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Splicing and Fiber Assembly Compatibility for Non-Zero Dispersion-Shifted Fiber and Standard Single-Mode Fiber

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As non-zero dispersion-shifted fibers (NZ-DSF) become more prevalent in the marketplace, system designers are interested in ensuring compatibility with the existing fiber plant.

NZ-DS fibers, such as Corning® LEAF® fiber with large effective area, Corning® SMF-LS™ fiber and Lucent Truewave fiber, are optimized for long distance, high data rate operation over the 1550 nm window. In this region, they have much lower dispersion than standard single-mode fiber.

To obtain the desired dispersion and effective area properties, NZ-DS fibers are fabricated with more complex physical profiles than standard single mode fiber. Also, for SMF-LS and Truewave fibers, the effective area and corresponding mode field diameter values are smaller than for fibers with large effective area such as LEAF fiber (see Table 1).

Because of these differences, NZ-DS fibers are effected more by critical parameters such as splicing conditions and procedures. To quantify this sensitivity and address compatibility with fiber assemblies such as pigtails and jumper cables, Corning Incorporated initiated a series of studies to compare NZ-DS fibers with single-mode fiber (SMF).

How NZ-DS Fibers Compare With SMF

Non-zero dispersion-shifted fibers are designed for multiple high bit-rate wavelengths in the 1550nm wavelength region over long system lengths. Single-mode fiber is optimized for use in the 1310 nm wavelength region, although 1550nm operation is possible at 10 gigabits per second but requires careful management of the dispersion. Table 1 summarizes some of the differences between the various fiber types:

Table 1: Summary of the differences between the various fiber types

	SMF	NZ-DSF with large effective area	NZ-DSF
Attenuation @ 1550 nm	0.25 dB/km	0.25 dB/km	0.25 dB/km
Typical Dispersion @ 1550 nm	17 ps/nm*km	4.2 ps/nm*km	4.5 ps/nm*km
Effective Area	80 μm^2	72 μm^2	50 μm^2 to 55 μm^2
Mode Field Diameter Range @ 1550 nm	9.6 µm to 11.2 µm	9.2 µm to 10.0 µm	7.8 µm to 9.0 µm

NZ-DS fibers are more inherently more sensitive to splicing due to their more complex physical design. The end angle of the cleave, splicing equipment and clean splicing conditions, are all critical parameters to achieving consistently low splice loss.

Splice loss is more sensitive to cleave end angle when splicing NZ-DSF compared with standard single-mode fiber. The impact of cleave end angle has been documented for the original dispersion-shifted fiber designs. Laboratory studies of the earlier designs show that end angles greater than two degrees can more than double the splice loss as compared to standard single-mode fiber, as indicated in Figure 1. Similar effects would be expected for NZ-DSF.

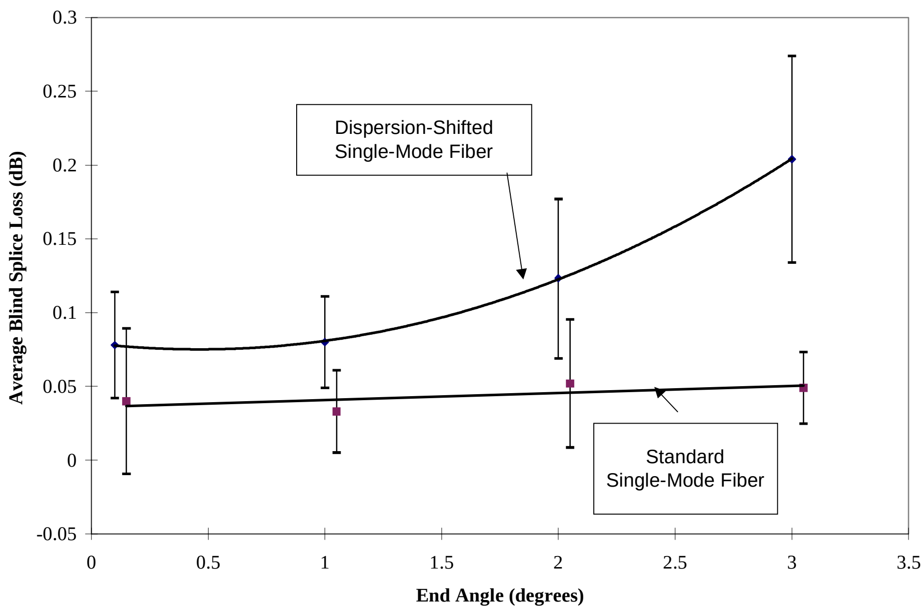


Figure 1: The effect of end angle on splice loss

Fortunately, splicing equipment continues to improve so that it is capable of splicing the new, more complex fiber designs. Manufacturers now offer adjustable machine settings that optimize splice performance for NZ-DS fibers and continue to refine splice loss algorithms that provide more accurate splice loss estimations. Splicing equipment manufacturers should be contacted directly for specific recommendations.

As always, cleanliness of the work area and equipment as well as equipment maintenance play an important role in achieving quality splices. The fiber stripper, cleaver and the splicer all have to be in top notch working condition. Time spent in advance preparation of the work area and equipment will increase productivity.

As early experience with SMF and recent experience with NZ-DSF indicated, uni-directional optical time domain reflectometer (OTDR) measurement of splice loss can be deceiving. Uni-directional measurements may indicate too high of a splice loss, while, in fact, the splice loss obtained with a bi-directional measurement proves low splice loss. Because of this, bi-directional measurements must be made to obtain accurate, reliable splice loss values. The uni-directional measurement error is primarily a function of the differences in the mode-field diameter (MFD) of the two fibers.

There are two factors to consider regarding the effect of mode-field mismatch when measuring splice loss.

1. The actual contribution to splice loss due to MFD mismatch, which is independent of the direction of measurement.
2. When measuring by OTDR, the apparent loss due to the way an OTDR performs measurements, which is an artifact of the OTDR measurement, and appears as a 'gainer' in one direction and a high loss in the other direction.

NZ-DSF users should expect to see greater occurrences of high one-way OTDR measurements due to the fiber's smaller MFD versus standard single-mode fiber. However, bi-directional testing of these splices will result in acceptable splice loss values.

Typically, because of the larger MFD, single-mode fiber splice loss values are lower than those of NZ-DS fibers. Single-mode fiber's splice loss averages between 0.2 and 0.3 dB, while typical NZ-DS fiber's splice loss averages between 0.4 and 0.5 dB. For all the various fiber types, the average splice loss values are well within typical splice loss budgets.

When splicing together two different types of fibers or “hybrid” fibers, elevated splice loss (both uni-directionally measured and actual splice loss values) should be expected due to mode field diameter mismatch. The MFD range for the different fibers are shown in Table 2.

Fiber	**MFD Range @ 1550 nm**
SMF	9.6 µm to 11.2 µm
NZ-DSF with large effective area	9.2 µm to 10.0 µm
NZ-DSF	7.8 µm to 9.0 µm

Table 2: Mode field diameters of various fiber types

As with heterogeneous fibers, hybrid fibers require either a bi-directional measurement by OTDR or a power through loss measurement. By performing OTDR bi-directional averaging, it is possible to eliminate backscatter effects and get the true splice loss, avoid over or under estimating splice loss and prevent unnecessary re-splices.

Splice studies for SMF, NZ-DSF and NZ-DSF with large effective area were recently completed at Corning’s Center for Fiber-Optic Testing. An active alignment splicer was used in all of the studies. The fibers selected for the studies included a wide range of mode-field diameters and core/clad offsets. Standard single-mode fiber splice settings were selected when performing the splicing. Because splicer set-up varies between models, it is suggested the splicing equipment manufacturers be contacted for recommended equipment set-up.

Keep in mind, when splicing dissimilar fibers, splice loss performance is better the closer the fibers' mode field diameters are. As shown below, when splicing NZ-DSF with large effective area to SMF, splice loss performance is better than when splicing NZ-DSF to SMF:

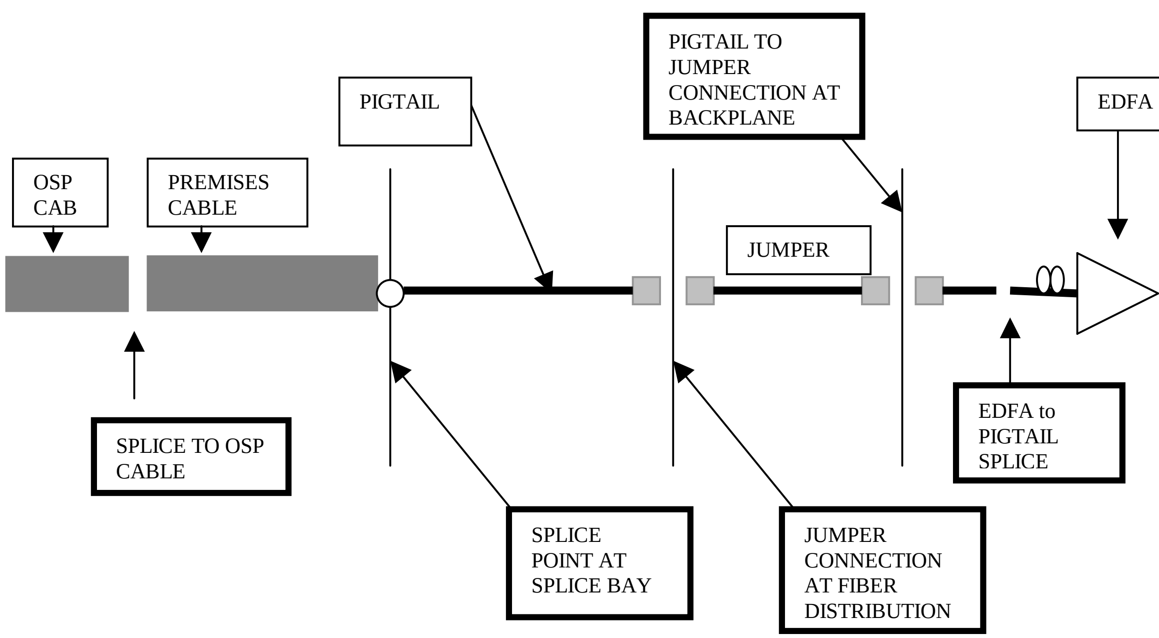
	Splice Loss (dB) @ 1550 nm	
	NZ-DSF with large effective area to SMF	**NZ-DSF to SMF**
Number of Splices	66	18
Average	0.11	0.15
Std. Dev.	0.029	0.028

With a proper understanding of the importance of bi-directional OTDR measurement in achieving accurate splice loss measurements, splicing NZ-DSF to itself and to SMF results in excellent splice performance.

Using SMF Assemblies in NZ-DSF Routes

It is not necessary to use NZ-DSF for pigtails and jumper cables in typical NZ-DSF routes. In fact, Corning recommends the continued use of SMF pigtails and jumper cables in all NZ-DSF systems.

Table 3 shows a study that compares the use of NZ-DSF pigtails and jumper cables in NZ-DSF routes. The following schematic displays the set-up at Site A. Typical splice and connector values are used to compare the expected performance differences of the two systems:



Schematic of Site A

Typical Performance Budget				
Item	**Using SMF Assemblies**		**Using NZ-DSF Assemblies**	
EDFA to pigtail splice	0.02 dB	SMF to SMF	0.15 dB	SMF to NZ-DSF
Pigtail to jumper connection at backplane	0.25 dB	SMF to SMF	0.34 dB	NZ-DSF to NZ-DSF
Jumper connection at fiber distribution frame	0.25 dB	SMF to SMF	0.34 dB	NZ-DSF to NZ-DSF
Splice point at splice bay	0.02 dB	SMF to SMF	0.04 dB	NZ-DSF to NZ-DSF
Splice to OSP cable	0.15 dB	SMF to NZ-DSF	0.04 dB	NZ-DSF to NZ-DSF
Total at Site A (1-5)	**0.69 dB**		**0.91 dB**	
Splice to OSP cable	0.15 dB	SMF to NZ-DSF	0.04 dB	NZ-DSF to NZ-DSF
Splice point at splice bay	0.02 dB	SMF to SMF	0.04 dB	NZ-DSF to NZ-DSF
Jumper connection at fiber distribution frame	0.25 dB	SMF to SMF	0.34 dB	NZ-DSF to NZ-DSF
Jumper to pigtail connection at backplane	0.25 dB	SMF to SMF	0.34 dB	NZ-DSF to NZ-DSF
Fiber-detector pigtail	---------	Note 2	---------	Note 2
Total at Site B (6-10)	**0.67 dB**		**0.76 dB**	
Total Loss at Site A & B	***1.36 dB***		***1.67 dB***	
Advantage of using SMF assemblies instead of NZ-DSF assemblies = *0.31* dB				

Table 3: Expected performance for SMF and NZ-DSF assemblies in NZ-DSF systems

Table 4 contains a study that compares the use of NZ-DSF with large effective area pigtails and jumper cables in NZ-DSF with large effective area routes:

Typical Performance Budget				
Item	**Using SMF Assemblies**		**Using NZ-DSF with Large Effective Area Assemblies**	
EDFA to pigtail splice	0.02 dB	SMF to SMF	0.11 dB	SMF to NZ-DSF w/large effective area
Pigtail to jumper connection at backplane	0.25 dB	SMF to SMF	0.29 dB	NZ-DSF w/large effective area to NZ-DSF w/large effective area
Jumper connection at fiber distribution frame	0.25 dB	SMF to SMF	0.29 dB	NZ-DSF w/large effective area to NZ-DSF w/large effective area
Splice point at splice bay	0.02 dB	SMF to SMF	0.05 dB	NZ-DSF w/large effective area to NZ-DSF w/large effective area
Splice to OSP cable	0.11 dB	SMF to	0.05 dB	NZ-DSF w/large effective

		NZ-DSF w/large effective area		area to NZ-DSF w/large effective area
Total at Site A (1-5)	**0.65 dB**		**0.79 dB**	
Splice to OSP cable	0.11 dB	SMF to NZ-DSF w/large effective area	0.05 dB	NZ-DSF w/large effective area to NZ-DSF w/large effective area
Splice point at splice bay	0.02 dB	SMF to SMF	0.05 dB	NZ-DSF w/large effective area to NZ-DSF w/large effective area
Jumper connection at fiber distribution frame	0.25 dB	SMF to SMF	0.29 dB	NZ-DSF w/large effective area to NZ-DSF w/large effective area
Jumper to pigtail connection at backplane	0.25 dB	SMF to SMF	0.29 dB	NZ-DSF w/large effective area to NZ-DSF w/large effective area
Fiber-detector pigtail	---------	Note 2	---------	Note 2
Total at Site B (6-10)	**0.63 dB**		**0.68 dB**	
Total Loss at Site A & B	***1.28 dB***		***1.47 dB***	
Advantage of using SMF assemblies instead of NZ-DSF with large effective area assemblies = *0.19* dB				

Table 4: Expected performance for SMF and NZ-DSF with large effective area assemblies in NZ-DSF with large effective area systems

For both comparisons, the following criteria was used:

Assumptions:

	Connector Loss	**Typical MFD**	**Fiber-Detector Loss**
SMF	.25 dB	10.4 μm	See Note 2
NZ-DSF w/large effective area	.29 dB	9.6 μm	See Note 2
NZ-DSF	.34 dB	8.4 μm	See Note 2

Note 1: Connector loss was calculated using Marcuse equations assuming same lateral offset to achieve 0.25 dB for SMF to SMF splice with the typical MFD values given.

Note 2: Assume that both NZ-DSF and NZ-DSF with large effective area pigtail-to-detector loss is equivalent to SMF pigtail-to-detector loss.

Using SMF assemblies in NZ-DSF with large effective area based configurations results in an overall lower loss (1.28 dB) than when using SMF assemblies in standard NZ-DSF based configurations (1.36 dB). The bottom line is that an all SMF pigtail/jumper configuration actually adds *0.31 dB* (typical) over a NZ-DSF based configuration and *0.19* (typical) over a NZ-DSF with large effective area based configuration.

Although many new networks are being built with NZ-DSF (G.655) fiber, Corning continues to recommend the use of SMF (G.652) fiber assemblies, patch cords and jumpers for all NZ-DSF routes. The length of these assemblies typically is sufficiently short so that dispersion accumulation is negligible. Therefore, the use of SMF will not impact the transmission characteristics of the system. However, using NZ-DS fiber in the these assemblies induces an additional loss (as noted in Table 3 and Table 4), and managing assembly inventories for various fiber types adds unnecessary complexity. Given added system margin, lower cost and lower complexity, it is clear that SMF should continue to be the fiber of choice for assemblies.

With attention to splicing practices and equipment set-up, NZ-DSF and NZ-DSF with large effective area offer the same ease of installation as standard single-mode fiber designs. System designers can feel confident that they can take advantage of all the benefits of the NZ-DSF design in their high data rate systems and still achieve excellent splice performance.