Deploying Reliable Optical Network Links

Jan 2024

Versa Networks

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Optical Network Physical Topology

Figure 1 shows an example of the constituents of a typical enterprise fiber optic link. It consists of two network elements whose communication link consists of fiber optic transceivers, fiber patch cables, patch panel connectors and fiber trunk cables providing the intra-floor connections. Shown in yellow lines are SMF cables terminating to single mode transceivers.

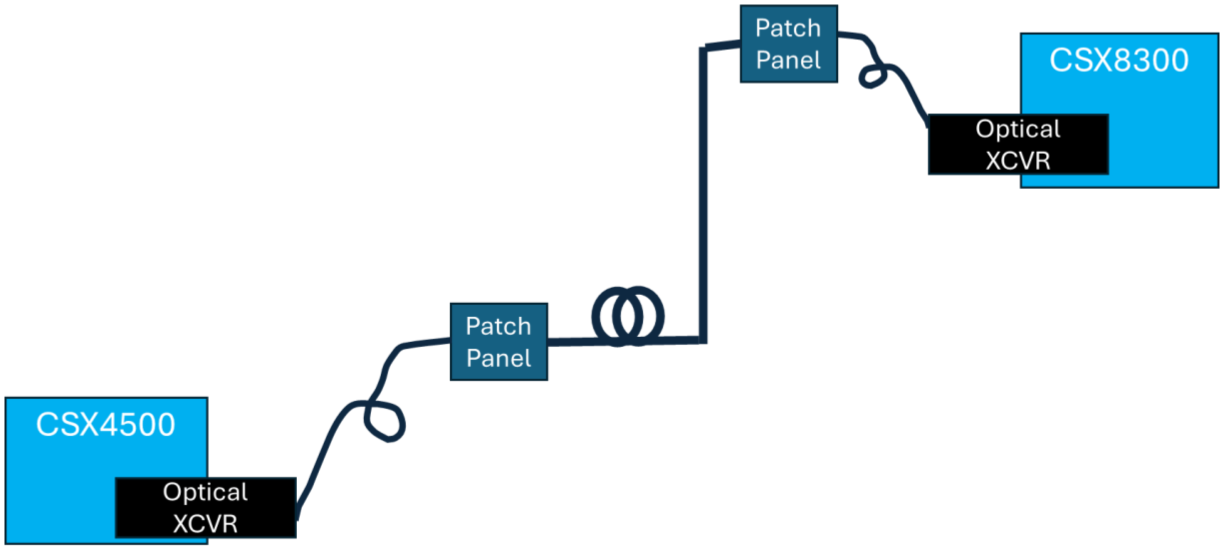


Figure 1 End to End Fiber Optic Link

Fiber Optics' Many Impairments

Deploying reliable optical networks requires understanding of the various factors intrinsic to optical links, specifically the many optical impairments that are present and means available to mitigate them.

- Contaminants on trunk / fiber patch cable ferrule tips or xcvr end face reflect light and thereby degrade return loss which can attenuate the signal as well as introduce more jitter. Inspecting and cleaning fiber connector ferrule tips and transceivers' end face can remove these contaminants. Keep a protective cap on unplugged fiber connectors to prevent contact with contaminants. Never use alcohol for wet cleaning without a way to ensure that it does not leave residue on the optical end face. Never clean bulkhead connectors or receptacle devices without having a means to inspect them.

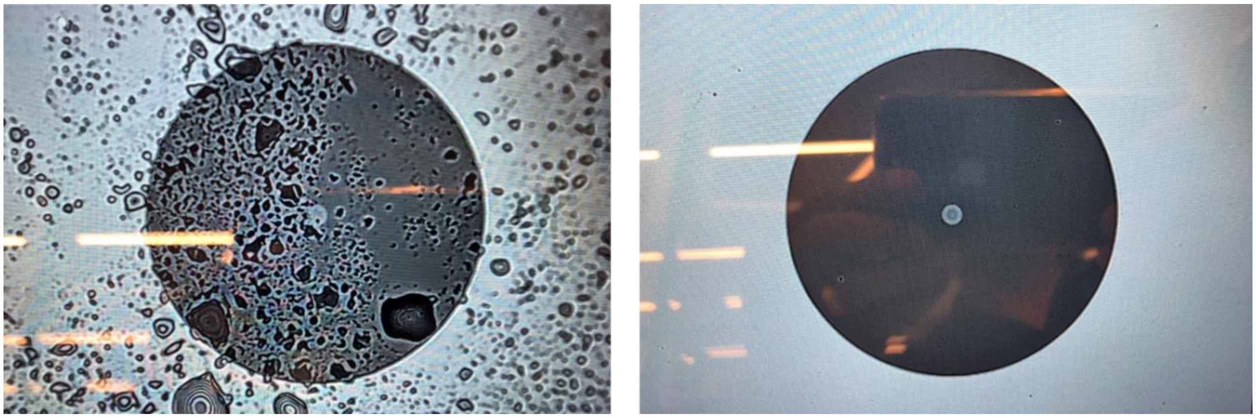


Figure 2 Dirty vs. clean Fiber Ferrule Tip

- Bends in optical fiber add attenuation as some light can escape. Fiber management adhering to minimum bend radius guidelines can control this impairment.

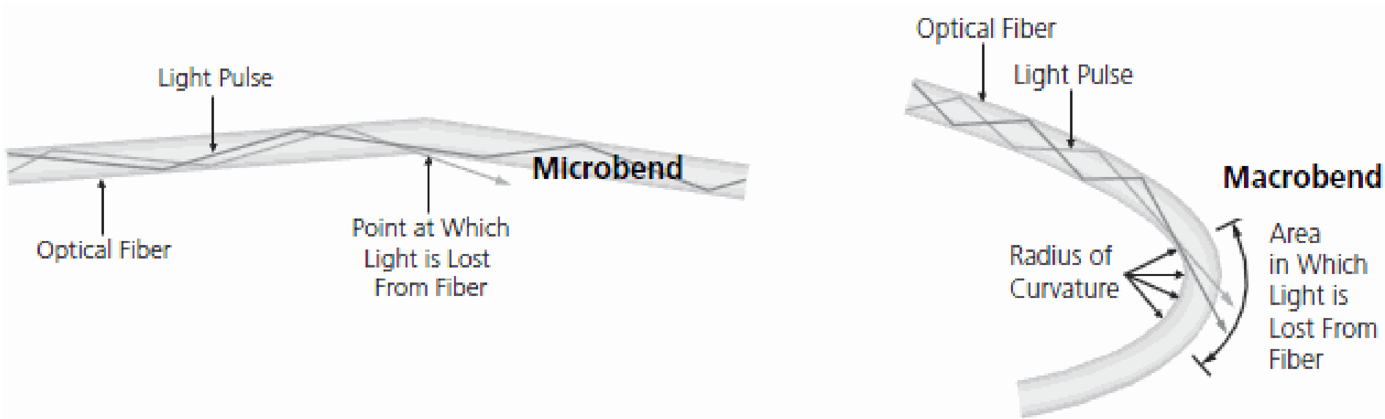


Figure 3 Fiber cable microbends and macrobends

- Inter Symbol Interference (ISI) caused by non-constant group delay of the transmission medium, namely the glass core, result in edges of adjacent data bits to overlap, causing the waveform of a symbol to spread out into succeeding symbols. DFE in serdes RX path is required to counteract these effects.

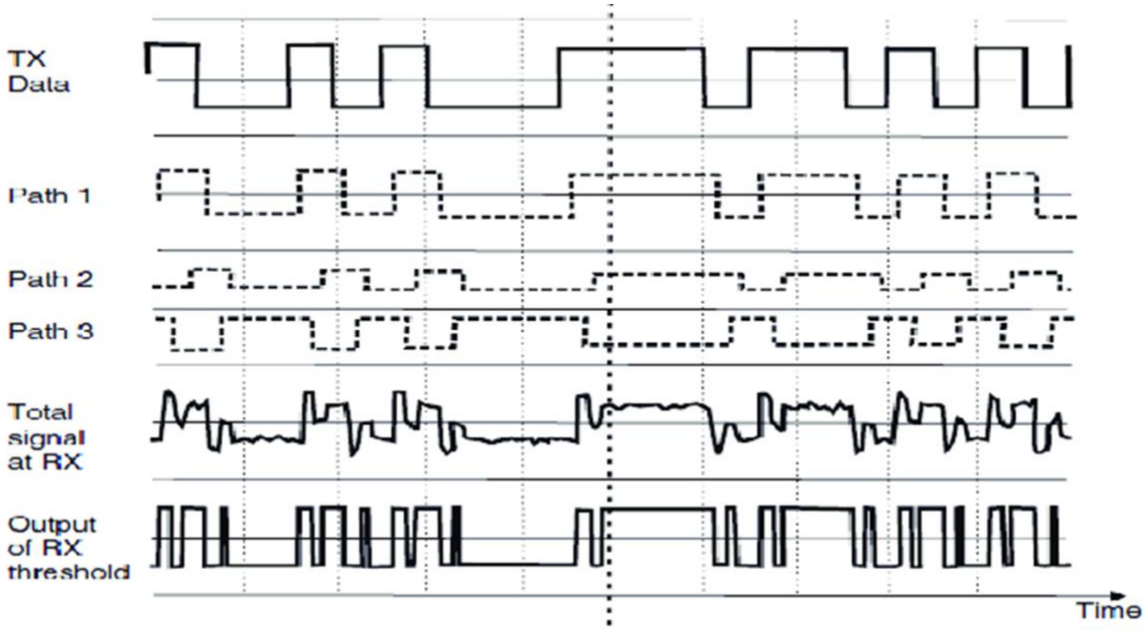


Figure 4 Inter Symbol Interference (ISI)

- Differential Mode Delay (DMD) in multi-mode fiber is caused by the difference in arrival times between the different modes (propagation paths) of light within the fiber which take slightly different paths and hence have different propagation delays. These are fundamental characteristics of multi-mode LED lasers and multi-mode optical fibers.

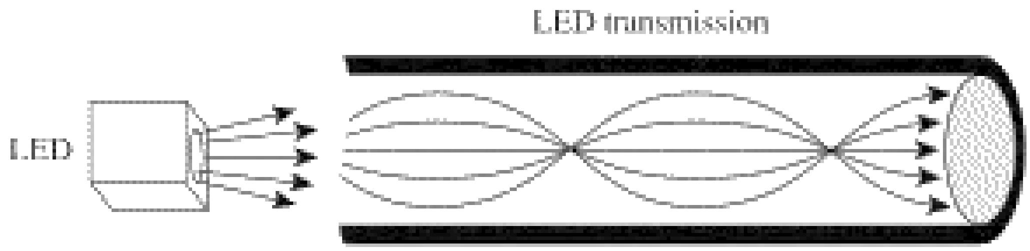


Figure 5 Multiple modes of an LED laser take different path paths

- The following impairments are mostly pertinent to longwave 1550nm (ER/ZR optics). Mitigation requires good EDC (Electronic Dispersion Compensation) technology.
  - Modal Dispersion (MD)
  - Chromatic dispersion (CD)
  - Polarization Mode Dispersion (PMD)

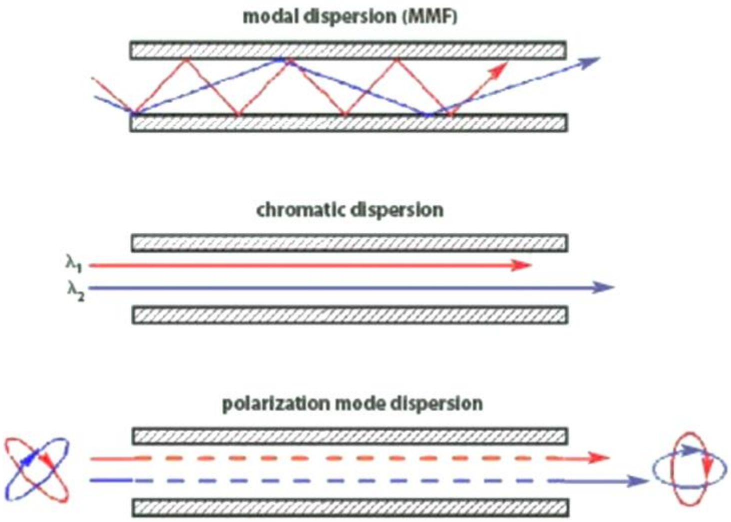


Figure 6 Various Factors that cause Dispersion

- Frequency dependent attenuation in fiber optic cable increases with frequency due to a number of factors, including absorption and scattering effects. Higher frequency signals are more easily absorbed by the medium they travel through due to certain molecular structures that are better at absorbing higher frequency waves leading to frequency dependent signal attenuation.

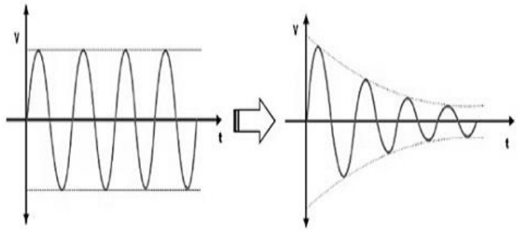


Figure 7 Frequency Dependent Signal Attenuation

- Non-ideal end face geometry can cause return loss (reflections) leading to signal attenuation and jitter. These are manufacturing defects which should have been inspected and rejected. Vendors supplying good quality fiber patch cables do this, vendors selling cheap fiber cables probably do not.

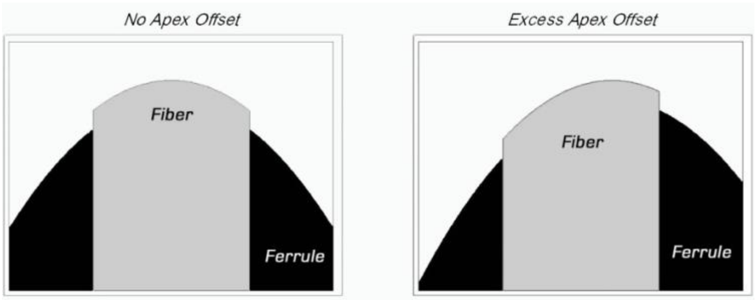


Figure 8 End face geometries

- 25GBASE-R and 100GBASE-R optical transceivers use re-timed interfaces. Clock and Data Recovery (CDR) circuits in the transceiver’s RX direction must recover clock from a highly distorted signal (attributed to many of the impairments described above) and provide a clean signal to Trident3 switch and visa versa. On TX, the CDR must remove PCB loss and jitter before outputting “clean eye” data onto the fiber. Some Manufacturer’s Transceivers cope better with these impairments than others.

Figure 9 Downward compatible SFP, SFP+, SFP28, QSFP, QSFP+, QSFP28

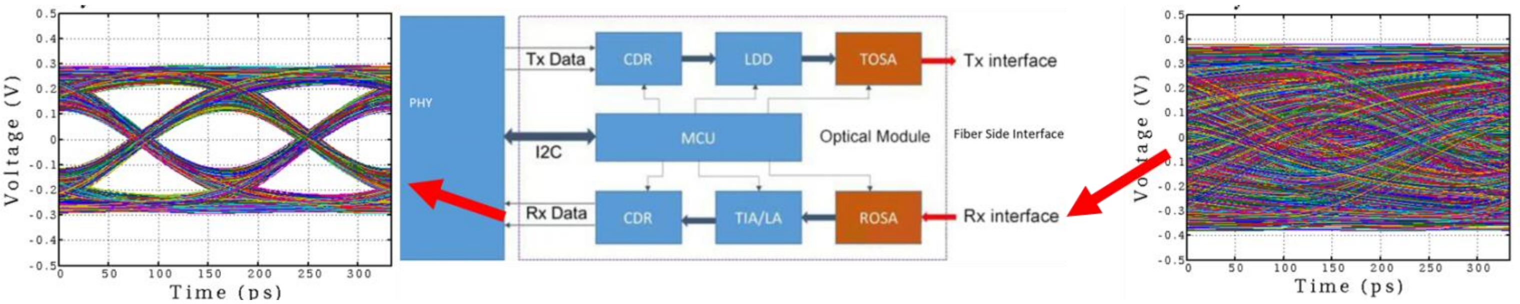


Figure 10 Transceiver CDRs eliminate accumulated wave distortion

Transceiver Qualification

Optical transceiver's transmit eye-mask and receive sensitivity are the most critical tests that validate a transceiver's performance.

Stressed Receiver Sensitivity (SRS) is a key performance test for an optical transceiver. This test measures how well the transceiver performs against impairments and determines the maximum reach or link margin available in the system. SRS measures how weak an input signal can get before hitting the BER threshold, a value above which a signal is considered to be degraded far enough and unfit for data communications.

For optical transceivers, two types of receiver sensitivity tests are important:

- Unstressed receiver sensitivity test is performed by simply connecting the transmitter to the receiver via a variable optical attenuator. BER values are plotted against different receiver power values. To achieve a certain BER, the receiver sensitivity (RX power) must be better than the threshold value as defined by the standard for Unstressed Receiver Sensitivity. Unstressed receiver sensitivity is expressed in two ways:
  - Average Power (dBm)
  - OMA (min)
- SRS test is performed by sending a degraded signal with poor extinction ratio, added sinusoidal horizontal & vertical jitter and inter-symbol interference (ISI) and use of a low pass 4th order Bessel-Thomson filter. The module passes the test if the measured minimum receive power at a specific BER remains at an accepted level. SRS is expressed as OMA (dBm).

Transmitter output eye compliance mask

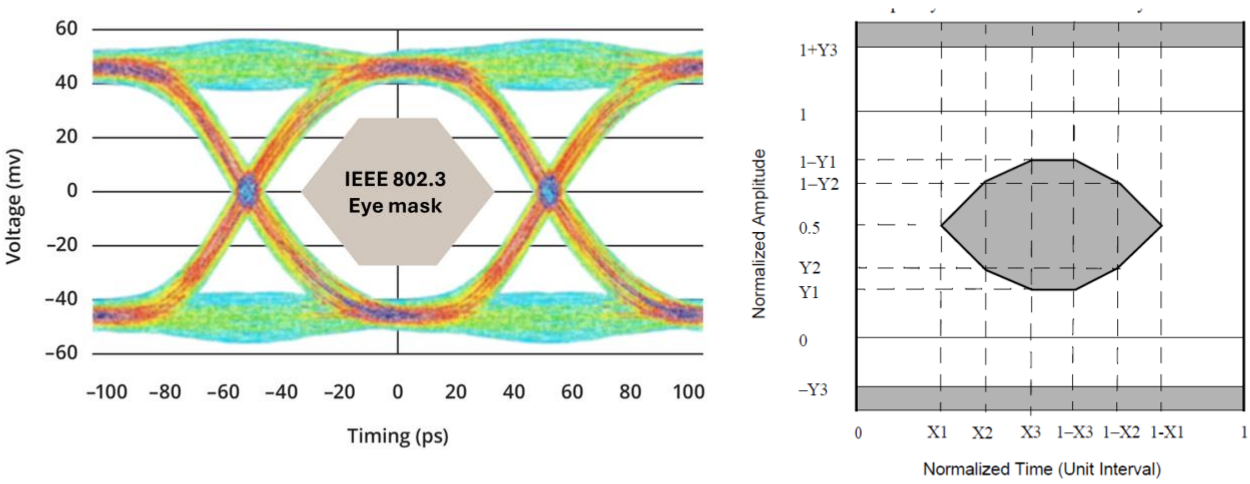
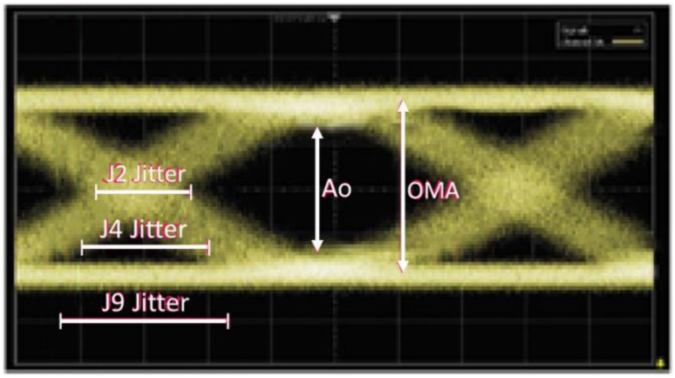


Figure 11 IEEE 802.3 CL 52-8 Transmitter output eye compliance mask

Receiver Compliance - Stressed receiver sensitivity eye mask.



25GBASE-LR CL 114.6.2 Receiver Compliance

Stressed receiver sensitivity mask

Optical Impairment Mitigation

Inside the network elements, the ethernet switch, as an example L2/L3 Switch, serdes TX on egress, applies Transmit Equalization then drives 25G NRZ data to the SFP over the 25GAUI electrical channel. The CDR in the transceiver recovers the clock then reclocks and reamplifies the data, resetting PCB trace induced signal loss and jitter, before handing it over to the laser modulation circuits which then outputs "good eye" data onto the fiber.

On Ingress, the transceiver receives data from the fiber, the CDR in transceiver RX path recovers clock then reclocks and reamplifies data, resetting fiber related signal loss and jitter before outputting onto the 25GAUI electrical channel to L2/L3 Switch RX. The L2/L3 Switch serdes RX provides sophisticated receive equalization to then recover error free data.

uP in the serdes executes firmware to perform Link Training, on link types where it is applicable like -KR & -CR, and controls adaptive equalization algorithms on the receive path. For optical links, where link training is not run, fixed TX equalization, derived based on SI analysis, must be applied.

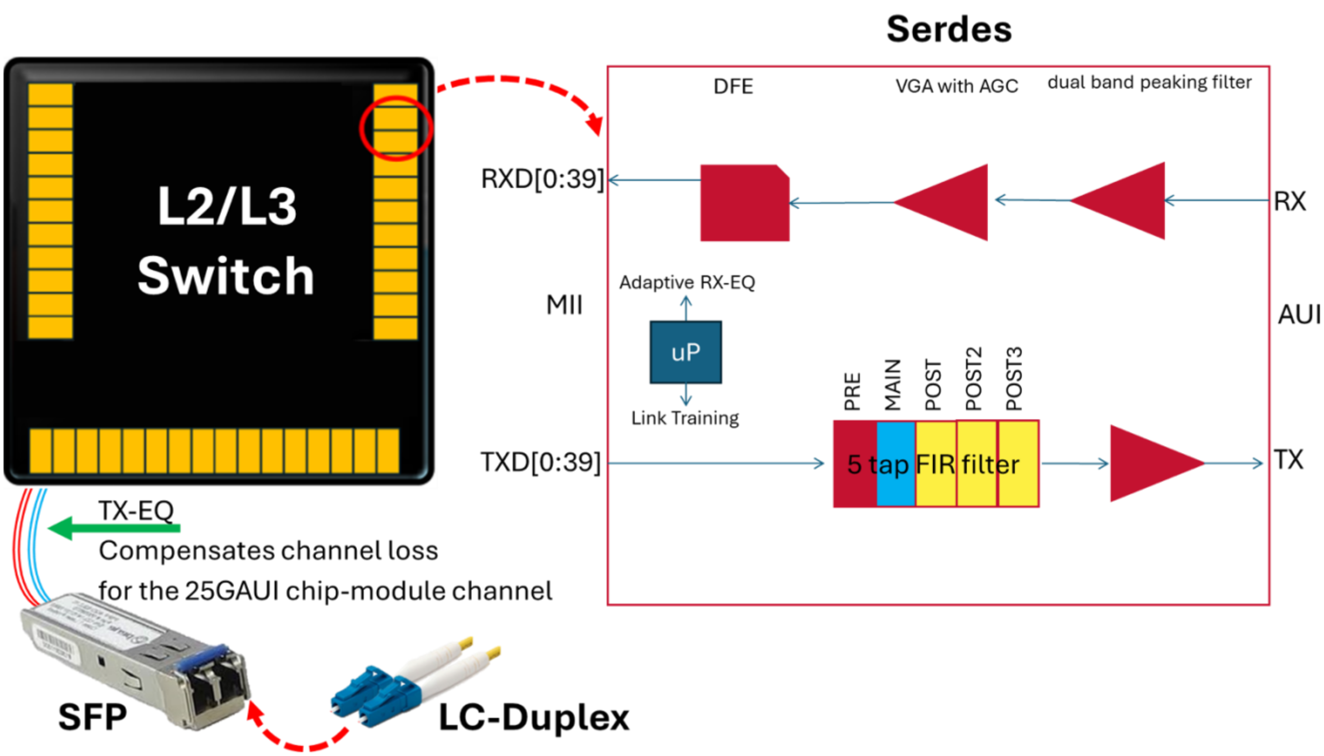
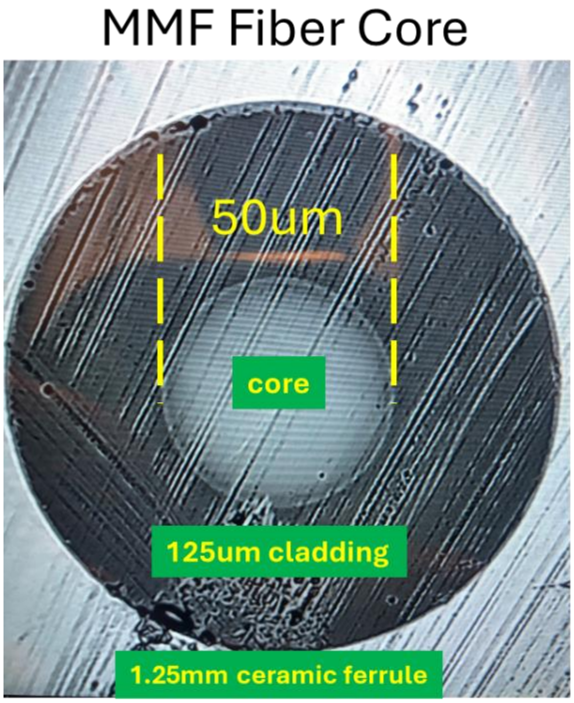
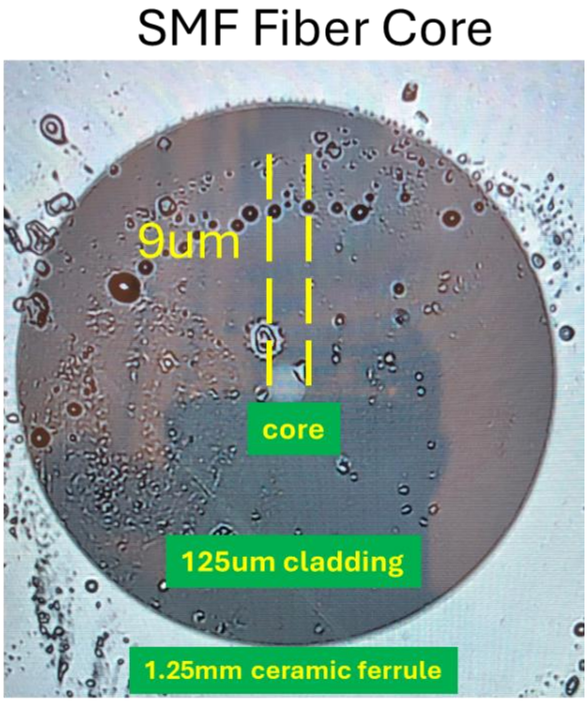


Figure 12 Key Functions that mitigate Fiber Impairments

MMF is more forgiving to impairments than SMF

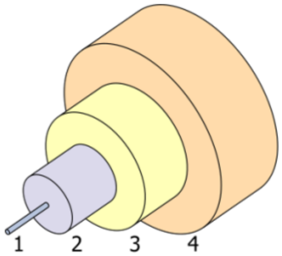
- Back reflections due to small impairments on MMF have much less impact than similar impairments on SMF.
- Many more light modes on MMF vs SMF hence small obstructions have less impact than SMF.
- SMF requires more jitter margin due to longer propagation distances.





Structure of a typical fiber

1. Core 9µm diameter for SMF, 50um for MMF
2. Cladding 125µm diameter for SMF & MMF
3. Buffer 250µm diameter for SMF & MMF
4. Jacket 900µm diameter for SMF & MMF
    - Yellow for SMF
    - Orange for MMF



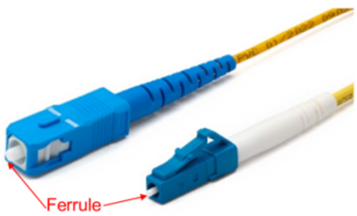


Figure 8 SC connector (Ø 2.5mm) on left. LC connector (Ø 1.25mm) on the right

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