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Corning® MetroCor™ Fiber and its Application in Metropolitan Networks

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Abstract

This report describes the testing of a new premium fiber developed by Corning Incorporated that has been optimized for metropolitan-based networks. The performance of MetroCor fiber is evaluated through experimental and system modeling. Comparative studies involving standard single-mode fibers (SSMFs) are also outlined. MetroCor fiber is a non-zero dispersion shifted fiber (NZDSF) and is ITU G.655 compliant. It is optimized to have a lower dispersion across the erbium doped fiber amplifier (EDFA) window compared to standard fibers and is designed to increase the maximum uncompensated reach of low cost, directly modulated (DM/DFB) lasers. The uncompensated reach of such systems can be extended from 100 km when using SSMFs to distances typically in excess of 400 km at 2.5 Gbps. In addition, the maximum uncompensated reach at 10 Gbps, when using externally modulated sources is also improved and again acts to simplify the complexity of these networks.

Introduction

If we consider the projections for wavelength division multiplexing (WDM) deployment, we find that the initial driver behind the technology is fiber exhaust and the fact that we must extract greater value and greater capacity from fibers already deployed. Although current WDM technology is expensive to deploy, it is a viable solution to many different scenarios. Subsequently, as WDM becomes more cost-effective and as it experiences the inevitable fall in price that has been so common with other technologies, we can expect its more rapid and widespread deployment. This anticipated growth is also supported by the fact that as bandwidth demand continues to grow exponentially, we will have little alternative but to develop new solutions that allow us to maximize existing systems and existing networks. Subsequently, the hurdles associated with migrating to this new technology will be vastly outweighed by the benefits of both cost-effectiveness and service flexibility and we can anticipate wide spread deployment of this technology within the next several years. In fact, in the year 2003, based on a Pioneer consulting report, we anticipate the dense wavelength division multiplexing (DWDM) impact in North America alone to exceed $800 million.

Wavelength division multiplexing within metropolitan networks will become increasingly significant and optical transparency within these networks will adopt an ever-increasing role. Moving to an all optical or a predominantly all optical environment will enable several key advantages. The first and most significant advantage will be the increased revenue potential that comes with managing wavelengths and not simply fibers. In other words, where re-sellers presently lease individual fibers, they will now be able to lease wavelengths on these fibers that will dramatically increase the revenue potential from these systems. Another significant advantage is increased speed to market as optical networking will enable new applications to be deployed faster since issues of compatibility between new applications and existing electronics will be eliminated. On the transport side, because optical transparency in very general terms will mean fewer transponders, there will also be more cost-effective upgrades particularly from 2.5 Gbps to 10 Gbps. Reduced space and power requirements will also reduce the maintenance costs of these systems. The final benefit will be improved speed of provisioning. Simply put, optical networking and dynamic bandwidth allocation will allow provisioning times for new customers and applications to be cut in half due to dynamic bandwidth allocation. This means that new services will be deployed along wavelengths as opposed to deploying new fibers, installing new electronics, and updating existing hardware. The benefits of optical networking, therefore, do not lie simply in deploying and maintaining new systems, but also lie in the increased revenue potential these networks will subsequently generate.

It is critical that optical fibers optimized for metropolitan networks are able to address these challenges. While the advantages of transparency include cost effectiveness and service flexibility, increased path lengths will also accompany transparency. These increased spans are unlikely to generate the level of attention surrounding nonlinearities that is the case in long haul. Focus will instead be diverted to dispersion management and in particular, to the impact of residual dispersion within these networks. It is primarily the impact of residual dispersion that needs to be addressed in future systems. Corning believes that emerging metropolitan-based networks will be optimized for the 1550 nm window and where bandwidth and capacity requirements will be adequately satisfied by data rates of 2.5 Gbps. In a continual migration toward higher data rates, these networks must address the economic and value propositions of these systems. In systems operating in the 1310 nm window and in systems not dispersion limited, there will be attenuation limitations due to the availability of suitable amplifiers. This is further compounded in systems operating in the 1400 nm band where the benefits of a low water peak capability have claimed an advantage. In these cases, not only is the availability of suitable amplifiers in question, but also other components such as transmitters or receivers are not freely available. This raises the question as to what real advantage such fibers as AllWave™ bring. Corning's approach is to enable future architectures to be more cost-effective. This can be accomplished by using mature components, by minimizing the dispersion limitations of these components, and by taking advantage of EDFA technology in the 1550 nm window.

This report will highlight those characteristics differentiating Corning's MetroCor fiber from standard fibers and will offer an explanation regarding the dispersion limitations prevalent in these networks. A performance summary will clearly outline the maximum uncompensated reach capabilities of MetroCor fiber when using directly modulated and externally modulated sources. Finally, the compatibility and performance in the 1310 nm window when using either Fabry-Perot (FP) or (DM/DFB) laser sources and the impact of coarse WDM will be evaluated.

MetroCor Fiber vs Standard Single Mode Fiber

Figure 1 outlines the main characteristics differentiating SSMF from MetroCor fiber. The illustration considers dispersion to be a function of wavelength and emphasizes the erbium window between 1530 and 1625 nm. SSMF is characterized by a zero dispersion wavelength at approximately 1310 nm and possesses a positive dispersion profile across the EDFA window. This is in contrast to MetroCor fiber where the zero dispersion is typically located at the opposing end of the window in the range of 1640 nm. The dispersion is negative across the EDFA window.

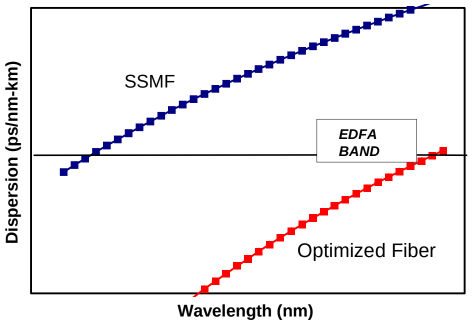

Figure 1. Standard Single Mode Fiber vs MetroCor Fiber.

It is the negative dispersion profile that offsets the positive chirp characterizing the directly modulated laser source and that ultimately leads to pulse compression at the beginning of the signal path. It is pulse compression that leads to additional path lengths of 200 km to 300 km and an increased path length indicates a negative dispersion shifted fiber is well suited to metropolitan networks, particularly those based on optical transparency.

Systems Architecture

The proposed architecture for which simulations in this report are based is shown in Figure 2. While results for other topologies exist, the foundation for this work is the concept of all-optical cross-connects and optical transparency within the network therefore ensuring growth potential and upgradability. However, the advantage of MetroCor fiber is not based solely on transparency and optical networking, but instead is aligned to any metropolitan network where optical path lengths of 100 km are exceeded. The architecture is comprised of a central interoffice (IOF) ring and six smaller access rings. The IOF ring in these simulations consists of six 50-km spans and six 8-km spans for each of the six access rings. These spans are anticipated to reflect worst case scenarios, i.e. longest spans, in any future network. More realistically, these spans could be reduced to smaller lengths of 25 km in the IOF ring and 4 km lengths in the access ring, therefore reducing worst case path lengths from 330 km to 165 km. The optical cross-connects that combine the IOF and access rings could include a liquid crystal switch, a wavelength add drop multiplexer (WADM) and an amplifier where the losses for these components are incorporated accordingly.

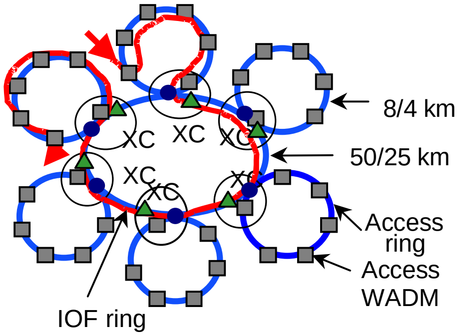

Figure 2. Architecture used for systems modeling at 2.5 Gbps and 10 Gbps. The central IOF ring is modeled as 300 km and the access ring as 50 km in length.

Due to cost and complexity, it is argued that dispersion compensation within the access ring becomes prohibitive, meaning that compensation and amplification is confined purely to the central IOF ring. The difficulty this creates is the ability to perfectly compensate any specific path between two nodes. An example would be to consider the longest, and in view of the nonlinearities therefore, the worst case path studied in these simulations. If this path is to be optimally compensated, then the worst case path would now lie between two closer access nodes within the architecture, therefore leading to residual dispersion within the network. Although large ring sizes and long optical path lengths will inevitably require amplification, they will also require either a low dispersion laser or a low dispersion or metro optimized fiber. The advantage of MetroCor fiber is that in addition to being a cost-effective solution, it also addresses residual dispersion within the network. This means that for typical path lengths, dispersion is no longer an issue for network planners.

MetroCor Fiber Performance Compared to Standard Fiber at 2.5 Gbps

Next generation metropolitan systems will likely be comprised of densely spaced (100–200 GHz) wavelengths in the conventional and long wavelength erbium bands (1530–1620 nm) at 2.5 Gbps transmission rates. For these applications, NZDSFs will offer a longer uncompensated reach capability compared to SSMF and Low Water Peak SSMFs due to smaller absolute dispersion value.

Added to this, negative dispersion shifted fibers, (–D NZDSFs) have the capability to provide even greater dispersion tolerance (up to four times compared to +D NZDSFs) due to the interaction with the positive chirp characterizing directly modulated sources. The enhanced performance of –D NZDSFs with directly modulated lasers has been verified through modeling and demonstration on the Nortel OPTera™ Metro system.

Simulations Using Directly Modulated Lasers

Figure 3 compares the performance of SSMF and MetroCor fiber. The performance is monitored in terms of Q (dB) versus wavelength (nm) for data rates at 2.5 Gbps. Directly modulated lasers are used in these simulations and where the limit for allowable impairments is 9.5 dB. For SSMF, a Q of 6.5 dB represents the worst case performance. For MetroCor fiber, the worst case Q is 11 dB. The impairment in system performance is attributed to the dispersion limitations of SSMF and if, in fact, dispersion compensation were incorporated into the network, then a more comparable performance between the two fiber types would be achieved.

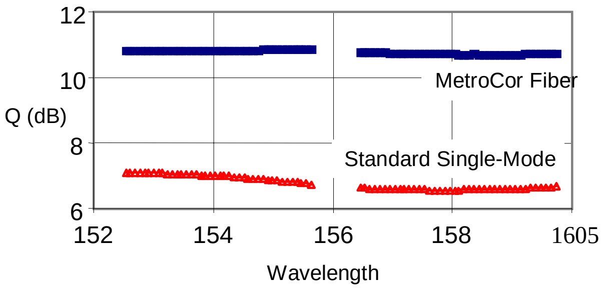

Figure 3. Directly modulated laser: 330 km @ 2.5 Gbps. Uncompensated.

Experimental Results – Corning/Nortel Testing

Joint Nortel/Corning testing and OPTera™ Metro system performance has supported these initial simulation results. An OPTera metro system hub was populated with three adjacent wavelength channels (1557.36 nm, 1562.23 nm and 1558.98 nm). Figure 4 shows the schematic of the negative dispersion fiber transmission line used in the experiment. Five spans with a total length of 418 km of Corning prototype fiber having a total dispersion of –2700 ps/nm at 1560 nm were used in the test. Four in-line amplifiers (Corning PureGain$^{\text{TM}}$ 2200 EDFA module) were used to compensate for the fiber loss. The variable optical attenuators (VOAs) were used to set the optical power level entering each EDFA to –23 dBm per channel and the pump drive currents were adjusted to achieve an optical signal output power of +3 dBm per channel. Measurements were also made over 160 km SMF-28$^{\text{TM}}$ fiber that has the same magnitude of dispersion as 418 km of –D NZDSF, but with the opposite sign (i.e. +2700 ps/nm).

For the SMF-28 fiber testing, the fiber was arranged with 100 km in the first span followed by 60 km in the second span and in this case, only a single in-line amplifier was used in the transmission line. No adjustments were made to the Nortel OPTera transceiver and receiver parameters. The measured receiver power penalties at BER = 10^{-11} as a function of fiber length for both SMF-28 fiber and MetroCor fiber with the overhead turned off are plotted in Figure 5. With the overhead turned off, the transmission distance of the SMF-28 fiber is limited to less than 160 km for a maximum induced power penalty of 2 dB. With the overhead turned on, this distance is reduced to shorter spans accordingly. However, for the negative dispersion shifted fiber, transmission distances of up to at least 418 km were possible and resulted in small negative power penalties with no sign of a BER floor above 10^{-12}. The shape of all three curves is also encouraging, as all three channels remain relatively smooth throughout the test length. In addition, they do not show the expected up-tick in limitation of the interaction of the negative dispersion with the positive chirp of the laser. The difference between the individual curves is attributed to the difference in laser performance as opposed to the difference in wavelengths.

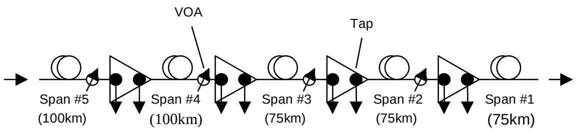

Figure 4. Optical configuration for OPTera system performance over prototype –D NZDSF.

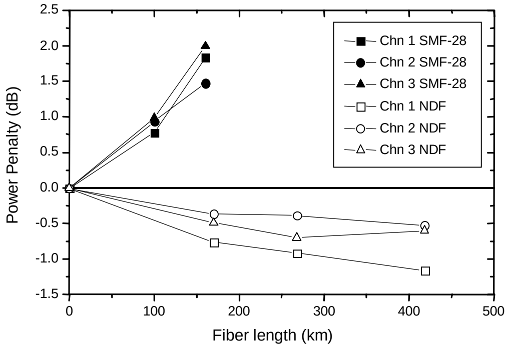

Figure 5. OPTera metro performance for SMF-28^{TM} and negative dispersion fiber. The receiver power penalty vs fiber length is monitored with the overhead turned off.

Experimental Results – Corning Testbed

Figure 6 represents recent results obtained from Corning's testbed facility in Somerset, New Jersey. The testbed has a 32-channel capability and is used to monitor MetroCor fiber within the conventional wavelength band of the EDFA window from 1530 nm to 1560 nm. In Figure 6, the performance of 300 km of SMF-28 fiber is compared to MetroCor fiber and the obvious advantage of MetroCor fiber is apparent. For MetroCor fiber, all channels exceed a bit error rate of 10^{-15} corresponding to Q greater than 9 dB. This is in contrast to SMF-28, where Q less than 3 dB can be observed, which is attributed to the dispersion limitations of the fiber.

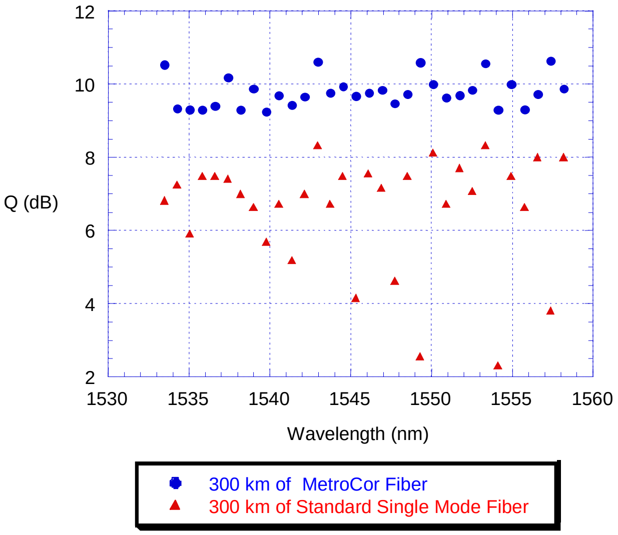

Figure 6. Result from Corning's test facility compares 300 km of MetroCor fiber to 300 km of SMF-28.

Three different laser vendors were used, and the difference in performance for the channel-to-channel is a combination of manufacturing variability and directly modulated laser design. Obviously, some laser sources are quite capable of spans greater than 200 km, however design of the system is enhanced when existing lasers are readily available.

MetroCor Fiber Performance Compared to Standard Fiber at 10 Gbps

When systems migrate to data rates of 10 Gbps and higher, with today's technology it is unavoidable that externally modulated sources will be used. While MetroCor fiber continues to demonstrate improved performance and increased uncompensated reach compared to standard fibers, a number of points first have to be clarified. The first is the use of externally modulated sources and the second is the increase in per channel powers. Whereas per-channel powers of 1 dBm have typically been used in simulations at 2.5 Gbps, per channel powers of 5 dBm are necessary at 10 Gbps. In addition, pre-amplification is also required at the receiver in order to address the thermal noise limitations. The distinguishing element here is that in point-to-point systems, which is the case in long haul systems, the upgrade path and the economics regarding the migration to higher data rates are relatively straightforward. However, in metro systems characterized by multiple transmitters and multiple receivers, this is no longer the case, and this migration could prove to be cost prohibitive due to the shear volume of components in these systems.

Maximum Uncompensated Reach

Maximum uncompensated reach studies determine distances that can be achieved within the network before dispersion compensation is required. For SSMFs at a wavelength of 1550 nm, the dispersion tolerance is typically 17-ps/nm km. This magnitude is significantly greater compared to MetroCor fiber, which is nominally –7.2 ps/nm km at this wavelength. In contrast to directly modulated lasers, externally modulated sources are characterized by a significantly smaller chirp, which can be biased to be either positive or negative. This means that the maximum uncompensated reach advantage of MetroCor fiber now relies more strongly on its reduced level of dispersion in this operating window. However, simulation results shown in Figure 7 demonstrate the advantage of MetroCor fiber and the improved performance anticipated at higher data rates. Figure 7 demonstrates that the maximum uncompensated reach for MetroCor fiber is 170 km and is dispersion limited within the C band as this is where the dispersion is greatest – see Figure 1. SSMFs on the other hand, are dispersion limited at spans exceeding 75 km. So although MetroCor fiber is optimized for data rates at 2.5 Gbps in order to exploit the positive chirp characterizing cost-effective sources, it also demonstrates an upgrade path and improved performance compared to standard fibers at data rates of 10 Gbps.

Fiber	Band	Maximum Uncompensated Reach (km)
-D NZDSF	C	**169**
-D NZDSF	L	**205**
SSMF	C	**83**
SSMF	L	**74**

Figure 7. Maximum uncompensated reach at 10 Gbps: MetroCor fiber vs standard single mode fiber.

Operation at 1310 nm – MetroCor Fiber vs Standard Fiber

At present, most metro systems currently run at 1310 nm using SSMF. In the case of Gigabit Ethernet, the standards permit the use of multi-mode Fabry-Perot lasers for up to 5 km over standard single-mode fiber. FP lasers have very little dispersion tolerance and are therefore not ideally suited to either +D or –D NZDSFs. However, distances approaching 5 km have been demonstrated using MetroCor fiber, which is in contrast to the 10 km that can be typically achieved using SMF-28 fiber. Directly modulated lasers on the other hand, have demonstrated error free performance over 40 km of MetroCor fiber using a commercial directly modulated DFB source at 1310 nm. The results indicate a negative power penalty. Results for 1310 nm OC-48-testing using uncooled DFB lasers are shown in Figure 8, where –1 dB power penalty after 40 km of MetroCor fiber is demonstrated when a Sumitomo device was used. This negative power penalty compared to SMF-28 fiber can be attributed to the chirp of the laser and the fact that a –D NZDSF leads to pulse compression and improved performance. Similar results were obtained for all five 1310 nm OC-48 uncooled transmitters tested. However, these results are for a limited number of devices, and commercial systems testing combined with a greater sampling size would be required in order to support these results.

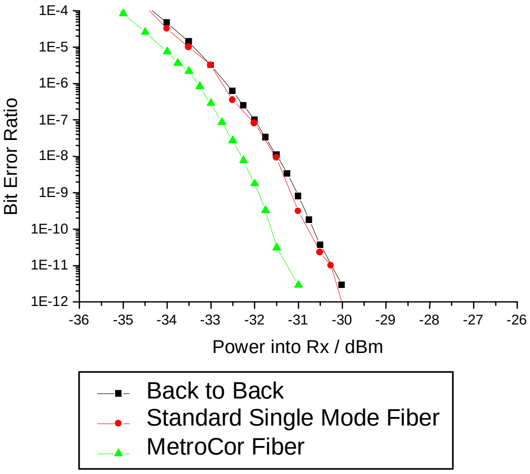

Figure 8. 1310 OC-48 testing (Sumitomo uncooled DFB). –1 dB power penalty after 40 km of MetroCor fiber.

Coarse Wavelength Division Multiplexing

Coarse WDM systems can potentially transmit widely spaced wavelengths (∪ 20 nm) across the entire 1300 nm – 1600 nm band and a low water peak capability claims an advantage in these systems. The water peak in silica fibers is at 1383 nm, but extends typically from 1375 nm to 1400 nm. Theoretically, the attenuation can be lowered to 0.27 dB/km in SSMF within this region by completely removing the hydroxyl (OH) ion. MetroCor fiber has been introduced with reduced water peak attenuation, but because no components presently exist in this window, it is difficult to see how systems at present can be advantaged. Nevertheless, MetroCor fiber has a low water peak capability of less than or equal to 0.40 dB/km. In coarse WDM, nonlinearities are not considered an issue for lengths shorter than 20 km. Consequently +D NZDSF which might be thought of as having an inherent disadvantage attributed to a zero dispersion point within the channel plan would be unaffected. At present, no amplification is possible within the 1400 nm window, and as systems move to DWDM the associated DEMUX losses will increase and therefore mean that amplification will be required. In fact, coarse WDM using as few as four channels over 35-km lengths will require amplification.

Conclusions

MetroCor fiber is a premium fiber that is optimized to address the specific challenges regarding performance and cost in metropolitan networks. In contrast to long haul, the typical lengths within the metropolitan network will lie between 120 km and 200 km, although lengths greater 300 km will not be uncommon. In addition to this, the impact of optical transparency and optical networking will only act to further increase these path lengths and increase the challenges facing network planners. To date there is no single solution that simultaneously satisfies the challenges of cost, dispersion management and residual dispersion within these networks. Metropolitan networks are characterized by multiple path lengths and need to be cost-effective due to the volume of components in these systems. To date dispersion related issues when using SSMFs come into effect at spans not much greater than 100 km and have to be addressed with either expensive, complicated compensation schemes, or alternatively even more expensive externally modulated sources. MetroCor fiber is set to change this. Its unique properties of a negative dispersion profile across the EDFA window mean that systems will no longer be dispersion limited and at the same time will be advantaged by low cost directly modulated sources. The unique combination of a positive chirp which characterizes these sources and the negative dispersion profile of an optimized fiber, mean that the uncompensated reach of these systems will be extended from 100 km when using SSMFs to distances typically exceeding 400 km.