# Introduction to optical fibers and their applications

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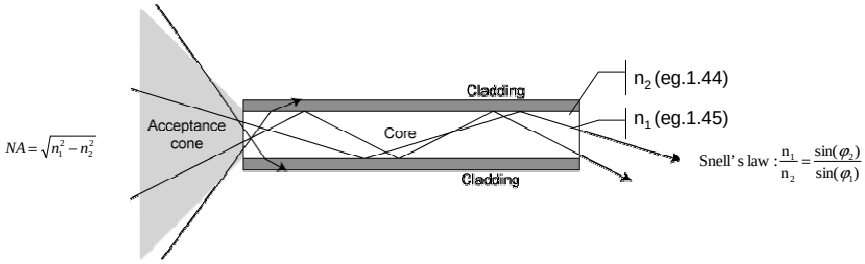
## Outline

- Introduction
- Optical fibers, patch cords and cables
- Optical fiber termination and alignment
- Application examples

## Introduction




$NA = \sqrt{n_1^2 - n_2^2}$

Snell's law : $\frac{n_1}{n_2} = \frac{\sin(\varphi_2)}{\sin(\varphi_1)}$

An optical fiber is a device that carries light along its length by means of internal reflection. A small difference in the light guide's refraction index (η) property between core and cladding (both silica):

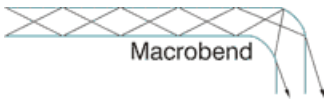
- is the cause of the *'total internal reflection'* (Snell's law)
- defines the maximum angle (Numerical Aperture) at which light is accepted at the fiber input

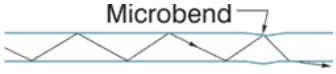


## Introduction

- If a fiber is bent at a too small radius, total internal reflection does no longer hold stand and light will leave the fiber causing (severe) optical losses.

- Two types of bending can be distinguished:
  - Macrobend
    Minimum radius over which a fiber can be bent, differs per fiber type. Values range between r=25 and r=75 [mm]. Check your data sheets for actual values.
  - Microbend
    Happens if fiber is squeezed to hard, e.g. by clamping the fiber



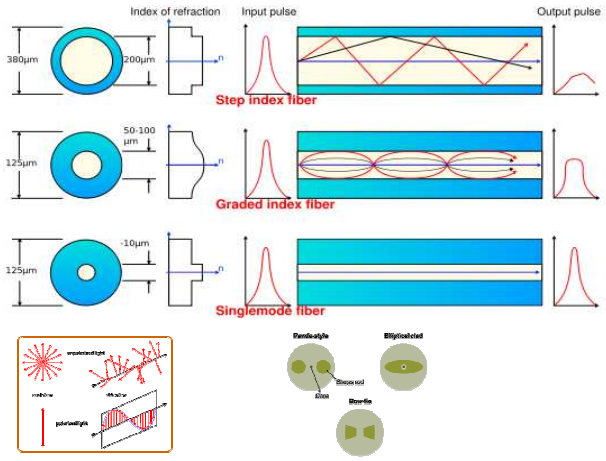
## Optical fibers, patch cords and cables

Step index multimode

Graded index multimode

Single Mode

Polarization Maintaining

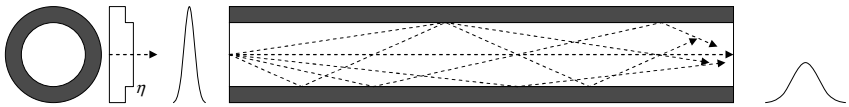





## Optical fibers, patch cords and cables

**Step Index Multi Mode fiber:**

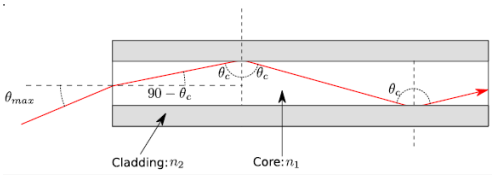
- Mostly used as 'light guide', e.g. for instrumentation purposes
- Large core diameter (100 – 1500 µm])
- Large NA (0.22, 0.29, 0.37, 0.43, …)
- Low-OH (for IR) and High-OH (for UV) versions

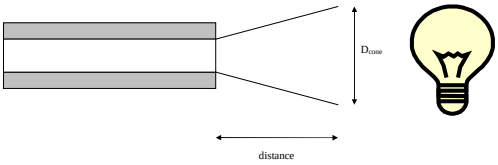


## Optical fibers, patch cords and cables

### Step Index Multi Mode fiber: NA - acceptance cone

$$NA = \sqrt{\eta_{core}^2 - \eta_{cladding}^2} = \eta_{air} * \sin(\theta_{\max})$$



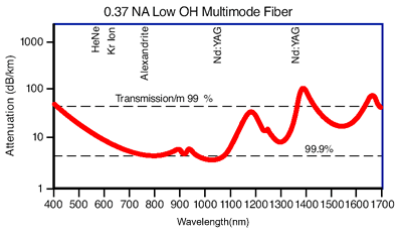

| NA | cone diameter [mm] at dist = x [mm] | | |
|---|---|---|---|
| | 0.5 | 1 | 2 |
| 0.22 | 0.23 | 0.45 | 0.90 |
| 0.29 | 0.30 | 0.61 | 1.21 |
| 0.37 | 0.40 | 0.80 | 1.59 |
| 0.43 | 0.48 | 0.95 | 1.91 |

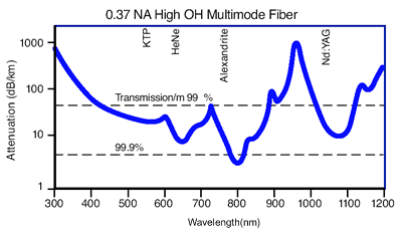


## Optical fibers, patch cords and cables

### Step Index Multi Mode fiber: OH-absorption

- Moisture inside the fibers causes light to be absorbed at certain peaks in the optical spectrum
- Low-OH fibers are applied in (near-) IR applications.
- High-OH fibers are notable for transparency in the (deep) UV region of the spectrum and exhibit high radiation resistance



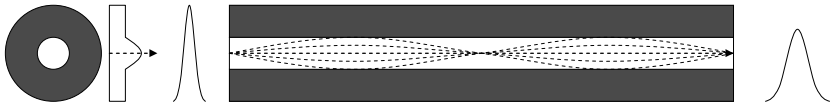



## Optical fibers, patch cords and cables

**Graded Index Multi Mode fiber:**

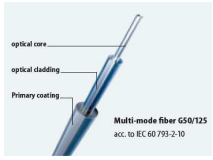
- Mostly used as ‘digital’ fiber for LAN application
- The graded refraction index reduces pulse dispersion and thus improves max. data rate (compared to Step Index fibers).
- High bit rates over short distances; e.g. 10Gbps over <550[m]
- Medium size core diameter: 50[µm] (OM2 and OM3)
- Typical wavelengths: 850 and 1310 [nm]

$\eta$





## Optical fibers, patch cords and cables




**G50/125** **Multi-mode fiber G50/125** acc. to IEC 60 793-2-10

**Geometry/mechanical properties**

| | | | |
|---|---|---|---|
| Core diameter (µm) | 50 ± 2.5 | Cladding non-circularity (%) | < 1 |
| Cladding diameter (µm) | 125 ± 2 | Core/Clad concentricity error (µm) | < 1.5 |
| Coating diameter (µm) | 245 ± 10 | Eccentricity of coating (µm) | < 10 |
| Core non-circularity (%) | < 5 | Screen-Test | 1 % stretching at 1 s ( ≙ 100 kpsi) |

| Transmission properties | Fiber type F (OM2) | | Fiber type G (OM2+) | | Fiber type H (OM2++) | | Fiber type I (OM3) | | Fiber type J (OM3+) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wavelength (nm) | 850 | 1300 | 850 | 1300 | 850 | 1300 | 850 | 1300 | 850 | 1300 |
| Attenuation max. (dB/km) | 3.0 | 1.0 | 2.7 | 0.8 | 2.7 | 0.7 | 2.5 | 0.7 | 2.5 | 0.7 |
| Bandwidth OFL min. (MHz · km) | 500 | 500 | 500 | 1000 | 600 | 1200 | 1500 | 500 | 3500 | 500 |
| Effective group of refraction | 1.483 | 1.478 | 1.483 | 1.478 | 1.483 | 1.478 | 1.483 | 1.478 | 1.483 | 1.475 |
| Numerical apperture | 0.200 ± 0.020 | | 0.200 ± 0.015 | | 0.200 ± 0.015 | | 0.200 ± 0.015 | | 0.200 ± 0.015 | |

## Optical fibers, patch cords and cables

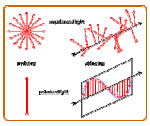
**Single Mode fiber:**

- Mostly used as ‘digital’ fiber for WAN applications, i.e. high bit rates over long distances (<10[Gbps] up to 60[km]),
- Small core diameter (typ. ~9 [µm]) results in a very low pulse dispersion
- Used with long wavelengths (typ. 1310, 1550 and 1625[nm])

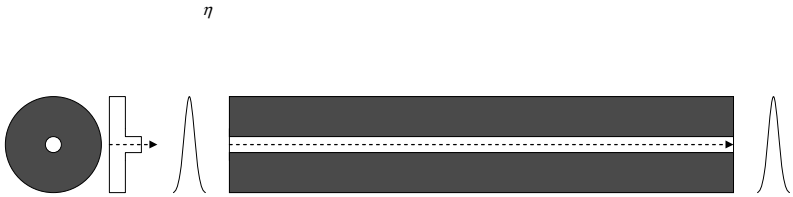



## Optical fibers, patch cords and cables

**Polarization Maintaining fiber:**



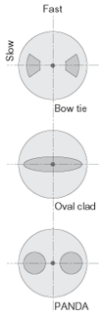
- Special form of a single mode fiber, optimized to maintain linear polarization along the length of the fiber.
- Used for various different applications; e.g. very long distance telecom (GAN), optical gyroscopes, laser beam delivery for lab instrumentation, IFM’s, etc.
- Very small core diameter (typ. 5-9 [µm], depending on the λ)

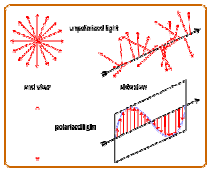


## Optical fibers, patch cords and cables

**Polarization Maintaining fiber:**

- PM fibers transport linear polarized light along the length of the fiber enforced by the “birefringence” characteristics of the fiber core.
- Birefringence is implemented by deliberately adding some stress rods during fiber production, which results in a small difference in optical density between the horizontal and the vertical axis. This difference in optical density results in a small difference in refraction index leading to a ‘fast’
  and a ‘slow’ optical axis.
- PM fibers are less (but not in-)sensitive to external stress, e.g. caused by bending.
- “Panda” is the most commonly used PM fiber



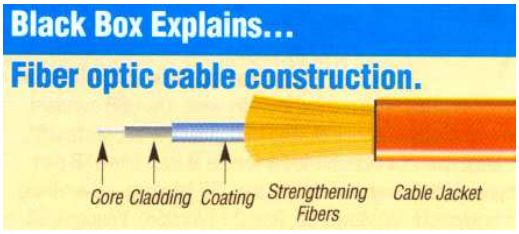


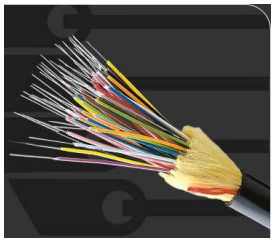
## Optical fibers, patch cords and cables

## Summary:

| Fiber | Instrumentation | Telecom |
|---|---|---|
| SI-MM | **microscopy, endoscopy, night vision, etc** | **Consumer Automotive (POF)** |
| GI-MM | | **LAN** |
| SM | | **WAN** |
| PM | **Laser beam delivery, optical gyroscopes** | **GAN** |

## Optical fibers, patch cords and cables

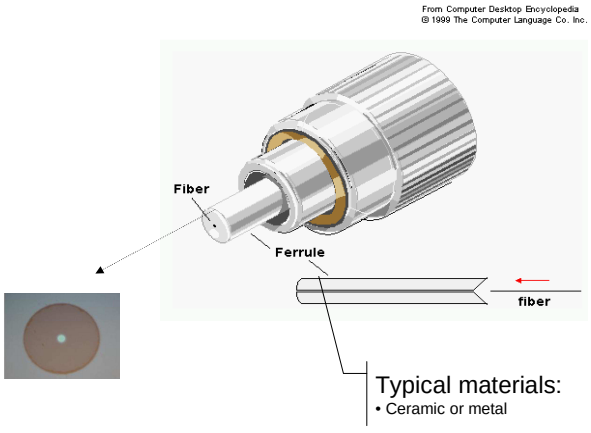


- **Optical fiber =**
  core + cladding (glass) + primary coating
- **Optical patch cord =**
  Optical fiber + strengthening fibers + cable jacket
- **Optical cable =**
  Multiple optical fibers + strengthening fibers + cable jacket

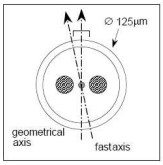


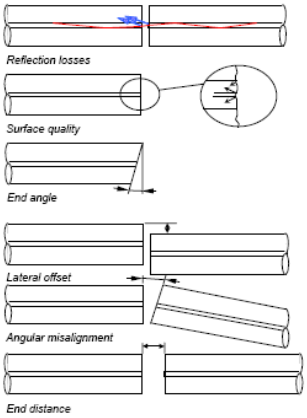
## Fiber termination and alignment



## Fiber termination and alignment

- Mechanical misalignment (see figure) at fiber crossings causes optical losses and back reflection
- Air gaps must be omitted
- Single Mode and Polarization Maintaining fibers (due to their small core) are much more sensitive to misalignment than multi-mode fibers.
- On top of that, Polarization Maintaining fibers are also very sensitive to angular misalignment



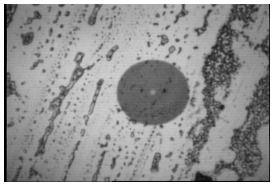


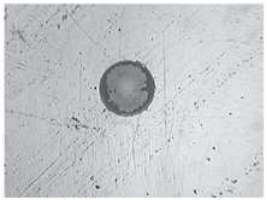

## Fiber termination and alignment


- **PC = Physical Contact**
- **UPC = Ultra PC**
- **APC = Angled PC**

## Fiber termination and alignment

- Fiber end faces should be
  - Clean:
    - Prevent pollution (use dust cap)
    - Use proper cleaning tools (lint free)
  - Free of scratches
    - Apply decent polishing
    - Prevent damaging (just protective cap)







## Fiber termination and alignment

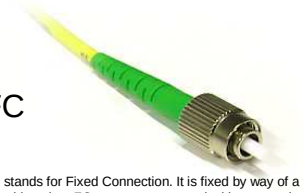
### ST

ST stands for Straight Tip- a quick release bayonet style connector developed by AT&T. STs were predominant in the late 80s and early 90s.

ST Connectors are among the most commonly used fiber optic connectors in networking applications. They are cylindrical with twist lock coupling, 2.5mm keyed ferrule. ST Connectors are used both short distance applications and long line systems. The ST connector has a bayonet mount and a long cylindrical ferrule to hold the fiber. Because they are spring-loaded, you have to make sure they are seated properly. They are easily inserted and removed due to their design. If you experience high light loss, try reconnecting.

ST connectors come in two versions: ST and ST-II. These are keyed and spring-loaded. They are push-in and twist types. They are rated for 500 mating cycles. The typical insertion loss for matched ST connectors is 0.25 dB.

### FC



FC stands for Fixed Connection. It is fixed by way of a threaded barrel housing. FC connectors are typical in test environments and for single mode applications. FC connectors were designed for use in high-vibration environments. The FC connector is the most popular connector used today. It can be seen in every area of the communications environment, from a telecoms distribution room to a LAN closet the FC has set the standard for optical fiber connectors. FCs are being replaced by SC and LC connectors.

FC connectors offer extremely precise positioning of the fiber optic cable with respect to the transmitter's optical source emitter and the receiver's optical detector. They feature a position locatable notch and a threaded receptacle.

FC connectors are generally constructed with a metal housing and are nickel-plated. They have ceramic ferrules and are rated for 500 mating cycles. The insertion loss for matched FC connectors is 0.25 dB.

## Fiber termination and alignment

SC

SC stands for Subscriber Connector- a general purpose push/pull style connector developed by NTT. SC has an advantage in keyed duplexibility to support send/receive channels.

SC Connectors are frequently used for newer network applications. The SC is a snap-in connector that is widely used in single mode systems for its performance. The SC connector is also available in a duplex configuration.

They offer low cost, simplicity, and durability. SC connectors provide for accurate alignment via their ceramic ferrules. The square, snap-in connector latches with a simple push-pull motion and is keyed. They feature a 2.5mm ferrule and molded housing for protection. Typical matched SC connectors are rated for 1000 mating cycles and have an insertion loss of 0.25 dB.

LC

LC stands for Lucent Connector. The LC is a small form-factor fiber optic connector.

The LC connector uses a 1.25 mm ferrule, half the size of the ST. Otherwise, it is a standard ceramic ferrule connector. The LC has good performance and is highly favored for single mode.



## Fiber termination and alignment

SMA

SMA is a fiber optic connector developed and manufactured by Amphenol Fiber Optic Products; it stands for SubMiniature version A.

SMA connectors use a threaded plug and socket. It was the first connector for optical fibers to be standardized. The SMA was designated as FOCIS-1 by the TIA.

In addition to their compact size, the SMA connector has exceptional mechanical durability. The SMA connector holds a single fiber. SMA connectors have a threaded coupling nut. The ferrule is traditionally made of steel, although ceramic versions are available.

SMA connectors come in two varieties: the SMA-905 has a straight ferrule, whereas the SMA-906 has a stepped ferrule design. The SMA-905 is a non-contact connector typically used in medical, industrial, and military applications. When two SMA 906 are mated together the stepped ferrule design allows an alignment sleeve to be used and therefore the connection has lower insertion loss. The SMA 905 does not have an alignment sleeve therefore the insertion loss of the 905 is higher than that of the 906

LSA/DIN

LSA connectors have an extra long ferrule which enables accurate alignment. LSA/DIN are also suitable for PM fiber connections. Because of this these connectors are often applied for Tele-communications, CATV, LAN, MAN, WAN, Test & Measurement, Industry, Medical, Sensors, etc

| | MULTIMODE 0° PC | SINGLE MODE 0° PC | SINGLE MODE 8° APC | UNITS |
|---|---|---|---|---|
| Insertion Loss (IL) | typ. 0.15 max. 0.4 | typ. 0.2 max. 0.4 | typ. 0.2 max. 0.4 | dB |
| Return Loss (RL) | min. 40 | typ. 50 | min. 70* | dB |
| Repeatability of IL | | max. ±0.1 | | dB |

* Measured with high precision reflectometer

## Fiber termination and alignment

MXL38999

Multi-fiber connector housing for up to 64 fibers. Each ferrule can have a PC, UPC or APC end face. Ferrules are aligned individually. Ferrule can hold fibers with outer diameters ranging from 80 to 650 um. Any mix of multi mode and single mode fbers is possible.

MPO/MTP

Multi-fiber connector housing up to 24 fibers in a single ferrule.

Ribbon Fiber Cables offer a compact, efficient, and versatile solution to applications requiring maximum connectivity in a minimum amount of space. Based on single ferrule MT technology, these cable assemblies provide up to 72 fiber connections in a single point, reducing the physical space and labor requirement, while providing the same bandwidth capacity of a multi-fiber cable with individual fiber/connector terminations per fiber. Both multi mode and single mode fibers are supported.

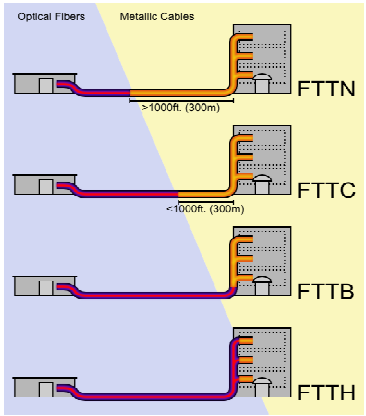
The advantage of utilizing Ribbon Fiber Cables resides in the ability to achieve a much higher density in patch panel, cable routing/ducting, and device connection environments, without compromising the quality or quantity of the connection.



## Optical fiber application examples

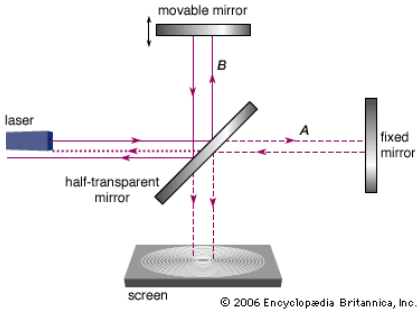
### Single Mode fibers:

- Fiber to the Node
- Fiber to the Curb/Cabinet
- Fiber to the Building
- Fiber to the Home



## Optical fiber application examples

- Michelson interferometer:
  - Based on measuring the phase difference of linear polarized laser light that travels two routes: fixed (A) and variable (B) light path
  - Remote laser beam delivery requires Polarization Maintaining fibers
  - Remote detection requires Step Index Multi Mode fibers






## Brands

SCHOTT glass made of ideas
CORNING
LEONI
ofs A Furukawa Company
timbercon Photonic design at the speed of light
POINT SOURCE
molex
tyco
LEMO
Fujikura EUROPE LTD
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