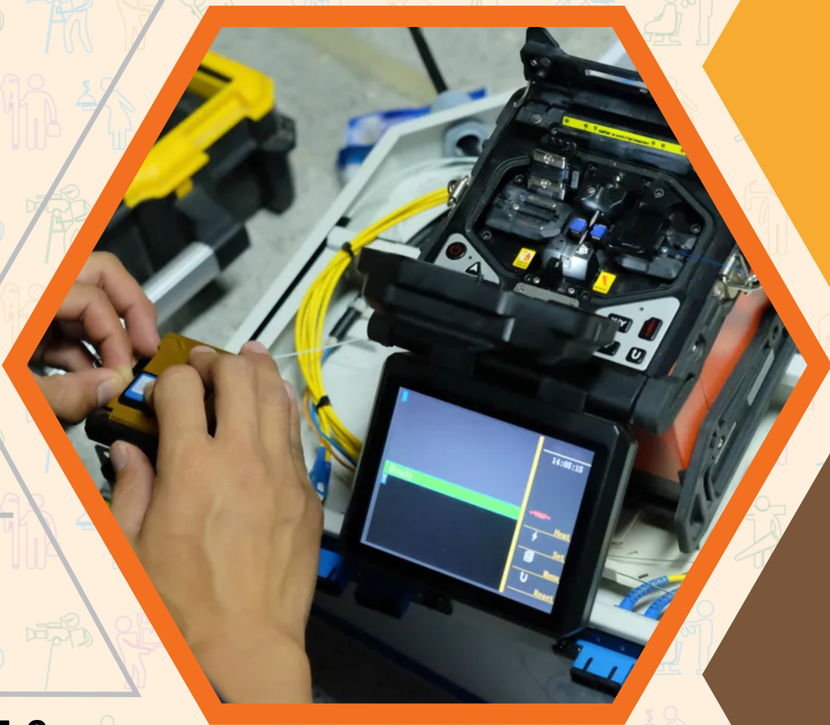
सत्यमेव जयते
GOVERNMENT OF INDIA
MINISTRY OF SKILL DEVELOPMENT
& ENTREPRENEURSHIP

Telecom Sector Skill Council

Participant Handbook



Sector
Telecom

Sub-Sector
Passive Infrastructure

Occupation
Operations and Maintenance - Passive Infrastructure

Reference ID: **TEL/Q6400,** Version **5.0**
NSQF Level **3.0**

Optical Fiber Splicer

This book is sponsored by
Telecom Sector Skill Council
Estel House,3rd Floor, Plot No: - 126, Sector-44
Gurgaon, Haryana 122003
Phone: 0124-2222222
Email: tssc@tsscindia.com
Website: www.tsscindia.com

First Edition, September 2025

> Skilling is building a better India.
> If we have to move India towards development then Skill Development should be our mission.

Shri Narendra Modi
Prime Minister of India

Telecom Sector Skill Council

Certificate

COMPLIANCE TO QUALIFICATION PACK– NATIONAL OCCUPATIONAL STANDARDS

is hereby issued by the

TELECOM SECTOR SKILL COUNCIL

for

SKILLING CONTENT : PARTICIPANT HANDBOOK

Complying to National Occupational Standards of

Job Role/ Qualification Pack: "**Optical Fiber Splicer"** QP No. **"TEL/Q6400" NSQF Level 3.0"**

Date of Issuance: 8th May 2025

Valid up to*: 30th April 2028

**Valid up to the next review date of the Qualification Pack or the 'Valid up to' date mentioned above (whichever is earlier)*

Authorised Signatory
(Telecom Sector Skill Council)

Acknowledgments

Telecom Sector Skill Council would like to express its gratitude to all the individuals and institutions who contributed in different ways towards the preparation of this "Participant Handbook". Without their contribution it could not have been completed. Special thanks are extended to those who collaborated in the preparation of its different modules. Sincere appreciation is also extended to all who provided peer review for these modules.

The preparation of this handbook would not have been possible without the Telecom Industry's support. Industry feedback has been extremely encouraging from inception to conclusion and it is with their input that we have tried to bridge the skill gaps existing today in the industry. This participant handbook is dedicated to the aspiring youth who desire to achieve special skills which will be a lifelong asset for their future endeavours.

About this book

India is currently the world's second-largest telecommunications market with a subscriber base of 1.20 billion and has registered strong growth in the last decade and a half. The Industry has grown over twenty times in just ten years. Telecommunication has supported the socioeconomic development of India and has played a significant role in narrowing down the rural-urban digital divide to some extent. The exponential growth witnessed by the telecom sector in the past decade has led to the development of telecom equipment manufacturing and other supporting industries.

Over the years, the telecom industry has created millions of jobs in India. The sector contributes around 6.5% to the country's GDP and has given employment to more than four million jobs, of which approximately 2.2 million direct and 1.8 million are indirect employees. The overall employment opportunities in the telecom sector are expected to grow by 20% in the country, implying additional jobs in the upcoming years.

This Participant handbook is designed to impart theoretical and practical skill training to students for becoming Optical Fiber Splicer in the Telecom Sector. Optical Fiber Splicer is responsible for ensuring efficient splicing of the optical fiber cables and test effectiveness and record the test results.

This Participant Handbook is based on Optical Fiber Splicer Qualification Pack (TEL/Q6400) and includes the following National Occupational Standards (NOSs):

1. TEL/N6400 – Splice Optical Fiber
2. TEL/N6401 – Test Effectiveness and Record Test Results
3. DGT/VSQ/N0101: Employability Skills (30 Hours)

The Key Learning Outcomes and the skills gained by the participant are defined in their respective units. Post this training, the participant will be able to manage the counter, promote and sell the products and respond to queries on products and services. We hope this Participant Handbook will provide sound learning support to our young friends to build an attractive careers in the telecom industry.

Symbols Used

Key Learning Outcomes

Steps

Tips

Notes

Practical

Unit Objectives

Table of Contents

It is recommended that all trainings include the appropriate Employability skills Module. Content for the same is available here:
https://www.skillindiadigital.gov.in/content/list

सत्यमेव जयते
GOVERNMENT OF INDIA
MINISTRY OF SKILL DEVELOPMENT
& ENTREPRENEURSHIP

1. Introduction to the sector and the job role of an Optical Fiber Splicer

Telecom Sector Skill Council

Unit 1.1 - Introduction to Telecom Sector and Role of an Optical Fiber Splicer

TEL/N6400

Key Learning Outcomes

By the end of this module, the participants will be able to:

1. Explain the importance of Telecom Sector.
2. Discuss the role and responsibilities of an Optical Fiber Splicer.

UNIT 1.1: Introduction to Telecom Sector and Role of an Optical Fiber Splicer

Unit Objectives

By the end of this unit, the participants will be able to:

1. Explain the significance of the telecom sector in modern communication and economic development.
2. Elucidate the key skills and technical expertise required for an Optical Fiber Splicer.
3. Describe the challenges faced in optical fiber Splicing.
4. Determine the impact of fiber optic technology on internet speed and connectivity.
5. Discuss the roles and responsibilities of an Optical Fiber Splicer.

1.1.1 Introduction to Telecom Industry

The Indian telecom industry has been one of the fastest-growing sectors in the country, striving to tap almost every potential customer with its services. Today, owning a mobile device is a basic necessity, and the demand for seamless connectivity continues to rise.

With the rapid expansion of the Information Technology (IT) sector, the telecom industry in India has experienced a major boom, leading to continuous market growth. Since the Indian population has become highly dependent on telecom services—and with several companies operating both in India and overseas—the sector often faces challenges in maintaining smooth operations amidst growing customer expectations. This study aims to provide insights into the current telecom sector and the measures being taken to enhance customer relationships.

Post-1991 liberalisation, privatisation, and globalisation, the Indian telecom market has become highly competitive, with multiple players operating simultaneously. In such an environment, companies are keen to understand customer perceptions of mobile services to refine their strategies and capture market share.

India remains the world's second-largest telecommunications market. As of March 2025, the total telephone subscriber base stood at around 1,200 million, with an overall tele-density of 85%. The internet subscriber base reached approximately 944 million, while broadband subscriptions grew to over 935 million wireless and about 45 million wired users by mid-2025.

Sector growth and infrastructure expansion:

Telecom infrastructure continues to expand rapidly, with the number of towers and mobile base transceiver stations (BTS) steadily increasing. This expansion has helped improve connectivity and service quality, especially in urban regions, though rural areas still face gaps.

Policy targets and initiatives:

The Government has launched the National Broadband Mission 2.0 (2025–30), aiming to provide optical fibre connectivity to all Gram Panchayats and key institutions, with at least 95% uptime, and to raise average fixed broadband speeds to 100 Mbps by 2030. In parallel, the Draft National Telecom Policy 2025 sets ambitious goals such as achieving 100% 4G coverage, 90% 5G coverage, 80% tower fibreisation, broadband access to 100 million households, and the rollout of 1 million public Wi-Fi hotspots by 2030.

Subscriber trends and market dynamics:

By May 2025, India's total telecom subscriber base reached about 1,207 million. Reliance Jio and Bharti Airtel together accounted for nearly all new subscriber additions, while Vodafone Idea and BSNL continued to lose market share. By June 2025, the total wireless subscriber base stood at approximately 1,171 million, driven largely by urban growth, though rural subscriptions showed a slight decline.

1.1.2 Various Sub-Sectors of the Telecom Industry

Telecommunication is a multi-dimensional industry. It is divided into the following subsectors:

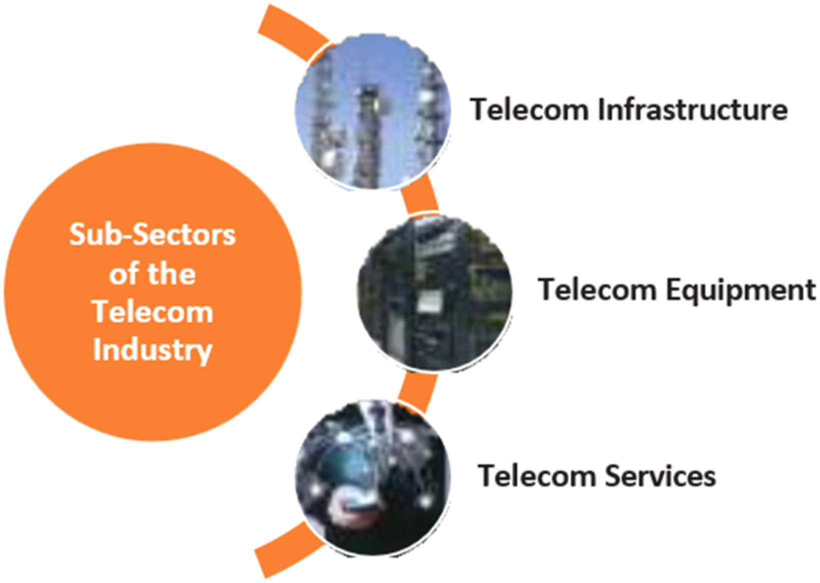


Fig. 1.1.1: Telecom Sub-Sectors

- Telecom Infrastructure - It is a physical medium through which all the data flows. This includes telephone wires, cables, microwaves, satellites, and mobile technology such as fifth-generation (5G) mobile networks.
- Telecom Equipment - It includes a wide range of communication technologies, from transmission lines and communication satellites to radios and answering machines. Examples of telecommunications equipment include switches, routers, voice-over-internet protocol (VoIP), and smartphones.
- Telecom Services – A service provided by a telecommunications provider or a specified set of user-information transfer capabilities provided to a group of users by a telecommunications system. It includes voice, data and other hosts of services.

The major segments within these sub-sectors include the following:

- Wireless communications
- Communications equipment
- Processing systems and products
- Long-distance carriers
- Domestic telecom services
- Foreign telecom services
- Diversified communication services

1.1.3 Broad Band Industry

Telecommunication plays a major role in economic and social development and has its scope across all technical fields. It integrates all telecommunication-related services in India and acts as a backbone for digital transformation.

The rapid improvement of internet and mobile technologies has had a significant impact on India's economic growth. Recognising this, the Government of India has placed strong emphasis on the development of the telecom industry. India continues to be the world's second-largest telecom market, after China.

However, broadband penetration and fixed broadband speeds in India still lag behind those of China. Strengthening broadband connectivity remains a key driver for digitalisation, economic inclusion, and innovation. The government has therefore prioritised expanding both mobile and fibre-based internet services to bridge the gap.

A major focus is on enhancing network connectivity in rural and semi-urban areas. The primary aim is to provide broadband access to every citizen of the country. Under the National Broadband Mission 2.0 (2025–30), the Government is targeting optical fibre connectivity for all Gram Panchayats and key institutions, ensuring at least 95% uptime. The mission also aims to raise average broadband speeds to 100 Mbps by 2030.

In line with this, rural and village-level networks are being upgraded to support high-speed internet, including the rollout of affordable 100 Mbps connections in villages through Panchayat-level initiatives. By doing so, India is working towards narrowing the rural-urban digital divide.

The Draft National Telecom Policy 2025 further outlines ambitious goals such as 100% 4G coverage, 90% 5G coverage by 2030, 80% fibreisation of towers, and 1 million public Wi-Fi hotspots across the country. These steps not only aim to improve connectivity but also attract foreign investment into the telecom sector, thereby creating new avenues for employment and skill development.

5G adoption and economic impact:

India has already rolled out 5G services across major cities and industrial hubs, with rapid expansion into smaller towns and rural regions underway. The adoption of 5G is expected to drive innovation in sectors like smart manufacturing, healthcare, education, transport, and agriculture, enabling applications such as IoT, automation, and AI-driven services.

According to projections, 5G technology could contribute around USD 450 billion to India's economy between 2023 and 2040. This transformative impact will strengthen India's digital ecosystem, enhance productivity, and support the government's vision of a digitally empowered society and knowledge economy.

With these initiatives, India is positioning itself strongly in the global telecom space and aspires to move closer to the top rank worldwide.

1.1.4 Optical Fibre Technology

Fibre optics is a technology used to transmit light using glass or plastic. These are used in communications, lighting and sensors. It works by sending signals through the fibre strands. This concept started 40 years ago in research labs in Chica go, USA. The fibres were replaced with the microwave and signals in the late 1980s.

In the 2000s, these were used to provide internet connection at home. In older days, these fibres were used in phone communication to transmit signals from senders to receivers. Later, these communications were taken over by mobile and wireless Internet systems. Most wireless products are dominant in today's market, and LANs utilise fibres to transmit signals and data.

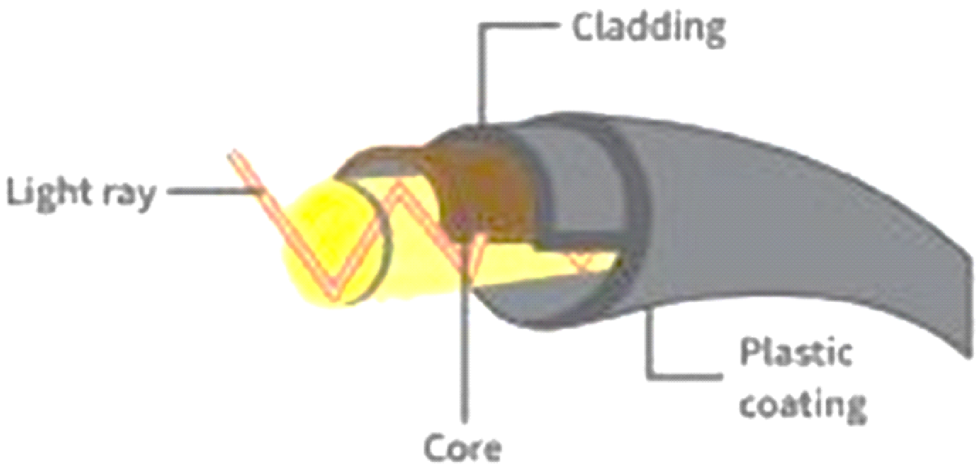


Fig. 1.1.2: Light travels through optical fibre

Applications:

- Mobile
- Network connections in the plane and other aircraft
- Network connections in ship and automobile industries
- Used in schools and traffic light controls
- Business use

Advantage:

- Reduced cost
- Efficiency

Significance of Optical Fibre:

- Flexibility
- Used in long-distance telecommunications
- Light transmission is due to internal reflection, which reduces the external signals
- Clear and error-free
- Allows twists and turns
- Can be used to transmit any wavelength.
- Can be used for single or bidirectional communication
- Use different transmission modes
- Cost-effective
- Have greater efficiency in transmitting the signals
- Low loss of signals
- Excellent linearity

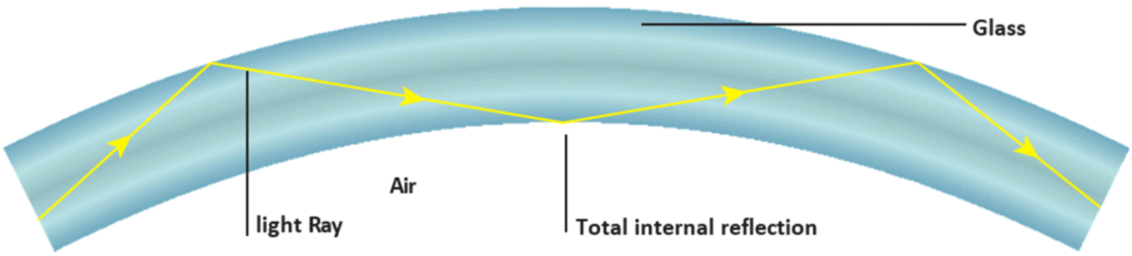


Fig. 1.1.3: Total Internal Reflection in Optical Fibre

Elements of Optical Fibre

There are mainly three elements present in optical fibre technology.

- Light source – It is placed at one end of the device. It receives signals and converts the
- electric signals to optic signals
- Fibre – It is connected from the origin to the destination to transmit light.
- The light detector – It is placed at the opposite end of the light source. It detects the signal and converts it into an electric signal. This leads to electric input.

1.1.5 Types of Optical Fibre

Optical fibre technology is associated with data transmission using light pulses travelling along with a long fibre which is typically made of glass or plastic. These facilitate the propagation of light along with the optical fibre depending on the requirement of power and distance of transmission.

Multi-mode fibre is used for shorter distances, while single-mode fibre is used for long-distance transmission.

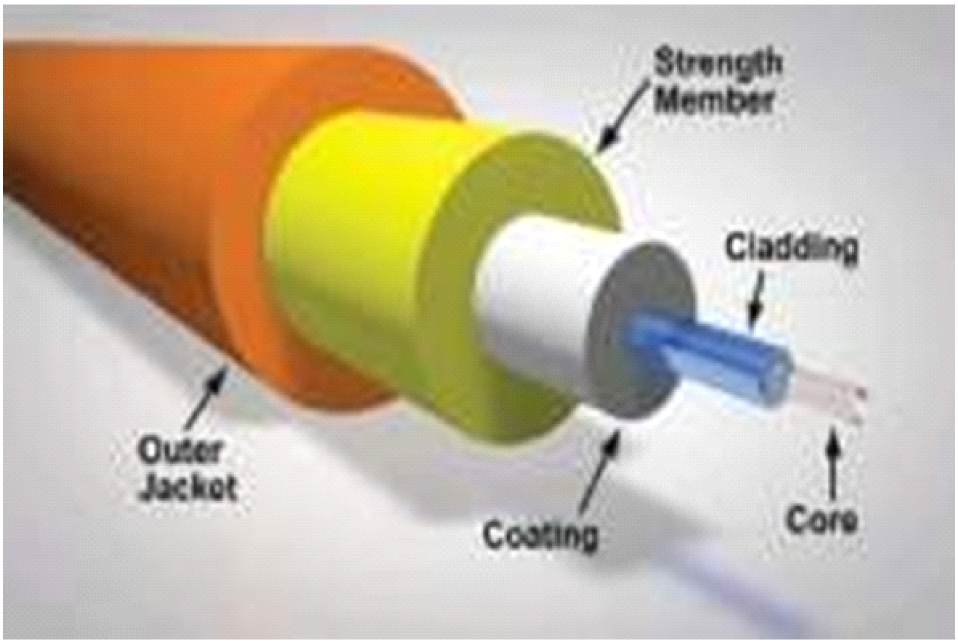


Fig. 1.1.4: Fibre Optics

Classification based on the refractive index:

- **Step Index Fibres -** It consists of a core surrounded by the cladding, which has a single uniform index of refraction
- **Graded Index Fibres -** The refractive index of the optical fibre decreases as the radial distance from the fibre axis increases

Classification based on the materials used:

- **Plastic Optical Fibres** - Polymethylmethacrylate is used as a core material for the transmission of light
- **Glass Fibres -** It consists of extremely fine glass fibres

Classification based on the mode of propagation of light:

- **Single-Mode Fibres -** Used for long-distance signal transmission
- **Multi-mode Fibres -** Used for short-distance signal transmission

The mode of propagation and refractive index of the core is used to form 4 combination types of optic fibres as follows:

- Step index-single mode fibres
- Graded index-Single mode fibres
- Step index-Multimode fibres
- Graded index-Multimode fibres

1.1.6 Optical Fibre Splicer

The telecom industry continues to demand a wide range of professionals to support its rapid growth. Among them, optical fibre splicers and telecom engineers are in particularly high demand due to the accelerated expansion of broadband and 5G networks. With large-scale fibreisation projects, rural digital connectivity initiatives, and private sector investments, employment opportunities in this domain are projected to rise significantly. Estimates suggest that the telecom industry will generate around 40 lakh direct and indirect jobs over the next five years.

Personal Attributes – Teamwork plays a critical role in the telecom sector, as the industry faces frequent challenges that require collective problem-solving and quick response. Professionals in this field must be resilient, capable of working under pressure, and focused on delivering solutions that maintain service continuity and enhance productivity.

Adherence to timelines and quality standards is vital, since tasks such as splicing, installation, and maintenance often affect entire networks and customer experiences. Additionally, professionals must possess effective communication skills—including knowledge of the local language in the regions where they work—because resolving broadband or connectivity issues often involves direct interaction with rural or semi-urban communities in their native languages.

In short, the role of an optical fibre splicer today demands a blend of technical expertise, teamwork, time management, and customer-centric communication, making it one of the most promising and employment-rich career paths within the telecom industry.

1.1.7 Need for Splicing of Optical Fibres

To overcome the drawbacks of optical fibre connectors, the splicing of optical fibres is used to maintain permanent connections between the two optical fibre cables. Splicing essentially provides permanent or semi-permanent joints.

Fig. 1.1.5: Fibre Optics Joints Closure

Optical fibres of various lengths, like more than 5kms, 10kms, etc., are not capable of a permanent connection and can't run longer, and are also not suitable for repeated connections and disconnection of cables.

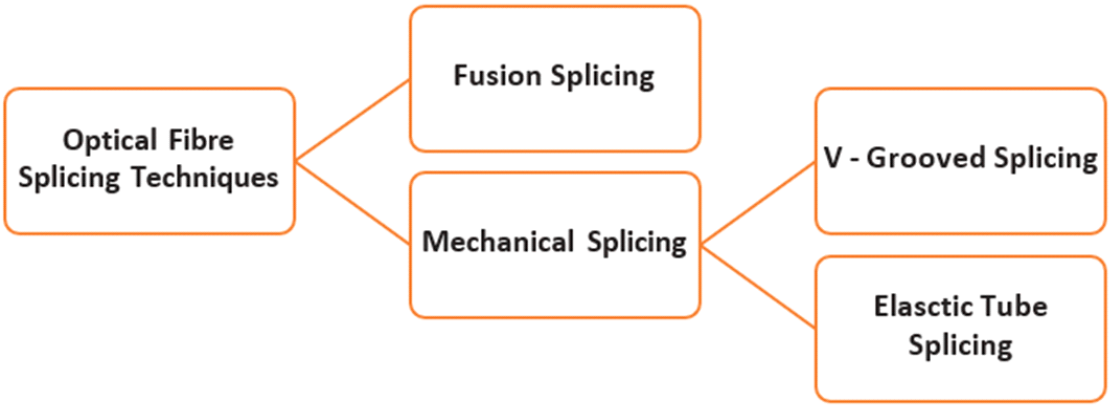
Hence, it is necessary to splice the fibre optic cables of two lengths to join them together, providing a sufficient permanent connection for a longer run.

Fig. 1.1.6: Splicing of Optical Fibre

Splicing Techniques

Advantages and Disadvantages of fibre splicing Advantages:

- Allows long-distance signal transmission
- Reduced reflection at the time of signal transmission
- Provides almost permanent connection of the fibres



Disadvantages:

- Fibre losses are higher than the acceptable limits
- Increase in the overall cost of the optical fibre communication system

1.1.8 Roles and Responsiblities of Optical Fibre Splicer

An Optical Fibre Splicer is responsible for installing, splicing, testing, maintaining, and repairing fibre optic cables used in high-speed communication systems. They ensure uninterrupted transmission of voice, data, and video services by handling both new installations and existing network upgrades.

Key Responsibilities:

- **Cable Installation & Maintenance**
  - Install, repair, and maintain underground, aerial, and inside plant fibre optic cables.
  - Perform fusion/mechanical splicing of fibre optic cables with precision.
  - Ensure proper cable terminations at cross-connects, hubs, patch panels, and routers.

- **Splicing & Troubleshooting**
  - Carry out splicing activities for network expansion and restoration.
  - Locate, diagnose, and repair cable faults to maintain existing networks without service interruption.
  - Perform OTDR testing, power meter/light source testing, and end-to-end signal verification.

- **Network Testing & Quality Assurance**
  - Conduct service provisioning tests to ensure reliable connectivity.
  - Verify network performance, bandwidth capacity, and optical signal levels.
  - Document test results and maintain accurate splicing records.

- **Site & Project Management**
  - Conduct site surveys and prepare feasibility/design drawings, technical manuals, and discrepancy reports.
  - Maintain project tracking details such as production logs, time sheets, and customer-mandated paperwork.
  - Ensure timely completion of assigned tasks within project deadlines.

- **Safety & Compliance**
  - Follow safety protocols and comply with legal/regulatory standards as per government and industry norms.
  - Maintain a safe and secure work environment while handling optical fibre, equipment, and chemicals.
  - Use appropriate PPE and adhere to electrical/laser safety procedures.

1.1.9 Physical Requirements of Optical Fibre Splicer

The requirements are as follows:

- Must have adequate physical strength, hand-eye coordination, and stamina to complete jobs in various areas.
- Must be able to clearly see and identify colours.
- Must be able to lift and carry up to 20 Kgs and push and pull 30-40 Kgs loads at a time.
- Must be able to stand and walk up to eight hours daily and climb multiple stairs while carrying materials weighing 10-20 Kgs.
- Must be able to ride a vehicle for up to four hours to travel to and from job sites.
- Must be able to work in varying temperatures and weather conditions.
- Exposure to characteristic construction site dangers.
- Must have the vision to allow differences in colours, shades and brightness.
- Must have flexibility in scheduling to meet the needs of the business.

1.1.10 Career progression of an Optical Fibre Splicer

A fibre optic splicer can determine their career goals through career progression. For example, they could start with a role such as a technician, progress to a title such as a team leader, and eventually end up with the title area manager.

A fibre optic splicer can work just about anywhere from big cities to rural areas, indoors or outdoors in big or small offices, buildings. He/she might work for a telephone company, an Internet service provider, a CATV company, an independent contractor, or even the military.

The typical career progression of an Optical Fibre Splicer is shown below:

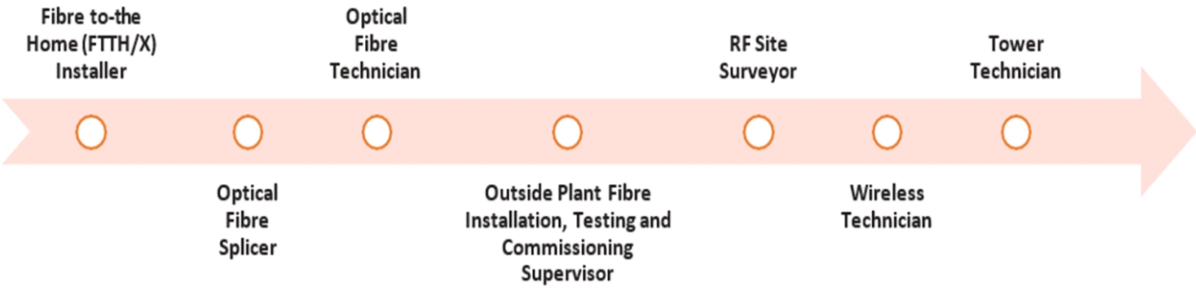


Fig. 1.1.8: Career Path of an Optical Fibre Splicer

1.1.11 Basics of Telecom

Any telecommunication system has three basic units:

- Transmitter - It takes information and converts it to a signal
- Transmission medium - Also called the "physical channel" that carries the signal
- Receiver - It takes the signal from the channel and converts it back into usable information

Fig. 1.1.9: Signal Transmission

Telecommunication over telephone lines is called:

- Point-to-point communication - Between one transmitter and one receiver
- Broadcast communication - Between one powerful transmitter and numerous low-power but sensitive receivers

Types of telecommunication networks

- Computer networks, ARPANET, Ethernet, Internet, Wireless networks
- Public switched telephone networks (PSTN)
- Packet-switched networks
- Radio network

1.1.12 Public Switched Telephone Network (PSTN)

- It is a standard telephone service. Some of the examples are BSNL, Airtel and MTNL.
- Public Switched Telephone Network, operated through "SWITCH" devices to open or close circuits, or it can break the electronic or certain path.
- This integrates the world circuit of telephone networks that are performed by na
- It consists of the fibre optic cable, telephonic lines, communication waves, networks, satellites and telephonic cables. These are interconnected with each other to communicate with anyone around the world.
- The telephone system network consists of mobile and telephones around the world.
- The process of PSTN – Dialling a person with whom we want to connect. The receiver gets the signal, picks the call, and exchanges the information. The circuit completes when they talk to each other

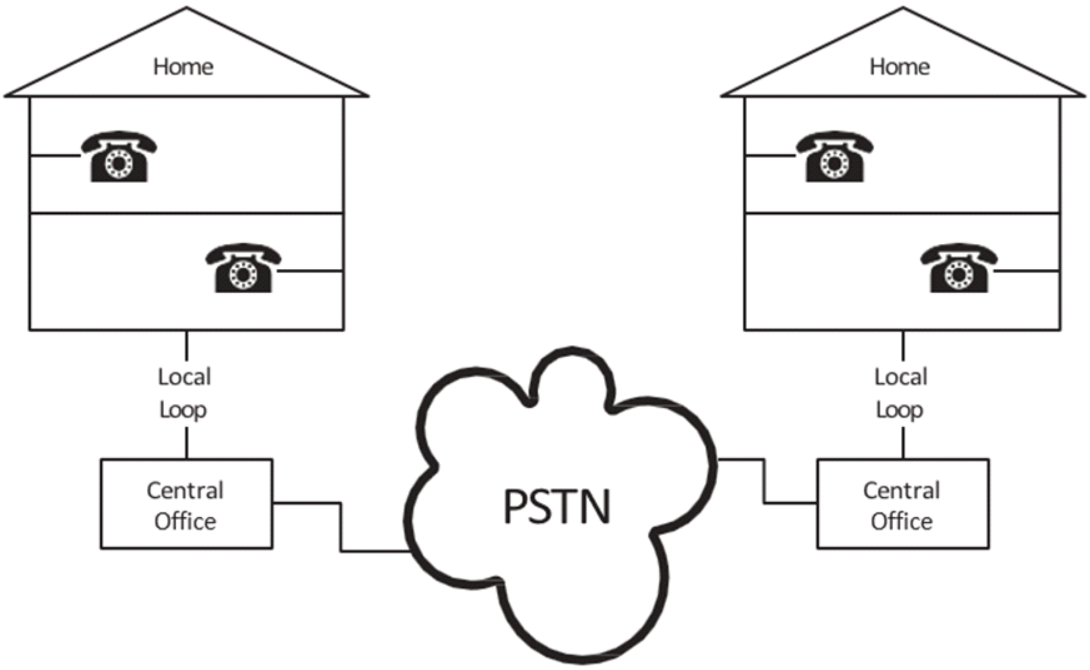


Fig. 1.1.10: A typical PSTN Network

1.1.13 Traditional Forms of Retailing in India

In telecom terminology, a transmission medium is a physical path between the transmitter and receiver, i.e., the channel through which data is exchanged from one place to another. Transmission Media can be broadly classified into the following types:

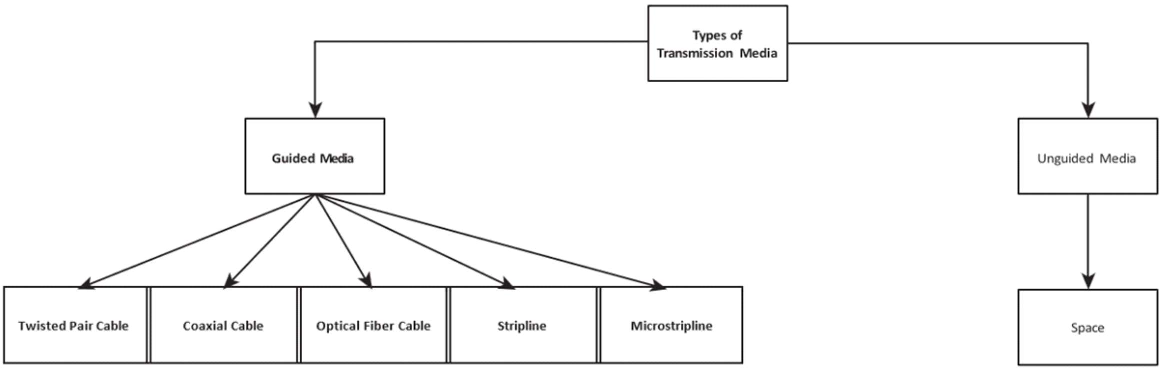


Fig. 1.1.11: Types of Transmission Media

Twisted pair cabling refers to wiring type. This consist of two conductors in a single circuit in which the conductors are twisted to cancel the electromagnetic induction from external sources.

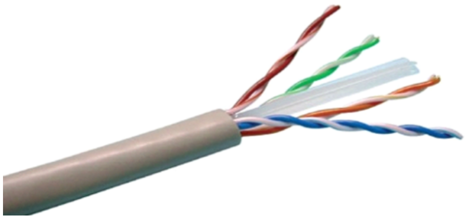


Fig. 1.1.12: Twisted Pair Cable

Coaxial cable was invented and designed in 1880 by the English engineer named Over Heaviside. It has a conductor which is layered by a tube insulator and a shield. Most of them have an outer jacket. This term coaxial is used as the inner conductor and jacket share the same geometric axis.

Fig. 1.1.13: Co-Axial Cable

Optical fibre cable consists of one or more than one optical fibre. These are coated with plastic plates and contain protective tubes which are stable in all climatic conditions.

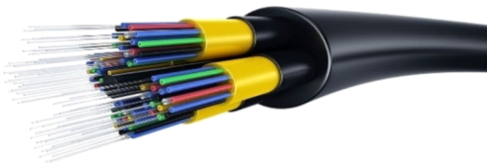


Fig 1.1.14: Fibre Optics

A microwave is an electromagnetic wave. It has a wavelength in the range of 0.001 –0.3 m, or sometimes shorter than that of a normal radio wavelength. They are larger than the IR. These wavelengths are used in microwave oven and other industrial processes. These are also used to carry the telecommunications.

Fig. 1.1.15: Microwave Antena

A satellite is a system that receives signals from any part of the earth and transmits them to a receiver on earth. The main function is communicating and transmitting the signal from the sender to the receiver.

Fig. 1.1.16: satellite system

Exercise

A. Short Questions:

1. Explain the significance of the telecom sector in modern communication and economic development.
2. List three key technical skills an Optical Fiber Splicer must possess.
3. Describe one major challenge faced in fiber optic splicing and how it can be addressed.
4. How does fiber optic technology impact internet speed and overall connectivity?
5. Outline the main roles and responsibilities of an Optical Fiber Splicer in network deployment.

B. Fill in the Blanks:

1. An Optical Fiber Splicer is responsible for __________ and __________ optical fibers.
2. The telecom sector contributes to economic development by enabling faster __________ and __________ transmission.
3. Precise __________ of fiber cores is critical to reduce signal loss during splicing.
4. Fiber optic cables provide high-speed data transmission due to the principle of __________.
5. One challenge in splicing optical fibers is ensuring proper __________ alignment to maintain signal quality.

C. Multiple Choice Questions (MCQs):

1. The telecom sector is crucial for modern communication primarily because it:
   a. Generates electricity
   b. Facilitates high-speed data and voice connectivity
   c. Manufactures optical fibers
   d. Regulates government policies

2. Which of the following is a key technical skill required for an Optical Fiber Splicer?
   a. Welding metal cables
   b. Precision fiber cleaving and splicing
   c. Installing electrical transformers
   d. Designing software algorithms

3. One major challenge faced in optical fiber splicing is:
   a. High voltage current in fibers
   b. Aligning fiber cores precisely to minimize signal loss
   c. Excessive fiber flexibility
   d. Overheating of fiber jackets

4. Fiber optic technology primarily improves:

   a. Electrical power transmission

   b. Internet speed and connectivity

   c. Radio signal quality

   d. Cable durability for plumbing

5. The responsibilities of an Optical Fiber Splicer include:

   a. Designing network routers

   b. Installing, splicing, and testing fiber optic cables

   c. Manufacturing telecom hardware

   d. Drafting government policies

   c. Manufacturing telecom hardware

   d. Drafting government policies

Notes

2. Splicing Optical Fiber

TEL/N6400

Key Learning Outcomes

By the end of this module, the participants will be able to:

1. Explain how to check the availability of tools, spares, and advanced equipment for fiber optic installations.
2. Describe the process of preparing cables for splicing in new installations.
3. Discuss how to maintain and troubleshoot laid Optical Fiber Cables (OFCs).
4. Elucidate the steps involved in performing advanced splicing operations with automation and precision.
5. Describe how to utilize advanced fiber testing tools and document the results.
6. Explain the specialized splicing techniques used for micro and nano fibers.

UNIT 2.1: Handling and Maintenance of Tools and Spares

Unit Objectives

By the end of this unit, the participants will be able to:

1. Describe the tools and equipment used for splicing, including fusion splicers, inspection tools, smart cleavers, robotic arms, and safety equipment, along with the proper handling of splicing consumables.
2. Demonstrate how to check the availability and functionality of advanced optical testing tools such as OTDR, power meter, OSA, CD analyzer, and PMD analyzer.
3. Show how to check for availability and manage advanced splicing tools, including automated splicers, robotic arms, cleavers, and inspection tools.
4. Demonstrate how to manage splicing consumables like joint kits, connectors, heat-shrink sleeves, and fiber optic enclosures.
5. Show how to ensure that splicing machines and testing equipment are calibrated and updated to meet precision standards, and coordinate repair or replacement of faulty tools.
6. Show how to use AI-enabled OTDR for fault detection and accurate loss measurement, and test signal quality with tools like OSA, CD analyzer, and PMD analyzer.

2.1.1 Characteristics of Optical Fibre

Total Internal Reflection

When a ray of light crosses an interface into a medium with a higher refractive index, it bends towards the normal. Conversely, light travelling across an interface from a higher refractive index medium to a lower refractive index medium bends away from the normal.

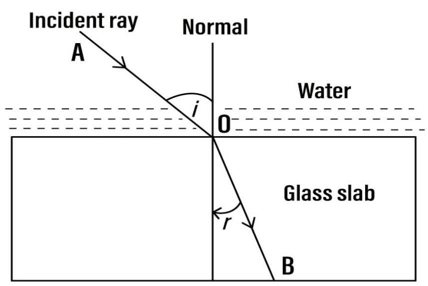


Fig. 2.1.1: Refraction of light

This has an interesting inference. At a specific angle, called the critical angle θc, the light travelling from a higher refractive index medium to a lower refractive index medium will be refracted at 90°. In other words, the light ray is refracted along the interface.

If the ray of light hits the interface at any angle larger than this critical angle, it will not pass through to the second medium. Instead, all of it will be reflected back into the first medium. This phenomenon is known as Total Internal Reflection.

Consider a ray of light passing from water into the air. The light emanating from the interface is bent towards the water. When the incident angle is increased sufficiently, the transmitted angle (in the air) reaches 90 degrees. It is at this point no light is transmitted into the air.

The critical angle θc is given by Snell's Law as:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Here, n_1 and n_2 are refractive indices of the media, and θ_1 and θ_2 are angles of incidence and refraction, respectively.

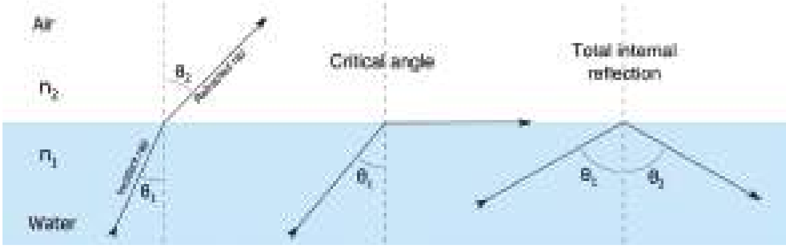


Fig. 2.1.2: Total Internal Reflection

To determine the critical angle, we find the value for θ_1 when θ_2 is equal to 90o and thus Sin θ1=1.

The resulting value of θ_1 is equal to the critical angle $\theta c = \theta_1 = \arcsin(n_1/n_2)$.

So the critical angle is only defined when n_1/n_2 is less than 1.

Optical fibres are based wholly on the principle of total internal reflection. This is explained in the following picture.

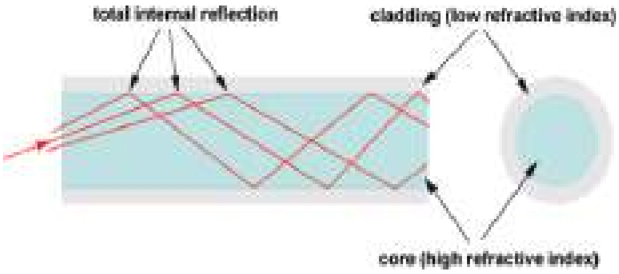


Fig 2.1.3 Refraction in optical fibre

Polarisation

A light wave that is vibrating in more than one plane is referred to as unpolarised light.

Polarised light waves are light waves in which the vibrations occur in a single plane. The process of transforming unpolarised light into polarised light is known as polarisation.

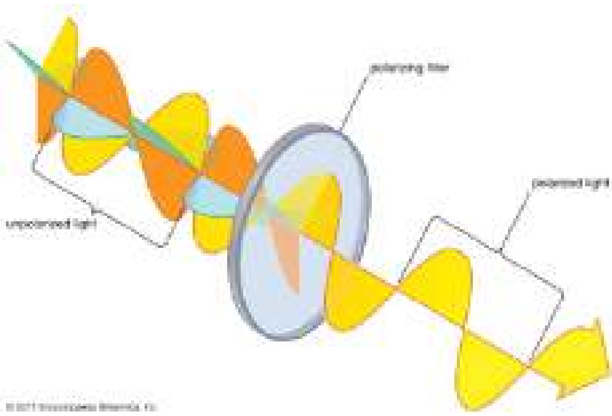


Fig. 2.1.4: Polarisation of Light

Attenuation

The attenuation of an optical fibre is the amount of light lost between input and output. Total attenuation is the sum of all losses. The attenuation of the optical fibre is a result of two factors:

- **Absorption -** The absorption is caused by the absorption of the light and conversion to heat by molecules in the glass.
- **Scattering -** Scattering occurs when light collides with individual atoms in the glass, which is anisotropic. Light scattered at angles outside the numerical aperture of the fibre will be absorbed into the cladding or transmitted back toward the source

Dispersion

Optical fibre dispersion describes the process of how an input signal broadens/spreads out as it propagates/travels down the fibre. Generally, dispersion in optical fibre cable includes modal dispersion, chromatic dispersion and polarisation mode dispersion.

2.1.2 Various Optical Equipment

Fibre Optic Tools:

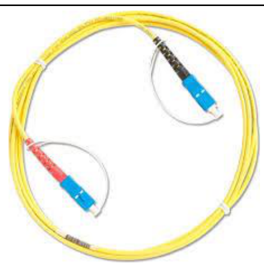
It is important to have proper tools and fibre for complete telecom communication.

Tools for Installer's Toolbox		Overview
1. Cable Preparation Tools		
Tubing Cutter		It is used to cut the cable jacket, and armour, cleanly without damaging fibers.
Rotary Cable Slitting & Ringing Tool		Used for slitting and ringing (circumferential cuts) on cable jackets.
Cable Jacket Stripper		Removes the protective outer jacket of fiber optic cables, approximately 2-3mm.
Fiber Optic Stripper		Helps to remove primary coating from fiber without nicking the optic fiber. It can also cut 2-3mm cable jacket.
Buffer Tube Stripper		Cuts jacket/buffer tubes in loose tube cables. It is similar to UTP jacket cutters and prevents fiber damage
Kevlar Scissors		Super sharp scissors used to cut Kevlar fibres in FO cable.

Tools for Installer's Toolbox		Overview
Lineman Scissors		Heavy-duty scissors for Cutting thicker cable materials.
2. Splicing & Termination Tools		
Crimp Tool		Crimps fiber optic connectors onto the cable. It is used in termination.
Scribe		Used to score and cleave fiber during termination. Sapphire or carbide are best.
Needle Nose Pliers		Used when accessing ripcords or strength members inside the fiber optic cable.
Tweezers		Used to handle and position individual fibers during splicing or termination.
Fusion splicer		Core tool that aligns and fuses fibers with electric arc.

Tools for Installer's Toolbox		Overview
Fibre cleaver		Precisely cleaves fiber ends for fusion splicing.
Fusion splice protectors		Protect the splice joint from stress and environmental factors. Use the type recommended by the fusion splicer, manufacturer
Mechanical splices		Alternative to fusion, used for joining fibers with mechanical alignment.
3. Polishing & Connectorization Tools		
Polishing Plate		Base surface for polishing.

Tools for Installer's Toolbox		Overview
Polishing Pad		Soft underlay beneath polishing film.
Polishing Puck		Insert connector into this polishing tool, lay on polishing paper. Holds the Ferrule connectors in place during polishing.
Connector Curing Oven		Used to cure epoxy in connectors. Portables and easy handling
Heat Cure, 2-Part Epoxy, 2.5 Gram		Adhesive for fixing connectors. "BiPax" package has epoxy and hardener in plastic pack-age that is mixed in the package. Can be used with many connectors at one time
Cheap scissors		Used to cut corner off epoxy package. Cheap once are available which can be used and throw.

Tools for Installer's Toolbox		Overview
Anaerobic Adhesive + Accelerator (optional)		Faster adhesive method. Used in anaerobic connector termination.
4. Testing & Inspection Tools		
Flashlight Continuity Tester (MM only) or Visual Fault Locator (VFL-red laser-SM or MM)		Used for Testing purpose-bright, visible light source for checking continuity or tracing fibers, VFL can find faults also.
Light source		Provides stable optical signal for testing.
Power meter adapters		Measures optical power at fiber ends. Can be used on 2.5mm ferrules.
Reference Test Cables		Pre-tested, low-loss cables for accurate measurements. To be used based on connector Types.
Connector Mating Adapters		Connectors with precision alignment sleeves (ceramic/metal preferred)-ST/ST, SC/SC, etc, or hybrid ST/SC

<table>
<tr><th colspan="2">Tools for Installer's Toolbox</th><th>Overview</th></tr>
<tr><td>Connector inspection microscope</td><td></td><td>Inspects end-faces of connectors for dirt, cracks, or defects.</td></tr>
<tr><td>ST Bare fiber adapter</td><td></td><td>Used in testing and it allows direct testing of bare fibers.</td></tr>
<tr><td>Optical Time Domain Reflecto meter (OTDR)</td><td>
</td><td>Used in OSP cables and troubleshoot problems. Advanced tool to measure loss, locate faults, and characterize fiber spans.</td></tr>
<tr><td colspan="3">5. Cleaning & Safety Equipment</td></tr>
<tr><td>Alcohol-saturated pads</td><td>
</td><td>Used to clean fibers and connectors before splicing/termination.</td></tr>
<tr><td>Wipes & Reagent-Grade Alcohol (99%+ ethanol)</td><td>
</td><td>For precision cleaning of fiber ends and equipment.</td></tr>
</table>

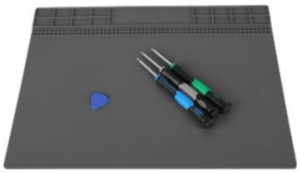
Tools for Installer's Toolbox		Overview
Lab wipes		Lint-free wipes for cleaning connectors/tools.
Dry connector cleaner		Dry connector cleaner
Trash Bin (with lid)		Safe disposal of fiber scraps. 1-pint deli container with lid works well.
Black work mat		Provides contrast background to easily see thin fibers. It helps see the fiber scraps to Clean.
Safety glasses		Protect eyes from fiber shards and laser light.

Table 2.1.1 Tools and Equipment used in Fibre Optics

2.1.3 Handling and Management of Splicing Consumables

Splicing consumables are essential materials used during the fiber optic splicing process. Proper handling and management of these consumables ensure splice reliability, minimize losses, and extend the lifespan of the splice.

Key Consumables:

- **Joint Kits:** Provide protective housing for fiber splices, ensuring mechanical strength and environmental sealing.
- **Connectors:** Used to terminate optical fibers for easy connection and disconnection of fiber optic links.
- **Heat-Shrink Sleeves:** Encase and protect the splice joint from dust, moisture, and physical damage.
- **Fiber Optic Enclosures:** Offer long-term protection for spliced fibers against harsh environmental conditions.

Best Practices for Handling and Management:

- **Storage:** Store consumables in clean, dust-free, and moisture-controlled environments.
- **Usage Monitoring:** Keep inventory records to avoid shortages during field operations.
- **Proper Handling:** Use clean, dry hands or gloves when handling to prevent contamination.
- **Disposal:** Dispose of fiber shards, cut-offs, and used consumables in designated sharps containers to ensure safety.

2.1.4 Inspection and Testing Tools for Fiber Optics

Inspection and testing tools are critical for ensuring the quality and integrity of splicing work. These tools allow technicians to identify defects, misalignments, or dirt before and after the splicing process.

Common Tools:

- **Fiber Inspection Microscope:** Enables magnified viewing of fiber end-faces to check for dirt, scratches, or cracks.
- **Video Inspection Probe:** A modern tool providing real-time visual output of fiber conditions.
- **VFL (Visual Fault Locator):** Emits visible red laser light to detect breaks, bends, or faulty connections in fibers.
- **Power Meter:** Measures the optical power of transmitted signals in dBm, ensuring expected signal strength is maintained.

Significance:

- Prevents signal losses due to contamination or damage.
- Helps maintain optical network performance standards.
- Provides quality assurance before final installation.

2.1.5 Advanced Optical Testing Instruments (OTDR, Power Meter, OSA, CD & PMD Analyzer)

Advanced testing instruments ensure high-quality network performance by identifying losses, reflections, and impairments in the fiber link.

a. OTDR (Optical Time Domain Reflectometer):

- Detects and locates faults, splices, and bends by sending pulses of light and analyzing reflections.
- Provides a graphical trace showing distances and attenuation along the fiber.

Fig. 2.1.5: OTDR

b. Optical Power Meter:

- Used with a light source to measure insertion losses.
- Ensures fibers are transmitting within required power ranges.

Fig. 2.1.6: Optical Power Meter

c. OSA (Optical Spectrum Analyzer):

- Measures wavelength accuracy, channel spacing, and signal-to-noise ratio in WDM systems.
- Essential for DWDM/CWDM network testing.

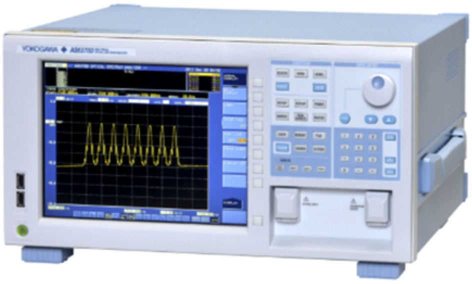


Fig. 2.1.7: OSA (Optical Spectrum Analyzer)

d. CD Analyzer (Chromatic Dispersion Analyzer):

- Evaluates pulse spreading due to wavelength dispersion, critical for high-speed long-distance links.

Fig.2.1.8: CD Analyzer

e. PMD Analyzer (Polarization Mode Dispersion Analyzer):

- Detects delays between polarization modes in the fiber, ensuring signal integrity in modern networks.

Fig. 2.1.9: PMD Analyzer

2.1.6 Advanced Splicing Tools (Automated Splicers, Robotic Arms, Cleavers, Inspection Tools)

Modern fiber splicing requires advanced tools that deliver precision, speed, and consistency.

a. Automated Fusion Splicers:

- Align fibers using image processing and arc fusion technology.
- Deliver low splice loss (<0.05 dB) with minimal human error.

b. Robotic Arms:

- Aid in positioning and holding fibers accurately during splicing.
- Enhance speed and repeatability in mass splicing operations.

c. Smart Cleavers:

- Provide precision end-face preparation with automated blade rotation and lifespan monitoring.
- Ensure flat, perpendicular cuts essential for high-quality splices.

d. Inspection Tools:

- Integrated cameras and software detect alignment and fiber defects before splicing.

Advantages of Advanced Tools:

- Reduce splice rejection rates.
- Increase splicing speed and efficiency.
- Maintain higher quality in high-capacity networks.

2.1.7 Calibration and Maintenance of Splicing and Testing Equipment

Calibration ensures the accuracy and reliability of splicing and testing equipment. Without proper calibration, measurement errors and splice failures can occur.

Calibration Guidelines:

- **Fusion Splicers:** Regularly calibrate arc power and fiber alignment systems.
- **OTDR and Power Meters:** Verify calibration with reference standards before field deployment.
- **Inspection Tools:** Clean and calibrate optical lenses to maintain precision.

Maintenance Practices:

1. Clean V-grooves, electrodes, and fiber clamps of splicers regularly.
2. Replace worn electrodes after the recommended number of splices.
3. Store equipment in shock-proof, dust-proof cases.
4. Perform periodic firmware updates to ensure compatibility with evolving standards.

2.1.8 Repair, Replacement, and Upgradation of Fiber Splicing Tools

Fiber splicing tools undergo wear and tear due to extensive usage in field and lab environments. Timely repair and upgradation enhance their performance and lifespan.

Repair Practices:

- Identify faulty components (electrodes, clamps, cleaver blades) and replace them immediately.
- Use only manufacturer-approved spare parts.

Replacement Guidelines:

- Replace consumable parts (electrodes, cleaver blades, sleeves) as per the manufacturer's lifecycle recommendation.
- Replace equipment when calibration and repairs no longer restore performance accuracy.

Upgradation Needs:

- Upgrade to automated and robotic splicers for large-scale operations.
- Replace traditional OTDRs with high-resolution, multi-wavelength OTDRs.
- Upgrade inspection tools with AI-based detection for improved fault recognition.

Outcome:

Ensures network reliability, minimizes downtime, and supports the deployment of next-generation fiber optic networks.

Notes

UNIT 2.2: Optical Fiber Fundamentals and Advanced Preparation Techniques

Unit Objectives

By the end of this unit, the participants will be able to:

1. Explain the structure, types, and materials of optical fibers, including core, cladding, and jacket properties, as well as the optical properties like attenuation, dispersion, and wavelength.
2. Discuss the basic physics of light transmission in optical fibers and how it relates to signal performance.
3. Explain the advanced characteristics of optical fibers and the features/functions of advanced splicing machines and testing equipment.
4. Describe the regulatory compliance practices for optical fiber installation and maintenance, and how they affect network planning and design.
6. Discuss the role of AI-powered tools for fault detection, predictive maintenance, and optimization in fiber networks.
7. Discuss the integration of splicing tasks with IoT-enabled smart network management systems and the principles of cloud-based systems for remote monitoring, reporting, and troubleshooting.
8. Demonstrate how to locate and identify fibers for splicing using automated mapping tools and network plans, while checking for physical damage with advanced inspection tools.
9. Show how to prepare optical fibers for splicing by removing jackets, cleaning cores with automated systems, and securing cables within bend radius and stress limits.
10. Demonstrate how to perform micro and nano fiber splicing using specialized tools and document splicing details digitally.

2.2.1 Specifications and Properties of Fibre Optic Cable

Optical fibre cables are highly sophisticated transmission mediums designed to carry light signals over long distances with minimal loss. To ensure their performance and reliability, fibre optic cables are evaluated based on their structural composition, materials, optical properties, and mechanical specifications.

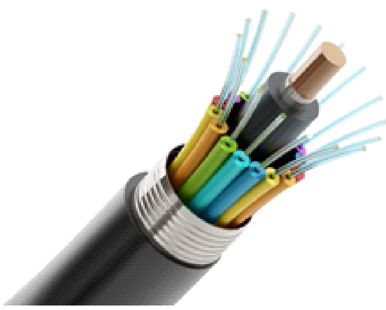


Fig. 2.2.1: Optical fibre cable

A. Structure and Materials of Optical Fibers

An optical fibre consists of three essential parts:

1. **Core**
   - The central region that transmits light signals.
   - Composed of ultra-pure silica glass doped with materials such as germanium to modify its refractive index.
   - Diameter: typically 8–10 µm for single-mode fibres and 50–62.5 µm for multi-mode fibres.
2. **Cladding**
   - Surrounds the core and has a slightly lower refractive index to facilitate total internal reflection (TIR), which keeps the light confined within the core.
   - Standard diameter: 125 µm.
   - Made from doped silica with fluorine or other elements.
3. **Jacket/Coating**
   - The outer protective layer made of polymers such as PVC, polyethylene, or Kevlar reinforcements.
   - Provides mechanical strength, abrasion resistance, and environmental protection.

B. Optical Properties of Optical Fibers

1. **Attenuation**
   - Loss of signal power during transmission.
   - Caused by scattering, absorption, and bending.
   - Measured in dB/km; typical values are 0.35 dB/km at 1310 nm and 0.20 dB/km at 1550 nm.

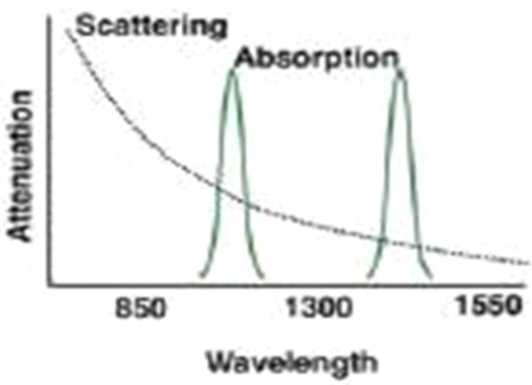


Fig. 2.2.2: Cable attenuation factors

2. **Dispersion**
   - Broadening of light pulses as they travel through the fibre, which can limit bandwidth.

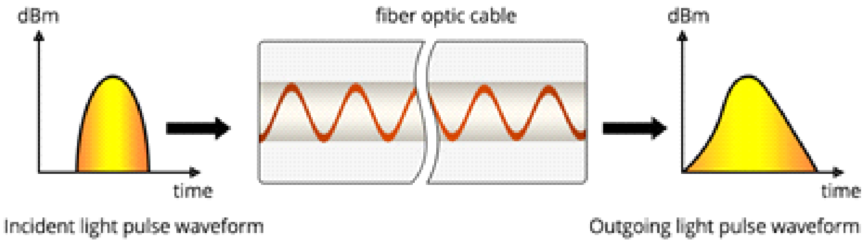


Fig. 2.2.3: Optical Fibre Dispersion

- Two major forms:
  - **Chromatic dispersion:** caused by different wavelengths traveling at different speeds.
  - **Polarization Mode Dispersion (PMD):** due to asymmetries in the fibre.

3. Wavelength Windows

- Optical fibres are designed to operate efficiently at specific wavelengths with minimum attenuation:
  - **850 nm (first window – multimode applications)**
  - **1310 nm (second window – single-mode, minimal dispersion)**
  - **1550 nm (third window – single-mode, lowest attenuation)**

C. Mechanical Specifications of Fibre Optic Cables

1. Tensile Strength

- Protects the cable from damage due to pulling forces during installation.
- **Short-term load:** Applied during installation, e.g., while pulling the cable through ducts.
- **Long-term (operating) load:** The cable should withstand light, continuous pressure in its installed state.
- Tensile strength depends on cable design and materials, as specified in the datasheet.

2. Bend Radius

- Defines the minimum radius the cable can be bent without causing excessive optical loss or physical damage.
- Two parameters are considered:
  - **Installation bend radius:** Minimum bend radius during installation when the cable is under stress.
  - **Long-term bend radius:** The bend radius allowed after installation.
- Bending cables over sharp corners can result in microbending and macrobending losses.

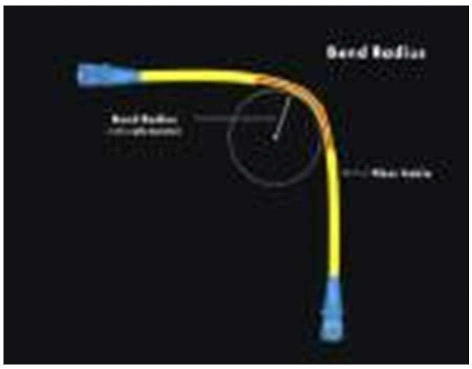


Fig. 2.2.4: Bend Radius

3. Crush and Impact Resistance

- Determines the cable's ability to resist external pressure and loads.
- **Testing procedure:** The cable is crushed between two plates while optical loss is measured.
- Important during installation in ducts and trays, especially when sharing space with heavy power cables.
- Key precautions:
  - Avoid crossing or stacking cables.
  - Prevent movement of already-installed cables to avoid micro-cracks or attenuation.

Comparison of Structures:

Parameter	Loose Tube	Tight Buffer	Breakout
Bend Radius	Larger	Smaller	Larger
Diameter	Larger	Smaller	Larger
Tensile Strength (Install)	Higher	Lower	Higher
Impact Resistance	Lower	Higher	Higher
Crush Resistance	Lower	Higher	Higher
Attenuation Change (Low Temp.)	Lower	Higher	Higher

4. Attenuation and Cable Losses

- Excessive crush or improper bending increases attenuation.
- Attenuation levels must remain within customer-defined thresholds.
- Factors influencing attenuation:
  - Fibre impurities.
  - Microbending and macrobending.
  - Environmental stress (temperature, moisture, vibration).

5. Fibre Optic Cable Continuity

Send a light signal into the cable using a continuity tester. While you're doing this, look at the other end of the cable closely. If the light is detectable in the fibre's core, there are no breaks in the fibre, and your cable is fit for use.

- Ensures light transmission from source to receiver is uninterrupted.
- Measured using a **light source and power meter** or a **Visual Fault Locator (VFL)**.
- Used to detect breaks, poor splices, or defective connectors.

Fig. 2.2.5: Fibre Optic Cable Continuity Tester

2.2.2 Factors Affecting OFC

There are two types of factors which affect the OFC, viz., natural and man-made.

Natural external factors		External cables					Internal cables	
		Trunk, junction and distribution					Customer premises	Central office
		Aerial	Buried	Duet	Tunnel	Under water	Building	
Temperature change	B	Cable sheath contraction with core thrusting out					–	–
	A	Increase of optical loss due to high and low temperature						
Very low temperature	B	Embrittlement of cable sheath under low temperature			–	–	–	–
	A	Crushing due to ice formation					–	–
Wind	B	Excess strain due to wind pressure	–	–	–	–	–	–
	A	Periodical excess strain due to cable dancing	–	–	–	–	–	–
Salt water	B	Corrosion of metal catenary	Corrosion of armour	–	–	Corrosion of armour	–	–
Rain and hot spring	B	Corrosion of metal catenary	Corrosion due to hot springs			–	–	–
Snow and ice	A	Sheath degradation, crushing and excess strain due to snow and ice	–	–	–	Sheath degradation and crushing due to ice	–	–
Water and moisture	A	Increase in optical loss due to water penetration. Decrease of strength of fibre					–	–
Sunshine	B	Degradation of sheath by UV rays	–	–	–	–	–	–
Lightning	B	Crushing damage due to lightning and haz-ards to personnel					–	–
Earthquakes and ship. ground subsidence and falling stones	B	Sheath deg-radation and impulsive excess strain due to falling stones	Cutting of cables due to ground movements		–	–	–	–
Condition of soil	B	–	Corrosion of armour	–	–	–	–	–
Rodents, birds and insects	B	Sheath damage due to birds, rodents and insects		–	–	–	–	–
Hydrogen	A	Increase in optical loss due to hydrogen					–	–
Water flow	B	–	–	–	–	Cable damage	–	–
Mould growth	B	–	–	Sheath damage	–	–	Sheath damage	–
A. Particular consideration for optical fibre cables.								
B. Intrinsic consideration for outside plant								

Table 2.2.1 Natural Factors

Man-made factors		External cables					Internal cables	
		Trunk, junction and distribution					Customer premises	Central office
		Aerial	Buried	Duet	Tunnel	Under water	Building	
Factory smoke and air pollution	B	Corrosion of metal	–	–	–	–	–	–
	B	Chemical attack on sheath	–	–	–	–	–	–
Traffic (cars, trucks)	B	–	Damage to cable sheath and joints due to creep. Transient optical loss due to vibration of fibres		–	–	–	–
Induced voltage (AC traction systems, power lines)	B	Damage to cable and hazards to personnel			–	–	–	–
DC current	B	–	Electrolytic corrosion	–	–	–	–	–
Petroleum gas leakage	B	–	Sheath degradation due to chemical attack	–	–	–	–	–
Fire	B	Sheath (and cable core) burning	–	–	Sheath (and cable core) burning	–	Sheath (and cable core) burning	
Nuclear radiation	B	Under consideration					–	–
Hydrogen	A	Increase in optical loss due to hydrogen					–	–
Installation practices	B	Cutting or breaking of the cables					–	–
	A/B	B-Strain due pulling-in for installation			A-Strain due pulling-in for installation		–	–
		–	–	–	A-Bending at pulley for installation			
	A/B	B-Bending & pulley for installation	B-Bending and squeezing due to burying machine		A-Bending at curve in duct	–	–	–
A Particular consideration for optical fibre cables								
B. Intrinsic consideration for outside plant								

Table 2.2.2 Man-made Factors

Man-made factors		External cables					Internal cables	
		Trunk, junction and distribution					Customer premises	Central office
		Aerial	Buried	Duet	Tunnel	Under water	Building	
Factory smoke and air pollution	B	Corrosion of metal	–	–	–	–	–	–
	B	Chemical attack on sheath	–	–	–	–	–	–
Traffic (cars, trucks)	B	–	Damage to cable sheath and joints due to creep. Transient optical loss due to vibration of fibres		–	–	–	–
Induced voltage (AC traction systems, power lines)	B	Damage to cable and hazards to personnel			–	–	–	–
DC current	B	–	Electrolytic corrosion	–	–	–	–	–
Petroleum gas leakage	B	–	Sheath degradation due to chemical attack	–	–	–	–	–
Fire	B	Sheath (and cable core) burning	–	–	Sheath (and cable core) burning	–	Sheath (and cable core) burning	
Nuclear radiation	B	Under consideration					–	–
Hydrogen	A	Increase in optical loss due to hydrogen					–	–
Installation practices	B	Cutting or breaking of the cables					–	–
	A/B	B-Strain due pulling-in for installation			A-Strain due pulling-in for installation		–	–
		–	–	–	A-Bending at pulley for installation			
	A/B	B-Bending & pulley for installation	B-Bending and squeezing due to burying machine		A-Bending at curve in duct	–	–	–
A Particular consideration for optical fibre cables								
B. Intrinsic consideration for outside plant								

Table 2.2.3 Mechanical Factors

2.2.3 Factors Affecting Choosing of Cables

Let us understand how to choose cables on the basis of various factors that affect the cable performance:

Mechanical and environmental factors	Coated optical fibres	Cable core	Strength member	Water blocking materials	Sheath materials
Residual fibre strain	A	A	A	–	B
Impulsive fibre strain	A	A	–	–	A
Fibre macro-bending	A	A	B	–	A
Fibre microbend-ing	A	A	B	B	B
Water	A	A	–	A	A
Moisture	B	–	–	–	A
Hydrogen	B	B	B	B	B
Lightning	–	–	A	B	A
Nuclear radiation	Under consideration				
A. Primary factor to be considered B. Secondary factor to be considered					

Table: 2.2.4: Considerable factors for choosing cables

2.2.4 Physics of Light Transmission in Optical Fibersa

Optical fibers rely on the fundamental physics of light to transmit information over long distances with minimal loss. The guiding principle behind their function is **Total Internal Reflection (TIR)**, supported by the design of the fiber core and cladding. The efficiency of light transmission depends on multiple factors, including modes of propagation, numerical aperture, scattering phenomena, and nonlinear effects.

i. Principle of Total Internal Reflection (TIR)

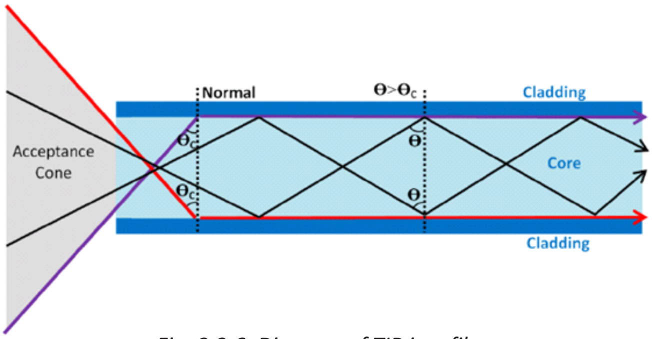


Fig. 2.2.6: Diagram of TIR in a fiber

When light passes from a denser medium (core, refractive index n_1) to a rarer medium (cladding, refractive index n_2), it bends away from the normal. If the incident angle exceeds the **critical angle (θc)**, the light is completely reflected back into the core.

- **Critical angle formula:**

θc=sin−1(n2n1)\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)θc=sin−1(n1n2)

- **Condition for TIR:**

n1>n2andθ>θcn_1 > n_2 \quad \text{and} \quad \theta > \theta_cn1>n2andθ>θc

- **Result:** Light is confined within the fiber core, bouncing along its length with negligible loss, forming the basis for optical communication.

Example: If core refractive index is 1.48 and cladding is 1.46,

θc=sin−1(1.461.48)≈80.3∘\theta_c = \sin^{-1}\left(\frac{1.46}{1.48}\right) ≈ 80.3^\circθc=sin−1(1.481.46)≈80.3∘

Thus, any light entering the fiber at an angle greater than 80.3° relative to the normal will be trapped inside.

ii. Modes of Propagation in Optical Fibers

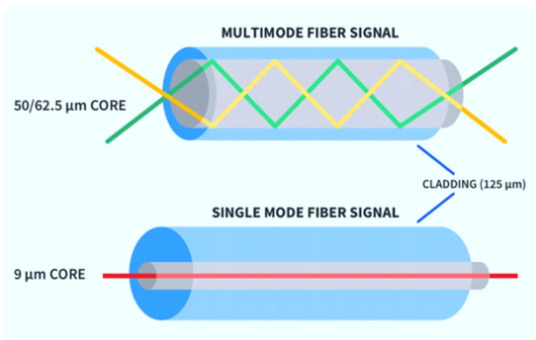


Fig. 2.2.7: Modes of Propagation in Optical Fibers

(a) Single-Mode Fibers (SMF):

- Core diameter: ~8–10 µm
- Wavelength range: 1310 nm and 1550 nm
- Supports only **one propagation path** for light.
- Advantage: **Low attenuation (0.2 dB/km at 1550 nm)** and **high bandwidth (>10 Tbps with DWDM)**.
- Application: Long-distance telecommunication, submarine cables, 5G backbone networks.

(b) Multi-Mode Fibers (MMF):

- Core diameter: 50 µm or 62.5 µm
- Supports **multiple light rays** (modes) propagating simultaneously.
- Disadvantage: Modal dispersion (different paths lead to different arrival times, causing pulse broadening).
- Application: Short-distance LANs, data centers, and campus networks.

Note: The **V-number (normalized frequency parameter)** decides if a fiber is single-mode or multi-mode:

V=2πaλn12−n22V = \frac{2\pi a}{\lambda} \sqrt{n_1^2 - n_2^2}V=λ2πan12−n22

- If **V < 2.405 → Single-mode fiber**
- If **V > 2.405 → Multi-mode fiber**

iii. Signal Performance Factors

(a) Numerical Aperture (NA):

Defines the **light-gathering ability** of the fiber.

NA=n12−n22NA = \sqrt{n_1^2 - n_2^2}NA=n12−n22

- Higher NA → More light accepted, but increased dispersion.
- Lower NA → Less dispersion, better for long-distance communication.

Example: If $n_1 = 1.48$ and $n_2 = 1.46$,

NA=1.482−1.462=0.242NA = \sqrt{1.48^2 - 1.46^2} = 0.242NA=1.482−1.462=0.242

Acceptance angle = $\sin^{-1}(NA) \approx 14°$.

b) Scattering Losses

- **Rayleigh Scattering:** Dominant in silica fibers, caused by microscopic density fluctuations in the glass.
  - Proportional to λ^{-4} (shorter wavelengths scatter more).
  - Explains why fibers perform best at 1310 nm and 1550 nm (lower scattering).
- **Mie Scattering:** Caused by impurities or structural defects.

Result: Scattering limits transmission distance and increases attenuation.

(c) Absorption Losses

- Due to impurities like OH^- ions in glass.
- Water peaks occur near 1383 nm (modern fibers suppress this).

2.2.5 Regulatory Compliance Practices in Fiber Networks

i. Standards and Guidelines

Compliance with international and national standards is critical to ensure **interoperability, performance, safety, and reliability** of fiber-optic networks. Some key standards include:

- **TIA/EIA-568 (Telecommunications Industry Association / Electronic Industries Alliance)**
  - Defines **structured cabling systems** for commercial buildings.
  - Covers **cable types, connector types, performance benchmarks, installation guidelines, and testing procedures**.
  - Ensures consistent quality and compatibility across vendors.
- **ITU-T Standards (International Telecommunication Union – Telecommunication Standardization Sector)**
  - **G.652**: Defines **standard single-mode fiber (SMF)** with low attenuation, widely used in long-haul and metro networks.
  - **G.655**: Non-zero dispersion-shifted fiber (NZDSF), optimized for **dense wavelength division multiplexing (DWDM)** to minimize nonlinear effects.
  - **G.657**: Bend-insensitive fibers, suitable for **FTTx (Fiber-to-the-x)** deployments in compact and high-density environments.
- **ISO/IEC 11801**
  - International standard for **generic cabling for customer premises**.
  - Defines structured cabling for data centers, enterprise networks, and telecommunication rooms.
  - Ensures global interoperability and vendor-neutral deployment.
- **National Standards** (where applicable)
  - Examples: **BS EN 50173 (Europe)**, **ANSI standards (USA)**, and **TEC/BSNL standards (India)** for local compliance.

ii. Installation Practices

Following **regulatory installation practices** reduces failures, maintains safety, and prolongs network life:

- **Minimum Bend Radius Compliance**
  - Fibers must not be bent below their specified radius (typically **20x the cable diameter** when under tension, **10x** when not).
  - Prevents **microbending and macrobending losses**, which degrade signal performance.
- **Fire Safety Regulations**
  - Use of **plenum-rated (OFNP), riser-rated (OFNR), and LSZH (Low-Smoke Zero-Halogen)** cables depending on building code requirements.
  - Ensures safety in case of fire, reducing toxic smoke and hazardous emissions.
- **Labeling and Documentation**
  - Each cable, patch panel, and termination point must be **clearly labeled** according to standards.
  - Proper documentation helps in **troubleshooting, upgrades, and audits**.
  - Reduces downtime during maintenance and prevents costly errors.

- **Testing and Certification**
    - Post-installation testing using **OTDR (Optical Time-Domain Reflectometer)**, **insertion loss tests**, and **end-to-end certification**.
    - Ensures that the installation meets both manufacturer and regulatory standards.

iii. Impact on Network Planning

Adhering to compliance and standards directly influences the success of fiber-optic network projects:

- **Avoidance of Costly Re-installations**
    - Non-compliant cabling often fails certification and needs to be reinstalled, leading to significant **time and financial losses**.
- **Ensures Interoperability Across Vendors**
    - Standard-compliant cables, connectors, and transceivers guarantee that **multi-vendor equipment works seamlessly together**.
- **Improves Network Safety & Reliability**
    - Compliance ensures networks can **withstand environmental stress, fire hazards, and long-term operational wear**.
    - Increases **MTBF (Mean Time Between Failures)** and lowers operational expenses.
- **Future-Proofing**
    - Standard-compliant cabling supports **upgrades (e.g., from 1G to 10G/40G/100G Ethernet)** without the need for massive infrastructure replacement.

2.2.6 Handling Optical Fibre Cable

Handling Process

Gentle handling is needed during OFC handling and installation, and even a little damage can cause performance reduction. In case of any damage, the OFC needs to be replaced to avoid damage, and OFC needs to be handled carefully.

Always wear a suitable safety Helmet, safety glasses with side shields, and protective gloves while handling OFC. Handle the fibre optic splinters similar to glass splinters. Never look directly through the end of fibre cables till you ensure that there is no light source at the other end.

Cable Unloading

- Precautions to be taken while cable loading/unloading:
- Must not drop the cable drum on the floor, which can cause damage to the cable
- Roll the drum from the truck onto the receiving platform, and this needs to be done at the same height.
- A forklift can act as an alternative to unloading the drums from the truck.
- Do not lose control while rolling the drums
- Before handling the next drum, roll the drum away from the boom of the ramp.

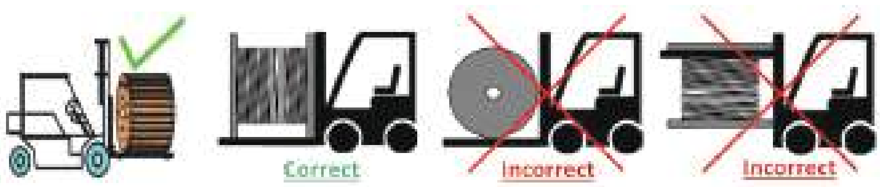


Fig. 2.2.8: Unloading OFC

Cable Unwrapping

- Precautions need to be taken while cable unwrapping:
- Drum wrappers help to protect the OFC from damage.
- All drums are wrapped by wooden laggings to avoid damage.
- Removing the whole wrapping from the drum before cable installation is not advised.

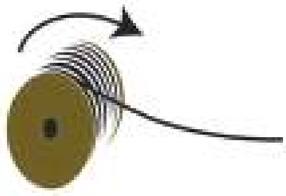


Fig. 2.2.9: Unwrapping OFC

Cable Storage

- Store the drums in an upright position. Any other position can cause winding defects.
- If the storage place is small, then store the completely wrapped drums on their flanges' edge.

Fig. 2.2.10: Storing OFC

Environmental Storage Issues:

- Wooden storage also can have a negative impact on the OFC. Wood materials can get degraded due to environmental factors, which can cause the degradation of wood.

Important Way to Address the issue

- Degradation can be avoided with in-house storage.
- In the case of storing outside, the wood storage needs to be hard, and no moist material should come in contact.
- Wood also needs to be prevented from insects which can cause degradation.
- It is important to close the drum using polythene to avoid moisture getting into the drum.

2.2.7 Pre Installation - Drum Inspection

One must check on the following points:

- It is important to test the drum for attenuation and damage before taking them to a site.
- Make sure that flanges are stencilled.
- Examine the above points of drum inspection before dispatching.
- Always have a backup drum.

Cable Inspection

Have a check on the following:

- In case of less clarification, remove the cable and examine it thoroughly.
- Have a check on the optical continuity, attenuation and length of the OFC.
- In case of any damage, contact the supplier for the replacement. 37 Optical Fibre
- Find the inner and outer end of the OFC.
- Remove pulling grips & end caps at both ends.
- Check the type and quantity of the cable
- Inspect the damage.
- Check on the manufacturer's default mistakes.

Opening the drum, check on the following:

- Drums need to be closed with wooden material with the help of an aluminium or iron strip.
- Remove the beans carefully to avoid damage to the cable.
- Use a strip cutter to cut.
- Place the hammer in between the iron strip cut and press the hammer at the opposite end so that the bean comes out of the flange.
- Carefully remove the beans without damaging the cable.
- Bend the straight nails with caution to avoid injury.
- Take out the thermal wrapper given over the cable. Preparation of Drum
- To prevent the cable from rubbing the drum flanges, arrange the cable drum in the pulling direction.
- To avoid the cable coming in contact with the floor, pay -out the cable from the top of the drum.

Preparation of Drum:

- To prevent the cable from rubbing the drum flanges, arrange the cable drum in the pulling direction.
- To avoid the cable coming in contact with the floor, pay -out the cable from the top of the drum.

Fig. 2.2.11: Preparing the drum

2.2.8 Colour Coding of Optical Fibre Cable

Colour codes are used in OFC to identify fibres, cables and connectors.

Cable Jacket Colours

Coloured outer jackets and/or prints may be used on Premises Distribution Cable, Premises Interconnect Cable or Interconnect Cord, or Premises Breakout Cable to identify the classification and fibre sizes of the fibre. Outdoor cables are generally black for protection against UV light, and markings are printed on the cable.

When coloured jackets are used to identify the type of fibre in cable containing only one fibre type, the colours shall be as indicated in the below table.

Other colours may be used, providing that the print on the outer jacket identifies fibre classifications. Such colours should be as agreed upon between manufacturer and user.

Unless otherwise specified, the outer jacket of the premises cable containing more than one fibre type shall use a printed legend to identify the quantities and types of fibres within the cable. The below table shows the preferred nomenclature for the various fibre types, for example, "12 Fibre, 8 x 50/125, 4 x SM." Some manufacturers use black as the jacket colour for hybrid or composite cables.

When the print on the outer jacket of the premises cable is used to identify the types and classifications of the fibre, the nomenclature of the below table is preferred for the various fibre types.

Fiber Type	Color Code		
	Non-military Applica-tions(3)	Military Applications	Suggested Print Nomenclature
Multimode (50/125) (OM2)	Orange	Orange	OM2, 50/125
Multimode (50/125) (850 nm Laser optimized) (OM3, OM4)	Aqua	Undefined	OM3 or OM4, 850 LO 50/125
Multimode (50/125) (850 nm Laser optimized) (OM5)	Lime Green	Undefined	OM5
Multimode (62.5/125) (OM1)	Orange	Slate	OM1, 62.5/125
Multimode (100/140)	Orange	Green	100/140
Single-mode (OS1, OS1a, OS2)	Yellow	Yellow	OS1, OS1a, OS2, SM/NZDS, SM
Polarization Maintaining Single-mode	Blue	Undefined	Undefined (2)

Table 2.2.5: Cable jacket colours

Connector Colour Codes

Since the earliest days of fibre optics, orange, black or grey was multi-mode and yellow single mode. However, the arrival of metallic connectors like the FC and ST made connector colour coding difficult, so coloured strain relief boots were often used.

Fiber type	Connector Body	Strain Relief/ Mating Adapter
62.5/125	Beige	Beige
50/125 OM2	Black	Black
50/125 laser optimized (OM3, OM4)	Aqua	Aqua
OM5 wideband fiber	Lime Green	Lime Green
Singlemode	Blue	Blue
Singlemode APC	Green	Green

Table 2.2.6 Connector Colour Codes

Fibre Colour Codes

Individual fibres will be colour coded for identification inside the cable or inside each tube in a loose tube cable. Fibres follow the convention created for telephone wires, except fibres are identified individually, not in pairs.

Buffer tubes follow the same colour sequence up to 12 tubes, then tubes 13-24 will repeat the colours with a black stripe (black will have a yellow stripe), tubes 25-36 will follow the same colour with an orange stripe, 37-48 use a green stripe, following the same colour code sequence for the stripe. Tubes containing more than 12 fibres will use binder tape to separate fibres into groups. Ribbon cables follow this colour sequence also.

For splicing, colour fibres are generally spliced to ensure continuity of colour codes throughout a cable run.

Fiber Number	Color
1	Blue
2	Orange
3	Green
4	Brown
5	Slate
6	White
7	Red
8	Black
9	Yellow
10	Violet
11	Rose
12	Aqua

Table 2.2.7: Fibre Colour Codes

2.2.9 Role of AI-Powered Tools in Fiber Networks

Artificial Intelligence (AI) is playing a transformative role in the planning, operation, and maintenance of modern fiber optic communication networks. With the rising demand for high-speed internet, video streaming, IoT connectivity, and 5G/6G infrastructure, manual network monitoring is no longer sufficient. AI-powered tools enable proactive fault management, intelligent traffic routing, and long-term sustainability of fiber networks.

1. Fault Detection and Diagnostics

- **Automated OTDR (Optical Time-Domain Reflectometer) Analysis:** Traditionally, technicians manually interpret OTDR traces to locate fiber breaks, splices, or bends. AI algorithms now process OTDR data in real time to detect anomalies such as micro-bends, connector faults, and splice losses.
- **Pattern Recognition:** Machine learning models classify common fault signatures, reducing false alarms and improving accuracy in fault localization.
- **Remote Fault Management:** Cloud-based AI systems allow central monitoring centers to detect and isolate faults across large fiber deployments without requiring on-site inspections.

Example: Google's AI-enabled fiber monitoring platform can detect fiber cuts within seconds, minimizing downtime.

2. Predictive Maintenance

- **Historical Data Analysis:** AI systems analyze years of maintenance logs, temperature fluctuations, and vibration data to predict when and where fiber degradation is likely to occur.
- **Condition-Based Maintenance (CBM):** Instead of waiting for failures, predictive AI tools alert operators before signal quality deteriorates, enabling scheduled, cost-efficient maintenance.
- **Environmental Impact Modeling:** AI considers external factors such as soil movement, construction activities, or rodent interference to forecast risk-prone regions.

Example: Telecom providers use predictive analytics to anticipate signal loss in submarine cables before it impacts global connectivity.

3. Network Optimization

- **Dynamic Traffic Routing:** AI-powered Software-Defined Networking (SDN) controllers re-route traffic in real time to avoid congestion, reduce latency, and maintain Quality of Service (QoS).
- **Bandwidth Allocation:** AI dynamically allocates bandwidth across users and services, ensuring fairness and prioritizing critical applications (e.g., telemedicine, financial transactions).
- **Performance Enhancement:** Algorithms optimize wavelength allocation in Dense Wavelength Division Multiplexing (DWDM) systems to maximize spectrum efficiency.

Example: AI-driven load balancing in FTTH (Fiber-to-the-Home) networks ensures uninterrupted video streaming even during peak hours.

4. Energy-Efficient Operations

- **Smart Power Management:** AI reduces energy consumption by powering down underutilized equipment during low-traffic periods.
- **Traffic Pattern Forecasting:** By analyzing long-term usage trends, AI predicts peak/off-peak cycles and adjusts network resources accordingly.
- **Sustainability Integration:** AI aligns fiber network operations with global green energy goals, reducing carbon footprints in telecom infrastructure.

Example: European operators use AI to cut energy use in optical amplifiers by up to 20% without affecting network reliability.

Key Benefits of AI in Fiber Networks:

- Faster fault detection → Reduced downtime.
- Predictive maintenance → Lower repair costs.
- Dynamic optimization → Higher efficiency and customer satisfaction.
- Energy-efficient operations → Sustainability and cost savings.

2.2.10 IoT and Cloud-Integrated Fiber Network Management

1. IoT-Enabled Smart Networks

The integration of **Internet of Things (IoT)** devices in fiber optic infrastructure enables real-time monitoring and intelligent management.

- **Smart Sensors at Critical Points**: IoT sensors are deployed at splicing points, junction boxes, and distribution hubs to measure temperature, humidity, vibration, and stress on fiber cables. This helps detect early signs of strain or possible faults before they impact service.
- **Automated Disturbance Detection**: Any unusual activity—such as excessive vibration due to construction work or sudden temperature fluctuations—triggers automated alerts sent to the control center or mobile devices of network engineers.
- **Edge-Level Intelligence**: Many IoT devices now have built-in processing power, enabling them to perform localized analytics (e.g., filtering noise vs. real issues) before sending data upstream.

Outcome: Faster detection of physical risks, improved preventive maintenance, and extended fiber lifespan.

2. Cloud-Based Remote Monitoring

Modern fiber networks increasingly rely on cloud platforms for monitoring, configuration, and control.

- **Real-Time Dashboards**: Network operators can access live status dashboards from any location, giving them visibility into latency, packet loss, fiber utilization, and fault locations.
- **Remote Firmware and Configuration Management**: Cloud platforms allow technicians to push firmware upgrades, configuration changes, or security patches remotely to Optical Line Terminals (OLTs), Optical Network Terminals (ONTs), and switches—reducing the need for on-site visits.
- **Cloud Analytics for Troubleshooting**: Historical logs and AI-enabled cloud analytics help identify recurring issues, such as fiber sections prone to micro-bends or frequent signal losses, thereby improving **root cause analysis**.

Outcome: Lower operational costs, quicker service restoration, and efficient resource utilization.

3. Advantages of IoT + Cloud Integration

The combined use of IoT and cloud platforms in fiber optic network management offers multiple strategic benefits:

- **Centralized Management**: Network administrators can monitor thousands of fiber connections from a single interface, ensuring consistency and simplifying troubleshooting.
- **Scalability**: As demand grows, cloud platforms can scale elastically to accommodate more IoT devices, more users, and larger data volumes—without expensive hardware upgrades.
- **Proactive Maintenance & Downtime Reduction**: With IoT sensors feeding real-time data into the cloud, predictive maintenance becomes possible. This ensures early fault detection, reducing downtime and preventing large-scale service disruptions.

2.2.11 Micro and Nano Fiber Splicing

As optical communication systems evolve toward higher capacities, smaller form factors, and greater precision, the demand for micro and nano-scale fiber splicing has increased. These advanced techniques are primarily used in high-density data centers, photonic integrated circuits (PICs), biomedical applications, and specialized sensing networks. Unlike conventional splicing, micro and nano splicing requires specialized tools, controlled environments, and digital documentation for traceability and optimization.

1. Specialized Tools for Micro and Nano Splicing

- **i. High-Precision Fusion Splicers**
  - Designed with sub-micron alignment accuracy.
  - Utilize **core-to-core active alignment** with auto-focus imaging systems.
- **ii. Nano-Positioning Stages**
  - Piezoelectric or robotic micro-positioners ensure controlled movement in nanometer ranges.
- **iii. Smart Cleavers**
  - Produce ultra-flat and angled cleaves with **cleave angle ≤ 0.3°**, essential for low-loss splicing.
- **iv. Optical Microscopes & Imaging Systems**
  - High-resolution digital microscopes monitor fiber alignment and splice arc discharge.
- **v. Environmental Control Chambers**
  - Maintain stable temperature, humidity, and dust-free conditions to prevent splice defects.

2. Splicing Procedure

- **i. Preparation**
  - Clean fibers using lint-free wipes and high-purity isopropyl alcohol.
  - Strip protective coatings with micro-strippers designed for fibers <125 µm.
- **ii. Cleaving**
  - Use a smart cleaver to achieve **precise cleave lengths and angles**.
  - Inspect cleave faces under a microscope before splicing.
- **iii. Alignment**
  - Place fibers on nano-positioning stages.
  - Activate **real-time auto-alignment software** to achieve core-to-core positioning.
- **iv. Fusion Process**
  - Apply controlled low-energy arc discharge or laser-based fusion.
  - Optimize splice parameters (arc duration, intensity) for minimal insertion loss (<0.05 dB).
- **v. Protection**
  - Use micro heat-shrink sleeves or UV-curable splice protectors.
  - For nano fibers, apply resin-based encapsulation to maintain mechanical strength.

3. Digital Documentation of Splicing

- **Automated Splicer Logs:** Record splice loss, cleave angle, arc parameters, and alignment images.
- **Cloud-Based Records:** Upload splice data to centralized systems for audit and compliance.
- **Graphical Reports:** Generate OTDR traces and loss graphs for each splice point.
- **Unique Splice IDs:** Assign barcodes or RFID tags to each splice for easy tracking.

4. Applications

- **Telecom Backbones:** Ensuring ultra-low-loss joints in submarine and long-haul systems.
- **Medical Devices:** Splicing nano-fibers in endoscopes and laser delivery systems.
- **Photonic Research:** Connecting microfibers to photonic chips with precision.
- **Defense & Aerospace:** Ruggedized nano splicing for harsh-environment sensors.

Notes

UNIT 2.3: Advanced Fiber Splicing and Network Integration

Unit Objectives

By the end of this unit, the participants will be able to:

1. Elucidate the different splicing techniques (mechanical, fusion, ribbon, twist, crimp, etc.), their applications, and best practices for minimizing splice loss and ensuring joint durability.
2. Describe the use of fiber pigtails, connectorized fiber, routing inside junction boxes, and the various fiber jointing techniques.
3. Discuss the techniques for splicing in challenging environments like outdoor, submarine, or underground networks, and how to mitigate environmental effects on fiber and splice joints.
4. Demonstrate how to install joint closures, splitters, and pigtails with weatherproofing, route connectorized fibers, and document compliance with network plans.
5. Describe the proper use of splice closures (heat-shrink vs. cold-shrink) and sealing techniques for weatherproofing in various environments.
6. Demonstrate how to identify fiber faults using OTDR, OFIs, robotic arms, and smart cleavers for maintenance in challenging environments.
7. Demonstrate how to coordinate with NOC for outage windows, perform fault inspections for microbends and environmental wear, clean fibers, replace damaged sections, re-splice fibers, and ensure proper weatherproofing of cables.
8. Demonstrate how to verify performance KPIs, generate automated reports for monitoring and compliance, and maintain documentation for network optimization.
9. Demonstrate how to operate fusion splicing machines with automation to minimize errors, and perform various splicing methods (mechanical, fusion, ribbon, etc.) for different applications.
10. Show how to ensure splice quality using real-time diagnostics, precision cleavers, and advanced imaging tools, while sealing splices with heat-shrink or cold-shrink closures for protection.
11. Elucidate the advanced fusion splicing process, including fiber preparation, splicing machine operation, and ribbon fiber splicing techniques.

2.3.1 Installing OFC

The actual installation process involves setting the cable, terminating it and then testing it. The following needs to be considered while installing an OFC:

- Always have the cable pulling plan.
- Make sure you have all the authorisation and permission documents.
- Make sure to have all the tools and devices while working.
- Make sure to share the plans with the installation team and stakeholders.
- It is a must for the installation team to know the access points and the splice locations.
- Once the network design gets completed, start the installation to make the operation communication system as per the design.
- The process of installation helps in choosing the contractor.
- The contractor needs to work with the customer during the installation project, which has the following stages:
    - o Designing the plan
    - o Installing
    - o Testing
    - o Troubleshooting
    - o Documenting
    - o Restoring

Steps of OFC Installation

- Once the plan has been made for the installation, the physical work starts based on the design
- The installation process turns the plan into an operating communication system
- It is important for the contractor to have experience in the process of installation

Following are the steps for installing an optical Fibre cable:

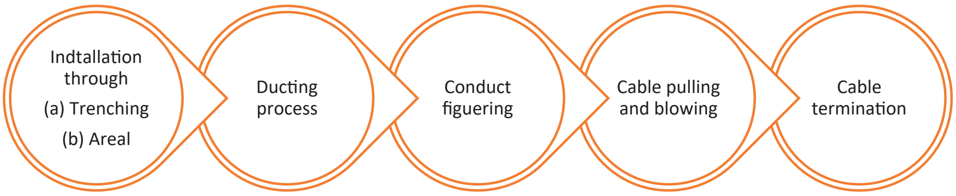


Fig. 2.3.1: OFC cable installation steps

Step 1 (a): Trenching

Trenching is a construction technique that involves digging a narrow channel in the ground for the installation, maintenance, or inspection of cables. This process takes time, and it is effective for short-distance applications

While digging the channel, obstructions are examined to avoid cable damage.

Trenching is often carried out in urban & suburban areas. It can be done using a machine or by manual methods. An appropriate width for a trench is 4 inches and a hole 20cm from the stand. The cable left for future splicing must have protective caps that must be sealed.

Always use warning tape to protect the OFC to prevent future digging. Mostly OFCs are buried under 3-4 feet to reduce the digging at the same place.

Process of Trenching:

- Dig a trench and bury the duct. It is about 4 inch plastic pipe and could have a pre-installed innerduct with a pulling tape to support the cable pulling process.
- For streets and sidewalks, directional boring is done to avoid surface digging.
- In dielectric cables and ducts, conductive marker tapes may be placed over the duct to facilitate future cable location and to warn anyone digging near the cable.

Fig. 2.3.2: Micro-trenching for optical fibre laying

- Trenching is generally done by using machinery.
  Some regions may need the trench to be dug by hand but to maintain speed; hand digging should only be done if essential.
- A trench should not be wider or deeper than what is required to maintain optimum trenching speed. The recommended minimum practical width of a trench is 4".

Precautions for Trenching:

- The cable should be buried at an undisturbed place.
- Ensure the cable is properly placed in the roadside trench and that future extending must not affect it.
- Take care of the route, which should not be affected by any natural process like drainage or other causes.
- Keep a label to indicate to others that the OFC has been installed.

Fig. 2.3.3: Trenching precautions

Step 1 (b): Aerial Cabling

An aerial cable is an insulated cable containing required fibres for a telecommunication line, which is suspended between utility poles or electricity pylons.

The aerial installation also requires specialised equipment and procedure. It is used in long-duration operations.

Cables in aerial runs can be damaged by the wind, ice, stretch and pull. Hence, external support is a must during installation. This process uses a strong wire which is used to secure the cable.

The cable is lashed for protection. The lashers are chosen with the use of lashing tools. It is an armour buffered tube fibre cable.

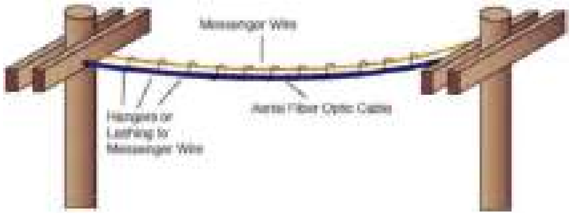


Fig. 2.3.4: Aerial cable installation

Step 2: Ducting Process

Ducts (or conduits) offer a highly protective environment for fibre-optic cables. They are typically buried, and then the cables are air-blown, jetted, pulled or pushed into the duct.

The major advantage of this process is that an old cable can be removed and a new cable can be installed. It causes no damage to the surrounding.

Ducting can be done through a manual or a mechanical process. A duct is made up of PVC material and must be twice the diameter of an OFC. Ducts are coated with an inner lining to protect the OFC from rubbing.

Various colours of lining are available for identification purposes. The installer measures the length of the duct, and it needs to be accurate and placed in the proper position.

Fig. 2.3.5: Duct installation of OFC

Step 3: Conduct figuring

Figure 8'ing'

- Mark two adjacent circles on the floor of 1.5 to 2-meter diameter so that they make a figure eight.
- Place pulled the cable from a pole or a pay-out trailer on this mark to make several layers, one on top of another.
- A cardboard sheet could be placed over each layer.

- Long lengths of cables and the ones with more weight require to be un-drummed to create more than one
- figure eight coils. This will facilitate turning over such coils for pulling in another direction.
- Turning figure 8 loop needs at least three persons; one at the centre and one at each end of the circle.
- Control winding of the cable either with hands or with cable drum brake to avert free running or jerking of
- the cable.

Fig. 2.3.6: Figure 8'ing' of OFC

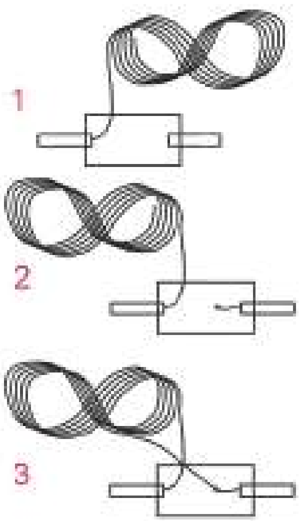


Fig. 2.3.7: Step-by-step process of Figure 8'ing' of OFC

Step 4: Cable Pulling & Blowing

Cable Pulling:

- Most organisations use cable connections for short distances and straight ways,
- which can be easily pulled with a hand. No equipment is needed.
- If the cable components are not locked, then the elongation in the jacket can occur, which can cause pullback of the cable.
- Equipment can be used to pull a cable with high mechanical force.
- Removing the jacket when pulling the cable using a pulling grip is important.
- It is essential to notice the pressure and force applied to the cable.
- It is necessary to use lubricants while pulling.

- It is very important to give only limited force while pulling.
- When using power in pulling, tension monitoring equipment should be used.
- Avoid twisting or bending during pulling
- For long runs, use two or more stages of pulling.
- Make sure enough cable is stored in the shape of 8.
- Initiate a pulling process in the middle location and then proceed in both directions.
- Rack the cable after pulling.
- The allowed pulling level is 3 feet/sec.

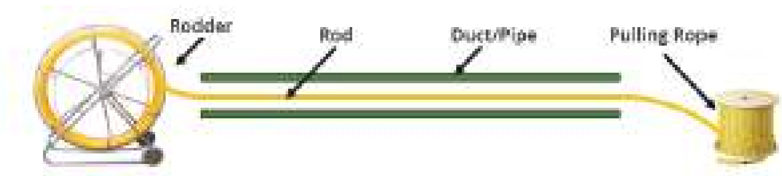


Fig. 2.3.8: Cable pulling

Cable Blowing:

The following steps need to be taken for cable blowing:

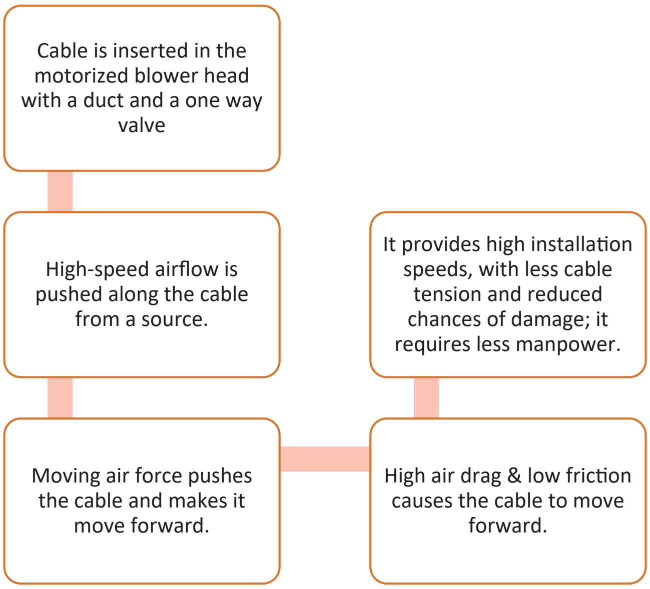


Fig. 2.3.9: Steps for cable blowing

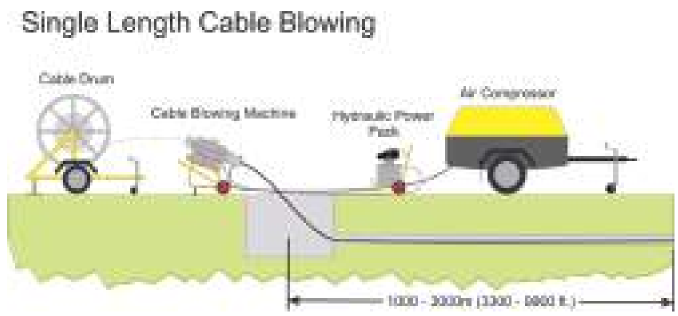


Fig. 2.3.10: Cable blowing process

Step 5: OFC Termination Method

There are 2 methods for terminating the fibre: The first is through the use of connectors that form a temporary joint, and the other is through splicing, which is actually connecting two bare fibre ends directly. The most common termination methods are:

- No-epoxy/no-polish
- Epoxy-and-polish
- Pigtail splicing

Steps to terminate OFC using fibre boot:

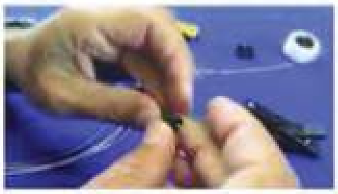
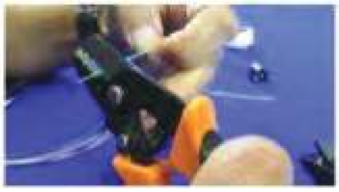
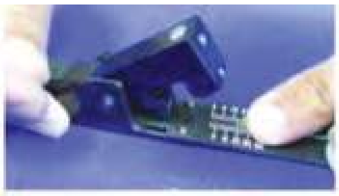
 Put on a fibre boot	 Measure 14 cm for striping as per specifications	 Strip the fibre using a wire stripper
 Use alcohol wipes to clean any residue	 Give the fibre a very slight bend	 Put the fibre in a cleaver holder at the 10.5 cm mark (as per specs) and cleave the fibre
 Put the fibre in the connector & squeeze the holder	 Slide the boot, and the connection is complete	

Fig. 2.3.11: Steps to terminate OFC using fibre boot

2.3.2 Fiber Splicing Techniques

Fiber splicing is the process of permanently or semi-permanently joining two optical fibers together to create a continuous optical path. It is a crucial skill in optical communication systems, ensuring low transmission loss and long-term durability of fiber optic networks. Splicing becomes necessary during cable installation, repair, or network expansion.

There are five major splicing techniques commonly employed in the industry:

1. **Mechanical Splicing**

Mechanical splicing involves the physical alignment of two optical fibers inside a mechanical fixture or sleeve that holds them in precise position. Instead of fusing the glass, it relies on mechanical pressure and index-matching gel to reduce signal loss.

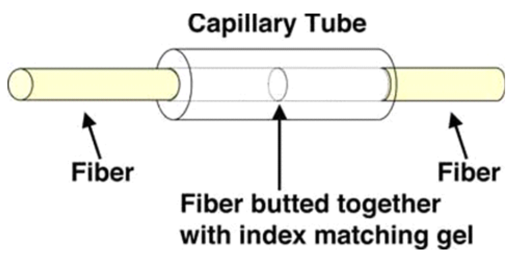


Fig. 2.3.12: Mechanical Splicing

Process:

1. Fibers are stripped and cleaned.
2. The fiber ends are cleaved with high precision.
3. The ends are aligned inside a mechanical splice unit.
4. An index-matching gel or adhesive is applied to reduce reflection and insertion loss.

Advantages:

- Fast and easy to perform.
- No special splicing machine required (cost-effective for small jobs).
- Useful for temporary or emergency repairs.

Limitations:

- Higher insertion loss (0.3–0.5 dB typical).
- Less durable in harsh environments.
- Long-term stability depends on gel and housing quality.

Applications:

- Emergency restoration work.
- Short-distance patching and testing.
- Networks where low cost is prioritized over long-term performance.

2. **Fusion Splicing**

Fusion splicing is the process of permanently joining two optical fibers by melting (fusing) their glass ends together using an electric arc or laser heat source.

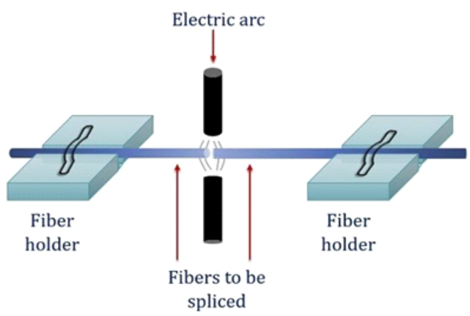


Fig.2.3.13: Fusion Splicing

Process:

1. Strip and clean the fiber coating.
2. Cleave the fiber ends with high accuracy.
3. Align fibers inside a fusion splicer (manual, semi-automatic, or automatic).
4. Use an electric arc to melt and fuse the ends.
5. Protect the splice with a heat-shrink sleeve.

Advantages:

- Lowest insertion loss (0.02–0.05 dB typical).
- Excellent return loss performance.
- Highly durable and reliable, suitable for all environments.

Limitations:

- Requires expensive fusion splicing machine.
- Skilled technicians are needed.
- Higher initial investment cost.

Applications:

- Long-haul telecommunication networks.
- Submarine and underground fiber optic cables.
- High-speed broadband and enterprise data centers.

3. Ribbon Splicing

Ribbon splicing is a specialized form of fusion splicing where an entire ribbon of 12–24 fibers is spliced simultaneously.

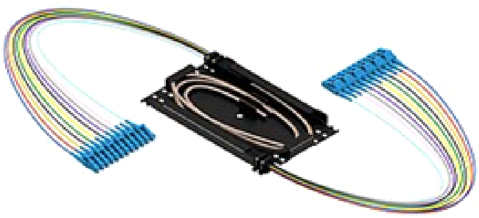


Fig. 2.3.14: Ribbon Splicing

Process:

1. Prepare ribbon fibers (strip and clean).
2. Align ribbons in a ribbon fusion splicer.
3. Fuse all fibers in one operation.
4. Protect using ribbon splice protectors.

Advantages:

- High efficiency: multiple fibers spliced at once.
- Consistent splice quality.
- Reduces overall splicing time in large projects.

Limitations:

- Requires specialized ribbon fusion splicer.
- Less flexibility for small-scale or single-fiber splicing.

Applications:

- Large-capacity backbone networks.
- Metropolitan and FTTH (Fiber-to-the-Home) deployments.
- Data center interconnections.

4. Twist Splicing

Twist splicing is a simple and low-cost method where two fibers are stripped, cleaved, and then twisted together to form a temporary joint.

Fig. 2.3.15: Twist Splicing

Process:

1. Strip and cleave fibers.
2. Align cores by twisting the ends together.
3. Apply protective gel or sleeve.

Advantages:

- No expensive equipment required.
- Quick and easy for temporary connections.

Limitations:

- Very high splice loss (>0.5 dB typical).
- Poor mechanical strength.
- Not suitable for long-term use.

Applications:

- Temporary testing setups.
- Emergency or provisional connections.

5. Crimp Splicing

Crimp splicing involves placing stripped fiber ends inside a crimp-type connector or sleeve, which is then compressed to hold fibers in alignment.

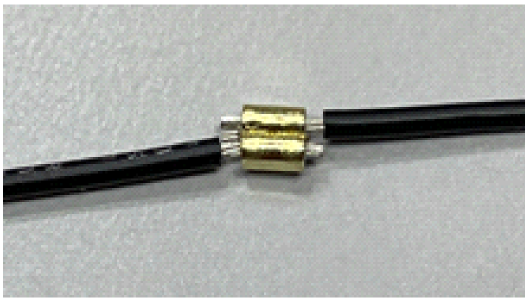


Fig. 2.3.16: Crimp Splicing

Process:

1. Strip and prepare fibers.
2. Insert into crimp connector housing.
3. Use crimping tool to secure alignment.
4. Optionally add adhesive for durability.

Advantages:

- Quick and simple method.
- Requires inexpensive crimping tools.
- Useful in connectorized fiber systems.

Limitations:

- Higher insertion loss compared to fusion splicing.
- Less durable than permanent methods.

Applications:

- Premises wiring and LAN systems.
- Connectorization for patch cords.
- Situations requiring easy re-termination.

Applications and Best Practices

Applications of Fiber Splicing:

- Repairing damaged fiber cables.
- Extending fiber links in network expansions.
- Integrating pigtails or patch cords for termination.
- Constructing backbone, metropolitan, and access networks.

Best Practices for Minimizing Splice Loss & Ensuring Durability:

1. **Precision Cleaving** – Use a high-quality cleaver to ensure flat, perpendicular fiber ends.
2. **Proper Alignment** – Ensure core alignment with mechanical holders or automatic fusion splicer.

3. **Cleanliness** – Always clean fibers with alcohol wipes; even microscopic dust increases splice loss.
4. **Use of Protection Sleeves** – Protect splices with heat-shrink sleeves or crimp-type protectors.
5. **Environmental Protection** – Seal joints inside closures, especially in outdoor/underground installations.
6. **Testing and Verification** – Use OTDR (Optical Time-Domain Reflectometer) and power meters to confirm low loss.
7. **Documentation** – Record splice points, test results, and network compliance for future reference.

2.3.3 Fiber Pigtails and Connectorization

1. Use of Fiber Pigtails

Fiber pigtails are short lengths of optical fiber, usually with a factory-terminated connector on one end and an unconnectorized bare fiber on the other end. They are widely used for splicing and connectorization in optical fiber networks.

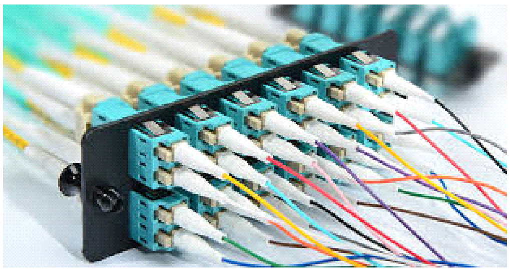


Fig. 2.3.17: Fiber Pigtails

- **Purpose**:
  - To provide a convenient method of connecting optical fibers to patch panels, equipment, or distribution frames.
  - To minimize insertion loss by using pre-polished connectors with controlled quality.
  - To enable easy repair and replacement of damaged connectors without disturbing the main fiber line.
- **Key Characteristics**:
  - Typically 1–2 meters in length.
  - Made of single-mode or multimode fiber depending on application.
  - Available with different connector types: SC, LC, ST, FC, MPO, etc.
- **Applications**:
  - Fiber to the Home (FTTH) connections.
  - Backbone to distribution point interconnections.
  - Equipment terminations (e.g., OLTs, switches, and routers).

2. Connectorized Fiber

Connectorized fibers are optical fibers terminated with standardized connectors at both ends. Unlike pigtails, which require splicing, connectorized fibers can be directly plugged into compatible ports or adapters.

- **Advantages**:
  - Quick installation without fusion splicing.
  - Standardized designs ensure compatibility across equipment vendors.
  - Allow easy disconnection and reconnection during testing, upgrades, or maintenance.
- **Limitations**:
  - Higher cost compared to splicing.
  - Slightly higher insertion loss than spliced connections.
  - Require careful handling to prevent dust or contamination at connector interfaces.
- **Common Connector Types**:
  - **SC (Subscriber Connector):** Push-pull, used in telecom and data networks.
  - **LC (Lucent Connector):** Compact form factor, widely used in high-density patch panels.
  - **ST (Straight Tip):** Bayonet-style, common in legacy networks.
  - **MPO/MTP:** Multi-fiber connectors for parallel optics in data centers.

3. Routing Inside Junction Boxes

Junction boxes, fiber enclosures, or distribution boxes house spliced and connectorized fibers in an organized, protected manner. Proper routing ensures minimal stress and reduces the chance of signal degradation.

- **Routing Guidelines**:
  - Maintain minimum bend radius (10× fiber diameter for static, 20× for dynamic).
  - Use cable ties, guides, or fiber management trays to secure fibers.
  - Avoid sharp bends and kinks that may cause microbending losses.
  - Separate spliced fibers and connectorized fibers in designated trays.
  - Ensure dust- and moisture-proof sealing in outdoor or underground boxes.
- **Best Practices**:
  - Label all fibers, connectors, and trays for easier maintenance.
  - Keep splice protectors properly aligned in splice holders.
  - Use color codes for fibers (as per ITU-T or TIA standards).

4. Fiber Jointing Techniques

Fiber jointing techniques are methods used to connect two fibers together either permanently (splicing) or temporarily (connectorization).

- **Fusion Splicing with Pigtails**:
    - The bare end of a pigtail is fusion-spliced to the network fiber.
    - Provides low splice loss (<0.1 dB) and long-term reliability.
    - Commonly used at termination points where equipment is connected.
- **Mechanical Splicing with Pigtails**:
    - The pigtail is mechanically joined with the network fiber inside a splice protector.
    - Faster but slightly higher splice loss (0.2–0.5 dB).
    - Useful for emergency repairs.
- **Direct Connectorization**:
    - Fibers are terminated directly with field-installable connectors (e.g., fast connectors).
    - Eliminates the need for splicing.
    - Suitable for drop connections in FTTH networks.
- **Hybrid Approaches**:
    - A combination of fusion splicing and connectorization is used in large-scale installations.
    - Example: Splicing feeder fibers to pigtails inside ODFs (Optical Distribution Frames), then patching with connectorized jumpers to equipment

2.3.4 Testing and Closing Activities

After installation, splicing and termination of the optical fibre, it must be tested for the following:

- Continuity and polarity
- End-to-end insertion loss
- Troubleshoot problems, if any
- Ensure marking for identification of route for future maintenance and troubleshooting
- Ensure appropriate cable markings as per recommended guidelines
- Backfill and clear site from debris and other items

Fig. 2.3.18: Testing equipment

2.3.5 Splicing in Challenging Environments

Optical fiber splicing in controlled laboratory or indoor conditions is relatively straightforward. However, many installations are carried out in challenging environments such as outdoor networks, underground ducts, and submarine cables, where environmental factors can directly impact splice quality and long-term reliability. Specialized techniques, protective measures, and equipment are therefore required to ensure minimum signal loss and maximum durability.

1. Outdoor Splicing

Outdoor fiber installations are exposed to temperature fluctuations, moisture, dust, and mechanical stresses. These conditions can affect splice joints if not properly addressed.

Challenges:

- Temperature variations leading to fiber expansion/contraction.
- UV radiation degrading protective coatings.
- Moisture ingress causing signal loss and corrosion of metallic components.
- Dust and dirt contamination during splicing.

Mitigation Techniques:

- Use of outdoor-rated splice closures with weatherproof gaskets and IP-rated sealing.
- Application of heat-shrink splice protectors with adhesive linings for moisture blocking.
- Performing splicing inside portable environmental splice enclosures or tents to avoid dust and wind interference.
- Ensuring the use of UV-resistant cables and protective jackets in exposed areas.

2. Underground Splicing

Underground networks often pass through ducts or are directly buried in soil, where they are subject to moisture, soil pressure, rodent activity, and chemical exposure.

Challenges:

- Water seepage and flooding inside manholes or ducts.
- Chemical attack from soil or groundwater.
- Physical damage due to excavation or rodent bites.

Mitigation Techniques:

- Splicing is carried out inside sealed joint closures placed within manholes or hand-holes.
- Use of gel-filled or water-blocking closures to prevent water ingress.
- Rodent-resistant cable jackets or armoured cables are used in susceptible areas.
- Proper drainage systems in manholes to prevent standing water around closures.
- Routine inspection and OTDR testing to detect early signs of water-induced splice loss.

3. Submarine Splicing

Submarine cable networks represent the most challenging environment for splicing, as they must withstand high water pressure, saltwater corrosion, and complete inaccessibility after deployment.

Challenges:

- High hydrostatic pressure at ocean depths.
- Saltwater corrosion of metallic components.
- Extreme difficulty of repairing splices after laying.
- Need for ultra-low splice loss to support long-haul transmission.

Mitigation Techniques:

- Use of special submarine splice housings designed to withstand deep-sea pressure.
- Encapsulation of splices in hermetically sealed, water-tight closures filled with protective gel.
- Use of fusion splicing only, as mechanical splicing is unreliable in submarine conditions.
- Splicing carried out in controlled shipboard laboratories just before cable laying, under stringent cleanliness standards.
- Extensive pre-deployment testing with OTDR to ensure splice loss is within sub-0.05 dB range.

4. General Best Practices Across Challenging Environments

1. **Environmental Protection:** Always enclose splices in closures rated for the specific environment (IP-68 for underwater/underground, UV-resistant for outdoor).
2. **Mechanical Stability:** Ensure proper strain relief so that tensile forces are not transmitted to splice joints.
3. **Cleanliness:** Use lint-free wipes and alcohol for fiber cleaning; even microscopic dust can cause high splice loss.
4. **Redundancy Planning:** Install spare fiber loops (service coils) at splice points to facilitate future maintenance or re-splicing.
5. **Documentation:** Record environmental conditions, closure types, splice loss values, and locations for future reference.

2.3.6 Installation of Joint Closures, Splitters, and Pigtails with Weatherproofing

After splicing and connectorization, optical fibers must be protected against mechanical damage, environmental stress, and moisture ingress. This is achieved through the proper use of joint closures, optical splitters, and pigtails, along with careful routing and documentation.

1. Installation of Joint Closures

A joint closure is a protective housing that accommodates fiber splices, connectors, and slack storage. Closures can be underground, aerial, wall-mounted, or submarine-rated, depending on the deployment.

Steps for Installation:

1. **Preparation:**
    - Clean the cable sheath and remove the outer jacket.
    - Expose buffer tubes and prepare fibers for splicing.
    - Leave extra service loops for future maintenance.
2. **Splicing and Placement:**
    - Splice fibers using fusion or mechanical methods.
    - Place splices in designated **splice trays** inside the closure.
    - Use **heat-shrink or cold-shrink splice protectors**.
3. **Sealing and Protection:**
    - Apply weatherproof gaskets or gel seals.
    - Close the housing securely to prevent moisture and dust ingress (IP-65/IP-68 rated).
    - Label the closure with ID tags for future identification.

Best Practices:

- Maintain **minimum bend radius** when routing fibers into closures.
- Use **strain-relief clamps** to prevent pulling forces on splices.
- Always test splices before final sealing.

2. Installation of Optical Splitters

Optical splitters are passive devices that divide a single input signal into multiple outputs, commonly used in FTTH (Fiber-to-the-Home) networks.

Steps for Installation:

1. **Mounting:** Place the splitter inside a fiber distribution box (FDB) or optical distribution frame (ODF).
2. **Connectorization:** Connect input and output ports with pre-terminated fibers or pigtails.
3. **Routing:** Securely route fibers into trays, ensuring bend radius compliance.
4. **Protection:** Seal the distribution box to protect against **dust, humidity, and UV exposure**.

Best Practices:

- Label all input/output ports for easy troubleshooting.
- Use color-coded patch cords as per ITU-T or TIA standards.
- Avoid sharp bends or over-tightened cable ties.

3. Installation of Pigtails

Fiber pigtails are short lengths of optical fiber with a pre-installed connector on one end, used for easy connection to active equipment.

Steps for Installation:

1. **Preparation:** Strip and clean the field fiber.
2. **Splicing:** Fusion splice the bare end of the pigtail to the network fiber.
3. **Protection:** Place the splice inside a splice tray and secure with splice protectors.
4. **Routing:** Route the connectorized end to an ODF or patch panel port.
5. **Finishing:** Ensure connectors are cleaned with isopropyl alcohol and lint-free wipes before insertion.

4. Weatherproofing Techniques

- **Heat-Shrink Closures:** Heat-shrink sleeves with adhesive provide tight, waterproof seals around splices.
- **Cold-Shrink Closures:** Pre-stretched rubber sleeves that contract onto the cable without heat.
- **Gel-Filled Closures:** Gel material blocks moisture and offers vibration damping.
- **IP-Rated Boxes:** Use IP-65/IP-68 enclosures for underground or outdoor installations.

Environmental Considerations:

- Use **UV-resistant housings** for outdoor installations.
- Apply **corrosion-resistant metallic parts** for coastal or submarine networks.
- Always ensure proper drainage and sealing in manholes for underground closures.

5. Routing of Connectorized Fibers

Proper routing ensures low signal loss and ease of maintenance.

Guidelines:

- Maintain bend radius (≥10× fiber diameter static, ≥20× dynamic).
- Use **fiber guides, trays, and tie-downs** for organization.
- Keep **pigtails and connectorized jumpers** separate from spliced fibers.
- Label each connectorized fiber at both ends (ODF and equipment side).

6. Documentation and Compliance with Network Plans

Accurate documentation is essential for network optimization, fault management, and regulatory compliance.

Documentation Steps:

1. Record splice points, closure IDs, splitter locations, and pigtail terminations.
2. Maintain OTDR test results and insertion loss values for each joint.
3. Update as-built network drawings with closure, splitter, and ODF layouts.
4. Assign unique fiber ID codes (color-coded and numbered).
5. Submit reports for compliance with industry standards (ITU-T G.652, TIA/EIA-568).

Best Practices:

- Keep both digital and physical records for future maintenance.
- Follow customer-approved network plans for closure/splitter locations.
- Use automated reporting tools where possible for KPI tracking.

2.3.7 Proper Use of Splice Closures and Sealing Techniques for Weatherproofing

In optical fiber networks, splice closures play a vital role in protecting spliced fibers and ensuring long-term reliability. They provide mechanical protection, environmental sealing, and strain relief, thereby preventing external elements such as moisture, dust, or mechanical stress from affecting the spliced fibers. Depending on the environment—outdoor, underground, or aerial—different closure types and sealing techniques are used to achieve weatherproofing.

Types of Splice Closures

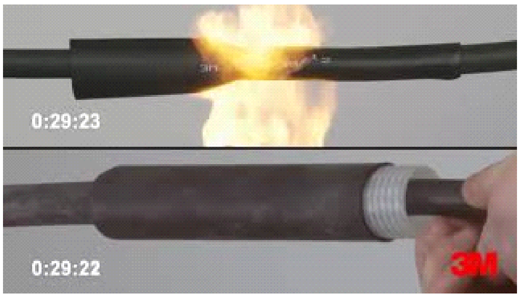


Fig. 2.3.19: Heat-Shrink and Cold Shrink Splice Closures

1. **Heat-Shrink Splice Closures**: These closures use a heat-shrinkable sleeve or tubing that is shrunk tightly over the cable entry points and splice area using a heat gun or torch.
   - **Applications**: Widely used in outdoor and underground networks where strong sealing against moisture and dust is required.
   - **Advantages**:
     - Provides a robust, long-lasting seal.
     - Resistant to water ingress and soil pressure.
     - Excellent protection in buried or submerged installations.
   - **Limitations**:
     - Requires heat application tools, making installation slower.
     - Not easily reusable once shrunk.

2. **Cold-Shrink Splice Closures**: These closures use pre-stretched elastic sleeves that contract to form a tight seal once the supporting core is removed.

   - **Applications**: Preferred in aerial and pole-mounted networks, or areas with limited access to heat tools.
   - **Advantages**:
     - Quick and easy installation.
     - No need for heat source, reducing fire hazards.
     - Reusable in certain designs.
   - **Limitations**:
     - Less robust in deep underground or submerged applications compared to heat-shrink.
     - Susceptible to UV degradation if not properly shielded.

Sealing Techniques for Weatherproofing

- **Gasket Sealing**: Rubber or polymer gaskets are compressed inside closure housings to prevent water and dust ingress. Common in dome-type closures.
- **Gel Sealing**: Gel-filled compartments envelop the fiber splices, providing a waterproof barrier. Effective in outdoor and underground use.
- **Heat-Sealing**: Heat-applied sleeves and adhesives bond to the cable sheath, ensuring a watertight connection in high-moisture environments.
- **Cold-Seal (Compression/Elastic)**: Mechanical compression seals or elastic sleeves secure around cable ports without the need for heat. Suitable for aerial and indoor networks.

Environment-Specific Applications

- **Underground Networks**:
  - Heat-shrink closures with gel sealing are preferred due to constant soil pressure and water exposure.
  - Dome-type closures are commonly used for better pressure resistance.
- **Aerial Installations**:
  - Cold-shrink closures or mechanical sealed closures are ideal for faster installation and minimal tool requirements.
  - UV-resistant materials are necessary to prevent degradation.
- **Submarine Applications**:
  - Heat-shrink closures with multiple protective layers and pressure-resistant sealing are mandatory.
  - Gel or resin encapsulation is often used to withstand saltwater corrosion.

2.3.8 Identifying Fiber Faults in Challenging Environments

Efficient fiber optic maintenance relies on the accurate identification of faults such as breaks, bends, high loss points, or connector defects. In outdoor, submarine, and underground installations, environmental and operational challenges require advanced tools and techniques for reliable diagnostics.

1. Optical Time Domain Reflectometer (OTDR)

- **Purpose:** Locates faults such as breaks, splices, bends, and connector losses along the length of the fiber.
- **Procedure:**
    1. Connect the OTDR to one end of the fiber.
    2. Launch a test pulse of light and observe backscattered and reflected signals.
    3. Analyze the trace to determine the exact distance to the fault.
- **Advantages:**
    - Detects faults up to several kilometers away.
    - Pinpoints precise fault locations, enabling targeted repair.
- **Application in Challenging Environments:**
    - Essential for submarine and long-haul underground networks where manual inspection is impractical.

2. Optical Fiber Identifier (OFI)

- **Purpose:** Detects live signals, traffic direction, and continuity in fibers without disrupting service.
- **Procedure:**
    1. Place the OFI clamp on the fiber.
    2. Monitor signal leakage and measure the optical power.
    3. Verify continuity and confirm signal presence without disconnection.
- **Advantages:**
    - Non-intrusive testing.
    - Minimizes downtime in operational networks.
- **Application in Challenging Environments:**
    - Ideal for outdoor or underground networks where service continuity is critical.

3. Robotic Arms in Submarine and Hazardous Areas

- **Purpose:** Perform splicing, fault localization, and repairs in environments inaccessible to humans.
- **Procedure:**
    1. Deploy remotely operated vehicles (ROVs) equipped with robotic arms.
    2. Retrieve damaged submarine cables or underground fibers.
    3. Conduct precision splicing and re-deployment in protective enclosures.
- **Advantages:**
    - Allows repair in deep-sea and high-risk environments.
    - Reduces human exposure to hazards.

- **Application:**
  - Submarine cable repair ships use robotic arms for locating and lifting faulty cable segments.

4. **Smart Cleavers**

- **Purpose:** Provide high-precision fiber end-face preparation before splicing.
- **Procedure:**
  1. Insert stripped and cleaned fiber into the smart cleaver.
  2. Automatically measure, align, and cleave to the required angle (typically 90°).
  3. Transfer prepared fibers for fusion splicing.
- **Advantages:**
  - Ensures consistent low-loss splicing.
  - Detects improper fiber conditions (scratches, chips, or incorrect length).
- **Application in Challenging Environments:**
  - Minimizes repeat splicing attempts in outdoor or underground conditions, improving efficiency.

2.3.9 Coordinated Fiber Fault Management and Restoration Procedures

1. Coordination with the Network Operations Center (NOC)

- **Outage Window Planning:**
  - Before beginning maintenance or repair activities, the field team must **obtain approval from the NOC** for an outage window.
  - This ensures service impact is minimized and alternate routing or redundancy is activated.
  - The NOC provides live monitoring and confirms the exact segment or node to be isolated.
- **Documentation Exchange:**
  - Engineers must log the **time, location, scope, and expected duration** of the intervention.
  - The NOC must be informed once the fiber section is restored for service validation.

2. Performing Fault Inspections

- **Microbends and Macrobends:**
  - Inspect fibers visually and with OTDR traces for high-attenuation points.
  - Microbends (minute fiber distortions) typically occur from improper cable routing, tight ties, or crushed protective tubing.
  - Macrobends result from excessive bend radius beyond the manufacturer's tolerance.

- **Environmental Wear:**
  - Outdoor fibers must be checked for UV degradation, rodent damage, water ingress, or corrosion of protective closures.
  - Underground fibers must be inspected for moisture seepage, soil pressure, and joint stress.
  - Submarine fibers require monitoring of cable armor, pressure seals, and external sheath integrity.

3. Cleaning Fibers

- **Dry Cleaning:** Use lint-free wipes and specialized fiber cleaning pens to remove dust and micro-contaminants.
- **Wet Cleaning:** Apply isopropyl alcohol or fiber cleaning solutions with wipes for oily or sticky residues.
- **Endface Inspection:** Use a fiber microscope to confirm the endface is free from scratches, dust, and contaminants.

4. Replacing Damaged Sections and Re-Splicing

- **Damaged Section Removal:**
  - Cut out compromised sections of fiber cable using precision shears.
  - Ensure sufficient slack is available for re-termination.
- **Splicing Procedure:**
  - Strip the protective coating and clean the fiber.
  - Cleave the fiber using a **high-precision or smart cleaver**.
  - Align and fuse fibers with a **fusion splicer** for minimal loss.
  - Verify splice quality using OTDR or a power meter.

5. Weatherproofing and Sealing

- **Splice Closures:**
  - Use **heat-shrink closures** with adhesive lining in high-moisture areas (outdoor, underground).
  - Use **cold-shrink closures** where heat application is impractical or for faster deployment.
- **Sealing Techniques:**
  - Apply **gel-filled gaskets, sealing tapes, and mechanical locks** to prevent dust, water, and rodent ingress.
  - Ensure **IP-rated enclosures** for harsh environments.
- **Final Compliance Check:**
  - Confirm routing and splicing match the **network plan and schematics**.
  - Document the restored section with splice loss, location details, and updated cable records.

2.3.10 Verifying Performance KPIs, Automated Reporting, and Documentation for Network Optimization

1. Verification of Performance KPIs

Key Performance Indicators (KPIs) are essential for evaluating the operational efficiency and reliability of an optical fiber network. After installation, splicing, or maintenance activities, field technicians must validate the following:

- **Optical Power Levels:** Measured at endpoints using Optical Power Meters (OPM) to confirm transmission meets design specifications.
- **Insertion Loss (IL):** Verified with an Optical Loss Test Set (OLTS) to ensure splice and connector losses remain within acceptable thresholds (<0.3 dB per splice).
- **Return Loss (RL):** Tested to minimize back reflections that may impair transmission, especially in high-speed or DWDM systems.
- **Bit Error Rate (BER):** Evaluated through network testing equipment to confirm signal integrity.
- **Latency and Jitter:** Particularly important for real-time applications (e.g., VoIP, 5G backhaul).

Procedure:

1. Connect test equipment at both ends of the fiber span.
2. Compare live readings with network design baselines.
3. Record deviations and escalate anomalies for corrective measures.

2. Generating Automated Reports

Automation in network monitoring ensures real-time visibility of system performance:

- **Use of NMS (Network Management Systems):** Integrated platforms collect data from OTDRs, OPMs, and inline monitoring devices.
- **Automated Alarms and Thresholds:** Systems trigger alerts when KPIs exceed pre-defined limits.
- **Reporting Tools:** Generate daily/weekly/monthly reports covering uptime, traffic loads, and incident summaries.
- **Compliance Monitoring:** Automated reporting formats align with regulatory requirements (e.g., TRAI, ITU-T, or organizational SLAs).

Procedure:

1. Configure monitoring equipment to feed data into the central NMS.
2. Define thresholds for KPI deviations.
3. Schedule automated reports for operational review and compliance checks.

3. Documentation for Network Optimization

Accurate documentation is vital for troubleshooting, audits, and future expansion:

- **Splice Records:** Include splice losses, joint closure IDs, and GPS locations.
- **Cable Routing Maps:** Updated after every installation or rerouting.

- **Maintenance Logs:** Document cleaning, re-splicing, and component replacement dates.
- **Performance Baseline Records:** Maintain initial KPIs as a reference point for trend analysis.
- **Optimization Records:** Use documented KPIs to identify areas of persistent degradation and recommend network upgrades (e.g., improved closures, better fiber types, or route diversions).

Procedure:

1. Update as-built documentation post-installation and repair.
2. Archive all automated reports in the central knowledge repository.
3. Cross-check logs with NOC records to ensure consistency.
4. Use long-term documentation for predictive maintenance and optimization.

2.3.11 Reporting and Documentation

Documentation is essential for reference and troubleshooting purposes. It is important to document the fibre designing and installation process of the fibre cable plant.

Major advantages of documentation:

- Proper planning and making a layout reduces the time and cost.
- The materials are pre-determined to avoid confusion.
- It leaves a path to update the existing plan.
- It speeds up the cable pulling and installation.
- It helps to track the process and to identify the mistakes.
- The testing documentation can help show the installation's accuracy and faults.
- It helps for routing the path easily.

Information record about the cable, splice, fibre, paths, etc. is a must and should be captured as follows:

Cable

- Manufacturer, type, ID, length & drum number
- Splice and terminalon points (at distance markers)

Fibre

Fibre type and size, splice and connectionon data, losses

Connection

- Types (splice or connectors and types), fibres connected, losses

Paths

- Where the link path goes in every cable

Storage

- A database that contains component, connetion, and test data can be used to store most of the data.

Fig. 2.3.20: Information record

Record storage importance:

- It is very important to store the records in a safe way.
- Always have more than one copy of the document.
- Spare copy is important while storing on a computer or paper.
- Make sure only an authorised person gets access to the records.

Content and update of the report:
Always make sure to capture the information given below:

- Pending issues
- Challenges
- Faults & serviceability
- NOC for cable integration
- Final closure of the job

2.3.12 Steps of Preparing the Cable for Splicing for New Installation

The first step is to mark the cable before putting it into the splicer. If you miss doing it, you will need to check which fibres go to which module, which is very inconvenient and confusing.

For marking, the below-shown paper labels are used, which usually come with the splice closure.

Fig. 2.3.21: Markings for optical fibre splicing

The next step is measuring fibres in the fibre optic cable organiser. However, when fusing a large number of optical fibres, they should still be measured, and the easiest way should be chosen: in a circle, without tricky complex loops and channel transitions. With most cable organisers, it is necessary to measure out: there will be serious problems when laying fibres unless you measure fibres in advance and think about how they will fit into the cable organiser after fusion.

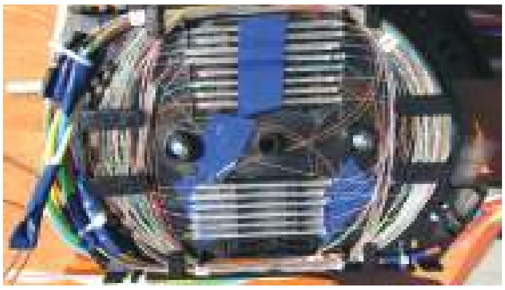


Fig. 2.3.22: Fibre optic cable organiser

When two optical fibres that are to be fused are in the modules, which enter the cable organiser "counter" each other, it is enough to measure each of them by simply laying several (usually two) turns and cutting off above the cradle, where it is planned to lay the FSPK (Fusion Splice Protection Kit) of this splice.

Use a protective sleeve (FSKP)

These are disposable composite heat shrink sleeve that protects the splice. These generally come with fibre optic splice closures/ODFs, and are inexpensive.

It consists of 3 parts: a tube of readily fusible plastic inside, a plastic tube with shrink properties outside, and iron wire for rigidity. The protective sleeves are put on one of the fibres to be fused (prior to fusion); when fibres are successfully fused, it is pushed to the splice site so that to completely hide the glass, and a slightly stretched fibre is put into the fusion splicer oven for about 20-40 seconds. The inner plastic melts inside the oven, wrapping the fused fibres, and the outer plastic is heat shrunk.

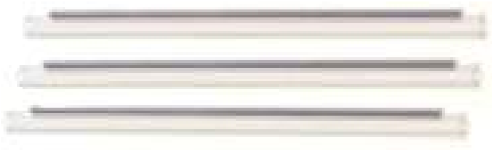


Fig. 2.3.23: Fusion Splice Protection Kit

When you cut the fibre optic with a fibre optic stripper, it is important to do everything slowly and carefully so that not to break optical fibres. If you cut the optical fibre too much, then after the fibre has been cleaved, the remaining tip will be too short, and the fibre container rollers may not be able to trap it. If you cut too little, then this cleaved tip will be so long that it won't fit in the fibre container and will stick out of it. Both options are undesirable.

However, suppose 2-3 splices in a row are unsuccessful. In that case, the fibre becomes short, and to save fibre, it is necessary to cut it short deliberately, just enough for the cleaver to cleave. The remaining tip can be put into the fibre container with tweezers or insulated with electrical tape.

Exercise

A. Short Questions:

1. Explain the difference between fusion splicing and mechanical splicing in terms of reliability and insertion loss.
2. List at least three key splicing consumables and explain their role in protecting fiber splices.
3. Describe how AI-powered tools can enhance fault detection and predictive maintenance in fiber networks.
4. Explain the purpose of routing connectorized fibers in junction boxes and maintaining proper bend radius.
5. What are the steps to prepare an optical fiber for splicing, and why is each step important?

B. Fill in the Blanks:

1. The protective sleeve used in fusion splicing is called a ___________.
2. ___________ splicing uses an electric arc to permanently join two optical fibers.
3. The minimum bend radius must be maintained to prevent ___________ losses or damage to fibers.
4. OTDR stands for ___________.
5. Heat-shrink and cold-shrink closures are primarily used to provide ___________ protection for fiber splices.

C. Multiple Choice Questions (MCQs):

1. Which of the following tools is used for precise cleaving of optical fibers before splicing?
   a. OTDR b. Smart cleaver
   c. Power meter d. Robotic arm
2. Heat-shrink and cold-shrink closures are primarily used for:
   a. Reducing signal loss in fiber cores b. Weatherproofing and protecting splices
   c. Measuring optical power d. Cleaning fiber ends
3. Which splicing technique provides the lowest insertion loss and highest long-term reliability?
   a. Mechanical splicing b. Fusion splicing
   c. Twist splicing d. Crimp splicing
4. In challenging environments like underground or submarine networks, which practice is essential for splice durability?
   a. Ignoring bend radius limits b. Using protective sleeves and closures
   c. Skipping pre-cleaning of fibers d. Using mechanical splicing exclusively
5. AI-enabled OTDR is used for:
   a. Splicing fibers manually b. Fault detection, loss measurement, and network diagnostics
   c. Routing fiber cables in junction boxes d. Sealing splices with heat-shrink sleeves

Notes

3. Testing and Recording Spliced Optical Fiber Performance

Unit 3.1 - Splice Protection, Testing, and Fault Mitigation

Unit 3.2 - Optical Fiber Testing, Documentation, and Predictive Maintenance

TEL/N6401

Key Learning Outcomes

By the end of this module, the participants will be able to:

1. Explain how advanced tools are used to test the effectiveness of a fiber splice.
2. Describe the process of recording test results for traceability and performance analysis in fiber splicing.

UNIT 3.1: Splice Protection, Testing, and Fault Mitigation

Unit Objectives

By the end of this unit, the participants will be able to:

1. Elucidate the techniques for sealing and protecting splice closures using heat shrinking and multi-diameter seals.
2. Determine the threshold values for optical losses and how to mitigate them effectively.
3. Discuss the risks associated with improper testing or splicing, including long-term impacts on network reliability.
4. Demonstrate how to use AI-enabled OTDR to analyze splice joints, diagnose faults, and ensure conformance to design specifications.
5. Show how to ensure optical losses (e.g., reflectance, return, insertion losses) remain within acceptable thresholds.
6. Demonstrate the process of sealing joint closures using heat shrinking, multi-diameter seals, or mechanical seals to protect against adverse environmental conditions.
7. Show how to strengthen splices using appropriate reinforcement materials like Fiber Reinforced Plastic (FRP).
8. Show how to properly place joints in the chamber and coil spare cables (loop) within the joint enclosure.

3.1.1 Splicing of OFC

It is a process of connecting two optical fibres permanently.

It is commonly used in long cable runs, which need more than one cable connection. This can connect different cables and can interlink various locations. It is used to terminate the single Fibres. It is commonly used in OSP applications because cables are pulled and terminated. There are two types of splicing:

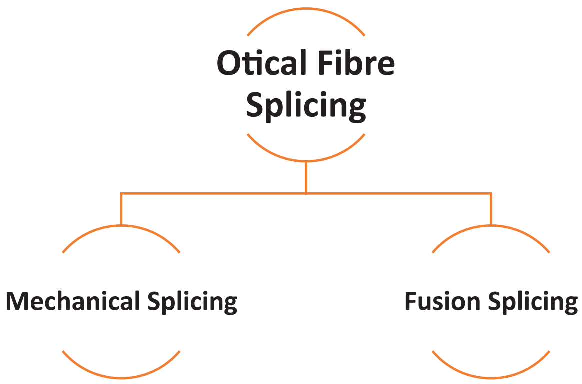


Fig. 3.1.1: Types of splicing of OFC

Why do we need to splice optical fibres?

Following are the reasons for carrying out 'Splicing':

- It is used when a long fibre cable is required
- It is used to connect two or more small fibre cables, which are bound to make a single connection using small cables
- Cut-off fibre links may need splicing to join them
- It is used in terminating the optical fibre to network and fibre panels

3.1.2 Types of Optical Fibre Splicing

As already discussed above, optical fibre splicing is of two types – Mechanical and Fusion. Let us discuss both types in detail.

Mechanical Splicing

This splicing technique comprises the precise alignment of two fibre optic cables, held in place by a self-contained assembly rather than a permanent bond. A mechanical splice is used to hold two fibre optic cables, allowing the light to pass through seamlessly, with a typical loss of around 10% (or 0.3 dB).

In this process, you must use an alignment device along with an index matching gel. The gel used must have a similar refractive index to enhance the light transmission across the joint, with minimal back reflection.

Steps to perform mechanical splicing:

Step 1: Prepare the fibres

The first step is to precisely strip the fibres of their protective coatings, jackets, tubes and strength.

Fig. 3.1.2: Preparing fibre for mechanical splicing

Step 2: Cleave the fibres

After stripping, the next step is to break your cables using a fibre cleaver. Now, use the cleaver to create a small, clean cut on the cables with ends perpendicular to the fibre axis.

Step 3: Mechanical joining of fibres

In this step, you just have to place the fibre accurately ends together in the mechanical splice unit. The index matching gel inside the equipment will do the rest, like linking the light to the ends of your cables. If using an older unit, you may have to use epoxy instead of the index matching gel to align the fibres correctly.

Step 4: Securing united fibres

Once done with these steps, place the fibres in a splice tray and then inside a splice closure. Now the completed mechanical splice renders its own protection for the splice. Ensure to seal the cables carefully, as this will prevent your cables from experiencing moisture damage.

Fig. 3.1.3: Mechanical Splicing

Types of mechanical splicing

V-Grooved Splicing

This technique takes a V-shaped substrate, and the two fibre ends are butted in the groove. Once the two are properly placed inside the groove, they are bonded by an index matching gel. This index matching gel provides proper grip to the connection. The V substrate can be composed of ceramic, plastic, silicon, or any metal.

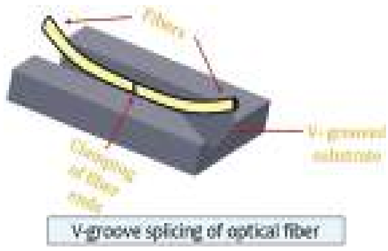


Fig. 3.1.4: Mechanical Splicing (V-Groove Splicing)

However, the fibre losses are more in this technique as compared to the fusion technique. These losses are due to the core and cladding diameter and core position with respect to the centre. Here, the two fibres do not form a continuous smooth connection as the joint is semi-permanent.

Elastic-Tube Splicing

It is a technique of splicing the fibre with the help of the elastic tube, which majorly finds its application in the case of multi-mode optical fibre. Here the fibre loss is similar to that of the fusion technique. However, the need for the equipment and skill is slightly less than the fusion splicing technique.

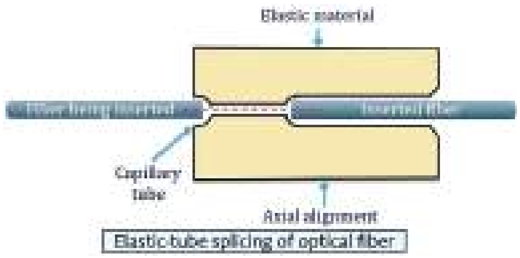


Fig. 3.1.5: Mechanical Splicing (Elastic-tube splicing)

Here, the elastic material is rubber, inside which a small hole is present. The diameter of this hole is less than the diameter of the fibre to be spliced. Tapering is done at the ends of both the fibres to allow easy insertion inside the tube.

When the fibre with a slightly larger diameter than the hole is inserted inside the hole, then it ultimately gets expanded. Due to this symmetricity, a proper alignment between the two fibres is achieved.

Fusion Splicing

Another method to join fibre optic cables together to form a permanent connection is fusion splicing. Here, a machine or an electric arc is used to produce heat and fuse/weld glass ends that are precisely aligned together for seamless transmission of light. It has a much lower attenuation of around 0.1 dB.

Fig. 3.1.5: Fusion Splicing

Overview of Fusion Splicing

Stripping the Fibre:

- It is a process of removing the protective layer, which is a polymer, from around the fibre.
- This process of splicing begins by fusing the two ends together.
- It is done by passing the fibre via a mechanical stripping device. We can also use a special procedure for stripping, which can be done using sulphuric acid.
- Sometimes, hot air is also used to remove the coating.
- There is also a method which uses chemicals under a defined time. It is called as solvent capture method.
- This procedure also helps to get rid of coatings and claddings.
- Tools used in cleaning the stripping and cleaving are very important.

Cleaning the Fibre:

- It is a process of cleaning the Fibres with alcohol and wipes like alcopad.
- Use of IPA is not advisable, as it attracts impurities.
- IPA is hygroscopic in nature, which is why it absorbs moisture.
- So, most aqueous-based cleaners are used in cleaning.

Cleaving the Fibre:

- The fibre is cleaved using the score and break method to make it flat and perpendicular to its axis.
- A microscope is used to analyse the quality of the fibre.

Splicing the Fibre

- Using core or cladding alignment, the fusion splicer automatically aligns the two cleaved fibres in the x,y,z plane; then, the fibres are fused together.
- Proof-test is done to confirm that the splice is firm enough to tolerate handling, packaging and prolonged use. Then, it is removed from the fusion splicer.
- Recoating is done, or a splice protector (heat shrinkable tube with strength membrane) is used to safeguard the bare fibre area.

Optical splicing procedure

- Placement of splicing process. Inspecting fibre optic splice closure content and the supplementary kits.

- Cable installation in the oval outlet.
- Cable preparation.
- Organisation of the fibres within the tray.
- Installing heat shrinkable sleeve and testing it.

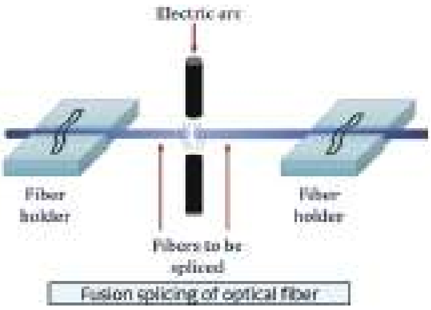


Fig. 3.1.7: Fusion splicing process

Fibre Spliced Still Unprotected

- The basic fusion splicing apparatus has two fixtures (sheath clamps) for mounting the fibres and two electrodes
- An inspection microscope is used to place ready fibre ends into the fusion-splicing apparatus. The fibres are then aligned and fused together
- Nichrome wire was used earlier in fusion splicing as the heating element to fuse fibres together
- Carbon dioxide (CO2) lasers, electric arcs, or gas flames are used to fuse the fibres.
- Electric arc fusion (arc fusion) has become a popular technique for splicing due to small-sized and automatic fusion splicers.
- Optical fibre connectors or mechanical splices can be used but have higher insertion losses, lower reliability and higher return losses than fusion splicing.

Fig. 3.1.8: Basic splicing instrument

Cable Preparation for Splicing

Following are the checks to prepare OFC for splicing:

- Check the installed cable and whether it has all the parameters as per the plan.
- Look for the damage or any issues
- Make sure those bend ratios are as per the measurement.
- Make sure that the cable is placed on a stable joining pit.
- Secure the cable properly to avoid damage.
- Check that the fibres are joined as per the colour coding and sequence.

Material and Equipment Used for Splicing

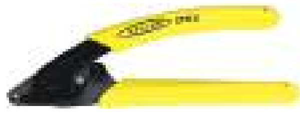
 Fibre optic cable	 Pig tail (2 in number)	 Stripper
 Mechanical splice	 Fusion splicer	 IPA cleaner & wipes
 Cleaver		

Table 3.1.1: Equipment Used for Splicing

Steps for fusion splicing

Step 1: Prepare the fibres

The first step is to strip the fibres of their protective coatings precisely.

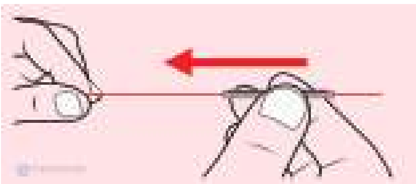


Fig. 3.1.9: Prepare the fibres

Then, similar to mechanical splicing, strip the protective coating around the optical fibre using a mechanical fibre stripper until you reach the bare fibre cores. Clean the stripping tools before starting the process.

Step 2: Clean and cleave the fibres

Clean the bare fibre using an Isopropyl Alcohol wipe. Do it twice using a different part of the wipe.

Once cleaned, avoid touching or contaminating the surface.

Now, use the cleaver to create a small, clean cut on the cables with ends perpendicular to the fibre axis.

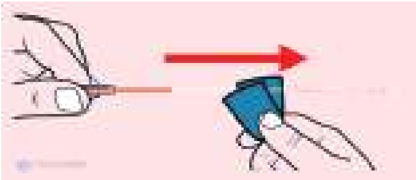


Fig. 3.1.10: Clean and cleave the fibres

Step 3: Fuse the fibres

The fibre is now ready to fuse using the fusion splicer. It involves the alignment of the fibres and heating to melt the fibre ends and fuse them.

Alignment can be manual or automatic, depending on the fusion splicer you are using. Once the end faces of the fibre are flawlessly aligned and centred on the electrodes, the splicer unit uses an electric arc to melt the two fibre ends and fuse them together.

Fig. 3.1.11: Fusion of fibres

If the fusion splicer stops the process in between, it may be due to the following issues:

- Poor alignment of the wires on their guides
- Fibres are not cleaved at a perfect 90-degree angle
- Due to the presence of some residual plastic cover or dirt on the end of the fibre

Step 4: Protect the fibre

A fusion splice usually has a tensile strength between 0.5 and 1.5 lbs and will not break during normal handling. Even then, it is advisable to provide protection from bending and pulling forces and ensure the fibre doesn't break during routine use.

After the fibres are successfully fused together, it's time to either re-apply a coating or use a splice protector.

You can use silicone gel, heat shrink plastic, or mechanical crimp protectors to secure the splice from external damage and breakage.

3.1.3 Tips for Better Splices

1. **Tips 1:** Thoroughly and frequently clean your splicing tools. When working with fibre, keep in mind that particles not visible to the naked eye could cause tremendous problems when working with fibre optics. Excessive cleaning of your fibre and tools will save you time and money.
2. **Tips 2:** Properly maintain and operate your cleaver. The cleaver is your most valuable tool in fibre splicing. Within mechanical splicing you need the proper angle to insure proper end faces or too much light escaping into the air gaps between the two fibres will occur. The index matching gel will eliminate most of the light escape but cannot overcome a low quality cleave
3. **Tips 3:** For Fusion splicing, you need an even more precise cleaver to achieve the exceptional low loss (0.05 dB and less). If you have a poor cleave the fibre ends might not melt together properly causing light loss and high reflection problems. Maintaining your cleaver by following manufacturer instructions for cleaning as well as using the tool properly will provide you with a long lasting piece of equipment and ensuring the job is done right the first time.
4. **Tips 4:** Fusion parameters must be adjusted minimally and methodically. If you start changing the fusion parameters on the splicer as soon as there is a hint of a problem you might lose your desired setting. Fusion time and fusion current are the two key factors for splicing. High time and low current result in the same outcome as high current and low time. Make sure to change one variable at a time and keep checking until you have found the right fusion parameters for your fibre type.

3.1.4 Evaluating Splices

Good Splices

You can look at the splice after the installation using both X and Y views. Some of the damage does not have any effect on the optical transmission. These are acceptable, and the examples for good splices are shown in the image given below. Some Fibres can cause white and black lines in the splice but are not considered faults. These are shown in the following figure:

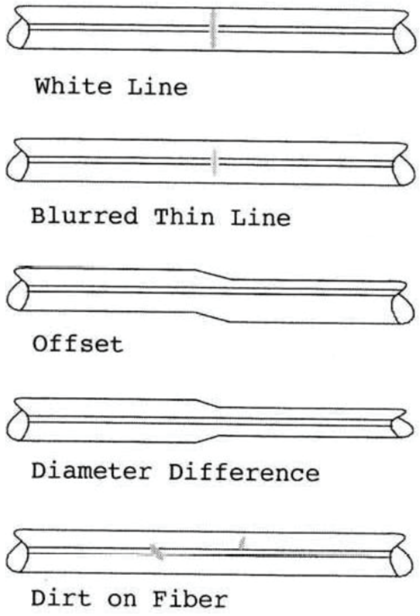


Fig. 3.1.12: These flaws do not affect optical transmission

Bad Splices

Splicing black spots or lines are known as bad splices, and these can be corrected. But they cannot be corrected more than twice. Other bad splices' identities are core offsets, bubbles and bulging splices.

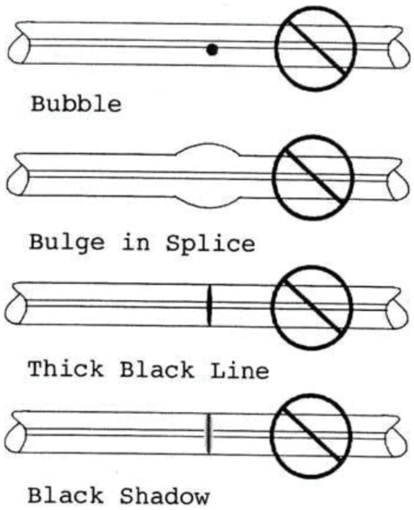
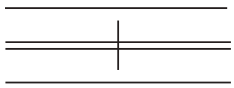


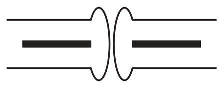
Fig. 3.1.13: These flaws require a redo

Splice Problem Troubleshooting

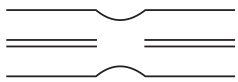
Some common problems and their likely causes are shown in the following figure:



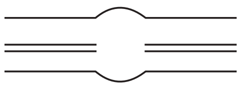
Not fused through
Fusion current too low. Pre-fusion time too short.



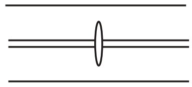
Contaminated electrodes. Fusion current much too high. Pre-fusion time much too long. Pre-fusion current much too high. Auto feed too small. Gap too large.



Current too high. Feed rate too slow. Pre-fusion time too long. Pre-fusion current too high. Gap too wide. Contaminated electrodes.



Enlargement
Auto-feed too fast.
Incorrect current.



Bubble or Inclusion
Contaminated fiber end faces. Poor cleave. Fusion current too high.. Pre-fusion current or time too low.

Additional problems

Fusion splicers generally have stored programs for most fibers and the user can modity those program parameters or create new ones. Refer to the instruction manual or ask the manufacturer is there is any question about using the splicer with the fiber you are installing.

It is sometimes necessary to splice older fibers, either in restoration or modifying networks. Older fibers may become brittle and hard to strip.

Fig. 3.1.14: Splice Problem Troubleshooting

3.1.5 Optical Fibre Safety Overview

- Keep all food and beverages out of the work area. If fiber particles are ingested they can cause internal hemorrhaging
- Wear disposable aprons to minimize fiber particles on your clothing, Fiber particles on your clothing can later get into food, drinks, and/or be ingested by other means.
- Always wear safety glasses with side shields and protective gloves. Treat fiber optic splinters the same as you would glass splinters.
- Never look directly into the end of fiber cables until you are positive that there is no light source at the other end. Use a fiber optic power meter to make certain the fiber is dark. When using an optical tracer or continuity checker, look at the fiber from an angle at least 6 inches away from your eye to determine if the visible light is present.
- Only work in well ventilated areas.
- Contact wearers must not handle their lenses until they have thoroughly washed their hands.
- Do not touch your eyes while working with fiber optic systems until they have been thoroughly washed.
- Keep all combustible materials safely away from the curing ovens.
- Put all cut fiber pieces in a safe place.
- Thoroughly clean your work area when you are done.
- Do not smoke while working with fiber optic systems.

Fig. 3.1.15: Safety rules

3.1.6 Splicing Safety – Norms and Rules

During splicing following safety rules must be followed:

- It is advised to wear safety goggles at all times of installation and other exercises and activities. You must insist the person working without a glass wear it
- Dispose of the bi-products at the proper disposal area. Make sure they are removed carefully, and no one gets harmed because of the waste
- Cover the tools before storing
- Clean the tools properly for the next use
- Always make use of FDU. You can replace FDU with the use of water or soda
- Always have scraps which can be used to pick the diffused products into the skin
- The objects and wastes are very tiny and can diffuse into the skin, which is very difficult to remove with bare hands. So, make sure to wear protective clothing
- Make use of scotch tape to pick the small pieces of fibre
- Use dark colour paper while working, because these can help show the small particles that are emitted while working
- Always use IPA, epoxy and anaerobic adhesive while working
- Always wipe the tool with alcohol
- Remember that epoxy cannot be removed from clothes
- Never touch any Fibre with bare hands or fingers
- Terminators are very hot from the curing ovens. So be cautious while handling them
- Be careful while handling a glass piece as it can cut the skin

3.1.7 Safe Handling Procedures for Optical Fibre Splicing

Objective:

Ensure all personnel follow proper safety protocols to prevent injuries, equipment damage, and network reliability issues during fibre optic splicing activities.

Key Safety Guidelines:

1. **Personal Protective Equipment (PPE):**
   - Always wear safety goggles to protect eyes from tiny fibre shards.
   - Use protective clothing (gloves, lab coats, or long sleeves) to prevent skin contact with fibre fragments or chemical adhesives.
2. **Handling Fibre Scraps:**
   - Collect fibre scraps immediately to avoid accidental embedding in skin.
   - Use scotch tape or tweezers to safely pick up tiny pieces of fibre.
   - Work over dark-colored surfaces to easily spot stray fibre fragments.
3. **Chemical Safety:**
   - Handle epoxy, anaerobic adhesives, and IPA carefully; avoid direct contact with skin and clothing.
   - Clean any spills immediately using proper disposal methods.
   - Avoid using IPA excessively as it attracts moisture; prefer aqueous-based cleaning solutions.
4. **Tool Safety and Maintenance:**
   - Always cover tools when not in use.
   - Clean all tools, cleavers, and strippers after each session to remove residue.
   - Inspect fusion splicers and mechanical splicing units before use.
5. **Splice Closure and Environmental Safety:**
   - Use Fiber Distribution Units (FDU) or water/soda alternatives to safely handle diffused particles.
   - Ensure proper sealing of splice closures to prevent moisture ingress.
   - Properly coil and secure spare fibres inside the joint closure to prevent bending or breakage.
6. **General Precautions:**
   - Never touch bare fibre ends with bare hands.
   - Dispose of all by-products and scraps in designated disposal areas.
   - Be aware of potential long-term hazards if safety procedures are ignored.

Notes

UNIT 3.2: Optical Fiber Testing, Documentation, and Predictive Maintenance

Unit Objectives

By the end of this unit, the participants will be able to:

1. Explain the procedures for documentation, reporting, and record-keeping as per company policies.
2. Discuss the protocols for testing optical fiber and ensuring quality assurance.
3. Describe the functions and applications of advanced optical testing tools, including AI-enabled OTDR and power meters.
4. Explain the concept of predictive maintenance and the role of AI-driven tools in minimizing downtime.
5. Demonstrate power source and power meter testing at both ends of the fiber to detect and eliminate cross-fiber issues.
6. Demonstrate predictive maintenance using data insights from AI-enabled tools to proactively identify potential faults.
7. Show how to integrate eco-friendly deployment techniques to minimize material waste during the testing process.
8. Demonstrate the process of maintaining a comprehensive jointing record for future reference.
9. Show how to record OTDR and power meter test results in the prescribed format.
10. Demonstrate how to submit test and jointing records to the appropriate authorities for validation and inspection.
11. Show how to update documentation on predictive maintenance and fault diagnostics conducted during testing.

3.2.1 Principles of Optical Transport Media

Optical Fibre works on the principle of Total Internal Reflection. When a ray of light strikes at the internal surface of optical fibre, such that the incidence angle is greater than the critical angle, then the incident light ray reflects in the same medium and this phenomenon repeats.

Optical Transport Network

OTN is a telecommunications industry-standard protocol defined in various ITU Recommendations, such as G.709 and G.798, that provides an efficient way to transport, switch, and multiplex different services onto high-capacity wavelengths across the optical network. Currently, network service providers rely on OTN-enabled technology in their optical networks to gain benefits that include increased resiliency, simplified operations, enhanced Service Level Agreements (SLA), an extended reach with Forward Error Correction (FEC), and the ability to efficiently maximise wavelength fill as well as guaranteed end-to-end service delivery.

OTN-enabled technology underpins next-generation optical networks with its ability to support flexible packet technologies that include new Ethernet interfaces, Multi-Protocol Label Switching (MPLS), Segment Routing, and Time Sensitive Networking (TSN), to name a few.

Optical Transport Medium

The OTM is the information structure transported across the optical interface. It has two parts:

- Digital structure
- Optical structure

The Optical Channel Payload Unit (OPU) contains the payload frames. The payload area of the OPU structure is comprised of end-user services such as IP, Ethernet, or any other protocol. The OPU overhead is associated with the mapping of client data into the payload area.

The Optical Channel Data Unit (ODU) contains the OPU overhead and payload area, plus added overhead Tandem Connection Monitoring (TCM), and so on. The ODU represents the OTN path service within an OTN network.

3.2.2 Signal Strength of Optical Fibre Cables

Signal strength is the magnitude of an electric field at a reference point, which is located at a significant distance from a transmitting antenna. This is expressed in terms of the signal power of the receiver or the voltage per length received by the reference antenna.

Fibre-optic internet has greater signal strength when compared to copper internet connections. The signal strength of the fibre-optic internet is unmatched as it does not degrade when the user moves away from the switch. This is particularly helpful when office spaces are located at a significant distance from the telecommunication rooms. Fibre-optic cables can run up to almost 25 miles before they lose signal strength, which makes them a better and stronger option overall.

Quality KPIs of Optical Fibre Cables

Fibre-optic cable has an astonishing bandwidth and is often restricted by the hardware on either side of the cable rather than the bandwidth of the cable itself.

Let us discuss some of the crucial factors affecting the performance of fibre optic installations.

1. **Poor connector terminations**
   - The connector chosen must match the existing patch panel connectors as the different types are not interchangeable and don't fit into one another.
   - If the fibre optic cabling connector ends are poorly terminated or the ends bent too sharply, then the light passing through will either be limited or at too low a range for the transmission to be connected. The light could still be shining through fibre optic cabling links but not have enough transmission quality to create the data link.
2. **Dirty connector ends**
   - The connector chosen must match the existing patch panel connectors as the different types are not interchangeable and don't fit into one another.
   - If the fibre optic cabling connector ends are poorly terminated or the ends bent too sharply, then the light passing through will either be limited or at too low a range for the transmission to be connected. The light could still be shining through fibre optic cabling links but not have enough transmission quality to create the data link.
3. **Poor installation**
   - Fibre optic cabling has a specific bend radius and pulling tension guideline when installing the main cabling runs. If the cable becomes stretched or bent too tightly, then the quality of light down the cable will be compromised which will result poor performance.
   - The cable construction has strands of Kevlar surrounding the inner cores, which protects the cable from being damaged. However, the fibre optic cable is at its weakest at the termination ends where the glass cores are exposed for termination. Adequate precaution should be taken at the termination ends to avoid excessive bending or crimping of the cable into place for termination, as this causes breaks in the cable cores. The correct termination box or panel should be selected to help eliminate this problem
4. **Patch leads**
   - With regular patching and un-patching, the patch leads can become scratched or dirty. The weakest part of the link creates the overall quality of the link, which means a poor patch lead can create a poor one overall. Fibre optic patch leads should be cleaned each time they are re-patched.
   - There are also several different categories of fibre optic cabling with different performance, core-sizes and suitability. Installing a lower category of the patch lead to a higher level cable, which will reduce the performance of the over link.

5. **Crossed over patch leads**
   - The main reason a fibre optic link doesn't work after installation is the patch leads are not patched for the correct fibre optic cabling link. In a standard fibre optic link core 1 on the transmitting end will send to core 2 on the receiving end and vice versa. However, some installations will directly match and connect the cores to transmit from position one and receive on position one. Crossover patch leads are used in this scenario to create the transmit and return loop.
   - The first way to check when a link doesn't work is by swapping around the patch lead cores at one end and re-testing the link.

3.2.2 Signal Strength of Optical Fibre Cables

Preventive maintenance means performing regularly scheduled maintenance activities to help prevent unexpected failures in the future.

- **Reception of an alarm or trouble reports**

  Testing and cable repair or removal after a fault are classified as post-fault maintenance. Both preventative maintenance and post-fault maintenance can be described as having three activities.

Maintenance category	Maintenance activity	Functions	Status
Preventative maintenance	**Surveillance** (e.g. Periodic testing)	Detection of fibre loss increase Detection of fibre deterioration Detection of water penetration	Optional (Note 1) Optional (Note 2) Optional
	Testing (e.g. Fibre degradation testing)	Measurement of fibre fault location Measurement of fibre strain distribution Measurement of water location.	Optional Optional (Note 2) Optional
	Control (e.g. Network element control)	Fibre identification Fibre transfer system	Optional Optional (Note 3)
Post-fault maintenance	**Surveillance** (e.g. Reception of transmission system alarm or customer trouble report)	Interface with path operation system Interface with customer service operation	Optional Optional
	Testing (e.g. Fibre fault testing)	Fault distinction between transmission equipment and fibre network Measurement of fibre fault location	Required Required
	Remedy (eg. Cable repair/removal)	Restoration/permanent repair Fibre identification Fibre transfer system	Required Required Required (Note 4)

NOTE 1-For point-to-point networks, the detection of fibre loss increase is recommended.
NOTE 2-Further study is required.
NOTE 3-When the monitoring system is multiplexed with the transmission signals onto working (active) fibres, synchronous control of fibre transfer may be an option.
NOTE 4-Fibre transfer may be achieved in a variety of ways, for example:

- by the use of fibre transfer splicing (optionally synchronous);
- by switching the transmission equipment to prior connected standby circuits which may be provided by a ring topology or diverse or duplicated fibre feeds.

Passive optical network elements such as splitters or wavelength division multiplexing components can be housed in casily replaceable units.

Table 3.2.1 Preventive maintenance

Conventional fibre optics maintenance has followed the concept of metallic cable maintenance, which is neither effective nor efficient because the knowledge about the bit-error rate is insufficient to determine whether the trouble is occurring in the transmission equipment or in the optical fibre network. Hence, a lot of time is taken in the series of work, starting from the reception of the trouble report to a return to normality.

Consequently, a need has risen to effectively and efficiently maintain fibre networks. However, this technique differs from that of metallic cable maintenance because optical fibre faults may be caused by residual strain, increased fibre loss, and water penetration.

The end of a fibre optic cable and the inner surface of an optical module lens constitute optical surfaces that should be properly cleaned and maintained to ensure optimum reliability and system performance.

Small oil micro-deposits and dust particles on fibre optic cable optical surfaces may cause a loss of light or degraded signal power which may ultimately cause intermittent problems in the optical connection. The figure shows the oil and dust that can collect on fibre cable connector tips and canals.

Fig. 3.2.1: Contamination on fibre optics

Laser power density may eventually burn contaminants into the optical surfaces causing the fibre to produce inaccurate results, effectively rendering it unusable.

By extension, contaminated cable connectors may often transfer contaminants and particulates into the "Optical Sub-Assembly" (OSA) barrels of the Optical Module they are inserted into.

The general practice of cleaning optical cables is a good and recommended habit to ensure overall system reliability and high performance.

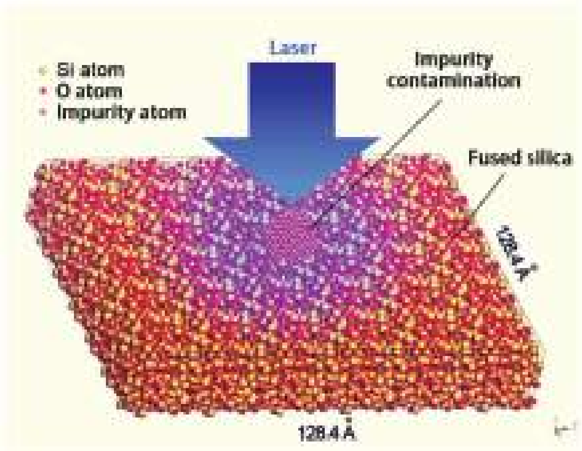


Fig. 3.2.2: Contamination on fibre optics

In fact, such kind of maintenance, which reviews fibre degradation and conducts required fibre degradation testing and fibre transfer control before any fibre fault occurs, is called preventive maintenance.

Unlike conventional cable maintenance, which is generally activated after trouble occurs, preventive maintenance takes action before a fibre fault occurs to ensure high reliability of the optical fibre cable network and therefore reduces the number of customer complaints and trouble reports.

Procedures for preventive maintenance:

1. **Measurement of fibre fault location -** The standard testing tool for fault locating is the Optical Time Domain Reflectometer (OTDR). It has adequate resolution to measure backs catter over even the longest fibre. A fault point caused by loss increase is easy to locate using a testing light on an active fibre as a remote unit to the fibre cable maintenance centre.
2. **Measurement of fibre strain distribution -** Fibre strain distributions, especially tensile strain distributions, in fibres, can be measured by Brillouin Optical fibre Time Domain Analysis (B-OTDA).
3. **Measurement of water location -** The water absorbent material in the sensor expands and causes a loss in the spare fibre due to macro bending. If the water-absorbent sensor is identified beforehand, the location where water was penetrated can be repaired as soon as the fibre loss is monitored.

3.2.4 Sealing Joints

Fibre optic splice closures protect fibre optic splices from the elements while providing fast and easy no-cost reentry. The closure comprises a plastic moulded dome-shaped housing with fibre management trays inside. There are five round cable entry ports and a single oval cable entry port for the main distribution cable. These ports are sealed using heat shrink sleeves and a blow torch. No special tools are required for assembling. They are available in different configurations. They have various cable constructions and splice capacities. Each tray can hold up to 24 fibres. There is a provision for fibre slack storage beneath the tray holder for expressed stranded fibre. The slack storage and splice capacity depend on factors such as cable construction, splice type and slack fibre lengths.

Fig. 3.2.3: Fibre optic splice closures

3.2.5 Heat Shrinking

Heat shrinkable tubes are often used for protecting the splices of single optical fibres and of optical ribbon fibres. This tube is applied over an end of a single fibre or of an optical fibre cable such as a ribbon fibre, and then the cable is spliced to another cable. At last, the heat-shrinkable tube is moved to cover the bare portions of the optical fibres and then heated, making it shrink and be firmly attached around the bare portions and to the splice.

During heating, it must be carefully observed that no air remains inside the shrinking tube since such remaining air degrades the tube's mechanical supporting and protecting function.

Fig. 3.2.4: Heat sink for fibre optics closure

3.2.6 Multi-diameter Seals

Optic cable, single mode or multi-mode types, are available as an airtight, gas-tight, fluid-tight, vacuum-tight bulkhead passthrough seal for both low and high Pressure And Vacuum Electrical uses for either pressure or vacuum or bi-directional pressures. Operating temperatures can vary depending on the design and materials from -200C to 200C or as required by the customer's use.

All PAVE seals are airtight and will pass a deficient helium leak test, regardless of the leak test shown on the drawings, which also can be modified upon customer request. In most cases, the seals are also capable of higher pressure as well than what may be shown on the drawings, with special designs capable of sealing up to 10,000 to 25,000 psi.

3.2.7 Alignment errors in fibre optic cable

Alignment error occurs when the laser beam deviates from its theoretical position relative to the actual position of the optical fibre, including longitudinal error l, lateral error d and angular error γ, as shown below.

Fig. 3.2.4: Alignment errors of fibre optic cable

Most optical networks have many fibre couplings, and even minor losses at these junctions will produce significant signal losses that cause problems in data transmission. Precise fibre alignment at the optical couplings in a network is, therefore, a pre-requisite for accurate and reliable optical data transmission since it produces the least signal loss before assembly or packaging of an optical system.

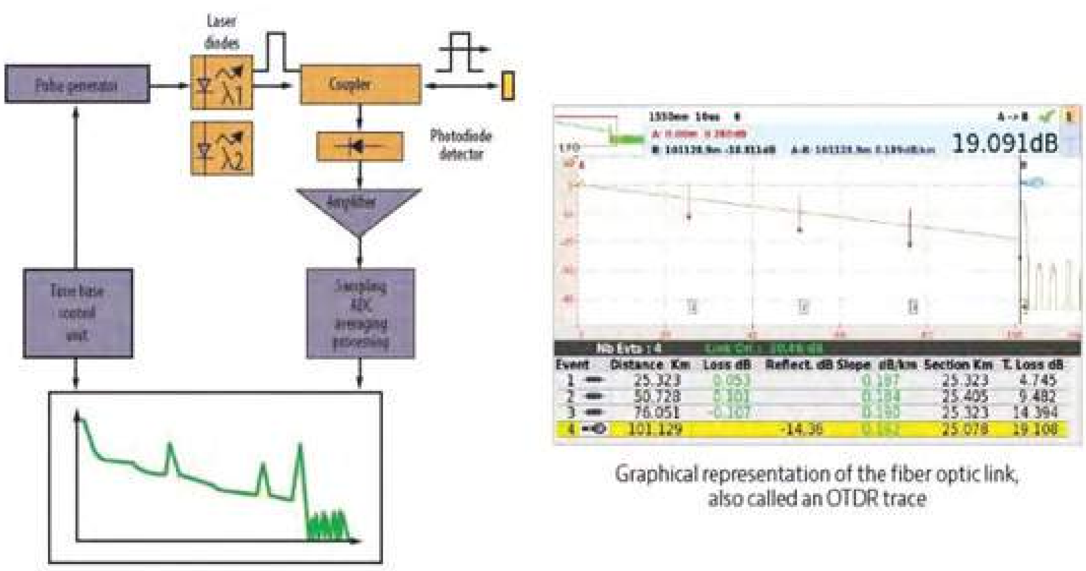
The minimal signal loss also results in the lowest optical power requirements, which, in turn, means fewer repeaters, lower capital costs and reduced incidence of failure.

- The first of these loss mechanisms, lateral misalignment, is the largest contributor to the total loss in a fibre connection. Lateral misalignment is the failure of the cross sections of the two fibre cores to overlap perfectly.
- Axial separation contributes to the connection loss when the end surfaces of the two fibres do not come into contact with each other.
- Angular misalignment's third loss mechanism generally does not contribute significantly to connection losses because manufacturing tolerances virtually eliminate this misalignment in connectors and splices and because the fibre connection itself is more tolerant of angular misalignments.

3.2.8 OTDR (Optical Time-Domain Refilectometer)

An OTDR is a fibre optics tester used to test optical networks that support telecommunications. It works like a 1D radar system. It is used to detect, locate, and measure elements at any location on a Fibre optic link.

An Optical Time Domain Reflectometer (OTDR) is a device that tests the integrity of a fibre cable and is used for building, certifying, maintaining, and troubleshooting fibre optic systems. It is a fibre optic instrument used to characterise, troubleshoot and maintain optical telecommunication networks. OTDR testing is performed by transmitting and analysing pulsed laser light travelling through an optical fibre. The measurement is unidirectional as the light is inserted at the extremity of the fibre optic cable link.



Graphical representation of the fiber optic link, also called an OTDR trace

OTDR block diagram

Fig. 3.2.5 OTDR Block Diagram

Need of an OTDR

- It ensures that the network delivers a reliable and robust service.
- The telecom industry business organisation wants to save the investment on the network that is protected.

- In an OTDR, every cable is tested, and quality is checked as 100%.
- Many tests are conducted on the OTDR.
- High level of accuracy is there.
- Troubleshooting is done.
- It is cost-effective
- The loss level is less
- One gets to know the exact fault or break of the fibre.

Fig. 3.2.6: Multimode ODTR for troubleshooting

3.2.9 Key OTDR specifications

- **Wavelengths:**
    - 850 nm and/or 1300 nm wavelengths are suitable for multi-mode fibre links.
    - 1310 nm and 1550 nm, and 1625 nm wavelengths are suitable for single-mode fibre links.
    - Filtered 1625 nm or 1650 nm are apt for in-service troubleshooting of single-mode fibre links.
    - CWDM wavelengths (from 1271 nm to 1611 nm with a channel spacing of 20 nm) are apt for commissioning and troubleshooting single-mode fibre links carrying CWDM transmission.
    - 1490 nm wavelength is apt for FTTH systems. The test can be done at 1490 nm, but it is recommended to test at 1550 nm to reduce additional costs.

  Investigating a wavelength will help to identify the fault location, and dual-wavelength will help to identify the Fibre bends and troubleshooting.

- **Dynamic Range:**

Wavelength	1310 nm	1550 nm	1310 nm	1550 nm	1310 nm	1550 nm	1310 nm	1550 nm
Dynamic range	35 dB	35 dB	40 dB	40 dB	45 dB	45 dB	50 dB	50 dB
Typical maximum OTDR measurement range	80 km	125 km	95 km	150 km	110 km	180 km	125 km	220 km

Table 3.2.2: Key OTDR specification table

It helps to identify the OTDR measurement, which is the longest pulse expressed in decibels dB.

- **Dead Zones:** Dead zones identify the events between fibre links. These are specified at the shortest pulse width and calculated in meters.
- **The event dead zone (EDZ):** It is the least distance where two consecutive reflective events (such as two pairs of connectors) can be traced by OTDR.
- **The Attenuation Dead Zone (ADZ):** It is the least distance are a reflective event (such as a pair of connectors) up to a non-reflective event (for instance, a splice).
- **Pulse Widths:** Dynamic range and dead zone relation are directly proportional. For testing long fibres, high dynamic range and wide pulse of light are needed. As the dynamic range increases, the pulse width increases, and the dead zone increases by the OTDR. For short distances, short pulse widths should be used to reduce the dead zones. The pulse width is specified in nanoseconds (ns) or microseconds.

  You must choose the OTDR based on the applications. There are various OTDR models which are available and used for different tests and needs. So, it is important to understand the OTDR to select it based on Client needs.

3.2.10 Other Important Product Specifications

- It is not difficult to operate the OTDR, but it needs the experience to handle it properly
- The correct interpretation, analysis and measurement can be done by an experienced candidate
- Less experienced candidates cannot accurately analyse the measurements in an OTDR
- Integration of the software into an OTDR instrument can help to calculate efficiently
- There is no experience needed for the person who handles the integrated OTDR system with the software with accurate

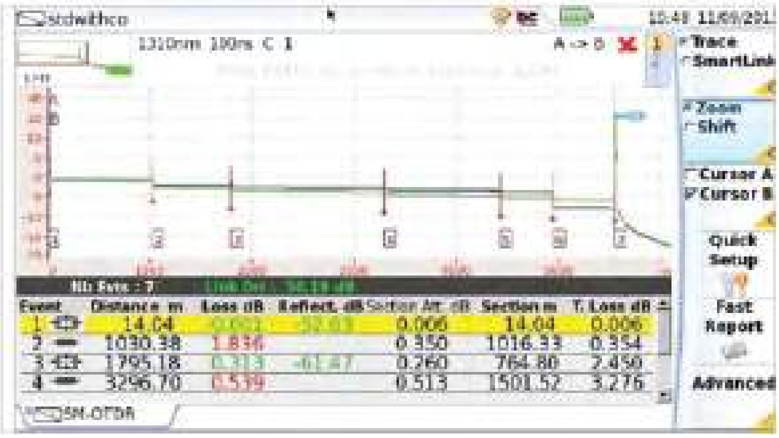


Fig. 3.2.7: OTDR Trace view

3.2.11 Factors to Take into Account when Choosing an OTDR

The size and the weight of the OTDR: Needs to be especially considered if climbing a cell tower or working inside a building is involved. The display size of the OTDR: Display size should be at least 5". OTDRs comprising small-sized displays are cheaper, but the OTDR trace analysis becomes difficult with them.

Battery life of the OTDR: The battery should last at least 8 hours so that an entire day of work can be done in the field.

Trace or results storage in the OTDR: The internal memory should be at least 128 MB with provision for external storage (such as USB memory sticks).

Bluetooth and/or Wi-Fi wireless technology: Wireless connectivity allows fast export of test results to PCs/laptops/tablets.

Modularity/Upgradability: An upgradeable platform is desirable, which could make it expensive while purchasing but will prove to be economical in the long run.

Post-processing software provision: This makes assessing and documenting test results easy and convenient, although the same can be done from the test instrument.

OTDR Best Practices: Several best practices ensure reliable OTDR testing. These are shown in the following figure:

Use of Launch/Receive Cables: These consist of rolls of fibre with specific distances. They must be connected to both ends of the fibre link to be tested. This enables qualifying the front end and the far end connectors with an OTDR. Their length is as per the link being tested; Multi-mode testing requires about 300 m to 500 m, and single-mode testing 1000m to 2000m. A very long haul requires about 4000 m.

Proactive Connector Inspection: Fibre connections should be properly examined with a fibre microscope probe to avoid dirty connections, improve the overall signal performance, and reduce network downtime and troubleshooting. Ensure that the fibre end faces are clean before mang them with connectors. OTDR port or launch/receive cable connectors need to be clean for OTDR measurement. It must be inspected and cleaned before connecting with the launch cable. A reliable fibre optic network will ensure customer satisfaction, customer loyalty, good returns on investment and sustained profits.

3.2.12 Losses in the Optical Fibre Cables

Losses in the optical fibre can be categorified into intrinsic optical fibre losses and extrinsic optical fibre loss depending on whether intrinsic fibre characteristics or operating conditions cause the loss. Intrinsic Optical Fibre Losses comprise absorption loss, dispersion loss and scattering loss caused by structural defects. Extrinsic Optical Fibre Losses contain splicing, connector, and bending loss.

The optical fibre consists of a number of glass fibres which transmit the information as light. The transmission of information through these fibres results in loss of information. The losses in optical fibre are Absorption loss, scattering loss, dispersion loss, radiation loss and coupling loss.

Fibre loss can also be called fibre optic attenuation or attenuation loss, which measures the amount of light loss between input and output. Factors causing fibre loss are various, such as intrinsic material absorption, bending, connector loss, etc.

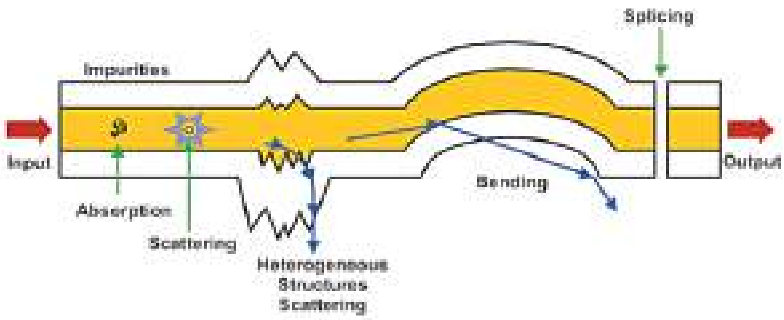


Fig. 3.2.8: Different losses in Fibre optics

Intrinsic Optical Fibre losses:

Absorption loss: Due to the presence of impurities in fibre cables, some of the residues still remain, resulting in absorption. The composition of the fibre and its fabrication of fibre results in absorption loss. There is the dissipation of optical power in the fibre cable. The wavelength of light and its concentration affects the amount of absorption.

Dispersion loss: In dispersion, the temporal spreading occurs when a light pulse propagates through an optical fibre. Sometimes, the propagation time delay causes the pulse to broaden. Delay distortion is another name for dispersion loss.

Scattering loss: Within the fibre, when there is an interaction of light with density fluctuation, scattering losses occur. There is a density change in the optical fibre when manufactured.

- **Linear Scattering Losses:** Linear scattering occurs when the energy is transferred from the dominant mode to the adjacent mode. In the dominant mode, the linear scattering is proportional to the input power injected. Mie scattering and Rayleigh scattering are two types of linear scattering.
- **Non-Linear Scattering Losses:** The optical fibre is said to operate in non-linear mode when the optical power at the output of the fibre does not change proportionally with the power change at the input of the fibre. Stimulated Raman Scattering and Stimulated Brillouin Scattering are two categories of non-linear scattering losses.

Splicing Loss: As we have already read, an optical fibre beam travelling through the core of an optical fibre cable will gradually lose its signal strength. This phenomenon is called attenuation or fibre optic loss. While there are various ways it could occur, attenuation also happens in the form of optical fibre splice loss.

Splice loss in optical fibre is defined as the part of optical power that is not transmitted through the splice and is radiated out of the fibre instead. It is measured in decibels (dB), and the formula is given:

$$\alpha splice = 10log10\ Pin/Ptrans$$

Here:

αsplice = Fibre splicing loss

Pin = Total power incident on the fusion splice

Plans = Desirable portion of the optical power transmitted across the fusion splice

splice loss in optical fibre is measured using Optical Time Domain Reflectometer (OTDR).

Bending loss or Radiative losses:

- The bending losses or radiative losses are more predominant when the fibre is curved.
- Radiation loss occurs in optical fibre due to bend. Bend occurs in optical fibre only for two reasons.
- First reason is that the curvature radius of the bend is much larger than the diameter of the fibre. The second reason is the micro bend. Bend losses mean that optical fibres exhibit additional propagation losses by coupling light from core modes (guided modes) to cladding modes when they are bent.
- There are two types of losses: micro bending losses and macro bending. Hence, Micro bending losses and Macro bending losses are two types of radiative or bending losses.

Connector Loss: Optical loss, also called attenuation, is simply the reduction of optical power induced by transmission through a medium such as a pair of fibre optic connectors. The 'return loss' is the amount of light reflected from a single discontinuity in an optical fibre link such as a connector pair.

Coupling Loss: Fibre optic systems face some communication losses, which occur from the material, cable length, cable bend, couple the more no of fibre optic cable, splicing the fibre cable etc. In coupling loss, the fibre coupler will act as a loss in that Fibre Optic System. Fibre coupler used for couple two fibre cable. During this coupling process, some light signal was lost in that Fibre Optic System, which is known as coupling loss.

3.1.13 Insertion Loss Test

Absolute & relative are the main two types of measurement. The measurement is represented in dB. The loss of power is calculated as the power that is lost in the place between the receiver and the transmitter. This can be a cable, a splice or a connector.

The loss of power is called optical loss, and it helps to calculate the performance of the cable, the connector and the splice.

Insertion Loss Test:

It is a simple test which is carried out between the light source and the power meter to detect the performance of the fibre optic link. There are two ends in which one end has the light source, and another has the transmitter connected to the fibre. The power loss is calculated at the transmitter site.

Tools used for Insertion Loss Test:

Following are the tools required for measuring 'Insertion Loss':

Fig. 3.2.9: Insertion loss tools

The steps to test the insertion loss are shown in the following figure:

Step 1: Inspect and clean end faces (alcohol wipes) prior to through adapters.

Step 2: Set up Light Source, Power Meter, e.g., adapters, power supply, data entry, etc. (Please note this equipment requires warm-up time for stabilisation).

Step 3: Setup launch cable for calibration before actual tests.

Step 4: Connect actual leads to the launch cable in order to check loss at one end.

Step 5: Connect actual leads to the launch cable in order to check loss at the end.

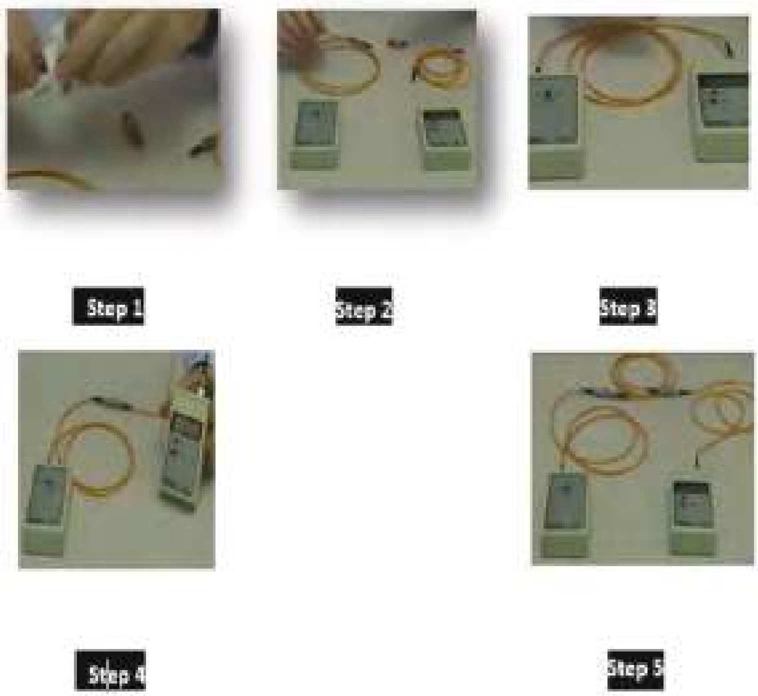


Fig. 3.2.10: Testing of insertion loss

Optical Return Loss Test procedure:

Optical return loss includes the following points:

- It is also called back reflection.
- This is calculated as the light that is reflected back from the fibre from the light source and the interference caused by the air connectors and the surface.
- The other name for this process is Fresnel reflection. This is caused when the light index refraction changes between the fibre and the air.
- This process is considered a primary problem, and it can also have a major effect on the mechanical splices.
- Mechanical splices have index matching to avoid this reflectance.

Fig. 3.2.11: Return loss

Insertion loss Test procedure:

Step 1 Optical Reference Loss (ORL) referencing: measure the output power level at the fibre jumper with a separate power meter.

Step 2 Measure the ORL of the front connector (jumper to test equipment connection). Needs the use of connectors.

Step 3 Connect to the fibre under test ORL is measured in dB and is a positive value. Higher the number, the smaller the reflection – giving the required result. ORL is generally measured at 1310, 1550 and 1625nm single-mode wavelength.

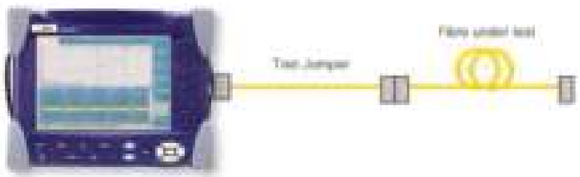


Fig. 3.2.12: Optical return loss test

Miscellaneous Test

- The other checks that should be done are shown in the following figure:
- Test the fibre joint with OTDR to verify conformance to design specifications.
- Seal off joint closure with heat shrinking/ mul diameter seals/ mechanical seals as suitable.
- Use FRP - fibre reinforced plastic to toughen the joint as needed.
- Test the fibre at both ends for cases of cross fibre using power source and power meter tests and ensure their removal.

Precautions to be taken:

- Joint is kept within the chamber carefully.
- Spare cable (loop) is rolled properly & placed within the joint.
- Sand is filled within the chamber up to the brim, and the chamber covers are laid properly.
- Joint indicator is placed 1 m behind the location of the chamber (away from the road).
- The indicator is painted in appropriate colour (such as yellow for the joint).

3.2.14 OTDR Creating a Work Report for Optical Fibre Construction

A work report that includes an OTDR trace is sometimes required after installation or maintenance is completed. The report function in the OTDR can create a report in PDF format that includes the measured data and can be used as a work report. This function supports batch processing, which can generate several reports in a single operation.

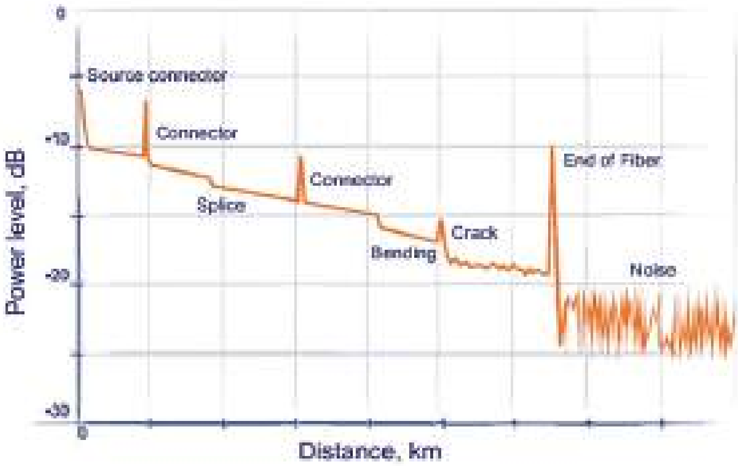


Fig. 3.2.13: OTDR report

The report includes the following information about measurement conditions, measurement data (OTDR traces, fibre end face image and trace overview, etc.) and analysis results (measurement results, marker information, event detection conditions, Pass/Fail judgment conditions, etc.). The format can be selected according to your preference.

Some of the measurement information such as serial number, model name, firmware number and measurement date cannot be modified, while other information such as company name, label, cable ID, fibre ID, fibre types, cable code, originating location, terminating location, construction procedure, etc. can be modified. All the information that can be modified is stored in advance for later recall.

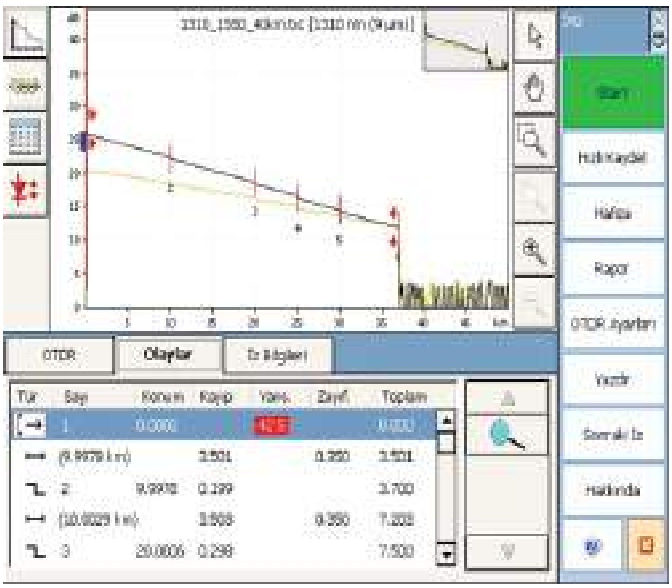


Fig. 3.2.14: OTDR report

Exercise

A. Short Questions:

1. Explain the process of Optical fibre splicing.
2. Elaborate the steps of Mechanical Splicing
3. Describe various types of splicing techniques.
4. Describe the process to evaluate splices
5. What are the safety rules of Fibre Optic Installation?

B. Fill in the Blanks:

1. The two main types of optical fibre splicing are __________ and __________.
2. In mechanical splicing, an __________ gel is used to enhance light transmission across the joint.
3. Optical fibre works on the principle of __________ __________ __________, where light reflects within the core at angles greater than the critical angle.
4. Preventive maintenance of fibre optic cables includes activities such as fibre cleaning, inspection, and __________ testing to detect potential faults before they occur.
5. Lateral, longitudinal, and angular misalignments are types of __________ errors that can cause signal loss in fibre optic connections.

C. Multiple Choice Questions (MCQs):

1. _____________ is a process of connecting two optical fibres permanently.
   a. Splicing of OFC
   b. Splicing of OBC
   c. Slicing of ODC
   d. none of the above

2. _______________ technique comprises the precise alignment of two fibre optic cables, held in place by a self-contained assembly rather than a permanent bond.
   a. Mechanical Splicing
   b. Manual Splicing
   c. Technical Splicing
   d. None of the above

3. A fusion splice usually has a tensile strength between 0.5 and____ lbs.
   a. 1.5
   b. 2.5
   c. 0.5
   d. None of the above

4. ____________________ is a process of removing the protective layer, which is a polymer, from around the fibre.

   a. Stripping the fibre
   b. Ripping the fibre
   c. pulling the fibre
   d. None of the above

5. ___________________ is a technique of splicing the fibre with the help of the elastic tube.

   a. Elastic-Tube Splicing
   b. Plastic-Tube Splicing
   c. Drastic-Tube Splicing
   d. None of the above

Notes

सत्यमेव जयते
GOVERNMENT OF INDIA
MINISTRY OF SKILL DEVELOPMENT
& ENTREPRENEURSHIP

4. Health, Safety, and Sustainable Practices in Fiber Splicing

Telecom Sector Skill Council

TEL/N6401

Key Learning Outcomes

By the end of this module, the participants will be able to:

1. Explain how advanced tools are used to test the effectiveness of a fiber splice.
2. Describe the process of recording test results for traceability and performance analysis in fiber splicing.

UNIT 4.1: Health, Safety, and Sustainablity Practices in Fiber Splicing

Unit Objectives

By the end of this unit, the participants will be able to:

1. Explain the procedures for recycling fiber waste and deploying eco-friendly materials during fiber splicing.
2. Describe Health, Safety, and Environment (HSE) protocols, including handling Earth Potential Rise (EPR).
3. Discuss the safe disposal of waste materials and adherence to global sustainability practices.
4. Elucidate the first-aid procedures for injuries such as electrical shocks, cuts, and falls.
5. Demonstrate how to check sites for potential health, safety, and environmental risks before beginning work.
6. Show how to use Personal Protective Equipment (PPE) such as helmets, safety glasses, gloves, and trench guards while splicing.
7. Demonstrate compliance with site-specific risk controls, OHS standards, and environmental guidelines.
8. Show how to identify and address environmental hazards like Earth Potential Rise (EPR) during testing and splicing.
9. Demonstrate the process of incorporating fiber waste recycling and adopting eco-friendly materials to align with global sustainability goals.
10. Show how to dispose of waste materials such as cut fibers in a safe and eco-friendly manner.

4.1.1 Introduction

Optical fibre splicing is a critical task in modern telecommunication networks. While technical precision is essential, it is equally important to adhere to Health, Safety, and Environmental (HSE) practices and to incorporate eco-friendly procedures to minimize environmental impact. This unit focuses on safe working practices, the correct use of Personal Protective Equipment (PPE), handling of site hazards, first-aid measures, and sustainable approaches to fibre waste management.

4.1.2 Health, Safety, and Environmental Protocols

Splicing optical fibres involves working with sharp fibre ends, chemical adhesives, and electrical equipment. To prevent accidents and maintain a safe working environment, technicians must follow established HSE protocols:

1. **Site Risk Assessment:**

   Before beginning work, conduct a thorough inspection of the site. Identify potential hazards such as exposed electrical conductors, tripping hazards, and the possibility of Earth Potential Rise (EPR) near substations or grounding systems.

2. **Personal Protective Equipment (PPE):**

   Always use appropriate PPE to minimize risk:

   - **Helmets:** Protect against falling objects in overhead installations or outdoor environments.
   - **Safety Glasses or Goggles:** Prevent fibre shards, dust, or chemical splashes from injuring the eyes.
   - **Gloves:** Protect hands from sharp fibres and chemical exposure.
   - **Trench Guards or Safety Footwear:** Reduce risk of injuries in trenches, pits, or uneven terrain.

3. **Compliance with Risk Controls and Standards:**

   Work in accordance with site-specific risk assessments, Occupational Health and Safety (OHS) standards, and environmental guidelines. Ensure all activities follow company policies and international safety practices.

4. **Handling Electrical Hazards and Earth Potential Rise (EPR):**

   EPR can occur when grounding systems carry high currents during faults, creating a voltage difference that may be hazardous. Workers must identify these areas and avoid direct contact with conductive surfaces. Use insulated tools and follow lockout/tagout procedures when working near live circuits.

4.1.3 First-Aid Procedures

Even with strict adherence to safety protocols, accidents can occur. All technicians should be trained in basic first-aid procedures:

- **Electrical Shock:** Immediately disconnect power and administer CPR if necessary. Avoid touching the victim until the source is de-energized.
- **Cuts from Fibre Ends or Tools:** Clean the wound, apply antiseptic, and cover with a sterile dressing. Avoid contact with bare fibre shards to prevent embedding fragments in the skin.
- **Falls or Physical Injuries:** Stabilize the injured person, immobilize fractures, and seek medical assistance as required.

4.1.4 Eco-Friendly Fiber Handling and Waste Management

Optical fibre installations generate waste materials such as cut fibres, protective coatings, and packaging. Implementing sustainable practices reduces environmental impact and aligns with global standards:

1. **Fiber Waste Recycling:**

   - Collect all fibre scraps in designated containers.
   - Avoid dispersing cut fibres on the worksite, as they can cause injuries or environmental contamination.
   - Recycle where possible through approved channels to recover glass or polymer materials.

2. **Eco-Friendly Materials Deployment:**
   - Use low-impact adhesives, heat shrink materials, and splice protectors that are biodegradable or recyclable.
   - Opt for reusable trays, closure kits, and packaging materials to reduce single-use waste.

3. **Safe Disposal of Waste:**
   - Dispose of cut fibres, gloves, wipes, and packaging in designated bio-safe or industrial waste containers.
   - Follow local and international guidelines for chemical waste, ensuring solvents, epoxy, and adhesives do not contaminate soil or water sources.

4. **Sustainable Site Practices:**
   - Minimize unnecessary cutting or removal of fibre strands.
   - Plan splice closures and slack storage efficiently to reduce material wastage.
   - Educate personnel on the environmental impact of improper disposal and the benefits of eco-friendly practices.

4.1.5 Pre-Work Safety Checklist

Before starting any splicing operation, technicians should:

- Inspect the site for hazards, including EPR and uneven terrain.
- Verify availability and proper usage of PPE.
- Ensure tools and equipment are in safe, clean, and working condition.
- Confirm that fibre waste containers and recycling procedures are ready.
- Review emergency procedures and first-aid kits.

Exercise

B. Short Questions:

1. Explain why it is important to conduct a site risk assessment before starting fibre splicing work.
2. List at least three types of Personal Protective Equipment (PPE) used in fibre splicing and their purpose.
3. Describe the procedures for recycling fibre waste and deploying eco-friendly materials.
4. What first-aid steps should be followed in case of an electrical shock during fibre splicing?
5. How does safe disposal of waste materials contribute to global sustainability practices?

B. Fill in the Blanks:

1. All fibre scraps and cut pieces must be collected in ___________ containers to prevent injury and environmental contamination.
2. Wearing ___________ protects the eyes from fibre shards and chemical splashes.
3. ___________ is a potential hazard near grounding systems that can create a dangerous voltage difference.
4. Heat shrink sleeves and reusable trays are examples of ___________ materials used during fibre splicing.
5. Conducting ___________ maintenance before any fault occurs helps reduce customer complaints and ensures network reliability.

C. Multiple Choice Questions (MCQs):

1. Which of the following is the safest way to handle fibre scraps during splicing?
   a. Sweep them with bare hands
   b. Collect them using scotch tape or designated containers
   c. Leave them on the work surface
   d. Wash them down the sink

2. What is the purpose of PPE (Personal Protective Equipment) in fibre splicing?
   a. To increase splicing speed
   b. To protect personnel from injuries and chemical exposure
   c. To improve signal strength
   d. To reduce fibre loss

3. Which environmental hazard is specifically addressed while working near grounding systems?
   a. Dust contamination
   b. Earth Potential Rise (EPR)
   c. Fibre misalignment
   d. Patch lead scratches

4. Which method is recommended for disposing of cut fibres and epoxy waste?

   a. Throwing into general trash
   b. Burning on-site
   c. Placing in designated bio-safe or industrial waste containers
   d. Flushing down drains

5. Which of the following is not considered part of preventive maintenance for optical fibre networks?

   a. Fibre cleaning and inspection
   b. Monitoring fibre degradation
   c. Immediate repair after fibre fault occurs
   d. Checking for water penetration

Notes

सत्यमेव जयते
GOVERNMENT OF INDIA
MINISTRY OF SKILL DEVELOPMENT
& ENTREPRENEURSHIP

Telecom Sector Skill Council

5. Employability Skills (30 Hours)

It is recommended that all training include the appropriate. Employability Skills Module. Content for the same can be accessed https://www.skillindiadigital.gov.in/content/list

DGT/VSQ/N0101

6. Annexure

Annexure I - QR Codes – Video Links

Annexure - I

QR Codes –Video Links

Module No.	Unit No.	Topic Name	Page No	Link for QR Code (s)	QR code (s)
Module 1: Introduction to the Telecom Sector and the Role of Optical Fibre Splicer	UNIT - 1.2: Tele-com Sector in India	1.2.1 Introduction to Telecom Industry	19	https://youtu.be/Cag-bcbivtM	Introduction to Telecom Industry
		1.2.3 Broad Band Industry		https://www.youtube.com/watch?v=5SoTmES2UKM	Broad Band Industry
		1.2.4 Optical Fibre Technology		https://www.youtube.com/watch?v=jZOg39v73c4	Optical Fibre Technology
		1.2.5 Types of Optical Fibre		https://www.youtube.com/watch?v=pavBq7HIoIE	Types of Optical Fibre
		1.2.6 Optical Fibre Splicer		https://www.youtube.com/watch?v=d-xth2HzVYU	Optical Fibre Splicer
	UNIT - 1.3: Tele-com Basics	1.3.1 Basics of Telecom		https://www.youtube.com/watch?v=xRFe9jWY0hg	Basics of Telecom

Module No.	Unit No.	Topic Name	Page No	Link for QR Code (s)	QR code (s)
Module 2: Prepare for Splicing Operations for New Installation	UNIT - 2.1 Manage tools and spares	2.1.1 Characteristics of Optical Fibre	52	https://www.youtube.com/watch?v=G-UyeFDsXlI	Characteristics of Optical Fibre
		2.1.2 Various Optical Equipment		https://www.youtube.com/watch?v=SDPfA8k0dUc	Various Optical Equipment
	UNIT - 2.2 Pre-Installation Procedures	2.2.1 Specifications of Fibre Optic Cable		https://www.youtube.com/watch?v=77dOO5hvd58	Specifications of Fibre Optic Cable
		2.2.3 Factors Affecting Choosing of Cables		https://www.youtube.com/watch?v=1oYYB7AGeMo	Factors Affecting Choosing of Cables
		2.2.6 Colour Coding of Optical Fibre Cable		https://www.youtube.com/watch?v=eCpujviAo9g	Colour Coding of Optical Fibre Cable
	UNIT - 2.3 Installation of Optical Fibre	2.2.1 Installing OFC		https://www.youtube.com/watch?v=fYwBgqDdLLQ	Installing OFC

Module No.	Unit No.	Topic Name	Page No	Link for QR Code (s)	QR code (s)
Module 3: Mainte-nance and Splicing of Optical Fibre	UNIT - 3.1: Optical Fibre Splicing	3.1.1 Splicing of OFC	73	https://www.youtube.com/watch?v=xba2MThR9Ls	Splicing of OFC
		3.1.2 Types of Optical Fibre Splicing		https://www.youtube.com/watch?v=rr9hHjYRbw8	Types of Optical Fibre Splicing
Module 4: Fibre Testing and Doc-umen-tation	UNIT - 4.1: Test-ing Opti-cal Fibre Cable	4.1.1 OTDR (Op-tical Time-Do-main Reflectom-eter)	89	https://www.youtube.com/watch?v=tXWa3xFUVGA	OTDR (Optical Time-Domain Reflectometer)

कौशल गुणवत्ता प्रगति

Skill India

कौशल भारत - कुशल भारत

सत्यमेव जयते

GOVERNMENT OF INDIA

MINISTRY OF SKILL DEVELOPMENT & ENTREPRENEURSHIP

N·S·D·C

RE IMAGINE FUTURE

Telecom Sector Skill Council

Telecom Sector Skill Council
Estel House,3rd Floor, Plot No: - 126, Sector-44
Gurgaon, Haryana 122003
Phone: 0124-2222222
Email: tssc@tsscindia.com
Website: www.tsscindia.com