OPTICAL FIBER JOINTS & CONNECTIONS

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Basic Fiber Optic Link

Transmitter  Connector  Cable

Splice  Cable  Receiver
OPTICAL FIBER JOINTS

- Technical requirement for both jointing & termination of transmission media

- Number of Joints or Connections
  - Link length between repeaters
  - Continuous length of fiber
  - Length of fiber cable practically or conveniently installed as continuous length

- Repeaters Spacing (A continuously increasing parameter)
  - Ranges from ≈ 40-60 km at 400 Mbits/s
  - ≈ 100 km at 2.4 Gb/s
  - ≈ 300 km at 1.7-10 Gb/s using SMDSFs
FIBER JOINTS

- Source- Fiber
- Fiber- Fiber
- Fiber- Detector

- Manufacturers supply *Electro-optical devices* (Sources and Detectors) with fiber optic *pigtail* to facilitate direct fiber-fiber connection

- IMPORTANT ASPECT IS FIBER-TO- FIBER CONNECTION WITH LOW LOSS AND MINIMUM DISTORTION
Two major categories of fiber joints

- **FIBER SPLICES**: Permanent or Semi-permanent joints
  - Soldering

- **FIBER CONNECTORS**: Demountable or Removable joints
  - Plugs or Sockets

- **FIBER COUPLERS**: Branching devices
  - Splitters or Combiners
  - Importance in Networks
Crucial aspect of fiber joints concerning *Optical Losses* associated with the connection

- **Fiber Alignment**

**LOSS MECHANISMS AT JOINTS**

1. Fresnel Reflection

   - Optical Loss encountered at the interfaces (Even when two fiber ends are smooth, perpendicular to fiber axes and perfectly aligned)

   - A small proportion of light may be reflected back into transmitting fiber causing attenuation at the joint.

   - **Fresnel Reflection**
Reflection Loss

- Occurs due to step changes in refractive index at jointed interface
  
  Glass – Air - Glass
Fraction of light reflected at a single interface

\[ r = \left( \frac{n_1 - n}{n_1 + n} \right)^2 \]

\( n_1 \): R.I. of core, \( n \): R.I. of interfacing medium (\( = 1 \) for air)

Loss in decibel due to FR at single interface

\[ \text{Loss}_{\text{Fres}} = -10 \log_{10}(1-r) \]

- Can be reduced to a very low level using index matching fluid in the gap between jointed fibers.
2. Deviation in Geometrical & Optical Parameters

- All light from one fiber is not transmitted to another fiber; Because of mismatch of mechanical dimension

Three major cases:

a) Core mismatch
b) NA mismatch
c) Index Profile
**Intrinsic Losses**

Losses due to:

- Fresnel Reflection
- Deviation in Geometrical & Optical parameters

➤ Minimized using fibers manufactured with lowest tolerance i.e. (same fiber)
Extrinsic Losses

- Losses due to some imperfection in splicing
  - Caused by Misalignment

Three possible types of misalignment at joint

(a) Longitudinal misalignment
(b) Lateral misalignment;
(c) Angular misalignment
(a) Loss due to lateral and longitudinal misalignment for a 50 μm core diameter GI fiber; (b) insertion loss due to angular misalignment for joints in two MMSI fibers with NA of 0.22 and 0.3.
FIBER SPLICES

- A permanent joint formed between two fibers

TWO BROAD CATEGORIES

- **Fusion Splicing or Welding**
  Accomplished by applying localized heating (a flame or an electric arc) at the interface between two butted, prealigned fiber ends causing them to soften and fuse.

- **Mechanical Splicing**
  Fibers are held in alignment by some mechanical means
  - Achieved by various methods;
    - Tube Splices
    - Groove Splices
MUST HAVE SMOOTH AND SQUARE END FACES

- End preparation achieved using suitable tools - “Cleavers” “Scribe and Break” or “Score and Break”

- Scoring of fiber surface under tension with cutting tool (Sapphire, Diamond or Tungsten Carbide blade)

Optical fiber end preparation: the principle of scribe and break cutting.
Fiber Cleavers

Two Action Cleaver:
Fiber cleaving &
Fusion splicing tool

One Action Cleaver

Handheld Cleaver
Cable Preparation Equipment

Multipack:

- Enhanced quality to prevent cracks and fiber strength degradation.
- Allow skill-free operation of factory fiber prep and field splicing applications.
- Equipped with a high precision tensile strip and automatic ultrasonic cleaning action.
Fusion Splicing of Optical Fibers

- Require Fiber end surfaces to be prepared for joint
- Heating of prepared fiber ends to fusion point with application of axial pressure between two fibers.
- Positioning & alignment using microscopes

Electric Arc Fusion splicing
Prefusion Method

- No need for end preparation

Prefusion method for accurate splicing

- Smaller Fresnel Reflection loss
- Typical Losses: 0.1 to 0.2 dB for MMF
Drawback: Fiber get weakened near splice ($\approx 30\%$)

- Fiber fracture occurs near the heat-affected zone adjacent to the fused joint.
- Splice be packaged to reduce tensile loading.
Protection of Joints

Protection Sleeves for spliced fibers

Fiber joint enclosures

Underground fiber splice tray
Mechanical Splicing

- Uses accurately produced rigid alignment tubes into which the prepared fiber ends are permanently bonded.

Techniques for tube splicing of optical fibers:

(a) Snug Tube Splice
(b) Loose Tube Splice; Square Cross section Capillary
Comparison of Two Approaches

Snug Tube Splices

• Exhibits problems with capillary tolerance requirements

• Losses $\approx$ up to 0.5 dB with Snug tube splice (ceramic capillaries) using MMGI and SM fibers.

Loose Tube Splices

• Avoids the critical tolerance requirements.

• Losses $\approx$ 0.1 dB with loose tube splice using MMGI fibers.
Ultra Splice

Ultra Splice: Reusable mechanical splice.

Average Loss $\cong 0.2$ dB
Groove Splices

- Use of grooves to secure the fibers to be jointed
  - better alignment to the prepared fiber ends.

V-groove splices

- **Insertion losses** ≈ 0.1 dB using jigs for producing V-groove splice.
Elastic Tube or Elastomeric Splice

- Comprises of two elastic parts (inner with V-groove) in compression to ensure alignment of fibers.

- Fibers of different diameters tend to be centred and hence successfully spliced.

- General loss ~ 0.25 dB for commercial product.
Spring Groove Splice

- Utilizes a **bracket** containing two **cylindrical pins**, which serve as an **alignment guide** for two prepared fibers.

- **An elastic element** (a spring) used to **press the fibers** into groove and maintain alignment of fiber ends.

![Cross-section Schematic](image)

**Mean Losses** $\approx 0.05$ dB with MMGI Fibers.

- Practically used in Italy.

**Springgroove Splice**:

(a) Expanded overview

(b) Cross-section Schematic
Secondary Alignment Techniques

- Alignment of secondary elements around the bare fibers
  - Increased ruggedness
  - Easy ground and polish of fiber end
  - Better termination

Drawbacks:

- Time consuming for termination
- Increased losses due to tolerances on secondary elements
  ⇒ Fiber misalignment.
Glass capillary tubes (Ferrules)

- Fixing of glass ferrules
- Alignment sleeve of metal or plastic in which glass tube fibers are aligned
- Average loss $\approx 0.2 \text{ dB}$

MMF mechanical splice using glass capillary tubes.
Rotary Splice

- Use glass capillary tubes for fiber termination with small eccentricity.

- Built-in offset and rotation, for excellent alignment

- Alignment accuracy of $0.05 \, \mu m$ using three glass rod alignment sleeves. (necessary for SMFs; 8-10 $\mu m$ MFD)

- **Mean Losses** $\approx 0.03 \, dB$ using Index matching gels (Not affected by skill levels of the splicer).

- **Used in large installations in USA**

Rotary Splice for SMF:

(a) Alignment using glass ferrules

(b) Glass rod alignment sleeve
MULTIPLE SPLICES

- Commercially available for splicing number of fibers simultaneously
  - Simultaneous Splicing of Five fibers in 5 minutes;
  - 15 minutes for five single fusion splicing.

- Splice Losses:
  - Ranging 0.04 to 0.12 dB - MM GI fibers
  - 0.13 to 0.4 dB – SM fibers.
A. Silicon Chip Array

- Utilize trapezoidal grooves of a silicon chip using a comb structure for fiber laying and top silicon chip
- End faces ground & polished after curing.

Average Splice loss ≈ 0.12 dB.

Multiple fibers splicing using a Silicon chip array
B. V-groove flat Chip

- Moulded from glass filled polymer resin
- Direct mass splicing of 12 fiber ribbons with simultaneous end preparation using ribbon grinding and polishing procedures.
- Fibers positioned in grooves in glass filled plastic substrate.
- Vacuum technique to hold fibers at position whilst cover plate is applied.

- Spring clips to hold assembly and hole in cover plate for index matching gel.

- **Average Splice Losses**
  \[ \approx 0.18 \text{ dB with MM fiber} \]

V-groove polymer resin ribbon fiber splice.
FIBER CONNECTORS

- Demountable fiber connectors
  - More difficult to achieve than fiber splices

- Must maintain similar tolerance requirements, but in a *removable fashion*.

- Must allow for repeated connection and disconnection without problems for fiber alignment - *without degradation in performance*.

- Must protect the fiber ends from damage – due to handling

- Must be insensitive to environmental factors (e.g. moisture & dust)

- Must cope with tensile load on the cable and can be fitted with relative ease.

- Should ideally be a *low cost component*,
Three Major Parts:

- **Fiber Termination**: protects and locates the fiber ends

- **Fiber end Alignment**: provide optimum optical coupling

- **Outer shell**: maintains the connection and fiber alignment, protects the fiber ends from the environment and provides adequate strength at the joint.

- **Losses in the range 0.2 to 0.3 dB**
A. Butt Jointed Connectors

- Alignment of two prepared fiber ends in close proximity (butted) to each other so that the fiber axes coincide.
B. Expanded-Beam Connectors

- Utilize interposed optics at the joint in order to *expand* the beam from the transmitting fiber end before *reducing* it again to a size compatible with the receiving fiber end.

*Figure 11.27* An expanded-beam connector.
Cylindrical Ferrule Connector

- Glass Ferrules with central drilled hole
- Concentric alignment sleeve

Ferrule Connectors: (a) structure of a basic ferrule connector; (b) structure of a watch jewel connector ferrule.

- Preparation of fiber ends before fixing the ferrules
- Insertion Losses $\approx 1$ to $2$ dB with MMSIF
- Watch jewel for close end approach and tolerance requirement
Ceramic Capillary Ferrules

- Ferrules made from ceramic material
- End preparation after fixing ceramic ferrules

- **Outstanding**
  - Thermal,
  - Mechanical
  - Chemical Resistance

- **Average Losses**
  - $\approx 0.2 \text{ dB with MMGI}$
  - $\approx 0.3 \text{ dB with SMF}$

ST series multimode fiber connector using ceramic capillary ferrules.
Commonly Used Connectors

FC Connectors  ST Connectors  SC Connector
DIN Connectors
(Spring loaded free-floating Zirconia ceramic ferrule)

MTRJ Connector

SMA Connector

Biconic Connectors

D4 Connectors
Biconical Connectors

- Widely used as part of jumper cable
- Fiber end faces polished after plug attachment

Mean insertion losses $\approx 0.21$ dB with connectors of 50$\mu$m diameter GI fibers.
Double Eccentric Connector

- Does not rely on a concentric sleeve approach
- Consists of two eccentric cylinders within outer plug.

- An active assembly adjustable, allowing close alignment of fiber ends
- Operation performed under inspection microscope or peak optical adjustment.

**Connector Structure**

- **Mean insertion loss** $\approx 0.48$ dB with MMGIFs reduces to 0.2 dB with index matching gel.

  ✓ Also used with SMFs giving losses 0.46 dB.
Duplex Fiber Connector

- Developed to provide two way communications
- Uses ferrules of different types

- Mostly used in LANs
- Commercially available for use in FDDI \( \approx \) loss of 0.6 dB.

Media interface plug with DFC
Multiple Fiber Connectors

- Utilizes V grooved Silicon chips for mounting

- Metal guiding rods and coil springs for precise alignment

- Average Losses
  - \( \approx 0.8 \) dB with MMFs
  - Reduced to 0.4 dB using index matching fluids

(a) Fiber ribbon connector  (b) SM Ten fiber connector.
EXPANDED BEAM CONNECTORS

- Collimating and refocusing the light from one fiber into the other.

Principle of Operation

- Very attractive for multi-fiber connections and edge connections for PCBs
Lens Coupled Expanded beam connectors

- Utilize spherical micro-lenses (50 µm Φ) for beam expansion and reduction.

(a) Two Micro lenses connector   (b) Moulded plastic lens connector

- Average Loss ≈ 1 dB, reduced to 0.7 dB with AR coating.
GRIN-rod Lenses

- An alternative lens geometry to facilitate efficient beam expansion and collimation
  - Arose from development of GI fiber waveguides
  - A cylindrical glass rod 0.5 to 2 mm in diameter with parabolic refractive index profile.
  - Light propagation is determined by the lens dimension and wavelength of the light.
  - Produce a collimated output beam with divergent angle of 1° to 5° from light source onto the opposite face of lens.
GRIN-rod Lenses

• Ray propagation determined by paraxial ray equation

\[
\frac{d^2 r}{dz^2} = \frac{1}{n} \frac{dn}{dr}
\]

➢ Solution is

\[
r = k_1 \cos A^{1/2} r + k_2 \sin A^{1/2} r \quad \rightarrow \text{A sinusoidal path}
\]

▪ Traversing of one sinusoidal period: one full pitch
Various fractional pitch GRIN-rod lenses

- 0.25, 0.23, 0.29 etc.

- SELFOC from Nippon Sheet Glass Co. Ltd.

- Losses $\approx 1$ dB

- Average Losses
  - $\approx 0.2$ dB with MMGI
  - $\approx 0.3$ dB with SMF
Fiber Reels, Connectors & Patch cords

Connectors

Adapters

Patch cords

FC/APC - FC/APC
SC/PC - SC/PC
ST/PC - ST/PC
LC/PC - LC/PC
E2000
MTRJ
Fiber Splicing and Connectorization kits
THANK YOU