White Paper

Selection of different ITU-T G.652 cabled -fibers in optical fiber networks

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Abstract
The selection of right fiber or cable in network deployment is very critical due to high deployment costs. In this paper, various operational factors affecting 100G transmission over G.652.D fiber -cables are discussed to make the right fiber selection for the long -haul network.

Keywords
ITU-T G.652.D Optical fiber, OSNR, Span Loss, Optical Fiber Networks

1. Introduction

Internet traffic is continuously growing with the demand for high speed broadband services, high performance tele-computing, mobile broadband access for smart portable devices, and high definition television and other bandwidth consuming applications. Network operators generally address this traffic growth using Dense Wavelength Division Multiplexing (DWDM) technologies and by increasing the number of deployed optical fibers in the network. Initially, single mode ITU-T.G.652 fiber was developed and optimized for operation at 1310 nm wavelength. However, due to reduced Rayleigh scattering at higher wavelengths and the invention of Erbium doped fiber amplifiers (EDFA) operating at 1550 nm, the transmission spectrum in long distance and metro -city networks moved to 1550 nm. As bit rate increased to 10 Gbit/s to meet capacity demands, large Chromatic Dispersion (CD) of G.652 fiber became a serious problem in long distance transmission at 1550 nm, which was resolved by introduction of dispersion compensation fiber (DCF) modules and by using ITU-T G.655 reduced dispersion fibers. As data rate continued to increase to 40 and 100 Gbit/s, the coherent modulation and demodulation technologies were introduced, which along with digital signal processing (DSP) made electronic compensation of CD possible. The DSP could also successfully mitigate Polarization Mode Dispersion (PMD) which dominates at high bit rates and longer transmission distance links. Therefore, CD and PMD are no longer an issue in long distance transmission. The cabled -fiber attenuation started becoming the limiting factor in long transmission distance. This led to a resurgence of G.652 fiber types which is now the dominant fiber deployed in long- haul and metro -city networks. The latest developments of G.652 fiber are targeted to reduce fiber attenuation allowing larger repeater spacing and longer distance data transmission. Optical fiber cable deployment is expensive because it requires complete geographical audit, high cost for digging and trenching streets, and right of way access to network points of presence. Therefore, it is important to deploy the right fiber, which not only meets today's network requirements, but also support future upgrades and is reliable over the fiber life time. This white paper provides an overview of various operational factors affecting100G signal transmission performance in long distance link and could be helpful in better decision making over fiber selection for the operator's network.

2. Factors affecting optical communication systems

In an optical communication system, information bearing electrical signal is converted into optical signal at the transmitter and then forwarded to a receiver placed thousands of kilometers away through an optical fiber. At the receiver, the optical signal is converted back to electrical signal and the information is recovered.

There are three key factors that can affect optical signal transmission in an optical network.

A. Optical power loss or Attenuation:

As the information carrying optical signal propagates inside an optical fiber, it loses optical power due to absorption, scattering, bending, splicing and other radiation losses. Due to these losses, the optical signal becomes very weak to reconstruct the information sent by the transmitter at the receiver. A term called Optical Signal to Noise Ratio (OSNR) is commonly used in power budget calculations. The target is to keep OSNR high enough so that the optical signal can be successfully detected at the receiver.

B. Dispersion:

Dispersion is a phenomenon of temporal broadening / spreading of the modulated optical signal while travelling through the optical fiber. Dispersion limits the information carrying capacity at high bit rates and long transmission link. In single mode optical fibers, there are two main types of dispersion: chromatic dispersion and polarization mode dispersion.

C. Non-linear effects:
Optical non-linear effects are mainly caused by high optical power density. As the optical power level and number of optical channels increases non-linear effects may become the limiting factor in optical transmission systems.

3. ITU-T G.652 category single mode optical fibers
ITU-T G.652 category non-dispersion -shifted single mode optical fiber is the most widely deployed optical fiber. According to CRU estimates, around 92% of global shipments of optical fibers are G.652 type fibers[1]. There are four types of G.652 fibers are mentioned in the ITU-T recommendations. In Table 1, key differential characteristics, transmission bands and applications are summarized. Again out of these four types of G.652 fibers, G.652.D fiber is most popular mainly due to its superior characteristics. Therefore, G.652.D fiber has been heavily researched for further performance improvement by optical fiber manufacturers. The improvement direction is mainly targeted towards overcoming optical signal attenuation, transmission non-linearity and PMD. Improving PMD values is not as significant due to the wide adaption of coherent receivers. Therefore, reducing optical attenuation and improvement in non-linearity parameters are the choices left. The recent developments in G.652.D category fibers are mostly focused to reduce attenuation.

Table 1: Differences between various categories of ITU-T G.652 fibers

Fiber Type	Key Differential Characteristics	Transmission bands	Applications
G.652.A	Max. PMD = 0.5 ps/√km	0 Band (1310 nm region) C Band (1550 nm region)	Support applications such as STM-16, STM-256, 10G up to 40 km
G.652.B	Max. Attenuation & Macro bend loss specified at 1625 nm; Max. PMD = 0.2 ps/√km	0 Band (1310 nm region) C Band (1550 nm region) L Band (1625 nm region)	Some higher bit rate applications like STM-64
G.652.C	Max. Attenuation specified at 1383 nm and 1310 to 1625 nm; Max. PMD = 0.5 ps/√km	0, E, 5, C, L bands	Similar to G.652.A. However, transmission bands extended to E, S and L. CWDM system.
G.652.D	Max. Attenuation specified at 1383 nm and 1310 to 1625 nm; Max. PMD = 0.2 ps/√km	0, E, 5, C, L bands	Similar to G.652.B. However, transmission bands extended to E, S and L. CWDM system.

A comparison between various characteristics of ITU-T G.652.D with Sterlite OH-LITE®, OH-LITE® (E), OH-LITE® (REDUCED LOSS) and Extreme Reduced Loss fibers are given in Table 2.

Table 2: Comparison between ITU-T G.652.D and Sterlite's OH-LITE® fibers and Extreme Reduced Loss fibers[2-5]

Attributes	ITU-T G.652.D	Sterlite OH-LITE®	Sterlite OH-LITE® (E)	Sterlite OH- LITE® (REDUCED LOSS)	Supplier - A EXTREME REDUCED LOSS
Maximum Attenuation at 1310 nm	0.4 dB/km	0.34 dB/km	0.33 dB/km	0.32 dB/km	0.31 dB/km
Maximum Attenuation at 1550 nm	0.3 dB/km	0.20 dB/km	0.19dB/km	0.18 dB/km	0.17 dB/km
Maximum Attenuation at 1625 nm	0.4 dB/km	0.23 dB/km	0.21dB/km	0.20 dB/km	0.20 dB/km
Maximum Attenuation at 1383 nm± 3 nm	0.4 dB/km	0.34 dB/km	0.31dB/km	0.31 dB/km	Not specified
Maximum Macro bend loss (100 Turns) on 30±1 mm radius mandrel	0.1 dB at 1625 nm	0.1 dB at 1625 nm	0.03 dB at 1625 nm	0.03 dB at 1625 nm	0.05 dB at 1625 nm

4. Fiber selection based on network requirements

Optical networks enable long distance high bit rate data transmission. The core network also known as the backbone network, has switches and routers spread over long distances (1000 km). Metro networks extend connectivity from the core network to the edge and provide traffic aggregation for a wide range of end user services within cities (~ 100 - 300 km). In core and metro network systems signals are transmitted over WDM / DWDM channels around 1550 nm.

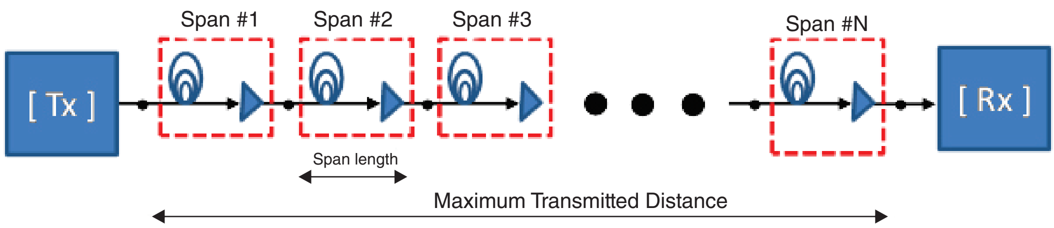

Figure 1: The optical fiber transport link

An architectural overview of an end to end optical transport link between optical switches/routers is shown in Fig. 1. In general, optical amplifiers are spaced 50 to 80 km apart depending on network operators. The span link is made by splicing several fiber cable segments, with each cable segment having a typical length of 4 km. At each cable splice junction point, there is an additional 10 turns of buffer fiber wrapped on 30 mm radius splice trays in the joint closures. Since there are many joint closures per span, therefore, the macro bend loss introduced by each Joint-Enclosure need to be considered in total span loss estimates. Typical link parameters for customer's network system operating with 100Gbit/s coherent systems in the C-band are given in Table 3.

The launch power per channel and target OSNR at receiver were considered after extensive propagation testing with 100G DWDM channels over amplified systems over 1840 km of Sterlite OH-LITE® (G.652.D) at Sterlite's Center of Excellence[6]. The optical fiber cable cuts are critical in many developing countries due to undergoing civil construction and infrastructure upgrades. These cabled-fiber cuts can significantly increase the span losses due to additional splice and macro bend loss at each joint closure. Therefore, it is essential to consider additional span loss due to cable cuts in the link design till end of life of fiber cable, which is typically for 25 years.

In an optical network the maximum transmission distance can be limited by various operational factors such as data rate per channel, span length, cable length, number of splices per span, number of cabled-fiber cuts during the lifetime of the fiber, mid-stage amplifier's dynamic gain range and noise figure, launch power, system margin including nonlinear penalty, fiber aging margin, etc.

Table 3:Specification of Network System Parameters

System Parameters		Typical Specification
OSNR for 100G Coherent Signal at PRE-SD-FEC BER of $1x10^{-2}$		14 dB
Target OSNR Including 3 dB System Margin		14+3 = 17 dB
Launch Power		0 dBm
EDFA Dynamic Gain Range		15 to 25 dB
EDFA Noise Figures		10.3 to 5.9 dB
Number of cabled-fiber cuts		2 or 14 cuts/year/1000 km
Mean Splice Loss at cable joints		0.05 dB
Number of splices at cable cut joints		1
Extra cable length at cut joints		10 m
Connector Loss per Span		2x0.5 =1.0 dB
Typical Cable Length		4 km
Macro-bend Loss in Joint Enclosure @ 1550 nm	G.652.D OH-LITE®	0.005 dB@10 Turns of 30 mm Radius
	G.652.D OH-LITE® (E)	0.0015 dB@10 Turns of 30 mm Radius
	G.652. D OH-LITE® (Reduced Loss)	0.0015 dB@10 turns of 30 mm Radius
	Supplier-A: (Extreme Reduced Loss)	0.0025 dB@10 turns of 30 mm Radius

For a long-haul optical network having roughly uniform span losses, OSNR at the receiver is calculated by the following formula

$$\mathbf{OSNR_{Rx} = 58 + P_{in}\ (dBm) - NF\ (dB) - Span\ loss(dB) - 10.1og_{10}\ (\#Span)}$$

Where,

Span Loss = Cabled Fiber attenuation x Span length + Connector loss + # Cable joints x (Splice loss + Macrobend loss) + # Cuts in 25 years per span x (Mean splice loss + Macrobend loss)

A numerical study of maximum transmission distance for 100 Gbit/s PDM-QPSK signals with a minimum OSNR of 17 dB (including 3 dB system margin and 14 dB OSNR requiredfor PRE-SD-FEC-BER of $1x10^{-2}$) was performed using different G.652.D cabled-fiber types in a network with different span length in the range of 50 to 100 km.

The study was performed for two different regional network architectures suffering from cabled-fiber cuts of 14 & 2 cuts/year/1000 km in developing countries (ex. India) and developed countries (Ex. US, Europe/ Japan), respectively. For a network suffering with cabled-fiber cuts of 2 cuts/year/1000 km, the variation of maximum transmission distance at different span length for different cabled-fiber types are shown in Table 4.

Table 4: Maximum transmission distance with cabled-fiber cuts of 2 cuts/year/1000 km

Span length (km)	# Normalized additional cabled-fiber cuts per span in 25 years	Maximum Transmission distance (in km) for different cabled-fiber types for 100Gbit/s @17 dB OSNR					
		Cabled fiber attenuation @1550 nm					
		0.22 dB/km	0.21 dB/km	0.20 dB/km	oig dB/km	0.18 dB/km	0.17 dB/km
		OH-LITE®	OH-LITE®	OH-LITE® (E)	OH-LITE® (Reduced Loss)	Supplier-A (Extreme Reduced Loss)	Supplier-A (Extreme Reduced Loss)
50	3	1850	1850	1850	1850	1850	1850
60	3	2250	2250	2250	2250	2250	2250
70	4	2150	2300	2450	2600	2600	2600
80	4	1950	2150	2350	2550	2750	2850
90	5	1500	1750	2000	2300	2550	2750
100	5	1100	1350	1650	1950	2250	2550

As evident in Table 4, there is no significant improvement in the maximum transmission distance in an optical network built of span length shorter than 60 km irrespective of use of reduced loss fiber-cable types. This is due to span losses are lower than the minimum gain of EDFA under operation. While in a link with span length longer than 60 km, the span loss becomes much larger than the minimum gain of EDFA. In such case, the received OSNR at the end of the link would directly benefit from lower attenuation characteristics of different cabled-fiber types. While at reduced span loss, the noise figure (NF) of EDFA is significantly increased and would degrade the received OSNR depending on NF-Gain characteristics of EDFA. In standard operation, the proportional gain in OSNR due to reduced loss fiber is higher than the proportional degradation due to EDFA NF. As a result, the overall received OSNR would relatively be improved in the link made of lower loss fiber-cables so that much longer maximum transmission distance can be achieved. For a network operating in very low cabled-fiber cut geographical region, this is an inherited bonus and it is recommended to make adequate fiber selection based on maximum transmission distance instead of deploying the lowest attenuation fibers only. The advantage in transmission reach is not monotonic with span length for any of the cabled-fiber choice. It is found that the maximum reach peaks at a certain value depending on the fiber choice which lies in the span length range of 70-80 km, approximately. It is also evident that all cabled-fibers are suitable in achieving a maximum transmission distance of 1100 km even with the span length upto 100 km.

Similar studies were performed for a network suffering from high cable cuts regions suffering a cut rate of 14 cuts/year/1000 km. The simulation results are presented in Table 5. It can be seen that there is no significant improvement in the maximum transmission distance in a network with span length shorter than 60 km irrespective of use of reduced loss fiber-cable types and was limited by minimum gain of mid span EDFAs. As the span length increases, the number of cable cuts increases which would increase the span loss and this would reduce the maximum transmission distance. For a network having span length longer than 100 km, it is recommended to use higher gain EDFAs since the span loss exceeds the maximum gain of EDFA considered in this study. Besides, a maximum transmission distance of 1150 km (~25% reduced than network with cabled-fiber cuts of 2 cuts/year/1000 km) could be achieved with a span length upto 90 km for all cabled-fiber types. However, the 'Reduced Loss' fibers maintained its proportional advantages in achieving longer maximum transmission distance for span length above 60 km.

Table 5: Maximum transmission distance with cabled-fiber cuts of 14 cuts/year/1000 km

Span length (km)	# Normalized additional cabled-fiber cuts per span in 25 years	Maximum Transmission distance (in km) for different cabled-fiber types for 100Gbit/s @17 dB OSNR					
		Cabled fiber attenuation @1550 nm					
		0.22 dB/km	0.21 dB/km	0.20 dB/km	oig dB/km	0.18 dB/km	0.17 dB/km
		OH-LITE®	OH-LITE®	OH-LITE® (E)	OH-LITE® (Reduced Loss)	Supplier-A (Extreme Reduced Loss)	Supplier-A (Extreme Reduced Loss)
50	18	1850	1850	1850	1850	1850	1850
60	21	2150	2200	2250	2250	2250	2250
70	25	1950	2100	2250	2400	2500	2600
80	28	1600	1800	2050	2250	2450	2600
90	32	1150	1350	1650	1900	2150	2400
100	35	*	*	1200	1500	1800	2050

(* span loss exceeds EDFA's maximum gain]

It can be seen that longer span length doesn't often result in longer maximum transmission distance despite using 'Extreme Reduced loss' fiber-cables. The best performance can be achieved if the span length is maintained between 60 to 80 km with all cabled-fiber types including 'Reduced Loss' and 'Extreme Reduced Loss' fibers. The presented results in this paper can be used as guideline for the operator in the selection of the right fiber considering the desired maximum transmission. The advantages and disadvantages of different G.652.D category fibers are summarized in Table 6.

Table 6: Comparison of different fiber types and selection strategy

Fiber Types	G.652.D OH-LITE®	G.652.D. OH-LITE® (E)	G.652.D OH-LITE® (REDUCED LOSS)	Extreme Reduced Loss
OSNR benefit	Reference	✓	✓✓	✓✓✓
Cabled-Fiber cuts keeping current commercial Amps	-	✓	✓✓	✓✓
Macro bend loss	-	✓	✓	✓
Reduced OH peak (Transmission in E-band)	-	✓✓	✓✓	X X
Interoperability with other G.652.D fibers	✓	✓	✓	X

In a long-haul network with span length shorter than 60 km, going from G.652.D (OH-LITE®) to 'Extreme Reduced Loss' fiber-cable would not give any extra benefit but will increase the deployment cost. While in case of longer span length than 60 km, a significant improvement in OSNR margin is possible in 'Reduced loss' fibers. If the span length is between 60 to 100 km using 'Extreme Reduced Loss' fibers provides some incremental benefit, which can be translated in resilience of network suffering from larger cabled-fiber cuts or in terms of achieving larger maximum transmission distance. But it is recommended to carefully choose the optimal link parameter for a given type of fiber to yield maximum benefits. Besides, the water peak attenuation at 1383±3 nm in 'Extreme Reduced Loss' fiber and its interoperability with other G.652.D fiber such as low splice loss are critical in the long-haul network. It will be challenging to achieve low splice loss between 'Extreme Reduced Loss' fiber and other G.652.D fiber types due to core material mismatch'. The network operator is advised to pay attention to these operational issues during the cabled-fiber selection process. These studies can be used as guideline for the operator in the selection of right cabled-fiber.

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