Practical Fiber Considerations for High-Capacity Systems: From Campus to Long Haul

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Abstract: The challenges and opportunities for optical fibers in high-capacity systems from Campus to Long-Haul is discussed. System enhancements can be delivered by constrained fiber zero-dispersion wavelengths, increased fiber bend resilience and reduced fiber outer diameter. © 2022 Corning Optical Communications.

1. Introduction

Modern telecommunication networks are chasing an ever-expanding demand for capacity from users. This requires network operators to use every means possible to avoid capacity exhaust. The telecommunication industry is, today, considering multiple bands of transmission and complex modulation schemes to deliver this capacity. The drive impacts all networks from Campus to Long Haul and it is leading to some interesting parallels. Very high-speed transmission designs in short reach networks are experiencing dispersion limitations last seen in the 1990's in long-haul [1]. Increasing fiber counts in long-haul networks will need the high density of fiber in cable of the kind implemented in short reach networks of the past decade [2]. From Campus to Long Haul, fiber design is coming into sharper focus for the practical implementation of high-capacity systems. In this paper, present and future fibers and cable technologies are described along with the impact of lambda-zero, fiber bend resilience and fiber outer diameter on high-capacity networks from Campus to Long Haul is analyzed.

2. Applications

2.1. Campus Networks

In recent years the IEEE have standardized transmission systems that operate over two and six kilometers (km) for Campus Networks using intensity modulated direct detection systems (IM/DD) that can deliver up to 400Gbps of data over four wavelengths using PAM4 modulation [3]. These systems provide high capacity, low power, and low-cost transmission in the O-Band (in comparison to Dense WDM (DWDM) or coherent alternatives). ITU-T G.652 fibers have a zero-dispersion wavelength within the range of 1300-1324 nanometers (nm); resulting in chromatic dispersion at its lowest in this window. In high-speed IM/DD systems the combination of directly modulated chirped lasers with short pulse widths leads to limitations on the pulse broadening allowable before such systems are rendered inoperable. These chromatic dispersion limitations in the O-Band are like those experienced in the C-Band in long haul DWDM systems of the 1990's. In that epoch long haul system designers turned to ITU-T G.655 non-zero dispersion shifted fibers to solve these issues. Dispersion shifted fibers have been proposed for O-Band applications in the present day [4], but the use of a different fiber is undesirable because it delivers a fiber that works for one transmission type but not necessarily others. ITU-T G.652.D standard is the most used fiber in modern networks and transmission systems are designed to operate with this base standard. Therefore, future transmission systems are most likely to operate over ITU-T G.652.D fiber. Difficulties can occur in installation when using dispersion shifted fibers within a predominantly G.652.D network. The mode field diameters (MFD) of dispersion shifted fiber are often incompatible with existing fiber plant. The MFD of a fiber is the numerical representation of the size of the light spot at a specific wavelength. When incompatible MFDs are spliced, differences in MFD at the joint can create ambiguities in the measurement of splice loss. In campus networks with many connections, this can lead to time consuming rework in splice, testing, and installation. Nevertheless, solutions need to be found for the chromatic dispersion limitations of these high-speed IM/DD high systems.

Adjusting lambda-zero dispersion wavelength range for extended short-length system links.

Positive dispersion is more damaging than negative dispersion because negative dispersion leads to pulse compression rather than spread. The use of Forward Error Correction (FEC) and negative chirp on the transmitted pulse can mitigate, but not totally negate, the effects of chromatic dispersion. One solution to the problem, is therefore the avoidance of lower zero-dispersion wavelength values (lambda-zero) for fiber in the allowable ITU-T G.652.D lambda-zero range since these values generate the highest positive dispersion in the window of transmission. Constraint of the lambda-zero range within an ITU-T G.652.D compliant fiber delivers reduced dispersion in the O-Band maintaining system performance to within acceptable levels. This means that link budgets can be relaxed, reducing complexity in the transceiver or link lengths extended. Simultaneously, compatibility with existing fiber plant is maintained and standards compliant operation, should transmission systems change in the future, is ensured. The available reduction in positive dispersion for an ITU-T G.652.D compliant, lambda-zero constrained fiber with a fiber lambda-zero distribution confined between 1312-1324 nm is shown in Fig 1. and compared with a standard ITU-T G.652.D fiber. This reduction in dispersion leads directly to a reduction in pulse spread. In the case of an IEEE LR4 PAM4 400G system, a six km link using ITU-T G.652.D standard fiber can be extended to nine km for the same pulse spread. For 100GBaud links in the O-Band the system impairments are even greater. The use of LAN WDM lasers with a tighter, 800GHz channel spacing, provides the option of 4 channels within the available transmission window and a longer reach of 10 km for links of this type [5]. Using a lambda-zero constrained fiber will deliver eight channels at 100GBaud over 10 km, effectively doubling the available bandwidth, whilst maintaining compliance with ITU-T G.652.D fiber.

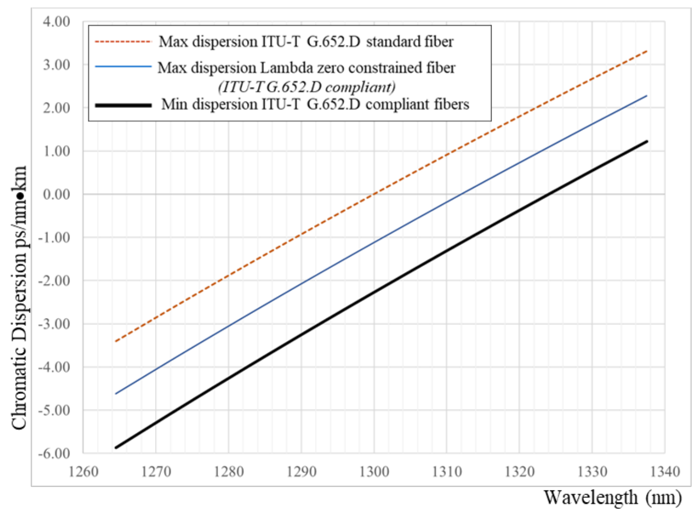

Fig. 1. Chromatic dispersion in the O-Band for a standard ITU-T G.652.D fiber and an ITU-T G.652.D compliant lambda-zero constrained fiber. The figure shows reduced chromatic dispersion can be achieved within the wavelengths of interest by constraining the lambda-zero values.

2.2. Long Haul Networks – Reduced fiber OD and increased macrobend resilience for higher bandwidths.

Capacity requirements in Long Haul networks are increasing at between 30-40% CAGR [6]. If active equipment capacity gains begin to slow due to the Shannon limit, at 30-40% traffic growth rate, cables laid today will require thousands of fibers to meet capacity demand over the cable lifetime of 20-25 years. The use of wide-band transmission in the S, C and L Bands have been proposed for increasing bandwidths and therefore capacity [7]. These systems require the stitching together of transmission bands, each using different amplification techniques, in engineered systems. While wide-band transmission provides a welcome increase of capacity of up to four times that of existing systems, the doubling of capacity every two-three years mean that the use of higher fiber counts in long haul networks is inevitable to deliver on market demands. While short reach networks are facing chromatic dispersion challenges, historically experienced in long-haul networks, so too long-haul networks will soon face challenges related to high fiber count requirements that have historically been faced by short reach networks. Whilst fiber counts will need to rise the available space for installation will not. This leads to the need for high fiber density in cable and results in cable designs that represent a more challenging bend environment than traditional loose tube cable designs [8]. The bends incurred in high density cables are the result of a constrained environment for the fiber in cable leading to microbend and/or macrobend related effects. Microbend tends to dominate in cable tubes with minimal free space. Example traces of attenuation increases for standard G.652.D fibers are shown in Fig 2. The macrobend trace is the loss expected from one, 30mm radius bend of a standard G.652.D fiber. Fig 2. demonstrates why the bend environment matters due to macrobend and microbend increase at longer wavelengths, co-incident with the window of transmission for wideband long-haul networks [9]. In recent years, the ITU has defined bend resilient fiber specifications in the ITU-T Recommendation G.657 [10]. These recommendations define the limits of expected attenuation at specific bend radii.

Reduced fiber OD and increased macrobend resilience for higher bandwidths.

Standard fibers used in networks of the past and still installed today are 242 µm in outer diameter (OD). Fibers are available, today, with smaller diameters of between 200-180 µm. These smaller diameter fibers allow a higher fiber in cable density supporting more bandwidth across a space constrained cabled link. Fibers of this type have been used extensively in short reach applications that demand very high fiber counts in constrained available space. Further reduction of fiber outer diameter may be possible by the reduction of either the cladding diameter of the fiber glass or further reductions in coating, reaching fiber ODs of approximately 160 µm [11]. Cabled densities using fibers of this OD could provide almost twice the number of fibers in cable for the same OD compared with current 242 µm designs [12]. Lower OD fibers are often designed with an ITU-T G.657 bend resilience, required to deliver low cabled attenuation within the bend environment found in high density cables. Careful design of fibers with low OD, ITU-T G.657 bend resilience and low attenuation, across a wide bandwidth provides an ideal medium for capacity and reach increase in Long-Haul networks that combine high fiber counts, within high density cables, with high and wide bandwidth DWDM coherent systems.

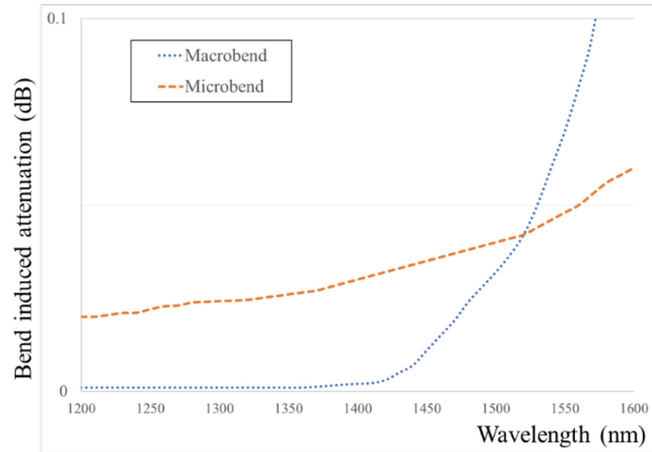

Fig 2. Example traces of bend induced attenuation with wavelength for a G.652.D fiber. Macrobend attenuation is shown for 1 turn of a 30mm radius mandrel. Tighter bend radii will induce higher attenuation. Bend related attenuation is most significant at longer wavelengths and can impact the fiber cabled attenuation in high density cable, at these wavelengths.

3. Conclusion

Careful fiber design can reduce complexity in transmission by delivering a low impairment environment, that can increase link margins, avoiding systems that are operating on the edge. In short reach high-capacity O-Band systems, a constrained lambda-zero fiber can increase reach by 50% or, under certain circumstances double bandwidths.
In Long Haul systems, even with an increase in capacity per fiber the ever-increasing demand for capacity will lead inevitably to higher fiber counts across network links. Reduced outer diameter geometries and increased bend resilience can deliver higher fiber counts within the same amount of space, thus significantly increasing available bandwidths across a link, without compromise on attenuation at longer wavelengths.

4. References

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