Field Measurements of Deployed Fiber

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Abstract: New generations of ultra-long haul (ULH) WDM equipment require detailed engineering design of the fiber links to enable 1500km, and longer reaches, between regenerations or terminations of optical signals. Dispersion compensation, optical power budgets and polarization mode dispersion penalty calculations must be based on actual measured fiber span values to enable these large system reaches. These considerations have led to dark fiber customer interest, as well as internal engineering interest in fiber characterization. Level 3 recently executed field measurements of deployed Corning LEAF® optical fiber cables. More than 70 spans of 90+km average length were studied, with six fibers measured per span. These optical fiber cable spans were deployed in the years 1999, 2000 and early 2001. These measurements included: polarization mode dispersion (PMD) at 1550nm, chromatic dispersion (CD) and dispersion slope in the C band, optical loss at 1550nm and 1625nm, optical time domain reflectometer (OTDR) measurements at 1550nm (including average bi-directional splice loss), and optical return loss. The OTDR measurements were executed using a launch reel. This provided relief from the instrument dead-zone, and thus measurements of the optical reflectivity and loss of the fiber patch panels were also available from the OTDR traces. The PMD was measured three times, consecutively. The largest value is taken as the PMD. Most of the span PMD measurements were fairly consistent (among the three measurements) with most PMD values less than 0.05 ps/√km. The CD was measured every 10nm from 1520 to 1570 nm. Almost all fibers had CD greater than 4 ps/nm-km at 1550nm and most were close to 4.2 ps/nm-km. The reflectivity of the connectors was found to be better than -50dB, in all but a few cases. The insertion loss of the connectors was found to be mostly less than 0.35dB. We will discuss the lessons learned in measuring the loss and reflection at the patch panels. The bi-directional average splice losses were mostly less than 0.05dB. The optical attenuation of the fiber (including splice loss and connector loss) were almost all below 0.225dB/km. These excellent results seen on the Level 3 network will ease the process of implementing ULH WDM systems, and the future 40Gbps systems. We will present detailed statistical summaries of these measurements of the Level 3 fiber network during this talk.

OCIS Codes: (060.2300) Fiber measurements; (060.2400) Fiber properties

1. Introduction

Level 3 recently measured optical parameters for its long haul fibers for demanding applications of its dark fiber customers. More and more customers are demanding detailed characteristics of dark fiber, even in metro environments where they are anticipating the deployment of 40Gbps transport equipment. Equipment vendors require the dispersion and loss values of fiber spans prior to engineering long haul transport links. We will present the results of these measurements for the Level 3 Communications Corning LEAF® NZDSF North American fiber plant. The Level 3 fiber plant was deployed from 1999 through early 2001. The fiber was manufactured by Corning during 1999 and 2000. For most of the spans measured, the cable is a 96 count fiber armored cable manufactured by Corning Cable Systems, formerly Siecor.

2. Characterization Measurements

The measurements include power meter readings at 1550nm and 1625nm (loss), optical return loss (ORL) at 1550nm, OTDR at 1550nm that measured the splice loss, polarization mode dispersion (PMD) at 1550nm, and chromatic dispersion (CD) in the C-band, with a few L-band measurements. In addition the connector return loss (connector reflectivity, CRL) and connector insertion loss were measured at the fiber distribution panels with the OTDR. The ORL measurement collects all the light scattered back into the instrument from throughout the length of the fiber, whereas the CRL only measures the reflectance at the connector endface. Figure 1 shows the testing configuration. For connector insertion loss, connector reflectivity (return loss) and OTDR readings, a launch reel of approximately 3 km of SMF-28 was inserted between the fiber distribution panel and the OTDR.

The instrument used for the chromatic dispersion measurement was the Nettest FD-440. The instrument used for the OTDR measurements was the Nettest CMA OTDR. For PMD measurements the Perkin Elmer Nexus -PMD was used. For ORL & Power Meter measurements the Nettest GN-6025/S50 was used. All connectors used were SC/UPC (ultra-polished connector) type single mode connectors.

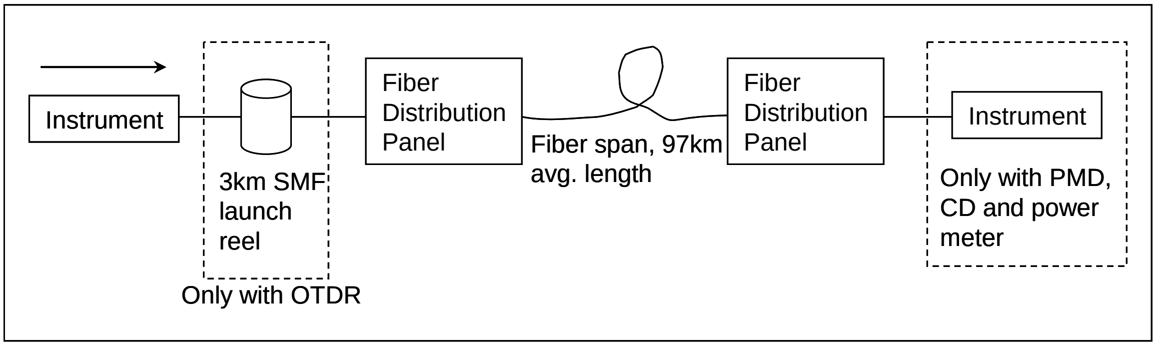

Fig. 1. Measurements schematic diagram.

3. Power Meter Measurements

The bidirectional average loss measurements (including the connector losses at each end and splice losses) of over 400 fibers are shown in Figure 2 (1550nm) and Figure 3 (1625nm). The bidirectional mean loss at 1550nm is 0.212 dB/km and the standard deviation is 0.0124 dB. The bidirectional mean loss at 1625nm is 0.220 dB/km and the standard deviation is 0.0178 dB. LEAF has excellent low loss characteristics at 1550nm. The low loss is partially due to the average 8.25 km distance between splice points, the low splice loss and the low connector loss (see below). The data points with unusually large loss values in Figure 2 have a known macro-bend loss problem due to deployment issues.

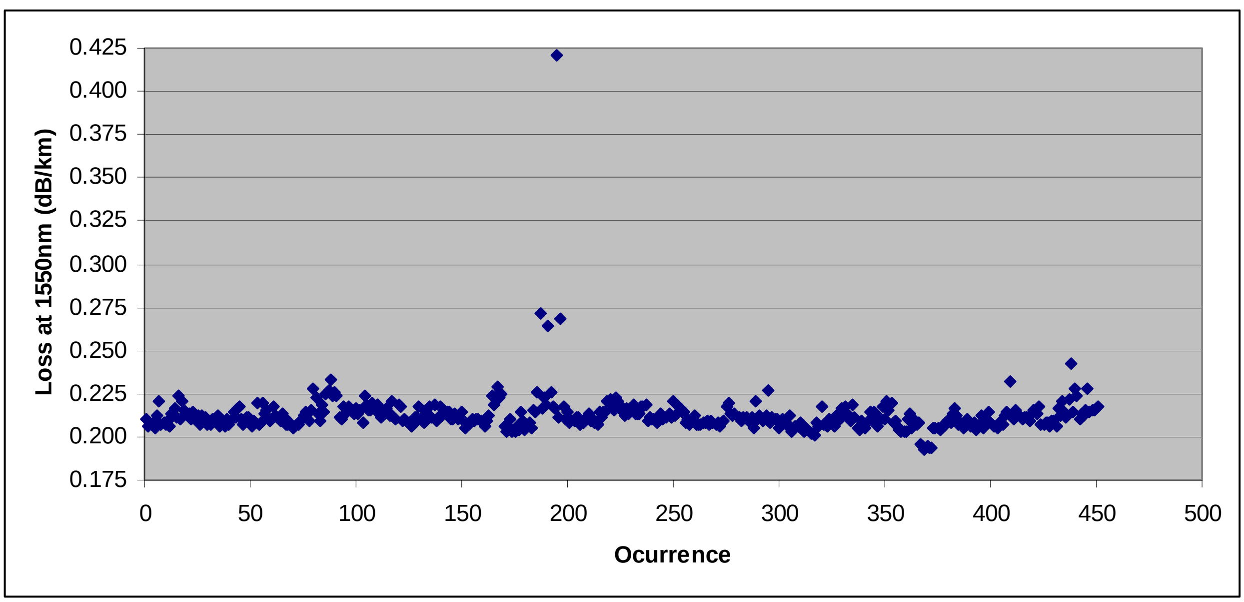

Fig. 2. Bi-directional average fiber loss data points, in dB/km, including connector losses at 1550nm.

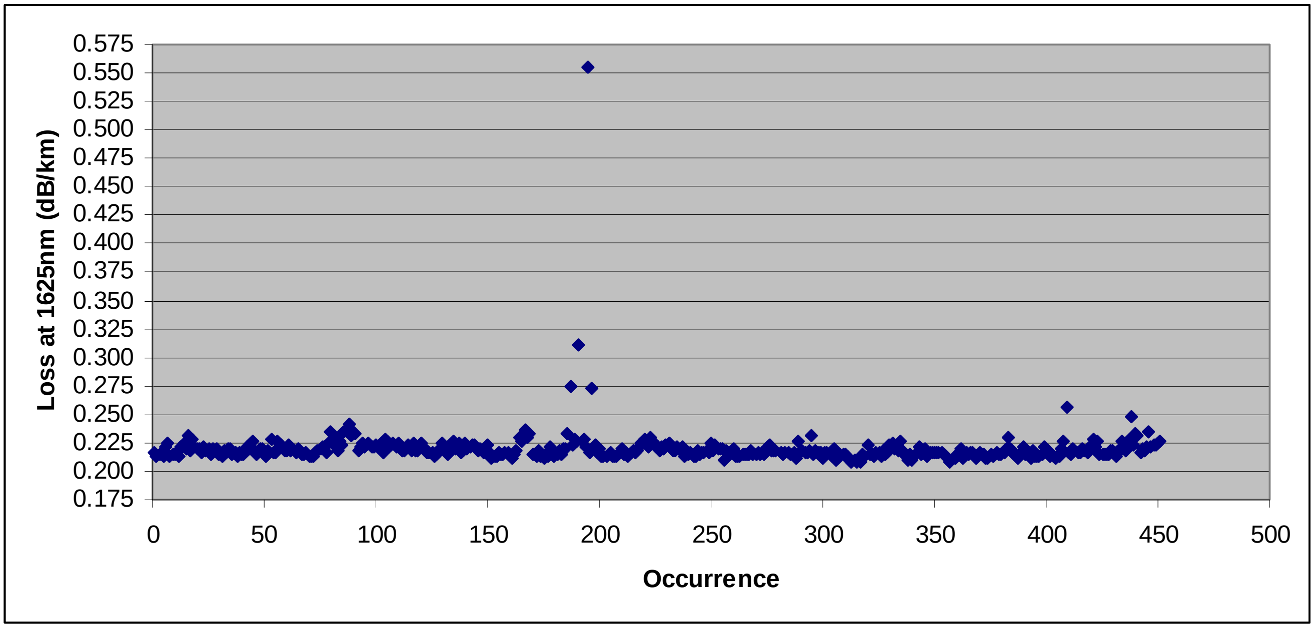

Fig. 3. Bi-directional average fiber loss data points, in dB/km, including connector losses at 1625nm

4. ORL and Connector Return Loss

There were over 900 ORL and connector return loss (CRL) measurements. The connector return loss was measured using the manufacturer's OTDR software for reflectivity of splices measurement. Figure 4 shows the connector return loss data and Figure 5 shows the ORL data.

The mean ORL is 31.3dB and the standard deviation is 0.73dB. The mean connector return loss is 54.3 dB and the standard deviation is 4.04 dB.

One point to note is that in almost all cases the ORL and CRL data was consistent for a fiber end. However there were many cases where the ORL exceeded 30dB, but the connector return loss was <40dB. This shows that the CRL measurement is more indicative of problems on the fiber end face than the ORL measurements. Also, in those cases where the initial CRL measurements did not exceed 50dB (approximately 150 cases), the fiber connectors were carefully re-cleaned and the measurements repeated. In almost all cases (>99%) the CRL was found to exceed 50dB after re-cleaning. In some of the cases (the lowest value CRL data points in figure 4), when the connectors were examined under a microscope, they were clearly damaged in the core area. Also, given that the ORL exceeded 30dB even when the connector return loss was much less than 50dB we conclude that connector return loss is a necessary measurement to ensure that the connector end faces are clean and polished.

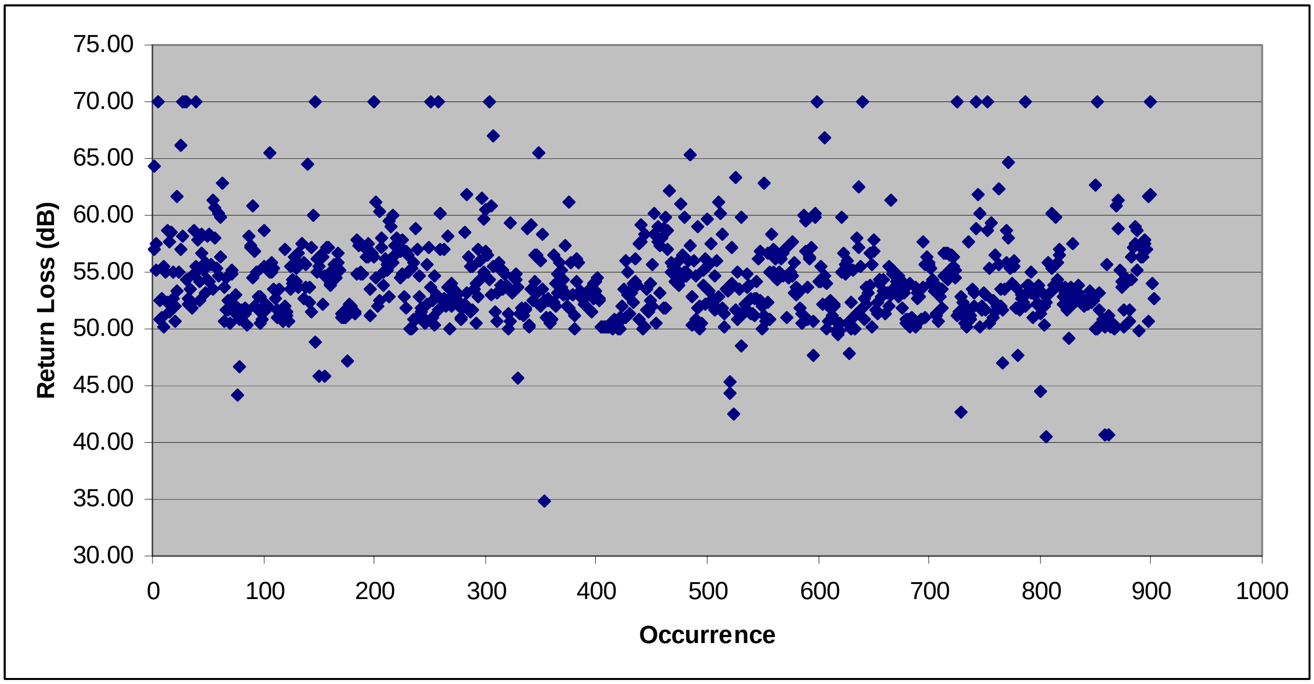

Fig. 4. Connector return loss (reflectivity) data points at 1550nm.

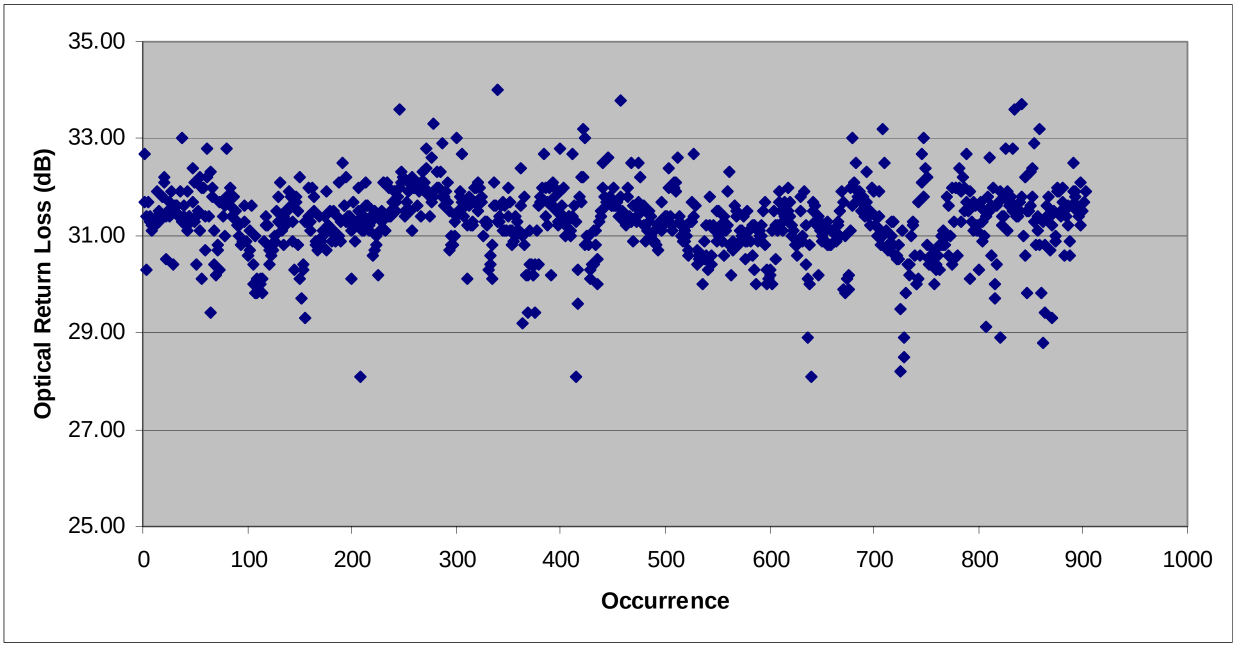

Fig. 5. Optical Return Loss (ORL) data points at 1550nm.

5. Connector Insertion Loss

There were over 900 connector insertion loss measurements. The OTDR software for splice loss measurements was used to determine the connector insertion loss. Figure 6 shows the data points. The mean loss is 0.200 dB and the standard deviation is 0.17 dB. The few large loss outliers are due to bad connector end faces. These will need to be replaced before use. We note that the vast majority of connectors have loss less than 0.4 dB. The typical specification is 0.5dB for connector insertion loss. However we note that these have been previously idle connectors (i.e. they haven't had connections and disconnections made with fiber patch cords) and their loss values will change with time and usage.

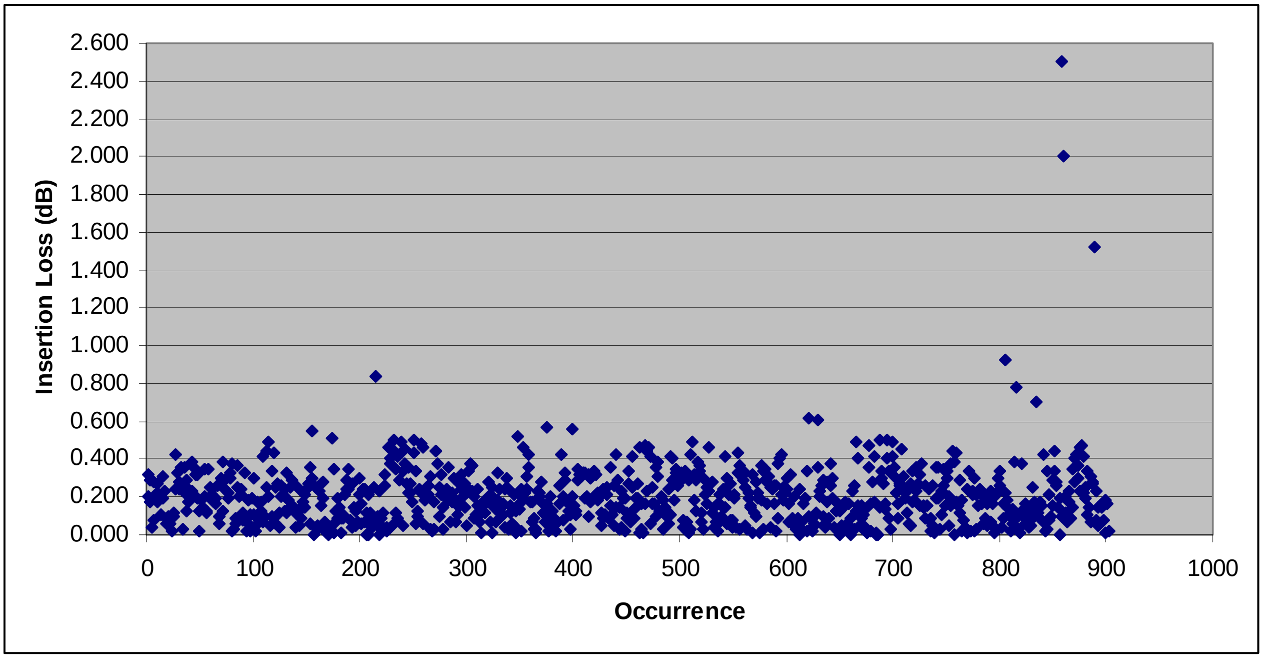

Fig. 6. Connector Insertion Loss data points at 1550nm

6. OTDR-Splice Loss

The OTDR readings were taken at 1550nm. The splices were identified for the path and the losses were measured using the manufacturers OTDR software. Figure 7 shows the average bi-directional splice loss data points, for the multiple splices per fiber span. The total number of splices represented here is 4900. The mean splice loss across these thousands of data points is 0.0421 dB, and the standard deviation is 0.0625 dB. However this data includes two large values (not shown in Figure 7, of 1.27 dB and 0.44 dB) from a known macro-bend problem due to a deployment issue. Without these two data points, the bidirectional mean splice loss is 0.0385 dB, and the standard deviation is 0.0134 dB. The fibers with the large macro-bending loss issue would not be used commercially due to their excessive loss. We also note that of all these splices, only one had reflectivity of greater than -70dB, and the measured value was -69.9dB.

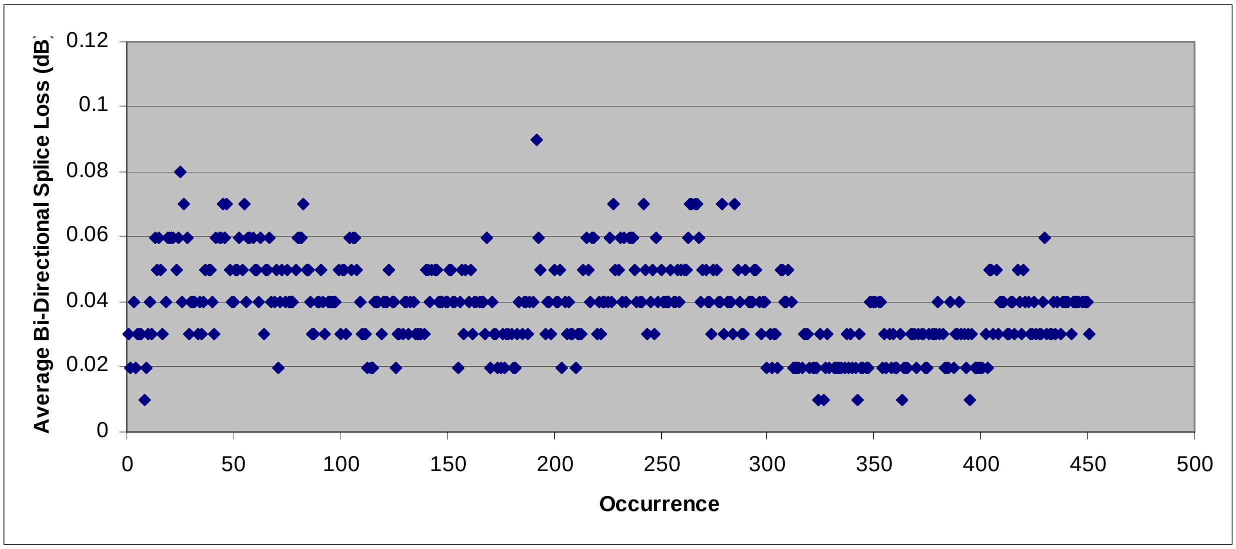

Fig. 7. Bidirectional average splice loss data points at 1550nm.

7. Polarization Mode Dispersion (PMD)

The PMD was measured for approximately 450 fibers with average length of 97.6 km. The measurement was repeated three times in each case, with the largest value used as the fiber PMD. In the large majority of cases the three values were very close, but in some cases they differed significantly. The measurements were made over three months at different times of the day and varied from the east coast, to the Midwest and the west coast. The specification for LEAF changed during the installation process. The earliest specification was <0.08ps/√km link value with < 0.2 ps/√km for maximum individual fiber value, and was changed to <0.04ps/√km with <0.1 ps/√km for maximum individual fiber value. We do not know which of the fiber spans measured were manufactured under which specification. In any event there were only a handful of fibers that did not meet the <0.08 spec, and most met the <0.04 spec. The data points are shown in Figure 8. The mean PMD value is 0.0352 ps/√km and the standard deviation is 0.0169ps/√km.

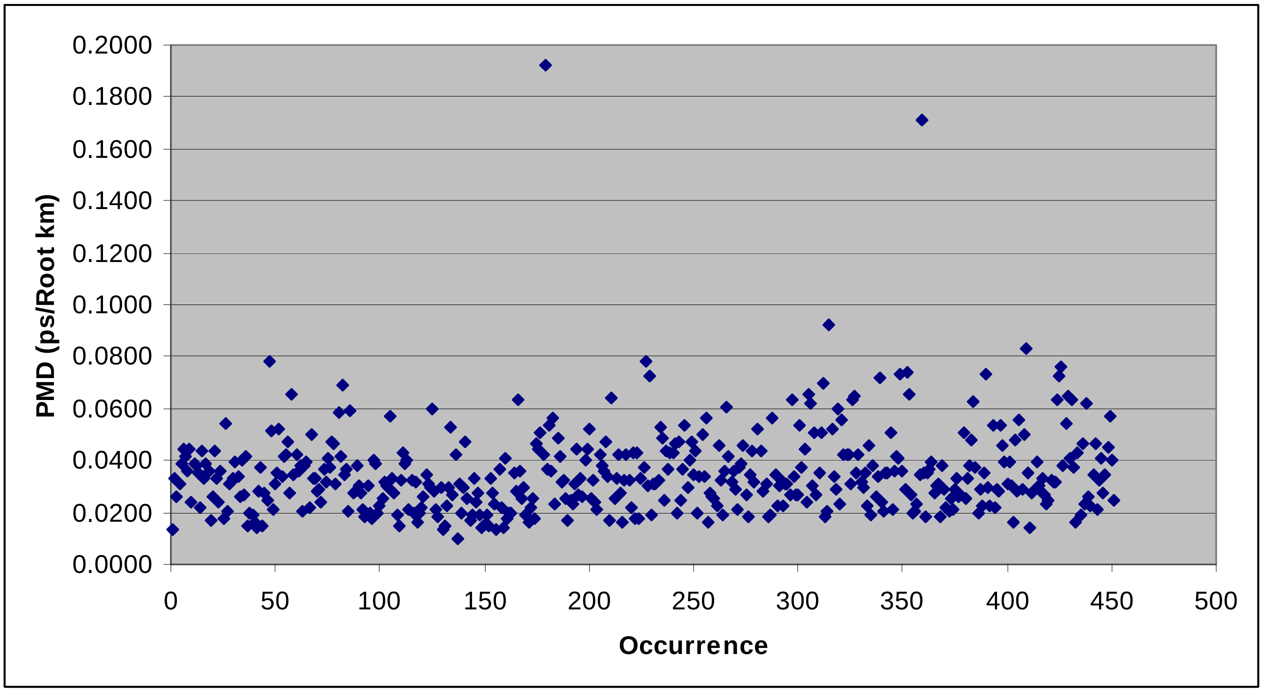

Fig. 8. PMD data points at 1550nm.

8. Chromatic Dispersion (CD)

The Chromatic dispersion specification for LEAF is between 2 and 6 ps/nm-km from 1530 to 1565nm. The measured results for 1550nm are shown in Figure 9. The mean chromatic dispersion value at 1550nm is 4.27 ps/nm-km and the standard deviation is 0.117 ps/nm-km. An overlay plot of CD across the C and L bands for 13 fibers is shown in Figure 10.

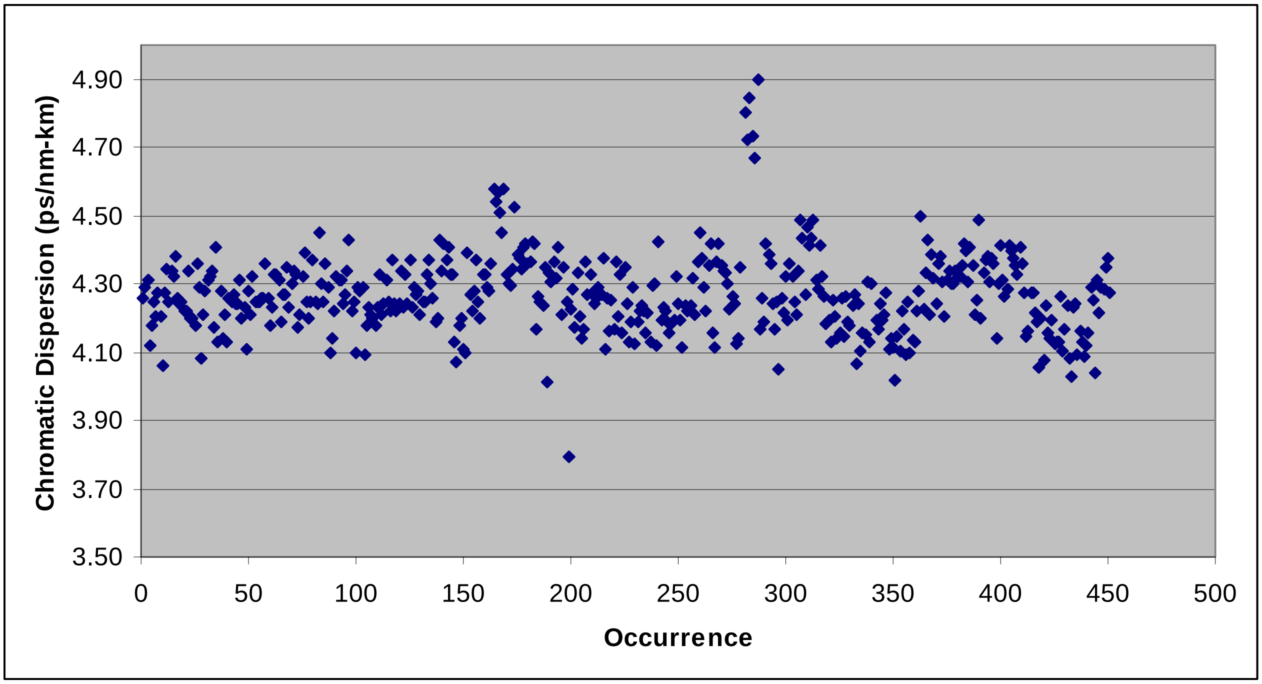

Fig. 9. Chromatic Dispersion data points at 1550nm.

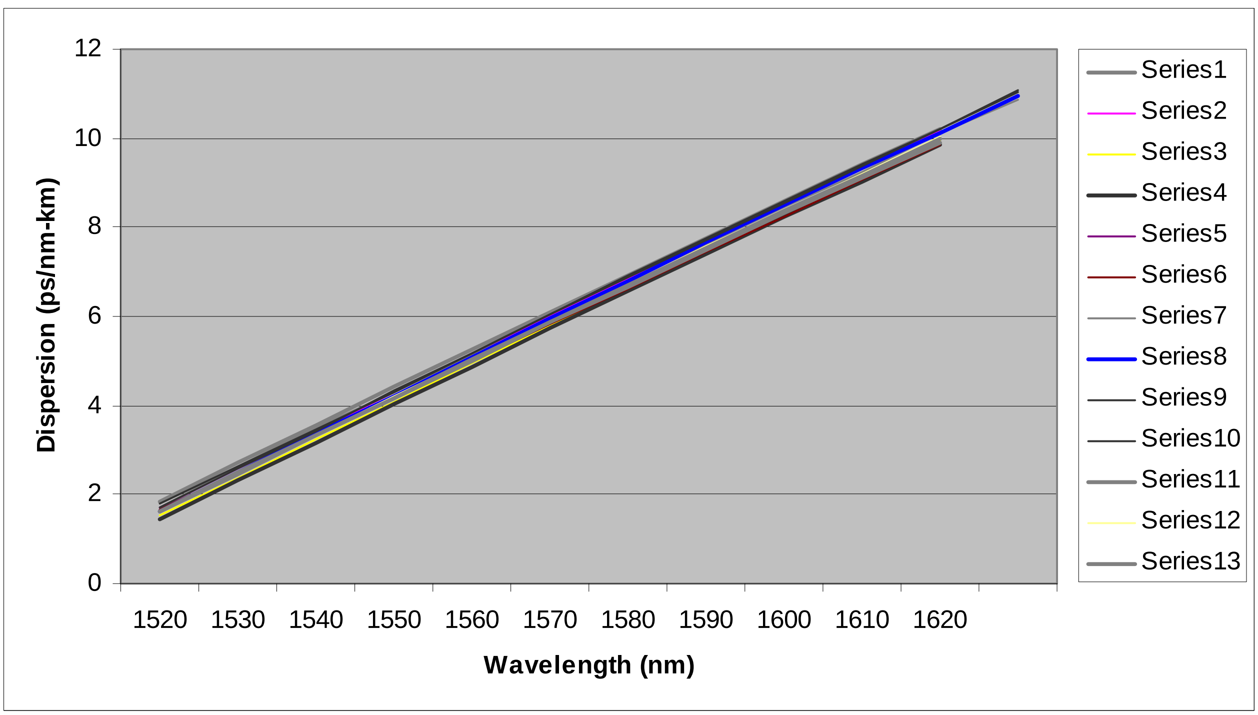

Fig. 10. Chromatic Dispersion plots for 13 fibers in the C and L bands.

9. Discussion

The correlation of good ORL with quality connector ends is now seen to be incorrect. The connector return loss gives a more accurate picture of the condition of the fiber distribution panel connector end faces. This measurement can be performed with an OTDR with a launch reel such that the dead zone is shorter than the launch reel, thus requiring minimal additional equipment beyond the standard issue instrumentation for field technicians. This measurement should be performed prior to turning up any lit services, or turning over dark fiber to a customer. This is critical for Raman amplified applications where a “large” reflection at the end face will generate system turn on issues.

Typically 25dB loss would have been used in the span design rule for a 100km span. The installed Level 3 fiber plant has a nominal 21.2dB measured span loss, including splice and connector losses, for a 100km span. Thus, even with a reasonable aging margin, a longer reach between regenerations is possible from the transport vendor’s equipment. This will lower the equipment costs for the dark fiber customer.

The PMD average result of 0.0352 ps/√km shows that the Corning LEAF Level 3 fiber plant is ready for 40Gbps applications where the PMD can be a significant (and expensive to correct) dispersion component limiting the reach between regenerations.

The average chromatic dispersion value (4.27 ps/nm-km) was found to be just slightly larger than the Corning nominal value of 4.2 ps/nm-km. This dispersion, along with the large effective area of LEAF limits the nonlinear impairments in long distance transport systems.

10. Conclusions

The measurements of the Level 3 North American installed long haul fiber plant demonstrated low loss, low PMD and low connector loss and reflectivity. The installed fiber plant had characteristics close to the manufacturer specifications, and much lower than the loss specifications (0.25dB/km at the time of purchase). A measurement of the connector return loss (reflectivity) is essential to understanding the quality of the fiber end face.

11. Acknowledgements

We would like to thank Matt Paoni and his team at Nettest Inc. for their diligent work in performing the measurements. We would also like to thank Jo Fenton and Jeremy Juliano of Level 3 for all their careful processing of the OTDR data. We also need to acknowledge the long hours and support from the Level 3 field services organization in enabling the testing at all the remote facilities.