Interoperability of Corning® LEAF® Fiber and Corning® MetroCor™ Fiber in Metropolitan Networks

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What is Corning® MetroCor™ Optical Fiber?

MetroCor optical fiber is a distinctive product that, when introduced in the early 2000s, addressed the need for low cost transmission and high capacity systems in metropolitan/medium distance networks. MetroCor fiber is a non-zero dispersion shifted fiber (NZDSF) operating in the C-band transmission region around 1550 nm. While most terrestrial single-mode fibers feature positive dispersion in the 1550 nm window, MetroCor fiber is designed with a moderate negative dispersion (-8 ps/nm-km) at 1550 nm. This feature enabled lower network costs by allowing extended reach to be achieved when coupled with relatively inexpensive directly modulated lasers (DMLs). Playing off the positive frequency chirp of DMLs with negative fiber dispersion allowed for extended reach without the need for signal regeneration or dispersion compensation modules (DCMs). MetroCor fiber supports both 2.5 Gb/s and 10 Gb/s data rates using DMLs.

DMLs and MetroCor™ Fiber: A Coupled Solution

DMLs were a popular choice for transmitters at data rates of 2.5 Gb/s for metro area networks. Today, most of the market utilizes standard single-mode fiber in these networks. Historical DMLs inherently had high positive frequency chirp associated with them. Chirp can be understood as the time dependence of the instantaneous frequency of a laser[1]. It affects the pulse transmission by causing the leading and trailing edges of the pulse to be comprised of slightly different frequencies thus propagating at different group velocities. If the chirp factor is positive, as always in the case of DMLs, then the optical wavelength of the leading edge of the pulse will be shorter (blue-shifted) and the trailing edge will be longer (red-shifted). See Figure 1.

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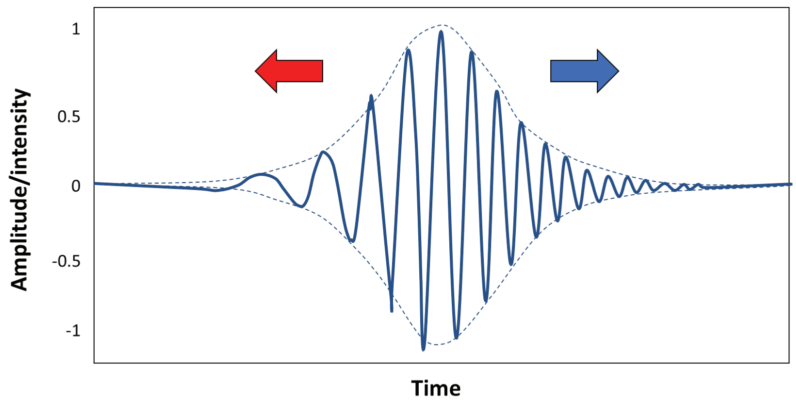

Figure 1: Positive Frequency Chirp (Up-Chirp)

Laser frequency chirp is related to the laser output power through the expression[1]:

$$\Delta v(t) = \frac{\alpha}{4\pi}\left(\underbrace{\frac{1}{P(t)}\frac{dP(t)}{dt}}_{\text{transient}} + \underbrace{\kappa P(t)}_{\text{adiabatic}}\right)$$

Equation 1. Frequency Chirp

Δv(t) = Frequency chirp variation
P(t) = Laser output optical power
α = Linewidth enhancement factor (Henry coefficient)
k = Adiabatic chirp coefficient

The first and second terms in the equation are characterized as the transient chirp and the adiabatic chirp, respectively. Transient chirp has significant magnitude during relaxation oscillations. Adiabatic chirp is related to the relaxation oscillation damping. DMLs are categorized as either transient-chirp dominant (DML-T), adiabatic-chirp dominant (DML-A), or with both transient and adiabatic chirp. DML-Ts exhibit overshoot and ringing in output power and frequency deviations[1]. This results in minor frequency differences between steady-state ones and zeros. DML-As exhibit damped oscillations and greater frequency differences between steady-state ones and zeros.

In positive dispersion fibers, the blue-shifted components of the pulse will have a higher group velocity and the red-shifted components will have a lower group velocity. This amplifies the effects of dispersion signal broadening, lowering the effective signal to noise ratio (OSNR) and chirp-induced power penalty will be observed. This penalty limits the reach of data and network performance and increases cost.

In negative dispersion fibers, such as MetroCor fiber, the blue-shifted components of the pulse will have a lower group velocity and the red-shifted components will have a higher group velocity. As a result, pulse compression occurs, effectively increasing the OSNR and transmission performance, thus improving system reach. Figure 2 illustrates the difference between positive and negative dispersion fibers with positive frequency chirp.

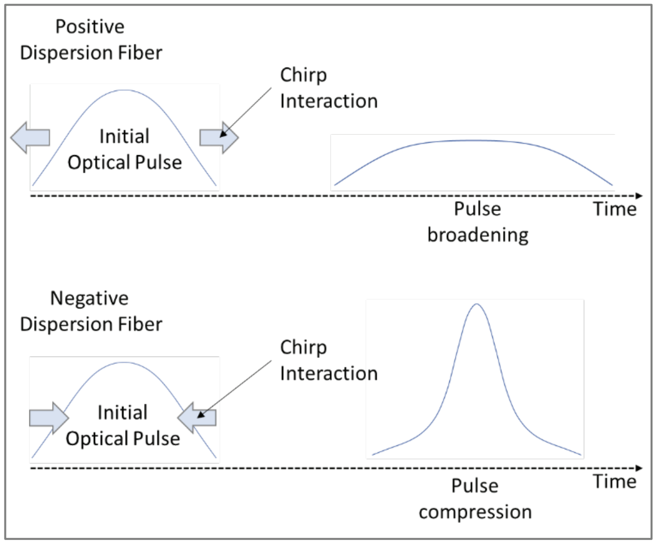

Figure 2: Chirp Interaction on Optical Pulse

Signal degradation due to the interaction of chirp with positive dispersion fiber is more significant for DML-Ts. For DML-As, the absolute value of dispersion and not its sign will play the major role in transmission performance.

DMLs operate by modulating an injection current, which is an input on-off electrical signal, that is applied to the laser diode. The laser diode responds by modulating the optical signal output. Modulation changes the laser properties directly leading to dispersion penalty over longer distances. In general, these properties of DMLs generate limitations on reach and data rate. The moderate negative dispersion of MetroCor fiber made this a suitable solution for operating with DMLs featuring high chirp. However, in the years since MetroCor fiber was introduced, upgrades have been made to DMLs, improving their reach and data rate capabilities. Frequency chirp has been reduced and, in some cases, eliminated, reducing the importance of selecting a fiber designed with negative dispersion.

Advancements in DML

As noted, DMLs are most widely used in 2.5 Gb/s data rate transmission. When data rates increase to 10 Gb/s and above, the frequency chirp of DMLs limit optical performance. Advancements have been made to DMLs to minimize the impact of chirp and maximize data transmission capability. Advancements include: electrical dispersion compensators (EDC), chirp-management and spectral filtering. DMLs can also be fine-tuned and the modulation current can be optimized for the optical fiber with which it is paired. In other situations, DMLs have been replaced with externally modulated lasers (EMLs). EMLs are like DMLs, however the laser diode is integrated with an electro-absorption modulator (EAM). The input on/off electrical signal is applied to the EAM section, not the laser diode as in a DML, to generate/modulate the optical signal output. The laser properties are not changed by process of modulation, so no laser chirp is introduced.

Technology advancements to DMLs and the use of EMLs have reduced the system reach benefit delivered by MetroCor fiber in metropolitan networks. Also, the use of coherent transceivers has improved network performance and minimizes chromatic dispersion. In the year 2000, the DMLs available then were capable of <100 km reach over of standard ITU-T Recommendation G.652 fiber; whereas today's DMLs are rated for 100 km over standard G.652 fiber at 2.5 Gb/s. As a consequence, and after careful assessment of market and technology trends, Corning has decided to obsolete MetroCor fiber from its portfolio of products. End-users looking to make repairs or implement extensions of their MetroCor fiber network should make alternative plans.

Considerations When Repairing and Extending on MetroCor™ Fiber Networks

In recent years, most sales of MetroCor fiber have been to support repairs and extension of existing MetroCor fiber networks. Alternative arrangements now need to be made and a different fiber type identified that minimizes the impact of dissimilar fibers contained in the same link. In the C-band window of operation (1530 – 1565 nm) dispersion is a limiting factor, as dispersion is cumulative over the link length. For a link comprised of MetroCor fiber, it is important to ensure that the cumulative dispersion over the link remains sufficiently negative to ensure mitigation of chirp effects if operating with an earlier design of DML that still generates significant chirp in the signal.

With MetroCor fiber no longer available, introducing a positive dispersion fiber, either splicing in a repair section or as an extension to a current link, will cause the cumulative dispersion of the link to become less negative, which will eventually impact the effectiveness of chirp mitigation. Terrestrial fiber options that can be considered are ITU-T G.655 NZDSF (e.g. LEAF fiber) or G.652 single-mode fiber (e.g. SMF-28®e+ fiber or SMF-28® Ultra fiber).

SMF-28e+ fiber and SMF-28 Ultra fiber have a high positive dispersion in the 1550 nm region (typically 17 ps/nm-km). LEAF fiber has low positive dispersion in the 1550 nm region (typically 4 ps/nm-km). The lower positive dispersion of LEAF fiber causes the cumulative dispersion of a link to be less impacted if introduced into a MetroCor fiber link as a repair or extension.

What is Corning® LEAF® Optical Fiber?

LEAF optical fiber is the most widely deployed NZDSF in the world. More than 40 million km of LEAF fiber has been sold since its introduction. LEAF fiber is optimized for operation in long-haul and metro networks. In addition to lower dispersion, LEAF fiber features industry leading large effective area within the ITU-T G.655 fiber category (LEAF fiber is typically 72 μm^2, most competitive products are 55 μm^2; this enables improved handling of high optical power. LEAF is also an industry leader in terms of delivering both the lowest polarization mode dispersion (PMD) and attenuation specifications of any NZDSF product. More information on LEAF fiber can be found on its Production Information sheet.

Inclusion of LEAF Fiber in a MetroCor™ Fiber Link

Dispersion calculations were done on a theoretical 80 km MetroCor fiber only link. Both LEAF and SMF-28e+ fiber was added to the existing link in 4 km extensions. Cumulative dispersion is represented over a course of 10x 4 km extensions. Similarly, the impact of cumulative dispersion was compared for LEAF fiber and SMF-28e+ fiber with 4 km repair sections (a repair being 4 km of MetroCor fiber are removed and 4 km of either SMF-28e+ fiber or LEAF fiber are spliced in). Figures 3 and 4 represents cumulative dispersion in scenarios of extensions and repairs. Note, as SMF-28e+ fiber and SMF-28 Ultra fiber have the same nominal dispersion at 1550 nm, the effect on cumulative dispersion is the same for the two products.

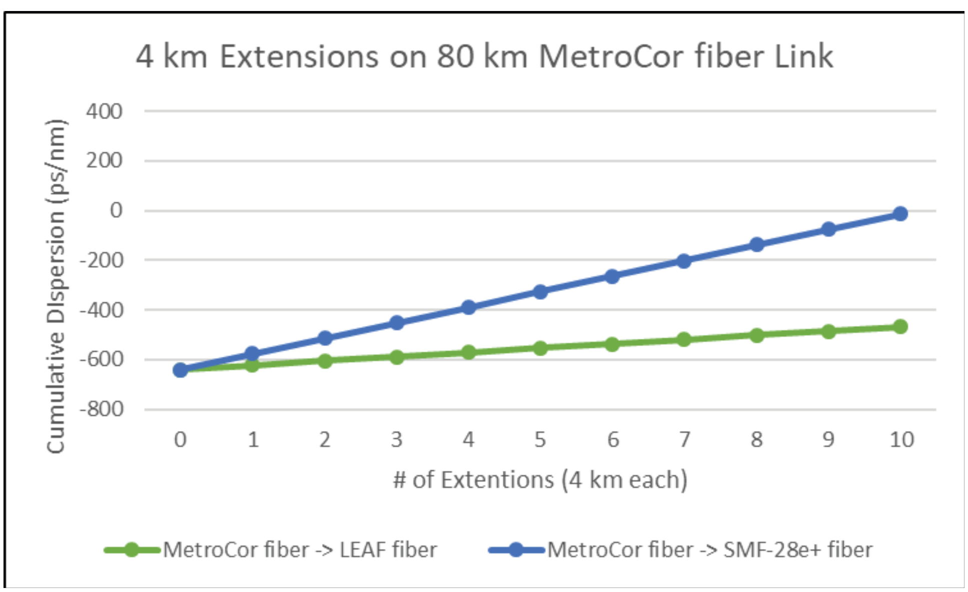

Figure 3: LEAF Fiber and SMF-28e+ Fiber Extension on MetroCor Fiber Link

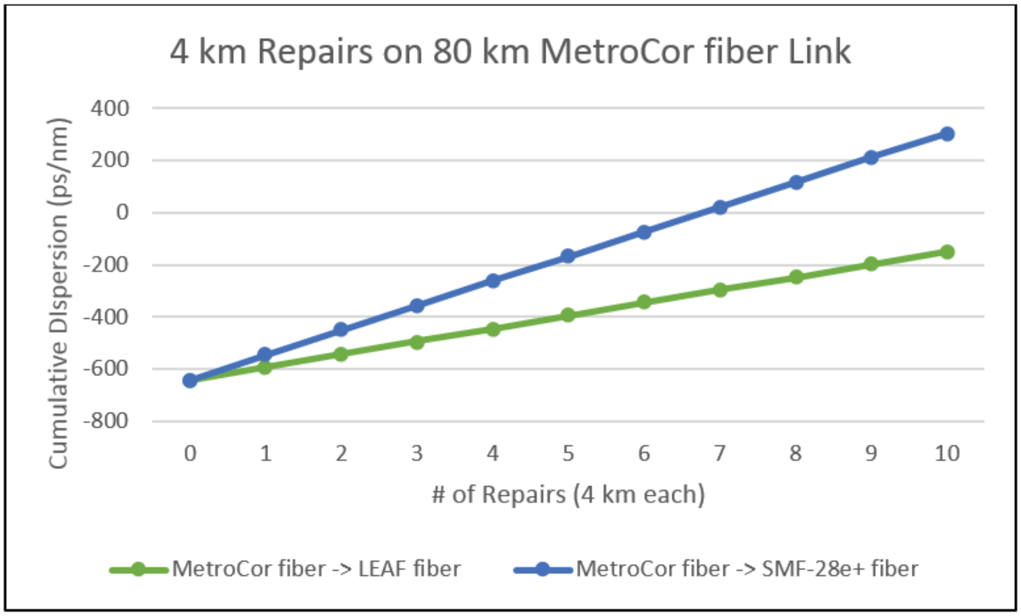

Figure 4: LEAF Fiber and SMF-28e+ Fiber Repairs on MetroCor Fiber Link

It is evident from these calculations that the impact on cumulative dispersion, and therefore on the effect of possible chirp mitigation, is minimized by using LEAF fiber as the replacement rather than SMF-28e+ fiber.

Splicing Loss Analysis

When splicing positive dispersion fiber into a MetroCor fiber link as a repair section, this creates two locations where heterogeneous splices enter the link. Heterogeneous splicing can generate higher loss due to mode field diameter (MFD) mismatch between fiber types and an overall power penalty for the link.

A splice study was conducted between Corning MetroCor fiber, LEAF fiber, and SMF-28 Ultra fiber. All fiber splices where completed using a commercially available fusion splicer with factory settings and measured on an Optical Time Domain Reflectometer (OTDR). Splices were measured in both directions in accordance with IEC 60793-1-40. The unidirectional loss values are averaged to determine the actual loss of the splice; known as bidirectional average. See Table 1.

Normal MFD at 1550 nm

MetroCor fiber:	8.1 μm
LEAF fiber:	9.6 μm
SMF-28 Ultra fiber:	10.4 μm

Note, as SMF-28e+ fiber and SMF-28 Ultra fiber have the same nominal MFD at 1550 nm, the performance of heterogeneous splicing with MetroCor fiber is the same for the two products.

MetroCor fiber exhibited better splice performance with LEAF fiber than with SMF-28 Ultra fiber due to closer MFD match. Average splice loss between MetroCor fiber and LEAF fiber was 0.12 dB whereas between MetroCor fiber and SMF-28 Ultra fiber was 0.21 dB. Considering a maintenance and repair section will introduce two locations of MFD mismatch splice points, LEAF fiber is a less disruptive alternative in MetroCor fiber links, delivering ~0.2 dB additional power compared to splicing in an SMF-28 Ultra fiber repair section.

Product Combination	Wavelength (nm)	Mean (dB)	Stdev.	Maximum (dB)
MetroCor™ fiber to MetroCor™ fiber	1550	0.05	0.023	0.12
MetroCor™ fiber to LEAF® fiber	1550	0.12	0.036	0.23
MetroCor™ fiber to SMF-28® Ultra fiber	1550	0.21	0.052	0.32

Table 1: Splice Data

Corning LEAF Optical Fiber – Most Suitable Replacement for MetroCor Fiber

As previously established, Corning LEAF optical fiber is a well-proven solution used in many networks globally whenever low-dispersion is required. With recent advancements in DMLs, DMLs display less positive frequency chirp, and so dispersion compensation through negative dispersion fibers like MetroCor fiber is of lower importance. Therefore, MetroCor fiber can be effectively substituted with a positive dispersion fiber, and LEAF fiber is the most effective alternative. Compared to regular G.652 fiber, LEAF fiber will provide better MFD matching to MetroCor fiber for reduced splice loss; a low positive dispersion at 1550 nm, equivalent to 25% of the value for G.652 single-mode fiber (SMF-28e+ fiber and SMF-28 Ultra), thus having a lower impact on the cumulative link dispersion. In comparison to MetroCor fiber's effective area of 65 μm^2, LEAF's larger effective area will also improve optical power management and signal strength in the network, while its lower attenuation will improve overall network OSNR. Consequently, Corning recommends LEAF fiber as the next best alternative to MetroCor fiber in any network.

References

1. Paloma R. Horche, Carmina del rio Campos, and Alfredo Martin Minguez, "Interaction of Semiconductor Laser Chirp with Fiber Dispersion: Impact on WDM Directly Modulated System Performance", CENICS 2011: The Fourth International Conference on Advances in Circuits, Electronics and Micro-electronics https://www.thinkmind.org/index.php?view=article&articleid=cenics_2011_1_40_60069

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