Switch of klystron power supply at AM position, beam voltage control knob to fully antic  lock wise and repeller voltage control knob to fully clock wise.  4. Rotate the knob of the frequency meter at one side fully.  5. The detector output is connected to CRO.  6. Switch on the klystron power supply and cooling fan.  7. Put on the beam voltage switch (HT) and rotate the beam voltage knob slowly up to 250v and observe the beam current  which do not increase more than 30ma. Do not change the beam voltage while taking the readings.  8. Change the repeller voltage slowly and watch the output on oscilloscope until maximum value is reached.  9. Tune the plunger of klystron mount for maximum output.  10. Rotate the frequency meter slowly and stop at that position, where there is lowest output on CRO. Read frequency  meter between two horizontal red lines and vertical marker.  11.Change the repeller voltage and read the output voltage on the CRO and carrier frequency for each repeller voltage to get different modes of the klystron.  12. Note the readings in tabular column for every repeller voltage and draw the graph for klystron modes  .  **MODEL GRAPH:**    **PRECAUTIONS**  1. To protect repeller from damage, the repeller negative voltage is always applied before anode beam voltage.  2. While modulating, repeller should never become positive with respect to cavity.  3. Cooling should be provided to reflex klystron.  **OBSERVATION:**  **Beam voltage (Vo) =200-250V, Beam current (I) =10-20 mA.**   |  |  |  | | --- | --- | --- | | **Mode of Operation** | **Repeller voltage(V)**  **(Anode Voltage)** | **Amplitude (V)**  **Reading from CRO**  **Or**  **VSWR meter reading** | | Mode  1 |  | **Min:**  **Max:**  **Min:** | | Mode  2 |  | **Min:**  **Max:**  **Min:** | | Mode  3 |  | **Min:**  **Max:**  **Min:** | | Mode  4 |  | **Min:**  **Max:**  **Min:** |   **RESULT:** The mode characteristics of the reflex klystron oscillator is observed and plotted. The given klystron exhibits  ---------- no. of modes and the carrier frequency are observed to be \_\_\_\_\_\_\_\_in mode 1, \_\_\_\_\_\_\_\_in mode 2,  \_\_\_\_\_\_\_\_in mode 3.  **FAQ**  **1 How many cavities Reflex Klystron does have?**  Only one  **2. On which principle Klystron tube operates?**  Velocity Modulation.  **3 What are the applications of reflex klystron**.  As an Oscillator, Microwave generator.  **4 On what principle Multi Cavity Klystron Amplifier works?**  Velocity modulation and Current modulation  **5 What are different modes in a reflex Klystron?**  They give same frequency but different transit time.  **6 The Secondary cavity in a two-cavity klystron is called?**  Catcher cavity  **7 What is the efficiency of Reflex Klystron?**  20% - 30%.  **8 The single cavity in Reflex Klystron is acts as?**  Both buncher and catcher cavity  **9 What should be the transit time?**  T = n +  **10 Why negative voltage is given to the Repeller?**  The electron beam should never reach the repeller because of the –ve field and returned back towards the gap.  **EXPERIMENT NO : 3**  **V-I CHARACTERISTICS OF GUNN DIODE**  **AIM**: - Study the characteristics of Gunn diode oscillator  **APPARATUS REQUIRED**: -   * X-Band Gunn Oscillator, * PIN modulator, Isolator, * Frequency meter, * Variable attenuator, * Detector Mount, * Matched termination, * Gunn power supply, * Wave guide stand, * BNC cable, Cooling fan and CRO.   **THEORY: -**The Gunn diode is a very useful source because it is simple, rugged, and compact. With a DC bias supply, the Gunn diode can generate 100 mW of power. From the DC V-I characteristics, we will see that the Gunn diode has a negative differential resistance region. It is a very common microwave source and is widely used. There are some bulk semiconductor materials such as Gallium arsenide (GA As), Indium phosphide (InP) and Cadmium Telluride (CdTe) have two closely spaced energy bands in the conduction band. At lower electric field strengths in the material, most of the electrons will be transmitted into higher energy band. In the higher energy band, the effective electron mass is longer and hence the electron mobility is lower than what it is in the lower energy band. Since the conductivity is directly proportional to the mobility there is an immediate range of electric field strengths for which the fraction of electrons that are transferred into higher energy low mobility conduction is such that the average mobility and hence conductivity decreases with an increase in the electric field strength. Thus, there is a range of voltage over which the current decreases with the increasing voltage and a negative instrumental of resistance is displayed by the device. A Gunn device is also called a transferred electronic device since the negative resistance arises from the transfer of electrons from the lower to higher energy band. The oscillations that occur in the material with energy band structure noted above was discovered by J.B.GUNN.  **PROCEDURE: -**  1. Set up the microwave test bench as shown in block diagram.  2.**Gunn diode bias knob -** fully anti-clockwise to keep the bias voltage to zero to start with.  **PIN bias knob** - fully anti-clockwise to keep the bias voltage to zero to start with  **PIN mode frequency** - middle position to keep frequency approx. to 1 kHz.  3. Do not apply any bias to PIN diode throughout the experiment.  4. Set the micrometer of Gunn oscillator cavity for required frequency of operation.  5. Switch on the Gunn power supply.  6. Measure the Gunn diode current corresponding to the various Gunn bias voltages in steps of 0.5 volts controlled by Gunn bias knob through the panel meter and DMP’s switch. Do not exceed the bias voltage above 10 V.  7. Plot the voltage reading and current reading on the graph.  8. Read the threshold voltage Vt that corresponds to maximum current from the graph.  **BLOCK DIAGRAM: -**    **MODEL GRAPH: -**    **TABULATION:**   |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Sl.No.** | **V-I Characteristics** | | **Gunn bias voltage Vs. Output Voltage** | | | **Gunn Bias Voltage** | **Gunn Bias Current** | **Gunn Bias Voltage** | **Output Voltage** | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  | |  |  |  |  |  |   **PRECAUTIONS**  **1. Do not keep Gunn bias knob at threshold position for more than 10-15 seconds.**  **2. Readings should be obtained as fast as possible otherwise excess heating may burn Gunn diode.**  **RESULT: -** Thus the characteristics were studied and plotted using Gunn Diode Oscillator  **FAQ**  **1 What are the basis of classification of microwave devices?**  Based on electrical behavior. - Based on conduction.  **2 What is Gunn Effect?**  There are periodic fluctuations of current passing through N type GaAs when applied voltage exceeded certain critical voltage.  **3 What are the applications of Gunn diode?**  Used as amplifier and oscillators.  **4 What is negative resistance?**  In negative resistance devices, voltage and current phases are 180° out of phase. Voltage drop across it is negative and (- I2 R) power is generated  **5 What are the advantages of Gunn diode.**  It has very less noise.  **6 What are the disadvantages of Gunn diode**  It is very temperature dependent. Frequency of oscillations changes with change in temperature.  **7 What is threshold voltage?**  It is that voltage on curve, which corresponds to maximum current.  **8 What is the role of PIN diode in the test setup?**  PIN diode is used to square modulate the output of Gunn oscillator.  **9 What is the role of Isolator in the test setup?**  To avoid the flow of reflected energy back to Gunn oscillator. This reflected energy shall destabilize the frequency, phase & amplitude of output wave from oscillator  **10. In a Gunn oscillator, Gunn diode is placed in a resonant cavity. In your opinion what shall be the effect of this**.  The frequency of oscillations shall be determined by the dimensions of the cavity, rather than by the diode itself  **EXPERIMENT NO : 4**  **CHARACTERISTICS OF ISOLATOR AND CIRCULATOR**  AIM: To verify the functional characteristics of X-band Microwave Isolator and Circulator.  APPARATUS   * Microwave source * Isolator * Frequency meter * Variable attenuator * Slotted line * Isolator and Circulator * Matched termination * CRO BNC probe.   **Theory:**  **Isolator:** An isolator is a two-port device that transfers energy from input to output with little attenuation and from output to input with very high attenuation  **The circulator** is defined as a device with ports arranged such that energy entering a port is coupled to an adjacent port but not coupled to other ports. Refer to the fig. wave incident on port 1 is coupled to port 2 only, a wave incident at port 2 is coupled to port 3 only and so on. Following are the basic parameters of isolator and circulator for study. A Circulator is defined as a device with ports arranged such that energy entering a port is coupled to an adjacent port but not coupled to other ports. This is depicted in fig. below. Circulator can have any number of ports.  **Note: Draw 2-port Isolator and 3-port Circulator schematic diagram in record note book.**  **The important parameters: -**  **1. Insertion loss**:- Insertion loss is the ratio of power detected at the output port to the power supplied by source to the input port measured with other ports terminated in the matched load Insertion loss describes how much energy is lost during the process of transferring a signal from one port of an isolator/circulator to another. It is essentially a measure of how much energy it costs a designer to use an isolator/circulator in their system. As stated above, isolators and circulators are passive components, so a signal traveling through them has to do so using its own energy. **As in any real system, there will be some attenuation to the signal as it travels through the device. This attenuation is called insertion loss, and it is measured in decibels (dB).** The higher the insertion loss, the more energy it costs to use the isolator or circulator. This energy is converted into heat on its way through the device. However, insertion loss specifications are relatively small, so the benefits a system receives from the use of an  isolator/circulator are usually worth the energy cost of implementing them. Typical insertion loss specifications are on the order of 0.4 dB for octave bandwidth units, however the specification can be as small as 0.15 dB for narrowband units, and as high as 1.7 dB for certain broadband units.  **2. Isolation:-**It is the ratio of power applied to the output that measured at input. This ratio is expressed in db. The isolation of circulator is measured with the third port terminated in a matched load.  **3. Input VSWR:-**The input VSWR of a circulator is the ratio of voltage maximum to voltage minimum of the standing wave existing in the line with all ports except the test port are matched.  **BLOCK DIAGRAM: -**      **Note: Microwave bench setup using Gunn diode Oscillator is also selected for this experiment**  **PROCEDURE: -**  1. Setup the components and equipment as shown in the figure shown above.  2. Energize the microwave source for maximum output for a particular frequency of operation.  3. Keep the Control. Knobs of Klystron power supply as below  **a. Beam voltage switch**  - OFF  **b. Mod switch**  - AM  **c. Beam Voltage knob** - Fully anticlockwise  **d. Reflector Voltage**  - Fully clockwise  **e. AM - Amplitude** - Around fully clockwise  **f. AM - Frequency knob** - Around Mid position.  4. Connect the excitation to port 1 of test isolator and measure the output power at port 2 using detector.  5. Reverse the direction of test isolator and measure the output power at port 1.  6. Connect the excitation to port 1 of circulator and measure the output at port 2 with port 3 terminated in matched load.  7. Interchange the position of detectors and MT and repeat  8. Repeat the procedure from step 3 for other ports of circulator.  PRECAUTIONS  1. To protect reflex klystron tube from the damage, negative voltage is always applied to repeller anode and kept above  2. While modulating repeller should never become positive with respect to cavity.  3. Cooling should be provided to Reflex Klystron.  **TABULATION:**  **ISOLATOR**   |  |  |  | | --- | --- | --- | | **Voltage at Port 1** | **Direction** | **Voltage at Port 2** | |  | Forward |  | |  | Reverse |  |   **CIRCULATOR**   |  |  |  |  | | --- | --- | --- | --- | | **CONDITION** | **PORT 1** | **PORT 2** | **PORT 3** | | 1 |  |  |  | | 2 |  |  |  | | 3 |  |  |  |   **RESULT:** Thus the functional characteristics of Isolator and Circulator are verified and their insertion and Isolation losses are also calculated.  **FAQ**  **1 What is an Isolator?**  It is a two-port device which has low insertion loss in forward direction and very high insertion loss in the opposite direction.  **2.What is Circulator**?  It is a multi-port junction that permits transmission in certain ways. For example, a wave incident at port 1 is coupled to port 2 only, wave incident at port 2 is coupled to port 3 only and so on.  **3 What is Insertion loss?**  It is the ratio power supplied by a source to the input port to the power detected at the output port  **4 What is Isolation?**  It is the ratio of power fed to input arm to the power detected at the not coupled port, with other ports terminated in to matched loads.  **5 What is input VSWR of a circulator or isolator?**  It is the ratio of voltage max. to voltage min. of the standing wave existing on line and others have matched terminations.  **6 What is Faraday rotation in Ferrites?**  When a linearly polarized wave along X-axis is made to travel through ferrite in the Z – direction, the plane of polarization of this wave will rotate with distance. This phenomenon is known as Faraday rotation.  **7 If direction of travel of wave reverses, does the direction of polarization change?**  No, the wave continues to rotate in the same direction even if the direction of travel of wave reverses.  **8 What is the function of resistive card in an isolator?**  Resistive card does not absorb any energy from the wave whose plane of polarization is perpendicular to its own plane and allows the wave to pass.  **9 How many ports a circulator can have?**  There is no restriction about number of ports. However, normally a circulator has four ports.  **10 What are the applications of circulator?**  It can be used as a duplexer in radar antenna system.  **EXPERIMENT NO : 5**  **CHARACTERISTICS OF E - PLANE TEE, H – PLANE TEE AND MAGIC TEE**  **AIM :** To verify the functional characteristics of E - plane Tee, H – plane Tee and Magic Tee.  .  **APPARATUS**   * Microwave source * Isolator * Frequency meter * Variable attenuator * Slotted line * Magic Tee * Matched termination * CRO BNC probe.   **Theory: -**  Magic tee is also known as hybrid tee or E-H plane tee. It is used to obtain completely matched three port tee junction. Magic tee can be used to measure the impedance as a duplexer and as a mixer. The reflex klystron makes use of velocity modulation to transform a continuous electron beam into microwave power. Electrons emitted from the cathode are accelerated and passed through the positive resonator towards negative reflector, which reflects the electrons and the electrons turn back through the resonator. Suppose the RF- field exists between the resonators, the electron accelerated or retarded, as the voltage at an increased velocity and the retarded electrons leave at the reduced velocity. As a result, returning electrons group together in bunches. As the electron bunches pass through the resonator, they interact with the voltage at resonator grids. If the bunches pass the grid at such a time that the electrons are slowed down by the voltage then energy will be delivered to the resonator, and the klystron will oscillate. The frequency is primarily determined by the dimensions of resonant cavity. Hence by changing the volume of the resonator, mechanical tuning of the klystron is possible. A small frequency change can be obtained by adjusting reflector voltage. This is called electronic tuning.  **Note: Draw the schematic diagram of 3-port H-plane tee, E-plane Tee and 4-port Magic tee in record note book.**  **PROCEDURE:**  1. Initially arrange the bench set-up without magic Tee and set an input of certain value by using CRO.  2. Connect the magic tee device as shown in the set-up.  3. Energize the microwave source at a particular frequency of operation.  4. Calculate S12, input to port 1 and measure output at port 2 by connecting the  detector mount, remaining all ports are terminated with matched load.  5. Calculate S1 by measuring the maximum and minimum voltage of the signal in the oscilloscope at port 1 by varying the slotted line. Hence,  **S1 = √(Vmax /Vmin)**  **S11 = (S1 -1)/ (S1 +1)**  6. Repeat steps 4 & 5 for all the remaining three ports  **BLOCK DIAGRAM:-**    **C:\Documents and Settings\user\Desktop\H E.JPG**  **OBSERVATION: -**  **E- PLANE**   |  |  |  |  | | --- | --- | --- | --- | | **CONDITION** | **PORT 1** | **PORT 2** | **PORT 3** | | 1 |  |  |  | | 2 |  |  |  | | 3 |  |  |  |   **H- PLANE**   |  |  |  |  | | --- | --- | --- | --- | | **CONDITION** | **PORT 1** | **PORT 2** | **PORT 3** | | 1 |  |  |  | | 2 |  |  |  | | 3 |  |  |  |   **MAGIC TEE**  **MAGIC TEE AS E – PLANE H - PLANE**   |  |  |  |  |  | | --- | --- | --- | --- | --- | | **CONDITION** | **PORT 1** | **PORT 2** | **PORT 3** | **PORT 4** | | 1 |  |  |  |  | | 2 |  |  |  |  | | 3 |  |  |  |  |   PRECAUTIONS  1. To protect repeller from damage the repeller negative voltage is always applied before anode voltage.  2. While modulating repeller should never become positive with respect to cavity.  3. Cooling should be provided to Reflex klystron.  **RESULT:-**The functional characteristics of E - plane Tee, H – plane Tee and Magic Tee were studied.  **FAQ**  **1 What are the various type of Tees.**  E - plane Tee, H – plane Tee, Magic Tee, Rat Race etc.  **2 What is H - plane Tee?**  An H-plane Tee is formed by cutting a rectangular slot along the width of a main waveguide and attaching another wave guide on the slot. It is three-port device.  **3.What is E - plane Tee?**  A rectangular slot is cut along the broader dimension of a wave guide and a sidearm is attached. This is a three-port device.  **4 What is Magic Tee?**  Rectangular slots are cut along the breadth and width of a long wave guide and side arms are attached. It is a Four-port device.  **5.What is the electric property of H-plane Tee?**  If equal input are given at ports 1&2 (collinear ports), the output at the port 3shall be the sum of these two inputs.  **6 What are the properties of E-plane Tee?**  If equal, in phase inputs are given at collinear ports, the output at port 3 shall be difference of the two i.e. zero. Similarly if same input is given at port 3, there shall be equal but opposite outputs at ports 1&2.  **7 What are the properties of Magic Tee?**  It has got the properties of both H & E plane Tees. However if some input is given to port 1, nothing comes out of 2.  **8 What are the applications of Magic Tee?**  - Used for measurement of impedance.  - Used as duplexer.  - Used as mixer.  **9 What is the isolation between E & H arm?**  It is defined as ratio of power supplied by generator connected to E-arm(port4) to the power detected at H-arm (port3) side arms 1&2 are terminated n matched load. Isolation 3-4 = 10 log10 P4 / P3  **10 Define Coupling Coefficient?**  10 Cij = 10 –α / 20 Where α is attenuation / isolation in db when i is input arm and j is output arm. Thus α = 10 log Pi / Pj Where Pi is the power delivered to arm i and Pj is power detected at j arm.  **EXPERIMENT NO : 6**  **MEASUREMENT OF RADIATION PATTERN AND GAIN OF HORN ANTENNA**  **AIM:** To study the directional characteristics of Horn Antenna and calculate gain and beam width values.  **APPARATUS REQUIRED**  Klystron Power Supply, Klystron with mount, Isolator, Frequency meter, Fixed Attenuator Detector, Parabolic Reflector, CRO.  **THEORY**  A horn antenna may be regarded as a flared out or opened out wave guide. A wave guide is capable of radiating radiation into open space provided the same is excited at one end and opened at the other end. However, the radiation is much greater through wave guide than the 2 wire transmission line. To overcome reflection and diffraction in the wave guide, the mouth of the waveguide is opened out which assumes the shape of a electromagnetic horn. If the wave guide is terminated by any type of horn, the abrupt discontinuity existed is replaced by a gradual transformation, then all the energy incident in forward direction in the waveguide will now be radiated, provided the impedance matching is proper. This improves directivity and reduces diffraction. If flaring is done only in one direction, then sectorial horn is produced. If flaring is done along both the walls, then pyramidal horn is obtained. By flaring the walls of the circular waveguide, a conical horn is formed. The fields inside the waveguide propagate in the same manner as in free space, but on reaching the mouth of the waveguide, these propagating fields continue to propagate in the same general direction but also starts spreading laterally and the wave front eventually becomes spherical. However this may be treated as transition region where the change over from the guided propagation to free space propagation occurs. Since the waveguide impedance & free space impedance are not equal, hence to avoid standing wave ratio, flaring of walls of waveguide is done which besides matching of impedance also provide concentrated radiation pattern i.e) greater directivity and narrower beam width. It is the flared structure that is given the name electromagnetic horn radiator. The function is to produce a uniform phase front with a larger aperture in comparison to waveguide and thus directivity is greater. If flare angle is very large, the wave front on the mouth of the horn will be curved rather than plane. This will result in non-uniform phase distribution over the aperture, resulting in increased beam width and reduced directivity, and vice versa occurs if the flare angle is very small. The directivity of the horn antenna is given as D = 7.5 A/λ2 where A area of horn mouth opening. Horn antennas are extensively used at microwave frequencies under the condition that power gain needed is moderate.  **Note: Draw the schematic diagram of HORN antenna.**  **Precautions**  1. Power flowing out of horns may damage retina of the eye so do not see directly inside the horn antenna  **PROCEDURE**   1. 1. Setup the equipments as shown in fig. Keeping the axis of both antennas in same axis line 2. 2. Energize the microwave source, and set mode 3 determine input power at transmitting antenna end by 3. connecting detector mount. 4. 3. Connect the transmitting antenna back. Turn the receiving horn to the left in 5° steps up to at least 60° and note 5. the corresponding voltage. 6. 4.Repeat the above step but this time turning the receiver to the right and note down the readings. 7. 5.Draw a relative power pattern ie, o/p vs angle. From diagram 3 dB beam width is determined.   **BLOCK DIAGRAM:-**    **MODEL GRAPH:-**     |  |  |  | | --- | --- | --- | | **Sl.No.** | **Angle** | **Output Voltage** | | 1 |  |  | | 2 |  |  | | 3 |  |  | | 4 |  |  | | 5 |  |  | | 6 |  |  | | 7 |  |  | | 8 |  |  | | 9 |  |  |   **OBSERVATION:-**   |  |  |  | | --- | --- | --- | | **Sl.No.** | **Distance between Antenna** | **Output Voltage** | | 1 |  |  | | 2 |  |  | | 3 |  |  | | 4 |  |  | | 5 |  |  | | 6 |  |  | | 7 |  |  | | 8 |  |  | | 9 |  |  |   **RESULT:** The directional pattern of the Horn antenna was obtained and the corresponding graph was drawn.  Beamwidth = ------------------ and Gain = ------------------  **FAQ**  **1 What is Horn antenna?**  This is an open-ended wave guide, in which open end is flared so that it looks like horn. It can be H plane, E plane, Pyramid horn or Conical horn.  **2 What is radiation pattern?**  It is a diagram of field strength or power intensity.  **3 What are various types of lobes**.  These are main lobe, side lobe, back lobe.  **4 Where in the lobe the intensity is maximum.**  At the centre of the lobe.  **5 Are side lobes / back lobes desirable? Discuss?**  These are not desirable but at the same time it is not possible to design an antenna without side lobes / back lobes. Through proper design, these can be reduced.  **6 What are the disadvantages of side lobes / back lobes?**  Loss of energy and susceptible to interference & jamming.  **7 What is beam width?**  The angle between two points on a main lobe where power intensity is half of the maximum power intensity.  **8 What is antenna gain?**  It is a measure of increased power radiated in the direction of target as compared with the power that would have been radiated from an isotropic antenna.  **9 What are the advantages of flaring?**  Flaring improves directivity, increases efficiency and reduces VSWR  **10 What are the various type of microwave antennas?**  Horn antenna, Lens antenna, Slot antenna and Micro strip antenna.  **EXPERIMENT NO : 7**  **CHARACTERISTICS OF DIRECTIONAL COUPLER**  **AIM :**-To study the function of directional coupler by measuring the Coupling factor  **APPARATUS :-**   * Microwave source (Klystron or Gunn diode) * Isolator * Frequency meter * Variable attenuator * Slotted line * Tunable probe * Detector mount * Matched termination * MHD coupler * Waveguide Stand * CRO , Cables and Accessories   **THEORY:-**  A directional coupler is a useful hybrid waveguide joint, which couples power in an auxiliary waveguide arm in one direction. It is a four-port device but one of the ports is terminated into a matched load.  **Characteristics of a Directional Coupler:-**  An ideal directional coupler has the following characteristics  1. If power is fed into port (1) the power is coupled in ports (2) and (3) i.e., power flows in the forward direction of the auxiliary arm port (3) but no power couples in port (4) i.e., in backward direction similarly power fed in (2) couples into ports (1) and (4) and not in (3).  2. All the four ports are matched, i.e. if three of them are terminated in matched loads, the fourth is automatically terminated in a matched load.  3. If power couples in reverse direction, power fed in (1) appears in ports (2) and (4) and nothing in (3), then such type of coupler is known as backward directional coupler. The conclusion is that in the auxiliary section the power is coupled in only one direction.  The coupling factor and Isolation are defined as  **Coupling (dB) = -10 log10[P1/P3]** where port 2 is terminated with matched load  **Isolation (dB) = -10 log10[P4/P1]** Where Port 1 is terminated with matched load  With built-in termination and power entering at Port I, the directivity of the coupler is a measure of separation  between incident wave and the reflected wave. Directivity is measured indirectly as follows.  Hence **Directivity D (dB) = -10 log10[P3/P4**]  Main line insertion loss is the attenuation introduced in the transmission line by insertion of coupler. It is defined as,  **Insertion Loss (dB) = -10 log10[P1/P2]**  **BLOCK DIAGRAM:-**    **PROCEDURE:-**  1. Set up the components and equipment as shown in fig.  2. Keep position of variable attenuator at minimum position.  3. Keep beam voltage knob fully anti-clock wise and repeller voltage to fully clockwise.  4. Switch on the Klystron power supply and oscilloscope.  5. Switch on beam voltage switch (HT) and set beam voltage to 200v by beam voltage control knob,  6. Keep amplifier knob of AM modulator to maximum position and rotate the repeller voltage  7. Measure the forward signal (P1) on CRO.  8. Connect the detector mount to the auxiliary arm of the coupler and measure the signal (P2).  9. Interchange the coupler such that the receiving end becomes Transmitting end and vice-versa.  10. Measure the signal in the auxiliary arm(P3).  11.Coupling factor is given by 10 log(P1/P3)  12. Isolation is given by 10 log(P1/P4)  **OBSERVATION:-**   |  |  |  |  |  | | --- | --- | --- | --- | --- | | **CONDITION** | **PORT 1** | **PORT 2** | **PORT 3** | **PORT 4** | | Forward Direction | Input= | Output= | Output= | Termination | | Reverse Direction |  |  |  |  |   **RESULT :-**  The performance characteristics of directional coupler were determined.  **FAQ**  **1 What is directional coupler?**  It is a combination of two wave guides electrically connected to each other through a hole or orifice. It is used to measure the power of EM wave by taking a small fraction of it.  **2 What is Coupling?**  Coupling, C(db) = 10 log 10 Pi / Pf  **3 What is Directivity?**  Directivity, D (db) = 10 log 10 Pf/ Pb  **4 What is Isolation?**  Isolation, I = 10 log 10 Pi / Pb.  **5 What is Insertion loss?**  Insertion loss = 10 log 10 Pi / Pr.  **6 In a two hole directional coupler, what is the distance between two holes?**  The distance is λg / 4.  **7 What is the material of directional coupler?**  These are two metallic rectangular wave-guides, made of brass / copper. These are finely polished and silver plated from inside  **8 Name a few other types of directional couplers?**  Two hole cross guide coupler.  - Two hole branching guide coupler  - Short slot coupler  - Bifurcated coupler  - Loop directional coupler  **9 In a directional coupler, are ports matched?**  All ports are perfectly matched to the junctions  **10 How many holes can be there in a Directional coupler?**   |  |  | | --- | --- | | It can be one, two or more than two depending upon requirement. Degree of coupling shall be decided by number and location of holes. |  |   **EXPERIMENT NO : 8**  **MEASUREMENT OF VSWR OF AN UNKNOWN LOAD**  **AIM**:-To determine the Standing-Wave Ratio and Reflection Coefficient  **THEORY:-**  The electromagnetic field at any point of a transmission line (e.g a wave guide) may be considered as the sum of two travelling waves. The incident wave propagates from the generator, the reflected wave propagates towards the generator. The reflected wave is set up by the reflection of the incident wave from a discontinuity on the line or from a load impedance not equal to the characteristic impedance of the line. The magnitude and phase of the reflected wave depends upon the amplitude and phase of the reflecting impedance. The magnitude also depends on the amplitude losses on the line. On a lossy line the reflected (and incident) wave will be attenuated. If the line is uniform and infinitely long there would be no reflected wave. The same applies for a line of finite length which is matched i.e. has a load equal to the characteristic impedance of the line. The presence of two travelling waves gives rise to standing wave along the line. The electrical (and mechanical) field varies periodically with distance. The maximum field strength is found where the two waves add in phase and the minimum where the two waves add in opposite phase. Figure above shows the voltage standing wave patterns for different load impedances. The distance between two successive minima (or maxima) is half the wavelength on the transmission line. The ratio between the electrical fields of the reflected and incident wave is called the voltage reflection coefficient, being a vector, which means that is phase varies along the transmission line. The voltage standing wave ratio VSWR on a transmission line is defined as the ratio between maximum and minimum field strengths along the line.  ρ = Er / Ei ,  S = Emax / Emin = (Ei + Er) / (Ei - Er)  =(S – 1) / (S+1)  **PROCEDURE:-**  1. Set up the equipment as shown in the figure.  2. Keep the variable attenuator in minimum position.  3. Keep the control knob of the Klystron power supply as below.  **Beam voltage**- OFF  **Mod switch**- AM  **Beam voltage knob**- Fully anti-clockwise  **Repeller voltage knob** - Fully clockwise  **AM amplitude knob**- Around fully clockwise  **AM frequency**- Mid position  5. Switch ON the Klystron power supply, CRO and cooling fan.  6. Switch ON the beam voltage and set beam voltage at 250V.  7. Rotate the reflector voltage knob to get Squire Wave in CRO .  8. Tune the output by turning the reflector voltage, amplitude and frequency of AM modulation.  9. Tune plunger of klystron mount and probe for maximum Voltage in CRO .  **BLOCK DIAGRAM:-**    PRECAUTIONS:-  1. To protect repeller from damage the repeller negative voltage is always applied before anode voltage.  2. While modulating repeller should never become positive with respect to cavity.  3. Cooling fan should be provided to reflex klystron.  **CALCULATION:-**  **1. To find VSWR**  **2. To find C**  **C***where*  **λ**  **∆x= [**Measure the distance between two successive minima position**]**  **3.To find F**  We know that C  **4. To find guide wavelength**  Measure the distance between two successive minima position twice the distance is  Wave guide length.  **λg = 2 ∆x where ∆x =** (d1-d2)  **5.To find SWR**  **SWR= λg /Π (d1-d2)**  **6. To find Reflection coefficient**  For different SWR, calculate the refection coefficient.  |**ρ| =**  **OBSERVATION:-**  **Type of Load : Horn Antenna**   |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | **Sl.No.** | **in cm ()** | **in cm ()** | **∆x= in cm** |  |  | | 1 |  |  |  |  |  | | 2 |  |  |  |  |  | | 3 |  |  |  |  |  |   **Type of Load : Matched Terminator**   |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | **Sl.No.** | **in cm ()** | **in cm ( )** | **∆x= in cm** |  |  | | 1 |  |  |  |  |  | | 2 |  |  |  |  |  | | 3 |  |  |  |  |  |   **Type of Load : Short Circuit**   |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | **Sl.No.** | **in cm ()** | **in cm ( )** | **∆x= in cm** |  |  | | 1 |  |  |  |  |  | | 2 |  |  |  |  |  | | 3 |  |  |  |  |  |   **MODEL GRAPH:-**    **RESULT:-**  The high Standing-Wave Ratio and Reflection Coefficient were found.  **Questions:**  1) What is standing wave?  2) What is reflection coefficient?  3) When do standing waves form?  4) How they are useful in microwave Engineering?  5) What is min. value of VSWR?  6) What is range of reflection coefficient? |
| |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **EXPERIMENT NO: 9**  **INTRODUCTION TO FIBER OPTICS COMMUNICATION**  Communication can be broadly defined as the transfer of information from one point to another. Before Fiber optics came along, the primary means of real time data communication was electrical in nature. It was accomplished by using copper wire or by modulating information on to an electromagnetic wave which acts as a carrier for the information signal. All these methods have one problem in common the communication had to be over a straight line path. Fiber optics provides an alternative means of sending information over significant distances using light energy. Light is utilized for communication has major advantages because it can be modulated at significant higher frequencies than electrical signals. That is till 1870, when an Irish physicist John Tyndall carried out a simple experiment. He filled a container with water and shone light into it. In the darkened room he pulled the bung from the opposite end of the container. The light shone out, of course but in which direction?  The light followed the curved path of water. The light was guided and a new science was born. This was due to a property of light called **refraction.**  **Theory of Fiber Optics** The principle of operation of optical fiber lies in the behaviour of light. It is a widely held view that light always travels in straight line and at constant speed. But that's not necessarily true as shown by Tyndall's experiment. To understand the propagation of light within an optical fiber it take into account refractive index of the dielectric medium. Refractive index of a medium is defined as the ratio of velocity of light in vacuum to velocity of light in medium.  Since, the velocity of light in any solid, transparent material is less than in vacuum the refractive index of such material is always greater than 1. A ray of light travels slowly in an optically dense medium than in the one that is less dense. Now, the direction that the light approaches the boundary between the two materials is very important. When a ray is incident on the interface between two dielectrics of differing refractive indices, refraction occurs. It may be observed that the ray approaching the interface is propagating in a dielectric of refractive index n1 and is at an angle to the normal at the surface of the interface. If the dielectric on the other side of interface has a refractive index which is less than n1, then the refraction is such that the ray path in this lower index medium is at where 2 is greater than 1.  The angle of incidence 1 and refraction and refraction 2 are related to each other and to refractive indices of dielectrics by Snell’s law of refraction which states that      **Total Internal Reflection:**  Since the angle of refraction is always greater than the angle of incidence. Thus when the angle of refraction is 90° and the refracted ray emerges parallel to the interface between the dielectrics the angle of incidence must be less than 90°. This is the limiting case of refraction and this angle of incidence is known as critical angle c. The value of critical angle is given by Angle of Incidence = Angle of Reflection  In case the angle of incidence is greater than the critical angle the light is reflected back into the  originating dielectric medium. This behavior of light is termed as Total Internal Reflection. Here,    This is the mechanism by which light may be considered to propagate down an optical fiber with low loss. Figure below illustrates the transmission of a light ray in an optical fiber via a series of total internal reflection at the interface of the silica core and slightly lower refractive index in the silica cladding The light ray shown in figure 3 is known as meridional ray as it passes through the axis of the fiber core. It is generally used when illustrating the fundamental transmission properties of optical fiber.    **Acceptance Angle:**  Since, only rays with an angle greater than critical angle at the core cladding interface are transmitted  by total internal reflection, it is clear that not all rays entering the fiber core will continue to be  propagated down the length.    Figure 4 illustrates a meridional ray at the critical angle c within the fiber at core cladding interface. It may be observed that this ray enters the fiber core at an angle θ at o the fiber axis and is refracted at the air-core interface before transmission to the core-cladding interface at the critical angle. Hence, any rays which are incident into the fiber core at an angle greater than θa will be transmitted to the core cladding interface at an angle less than θc and will not be totally internally reflected instead will be refracted into the cladding and eventually lost by radiation. Thus, for rays to be transmitted by total internal reflection within the fiber core they must be incident on the fiber core within an acceptance cone defined by conical half angle θa .Hence, θa is the maximum angle to the axis at which light may enter the fiber in order to be propagated and is referred to as the acceptance angle for the fiber.  **Numerical Aperture:**  It gives the relationship between the acceptance angle and the refractive indices of the three media  involved viz. the core, the cladding and air.  **Numerical Aperture =n0 sinθa =**  Where,  n0 = Refractive index of air  n1 = Refractive index of core  n2 = Refractive index of cladding  The Numerical Aperture is a very useful measure of light collecting ability of a fiber.    Here, the information source provides an amplified electrical signal to a transmitter comprising an electrical stage, which drives an optical source to give conversion, may be either a semiconductor laser or LED. The optical source, which provides an electrical to optical conversion an optical fiber cable used for transmission of signal and the receiver, consists of an optical detector, which drives a further electrical stage and hence provides demodulation of optical carrier. This electrical signal is amplified and applied to the destination. e.g. speaker photo diodes (P-I-N or avalanche) and in some instances photo transistors and photo conductors are utilized for detection of optical signal and optical to electrical conversion. The optical carrier may be modulated using an analog or digital information signal. Analog modulation involves the variation of light emitted from the optical source in continuous manner. In digital modulation however, discrete changes in the light intensity are obtained (i.e. ‘On Off’ pulses). Although often simpler to implement, analog modulation with an optical fiber communication system is less efficient, requiring a far higher signal to noise ratio at the receiver than digital modulation. Also, linearity needed for analog modulation with an optical fiber communication system is less efficient, requiring a far higher signal to noise ratio at the receiver than digital modulation. Also, linearity needed for analog modulation is not provided by semiconductor optical sources especially at high modulation frequencies.  **ADVANTAGES OF FIBER OPTIC SYSTEM**  **1. Enormous potential band width (BW)**  The optical carrier frequency in the range Hz. (generally near infrared around GHz) yields a far greater potential transmission B.W. (Bandwidth) then metallic cable system. (i.e. coaxial cable Bandwidth up to 500 MHz) or even millimeter wave radio system. (i.e. system. Currently operating with modulation Bandwidth of 700 MHz) at present the Bandwidth available to fiber system is not fully utilized by modulation at several GHz over hundred Km. and hundreds of MHz over 300 Km with intervening electronics (repeaters) is possible. There-fore the information carrying capacity of optical fiber system has proved far superior to best copper cable available, by comparison losses in coaxial cable systems restrict. A much-enhanced Bandwidth utilization for an optical fiber can be achieved by transmitting several optical signals each at different centre wave lengths in parallel on the same fiber. This wavelength division multiplexed operation particularly with dense packing of the optical wave length or (fine frequency spacing) offers potential information carrying capacity.  **2. Small size and weight**  Optical fibers have very small diameter. Hence, when they are covered with protective coatings, they are far smaller & lighter. This is a tremendous boon towards the alleviation of duct congestion in cities and allowing expansion of signal transmission in mobiles e.g. aircrafts, ships etc.  **3. Electrical isolation**  Optical fibers are fabricated from glass or plastic polymers, they are electrical insulators therefore they do not exhibit earth loop and interface problems. This property makes them suited for communication in electrically hazardous environment as fiber create no arcing or spark hazard at abrasions or short circuit & usually fiber do not contain sufficient energy to ignite vapors or gases  **4. Immunity to interference and cross talk**  Optical fibers form a dielectric wave guide and therefore are free from Electro Magnetic Interference (EMI), Radio Frequency Interference (RFI) or switching transients. It is not susceptible to lightening striker if used overhead rather than underground. More-over it is easy to ensure that there is no optical interference between fibers  **5. Signal security**  The light from optical fibers does not radiate significantly and therefore they provide a high degree of signal security. A transmitted optical signal cannot be obtained from a fiber in a non-invasive manner (i.e. without drawing optical power form the fiber). In theory, any attempt to acquire a message signal transmitted optically may be detected. This feature is obviously attractive for military & banking.  **6. Low transmission loss**  Optical fibers result in low attenuation or transmission loss in comparison with the best copper conductor. It facilitates the implementation of communication links with extremely wide repeater spacing thus reducing both system cost and complexity. This quality along with already proven modulation B W capability of fiber cable, it is used in long haul telecommunication applications.  **7. Potential Low Cost**  The glass which generally provides optical fiber transmission medium is made of sand not a scarce resource. In comparison with copper conductors, optical fiber offers low-cost line communication.  **CHARACTERISTICS OF OPTICAL FIBER**  **The Optic Fiber:**  The simplest fiber optic cable consists of two concentric layers of transparent materials. The inner portion (the core) transports the light; the outer covering (the cladding) must have a lower refractive index than the core so the two of them are made of different material  To provide mechanical protection for the cladding an additional plastic layer, the Primary Buffer is added. Some constructions of optic fiber have additional layers of buffer, which are then referred to as Secondary Buffer. It is very important to note that the whole fiber-Core, Cladding & Primary Buffer is solid and the light is confined to the core by the Total Internal Reflection due to the difference in the refractive index of the core as compared to that of cladding.    **Single Mode v/s Multi mode:**  As we have already seen that there are particular angles of propagation defined by cone of acceptance, which are able to be transmitted down the optic fiber. At these angles, the electromagnetic wave which is the light can set up a number of complete patterns across the fiber. The number of complete pattern scaled Modes depends on the dimensions of the optic fiber core. There are essentially two different types of fiber optic transmission schemes in use  1. Single mode  2. Multi-mode  **Single Mode:**  As the name suggests the single mode cable is able to propagate only one mode (electro magnetic wave). This is used in long distance and/or, high speed communication. It is beneficial over long distances since it completely eliminates a problem known as Inter Modal Dispersion associated with multimode cables. All our long distance telephone conversations are now carried by single mode optic-fiber system over at least some part of the route. Multimode the term multimode means that the diameter of the fiber optic core is large enough to propagate more than one mode (electro magnetic wave). Because of the multiple modes the pulse that is transmitted down the fiber tends to become stretched over distance this is referred to as dispersion &has the effect of bandwidth. These are typically used in applications such as LAN (Local Area Networks) &FDDI(Fiber Distributed Area Interface)  **Step Index and Graded Index Fibers:**  The first type of fiber optic cable used was called step index. In this design, the cladding has a different index of refraction than the core. The light bounces off the side and is reflected back into the fiber core. The problem with this design is that the reflected light must travel a slightly longer distance, than that which travels down the center of the fiber, thus limiting the maximum transmission rate. This design was improved with the use of graded index fiber. In this design, the index of refraction decreases in proportion to the distance away from the center of the fiber core. The light moves more quickly in the outer portion thus compensating for the additional distance. The change in index has the  effect of bending. This change increases the transmission capacity by a factor. In the newest single mode design, the diameter of the fiber core is so small that all the light travels in a straight line. Even the latest fiberoptic facility in use today uses less than 5 % of the maximum theoretical capacity of a single mode fiber.  **Some of the optical fibers in use are:**  **1.** Multimode step index fibers.  **2.** Multimode graded index fibers.  **3.** Single mode step index fibers.  **4.** Plastic - clad fibers.  **5.** All plastic fibers.  Dimensions of fiber optic cables are written as a ratio e.g. a cable with cladding diameter of 125microns and fiber core diameter of 62.5 or 50 microns will be referred to as 62 .5/125 or 50/ 125 fiber.  **Choice of operating frequency:**  Once we had the laser and the new optic fiber available, everything was in place for a significant upsurge in communications. This resulted in two driving forces: one towards the ability to send more data faster and secondly to send the data to greater distances without being re-amplified.  **More Data More Data Faster:**  As the transmission rate of data is increased, the required bandwidth increases and this can best be accommodated by increasing the carrier frequency. This premise has stood us in good stead over many years. The speech and poor quality music transmissions on the medium frequency, AM radio, give way to the higher frequency of FM radios which accommodate the increased bandwidth necessary for improved music quality. When television required even higher data rates, we responded by moving to even higher frequencies. These previous experiences rather suggested that the light used for fiber optic-communications should be of the highest frequency possible. But there was a surprise in store.  **Lower frequencies mean lower losses:**  The first experiments used visible light of different colours (frequencies). As the losses were measured, we found that the higher frequencies caused more losses. The losses actually increased by the 4th power of the frequency. This means that a trebling of the frequency would result in the losses increasing by 34 or 81 times the two conflicting influences:  High frequency = high data rates Low frequency = long ranges  At the moment, long distance communication is more important than achieving the ultimate in data transmission rates. Therefore, in most real installations, we tend to go for the relatively low frequencies of infrared light, which is just below the visible spectrum.  **LOSSES IN OPTIC FIBER**  **1.Attenuation**  Transmission of light is not 100% efficient. Some photons of light are lost, causing attenuation of signal. Several mechanisms are involved, including absorption by materials within the fiber, scattering of light out of the core caused by environmental factors. The degree of attenuation depends on the wavelength of light transmitted. Attenuation measures the reduction in signal strength by comparing output power with input power. Measurements are made in decibles (dB). It is defined as dB loss    **2. Material absorption losses**  It is a loss mechanism related to the material composition and fabrication process of the fiber which result in the dissipation of some of the transmitted optical power as heat in wave guide. The absorption of light may be intrinsic (caused by one or more major components of glass) or extrinsic (caused by impurities within the glass).  **3. Linear scattering losses**  Linear scattering mechanisms cause the transfer of some or all of the optical power contained within one propagating mode to be transferred linearly (proportionally) into a different mode. This process tends to result in attenuation of the transmitted light as the transfer may be to a leaky or radiation mode which does not continue to propagate within the fiber core, but is radiated from the fiber. It is mainly of two types.  **a.** Ray Leigh Scattering  **b.** Mie Scattering  **Ray Leigh Scattering:**  When the infrared light strikes a very - very small place where the materials in the glass are imperfectly mixed. This gives rise to localized changes in the refractive index resulting in the light being scattered in all directions. Some of the light escapes the optic fiber some continues in the correct direction and some is returned towards the light source. This is called back scatter    **Mie scattering**  These result from the non perfect cylindrical structure of the waveguide. It may be the caused by the imperfections such as irregularities in the core cladding interface core, cladding refractive index difference along the fiber length, diameter fluctuations strains and bubbles The scattering created by such in homogeneities is mainly in the forward direction.  **EXPERIMENT NO : 10**  **SETTING UP A FIBER OPTIC ANALOG LINK**  **AIM: -** To obtain intensity modulation of the analog signal, transmit it over a fiber optic cable and demodulate the same at the receiver and to get back the original signal.  **APPARATUS: -**  **1.** Dual trace oscilloscope 20 MHz  2. Optical fiber cable  3. Fiber Optic  4. Trainer kit and Connector wire.  **THEORY:**  In optical fibre communication system, electrical signal is first converted into optical signal with the help of E/O conversion device as LED. After this optical signal is transmitted through optical fiber, it is retrieved in its original electrical form with the help of O/E conversion device as photo detector. Different technologies employed in chip fabrication lead to significant variation in parameters for various emitter diodes. All the emitters distinguish themselves in offering high output power coupled in to the important peak wavelength of emission, conversion efficiency, to be useful in fiber transmission applications as LED must have a high radiance output. Fast emission response time and high quantum efficiency, its radiance is a measure of optical power radiated into unit solid angle per unit area of the emitting light source. High radiances are necessary to couple sufficiently high optical power levels into a fiber Modulation: In order to transmit information via an optical fiber communication system it is necessary to modulate a property of the light with the information signal. This property may be intensity, frequency, phase with either digital or analog signals. The choices are indicated by the characteristics of optical fiber, the available optical sources and detectors, and considerations of the overall system.  **Intensity modulation:**  In this system the information signal is used to control the intensity of the source. At the far end, the variation in the amplitude of the received signal is used to recover the original information signal.    The audio input signal is used to control the current through an LED which in turn controls the light output. The light is conveyed to the detector 1 circuit by optic fiber. The detector is a photo transistor which converts the incoming light to a small current which flows through a series resistor. This gives rise to a voltage whose amplitude is controlled by the received light intensity. The voltage is now amplified within the detector circuit and if necessary, amplified further by amplifier circuit.  **PROCEDURE:-**  **1.** Connect Power Supply to board as shown in figure  **2.** Make the following connection.  **a.** Function generator 1KHz sine wave output to input socket of emitter 1 circuit via 4mm lead.  **b.** Connect optic fiber between emitter l’s output and detector 1’s input.  **c.** Connect Detector 1 output to amplifier 1 input socket via 4nm lead.  **3.** Switch on the Power Supply.  **4.** Set the amplitude of the function generator to 2V p  **5.** Observe the transmitted and received signal on CRO. Vo (output voltage) should be in the same order as  Vin (input voltage).  **6.** Next set Vin to suitable values and note the values of Vo.  **7.** Tabulate and plot a graph Vo versus Vin & compute Vo/Vin.  **BLOCK DIAGRAM:-**    **OBSERVATION:-**   |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | **Sl.No.** | **Frequency** | **Input Signal** | | **Output Signal** | | | **Amplitude in V** | **Time in mS** | **Amplitude in V** | **Time in mS** | | 1 |  |  |  |  |  | | 2 |  |  |  |  |  | | 3 |  |  |  |  |  | | 4 |  |  |  |  |  | | 5 |  |  |  |  |  |   **MODEL GRAPH:-**    **RESULT:-** Fiber Optic Analog link characteristics of are measured and graph are drawn.  **EXPERIMENT NO : 11**  **SETTING UP A FIBER OPTIC DIGITAL LINK**  **AIM: -** To obtain intensity modulation of digital signal, transmit it over fiber optic cable and demodulate the same at the receiver end to get back the original signal.  **APPARATUS: -**  **1.** Dual trace oscilloscope 20 MHz  2.Optical fiber cable  3. Fiber Optic Trainer kit  4. Connector wire.  **THEORY:**  With digital modulation, discrete changes in light intensity are obtained (i.e. ‘On-Off’ pulses) figure shows a block schematic of a typical digital optical fiber link.    Initially, input digital signal from the information source is suitably encoded for optical transmission. The LED drive circuit directly modulates the intensity of the light with encoded digital signal. Hence, a digital optical signal is launched into the optical fiber cable. The photo transistor used as detector is followed by an amplifier to provide gain. Finally the signal obtained is decoded to give the original digital information.  **Digital Bias Voltage:**  In case of a digital signal the only information which needs to be conveyed is the ON state and ‘Off’  state. The digital Input signal is entirely positive going as shown in figure So, there is no negative part of the signal to be lost and furthermore any distortion due to non-linearity  of the characteristic is of no importance - all we need to know is whether the signal is ‘On’ or ‘Off’.  There is no need therefore to generate a bias voltage.  **PROCEDURE:-**  **1.** Connect Power Supply to board as shown in figure  **2.** Make the following connection.  **a.** Function generator 1KHz sine wave output to input socket of emitter 1 circuit via 4mm lead.  **b.** Connect optic fiber between emitter l’s output and detector 1’s input.  **c.** Connect Detector 1 output to amplifier 1 input socket via 4nm lead.  **3.** Switch on the Power Supply  **BLOCK DIAGRAM:-**    **MODEL GRAPH:-**    **OBSERVATION:-**   |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | **Sl.No.** | **Frequency** | **Input Signal** | | **Output Signal** | | | **Amplitude in V** | **Time in mS** | **Amplitude in V** | **Time in mS** | | 1 |  |  |  |  |  | | 2 |  |  |  |  |  | | 3 |  |  |  |  |  | | 4 |  |  |  |  |  | | 5 |  |  |  |  |  |   **RESULT:-**Fiber Optic Digital link characteristics of are measured and graph are drawn.  **EXPERIMENT NO : 12**  **MEASUREMENT OF NUMERICAL APERTURE**  **AIM**:- To measurement of the Numerical Aperture (NA) of Optical Fiber.  **APPARATUS REQUIRED**:-  1. ST2502 trainer with power supply cord  2. Optical Fiber cable.  3. Numerical Aperture measurement Jig/Paper & Scale  **THEORY:-**The numerical aperture refers to maximum angle at which the incident on fiber end is totally internally reflected and is transmitted along the fiber. The cone formed by rotation of this angle along the axis of the fiber is the cone of acceptance of fiber. if light ray should strike the fiber end within this cone of acceptance it will be transmitted properly else it is refracted out of fiber  **PROCEDURE:-**  1. Connections is made as per the circuit diagram. Insert a Fiber Cable into a cap of LED.  2. Connect the other end of fiber cable to the Numerical Aperture Measurement jig. Hold the white screen  facing the red spot .  3. Record the distance of screen from the fiber end L and note the diameter W of the spot. the fiber such that  its cut face is perpendicular to the axis of the fiber.  4. Hold fiber vertically at a suitable distance to make Compute the numerical aperture from the formula given  below  **5**. Mean radius is calculated by  **DIAGRAM FOR NUMERICAL APERTURE:-**    **OBSERVATION:-**   |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **Sl.No.** | **d** | **PQ** | **MN** | **Mean Radius** |  |  | | 1 |  |  |  |  |  |  | | 2 |  |  |  |  |  |  | | 3 |  |  |  |  |  |  | | 4 |  |  |  |  |  |  | | 5 |  |  |  |  |  |  |   **RESULT:**-Thus the Numerical Aperture (NA) of given Optical Fiber is calculated.  **EXPERIMENT NO : 13**  **MEASUREMENT OF PROPAGATION LOSS AND BENDING LOSS IN OPTICAL FIBER**  **AIM: -** To measure propagation or attenuation loss and bending loss in optical fiber  **APPARATUS: -**  **1.** Dual trace oscilloscope 20 MHz  2.Optical fiber cable  3. Fiber Optic Trainer kit  4. Connector wire.  **THEORY:-**  **Attenuation** is loss of power. During transit, light pulse lose some of their photons, thus reduce their amplitude. Attenuation for a fiber is usually specified in decibels per kilometer. For commercially available fibers attenuation ranges from 1dB/km for premium small-core glass fibers to over2000dB/Km for a large core plastic fiber. Loss is by definition negative decibels. In common usage, discussions of loss omit the negative sign. The basic measurement for loss in a fiber is done by taking the logarithmic ratio of the input power (Pi) to the output power (Po).    Where α is Loss in dB / Meter  Whenever the condition for angle of incidence of the incident light is violated the losses are introduced due to refraction of light. This occurs when fiber is subjected to **bending**. Lower the radius of curvature more is the loss.  **BLOCK DIAGRAM FOR ATTENUATION:-**    **PROCEDURE FOR ATTENUATION:-**  1. Connections is made as per the circuit diagram. Insert a Fiber Cable into a cap of LED.  2. Measure the light output using the signal strength  3. Calculate the Attenuation using the formula.    Where α is Loss in dB / Meter, Pi Reference reading by 1m fiber and Po Reference reading by 3m fiber  **BLOCK DIAGRAM FOR BENDING LOSS:-**    **PROCEDURE FOR BENDING:-**  1. Connections is made as per the circuit diagram. Insert a Fiber Cable into a cap of LED.  2. Take the portion of Fiber and bend it to various diameter.  3. Measure the signal strength for each bend.  **OBSERVATION:-**  **FOR ATTENUATION LOSS**   |  |  |  |  | | --- | --- | --- | --- | | **Sl.No.** | **Length** | **Amplitude** | **Time** | | 1 |  |  |  | | 2 |  |  |  | | 3 |  |  |  |   **FOR BENDING LOSS**   |  |  |  |  | | --- | --- | --- | --- | | **Sl.No.** | **Bend Length** | **Amplitude** | **Time** | | 1 |  |  |  | | 2 |  |  |  | | 3 |  |  |  |   **MODEL GRAPH:-**    **RESULT:-**  Thus the measurement of attenuation loss and bending loss in optical fiber are calculated. |  | |