3M

Fibrlok™ II Universal Optical Fiber Splice 2529

Technical Report of Performance with Square Cleave

May 2003
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Contents

1.0 Product Description

The 3M™ Fibrlok™ II Universal Optical Fiber Splice 2529 is a high-performance, easy-to-use mechanical optical fiber splice. The Fibrlok II Universal Splice can be used with either single-mode or multimode fibers with a cladding diameter of 125 microns. It will accommodate any combination of fibers with coating diameters from 250 µm to 900 µm. In addition, the Universal Optical Fiber Splice incorporates a single cleave length for splicing both 250 and 900-micron coated fibers and provides the ability to “reposition” fibers for increased splicing yields.

The splice consists of four molded polymeric components and an aluminum alloy alignment element. The four polymeric components are Jacket, End Plug (2), and Cap. The jacket is provided with a compartment to house the aluminum alloy element. The end plugs are attached to each end of the jacket and locate the element laterally within the splice jacket. Each splice end plug contains a fiber entry port which is used to guide either 250 or 900-micron coated optical fiber into the alignment element. During splice actuation, the cap acts on the element to align and secure the fibers within the splice. All splice components are factory-assembled. An index matching gel is pre-installed in the splice element.

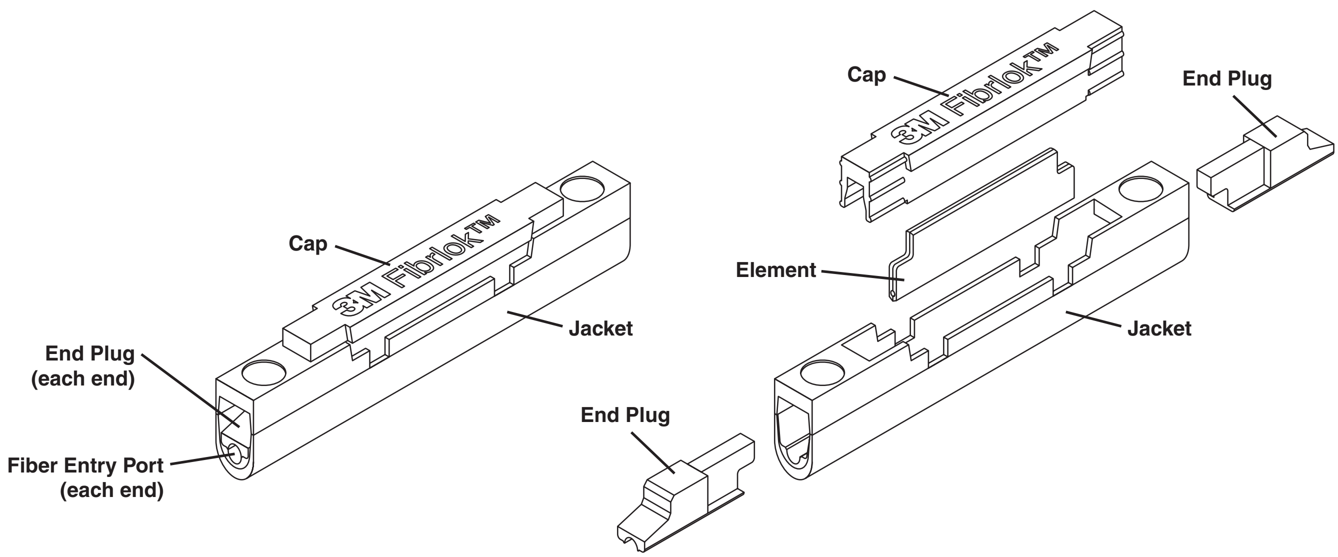


Fig. 1—Fibrlok II Universal Optical Fiber Optic Splice

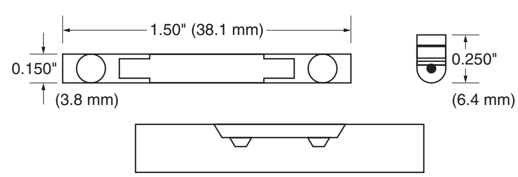


Fig. 2—Fibrlok II Universal Optical Fiber Optic Splice Dimensions

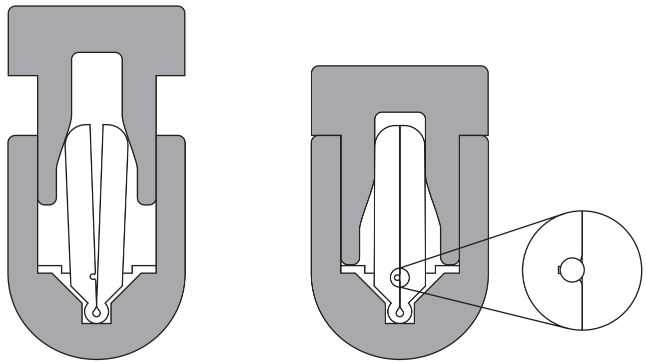


Fig. 3—3M™ Fibrlok™ II Universal Optical Fiber Optic Splice Cross-Section

The 3M™ Fibrlok™ II is held within the 3M™ Fibrlok™ Assembly Tool 2501 when the splice is made in the field. After the fibers are inserted into the splice, the cap is depressed with the Assembly Tool. The motion of the cap squeezes the “legs” of the element so the “legs” come together. The fibers are permanently aligned and gripped in the splice when the cap is actuated.

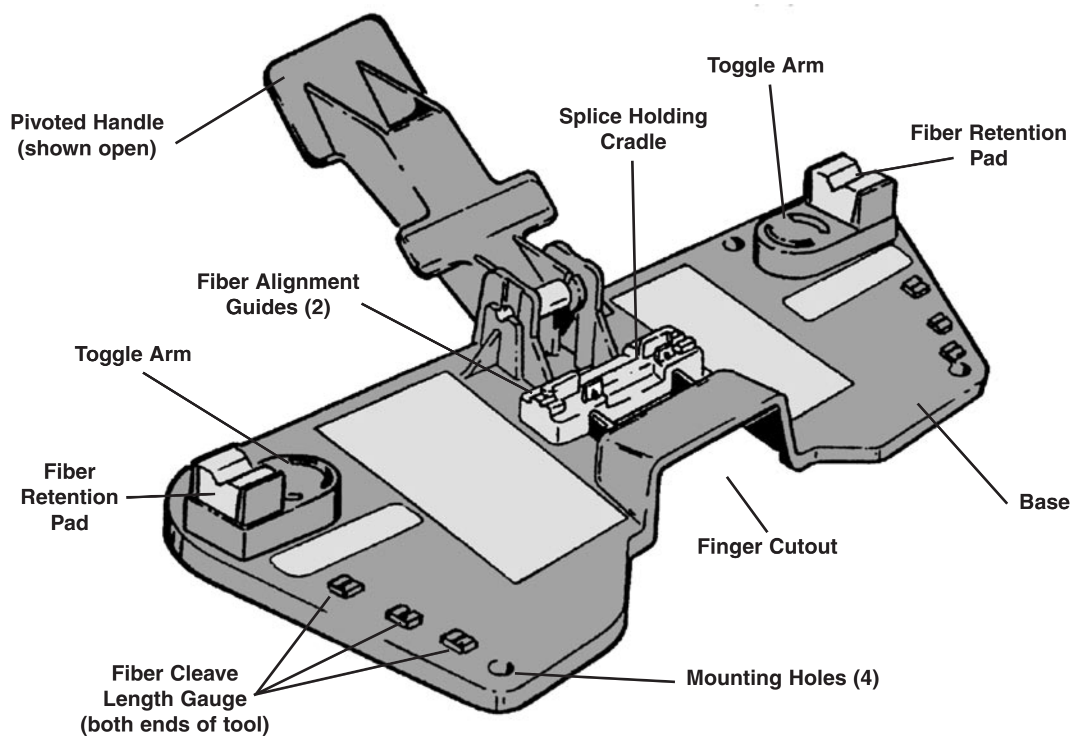


Fig. 4—Fibrlok™ Assembly Tool 2501

2.0 Test Program Overview

To assess the long term performance of the 3M™ Fibrlok™ II Universal Optical Fiber Splice, the splices were subjected to a number of tests which exposed the splices to conditions more severe than those anticipated in actual use.

The test samples used for all of the tests were produced in the 3M Austin, Texas manufacturing facility. Testing of the splices occurred in the 3M Fiber Optics Test Laboratory in Austin. The tests are based on telephone industry specifications and are believed to represent the most severe requirements of that industry.

The tests described in this Technical Report were conducted using Corning™ SMF-28™ 250-micron coated fiber and Fibrlok II Universal Optical Fiber Splices 2529. All splice samples were constructed using "heterogeneous" optical fiber (fibers of the same type, but from different lots). Initial loss and reflectance were measured with a Tektronix Fibermaster TFP2 OTDR using a 100-ns pulse width and the fiber manufacturer's recommended backscatter coefficient.

All splices were prepared using square cleaves (*Figure 5*).

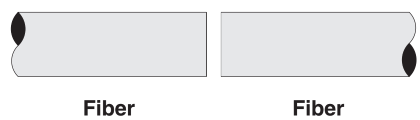


Fig. 5—Square Cleave

3.0 Installation Conditions

The Installation Conditions testing is intended to analyze the actual operation of splicing fibers under a variety of installation conditions using high and low extremes for temperature and humidity.

Splices using single mode fiber were constructed under the following environmental conditions:

Test	Temperature	Relative Humidity
Low Temperature	0°C (32°F)	Uncontrolled
High Temperature	45°C (113°F)	15%
High Humidity	23°C (73°F)	90%
Low Humidity	23°C (73°F)	15%

Procedure:

Splices were constructed in a walk-in controlled environmental test chamber that was large enough to accommodate test personnel and splicing equipment. Splice loss and reflectance were measured using two-way OTDR measurements. Splices, fiber and splice assembly tools were all allowed to come to thermal equilibrium prior to splice assembly.

3.1 Summary of Results - Installation Conditions

"Conforming" splices are defined as splices which exhibit insertion loss of less than or equal to 0.20 dB, have a splice reflectance no greater than -40 dB, and are capable of withstanding a minimum tensile load of 4.4 N (1.0 lb-f). For each test condition, splices were constructed until 20 "conforming" splices had been obtained. Loss and reflectance for each "conforming" splice was measured using the OTDR.

Splice yield is defined as the number of "conforming" splices (i.e. ≤0.20 dB) divided by the total number of splices constructed.

Mean loss is the average splice loss (dB) of the twenty "conforming" splices constructed for each set of installation conditions.

Reflectance values listed represent minimum and maximum measured reflectance at the installation temperature.

3.2 Test Results for both 1310 nm and 1550 nm

1310 nm 250 µm to 250 µm

Test	Mean Loss	Max Loss	Splice Yield	Lowest Measured Reflectance	Highest Measured Reflectance
Low Temperature	0.08 dB	0.12 dB	100 %	-65.0 dB	-47.7 dB
High Temperature	0.08 dB	0.15 dB	100 %	-65.0 dB	-49.0 dB
High Humidity	0.12 dB	0.59 dB	91 %	-65.0 dB	-40.0 dB
Low Humidity	0.07 dB	0.16 dB	100 %	-65.0 dB	-58.0 dB

1550 nm 250 µm to 250 µm

Test	Mean Loss	Max Loss	Splice Yield	Lowest Measured Reflectance	Highest Measured Reflectance
Low Temperature	0.10 dB	0.11 dB	100 %	-65.0 dB	-44.6 dB
High Temperature	0.07 dB	0.13 dB	100 %	-65.0 dB	-51.6 dB
High Humidity	0.09 dB	0.29 dB	91 %	-65.0 dB	-37.2 dB
Low Humidity	0.07 dB	0.14 dB	100 %	-65.0 dB	-55.7 dB

4.0 Environmental Life Test Series

The Environmental Life Test Series is designed to analyze the life test performance of the splice including vibration, temperature cycling, water immersion, and environmental degradation (final tensile testing). 3M performed the environmental tests described below referencing the test methods stated in Telcordia 765.

Prior to testing, the splices were placed in a vertical orientation and conditioned for 15 days at 60°C (140°F). Splices undergoing the Environmental Life Test Series were then spliced and subjected to the following sequential life tests as indicated below:

4.0.1 **Initial Splice Loss and Splice Yield** – 3M™ Fibrlok™ II Universal Splices were constructed until thirty splices were constructed with loss ≤0.2 dB. Splice yield was calculated by dividing the total number of conforming (≤0.2 dB) splices by the number of splices made. Mean splice loss was calculated.

4.0.2 **Splice Strength** – The thirty Fibrlok II Universal Splices were tested with a 4.4 N (1.0 lb-f) tensile load applied to the splice for five seconds, and the change in splice insertion loss was measured.

4.0.3 **Vibration Splice Loss** – The thirty Fibrlok II Universal Splices were mounted in a Fibrlok Splice Organizer Tray 2524, attached to a vibration test unit, and subjected to simple harmonic motion having an amplitude of 0.76 mm (0.03 inch) and 1.52 mm (0.06 inch) maximum total excursion. The vibration frequency was varied between 10 and 55 Hz. The entire frequency range, from 10 to 55 to 10 Hz, is traversed in approximately one minute. The splices were tested for two hours in each of three mutually perpendicular planes per EIA Standard FOTP 11, Condition I (IEC 61300-2-1). Change in insertion loss during vibration was measured.

4.0.4 **Temperature Cycling (100 cycles)** – The thirty Fibrlok II Universal Splices were subjected to temperature cycles (uncontrolled humidity) from -40°C to +80°C (-40°F to 176°F) with a temperature rate change of 2°C (3.6°F) per minute (one-hour transition time) and a two-hour dwell time at the temperature extremes. Loss and reflectance were measured during Temperature Cycling.

4.0.5 **Water Immersion** – Following the completion of first 100 temperature cycles, splices were immersed in distilled water for 7 days at a temperature of 43°C (109°F). Splice loss and reflectance measurements at 23°C (73°F) were taken before water immersion and at one day after Water Immersion.

4.0.6 **Temperature Cycling (100 cycles)** – Splices were temperature cycled for 100 additional cycles from -40°C to +80°C (-40°F to 176°F). Loss and reflectance were measured during Temperature Cycling.

4.0.7 **Environmental Degradation** – A 4.4 N (1.0 lb-f) tensile load was applied to the splice for five seconds and change in loss was measured.

4.1 Summary of Results - Environmental Life Test Series

Note: ***Measurement error for splice loss is estimated to be ±0.04 dB. This experimental error should be applied when considering splice loss measurements for individual splice losses only and is not applied to statistical means.***

Reflectance values are reported as measured. No estimate of measurement error has been calculated for these values. Loss measurements were calculated bidirectionally. Reflection was measured in only one direction. Tensile testing was done with a fixture employing a Chatillon force gauge to monitor force.

Values are reported for measurements taken at 1300 nm and 1550 nm.

4.1.1 Initial Splice Loss

After the splices were heat aged at 60°C (140°F) for 15 days, thirty "conforming" 3M™ Fibrlok™ II Universal Splices were constructed for testing in the Environmental Life Test Series. Of the splices prepared for this sample group, mean splice loss was 0.05 dB at 1300 nm and 0.04 dB at 1550 nm. Splice yield for this sample group was 100%.

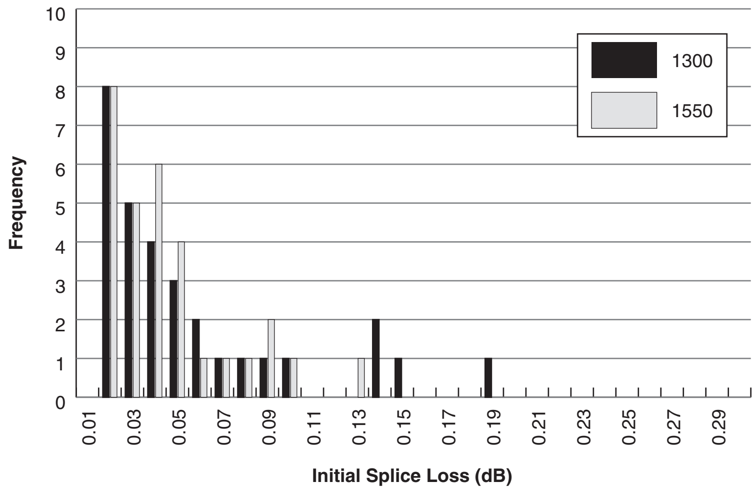


Fig. 6—Initial Splice Loss (dB)

4.1.1–4.1.7 Summary of Results (250 µm to 250 µm)

Section	Test	Wavelength	Mean Loss	Max Loss	Mean Change in Loss	Average Reflectance	Maximum Reflectance
4.1.1	**Initial Splice Loss**	1300 nm	0.05 dB	0.19 dB	N/A	-63.7 dB	-54.3 dB
	(100% Yield)	1550 nm	0.04 dB	0.13 dB	N/A	-59.7 dB	-51.8 dB
4.1.2	**Splice Strength**	1300 nm	0.05 dB	0.21 dB	0.00 dB	-63.9 dB	-55.1 dB
		1550 nm	0.05 dB	0.16 dB	0.01 dB	-58.6 dB	-52.4 dB
4.1.3	**Vibration**	1300 nm	0.05 dB	0.18 dB	0.00 dB	-63.9 dB	-55.1 dB
		1550 nm	0.05 dB	0.17 dB	0.01 dB	-52.0 dB	-52.2 dB
4.1.4	**Temp Cycle**	1300 nm @ -40°C	0.05 dB	0.17 dB	-0.01 dB	-39.6 dB	-37.2 dB
	(100 cycles)	@ +23°C	0.05 dB	0.19 dB	0.00 dB	-63.8 dB	-54.6 dB
		@ +80°C	0.05 dB	0.18 dB	0.00 dB	-41.0 dB	-38.0 dB
		1550 nm @ -40°C	0.03 dB	0.13 dB	-0.01 dB	-38.7 dB	-35.1 dB
		@ +23°C	0.05 dB	0.15 dB	0.01 dB	-62.5 dB	-51.8 dB
		@ +80°C	0.03 dB	0.13 dB	-0.01 dB	-40.3 dB	-37.5 dB
4.1.5	**Water**	1300 nm @ +23°C	0.05 dB	0.19 dB	0.00 dB	-64.4 dB	-57.6 dB
	Immersion	1550 nm @ +23°C	0.04 dB	0.15 dB	-0.01 dB	-61.4 dB	-54.6dB
4.1.6	**Temp Cycle**	1300 nm @ -40°C	0.05 dB	0.19 dB	0.00 dB	-39.5 dB	-37.0 dB
	(200 cycles)	@ +23°C	0.05 dB	0.20 dB	0.00 dB	-57.6 dB	-54.5 dB
		@ +80°C	0.05 dB	0.19 dB	-0.01 dB	-40.9 dB	-37.7 dB
		1550 nm @ -40°C	0.03 dB	0.14 dB	-0.02 dB	-38.6 dB	-35.3 dB
		@ +23°C	0.05 dB	0.15 dB	0.01 dB	-62.3 dB	-55.3 dB
		@ +80°C	0.03 dB	0.15 dB	-0.01 dB	-40.5 dB	-37.4 dB
4.1.7	**Environmental**	1300 nm	0.05 dB	0.20 dB	0.00 dB	-64.3 dB	-57.5 dB
	Degradation	1550 nm	0.05 dB	0.15 dB	0.01 dB	-62.7 dB	-54.7 dB

Notes: During the Environmental Degradation Test, two fibers broke outside of the splice and were not included in the loss and reflection calculations for this test.

The average reflectance of the test samples at +23°C is less than reported above. The measured reflectance is limited by the test system's capability to measure small reflectances. For additional information concerning the relationship between operating temperature and reflectance, refer to Appendix A.

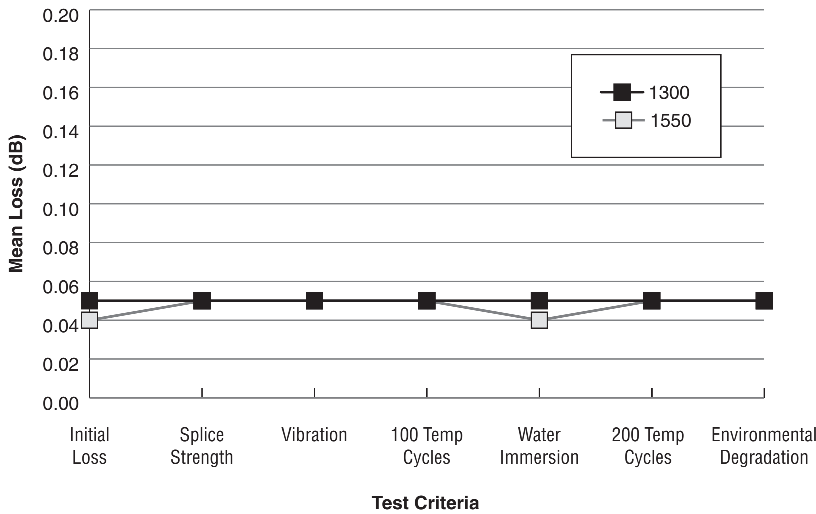


Fig. 7—Environmental Life Test Series

5.0 Extended Reliability Analysis

In addition to the standard Environmental Life Tests performed according to the parameters in Telcordia 765, the Extended Reliability Analysis provides information on historic field performance, extended water immersion, extended high humidity & high temperature exposure, chemical resistance and fungal resistance.

These test results demonstrate the performance of the 3M™ Fibrlok™ II splice as a permanent splice.

5.1 Historic Field Performance

Objective: Determine and quantify the long term field performance of Fibrlok Splicing Systems.

Since the Fibrlok Splice was introduced in 1988, over 8,000,000 Fibrlok, Fibrlok II, and Fibrlok Multi-Fiber Splices have been sold and installed. The performance stability of the optical couplant used in these splices is shown in Figure 8 and 9. These splices were placed in field service in 1989 and 1990, and the measurements were taken in 1994. This snapshot of these splices shows excellent performance over time. (The OTDR could not read reflectance greater than 65 dB, thus any splices that were better than 65 dB register as 65 dB.)

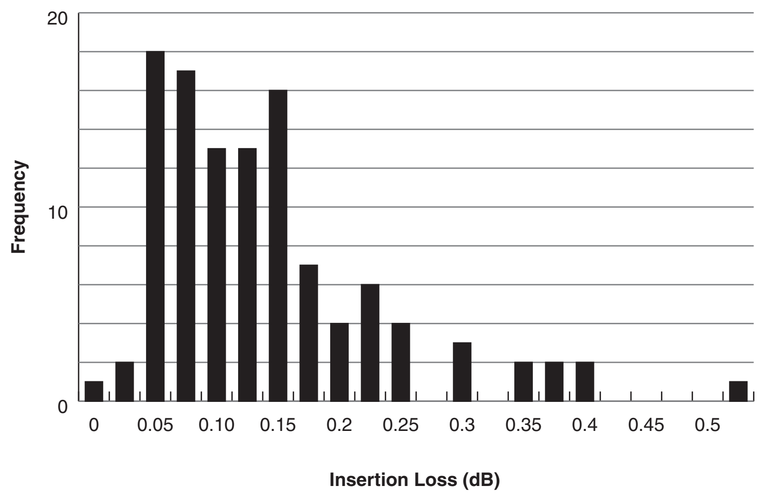


Fig. 8—Frequency distribution of the absolute insertion loss values of single fiber splices after being in service for 4–5 years (installed in 1989 and 1990).

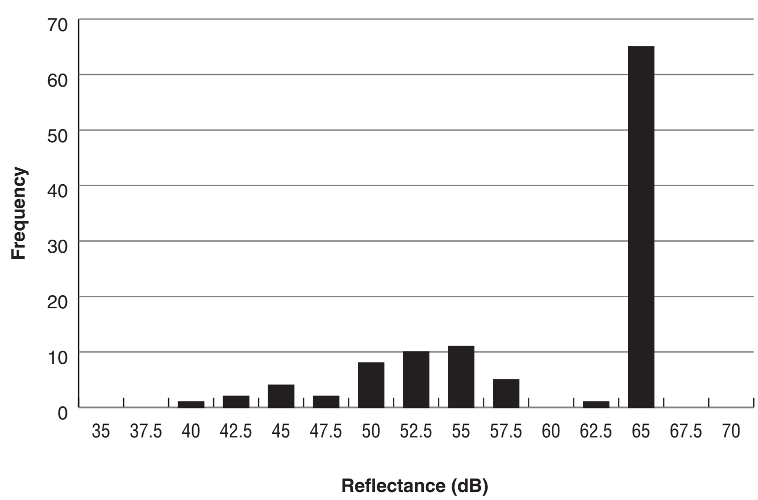


Fig. 9—Frequency distribution of the absolute reflectance values of single fiber splices after being in service for 4–5 years (installed in 1989 and 1990).

5.2 Extended Water Immersion

Objective: Determine the effect of water immersion on the performance characteristics of the 3M™ Optical Couplant and the 3M™ Fibrlok™ Splicing Systems.

The standard test for optical fiber splices is 7 days, as shown in section 4 of this report. Fibrlok II and Fibrlok Multi-Fiber Splices were tested to determine the effect of prolonged water immersion on the optical couplant beyond the standard test parameter.

Figure 10 shows the insertion loss of thirty Fibrlok splices after they were immersed in distilled water for thirty months (over 21,000 hours) at room temperature. The highest loss in this test is measured at under 0.20 dB. Loss measurements taken prior to water immersion indicate a maximum splice loss under 0.20 dB as well.

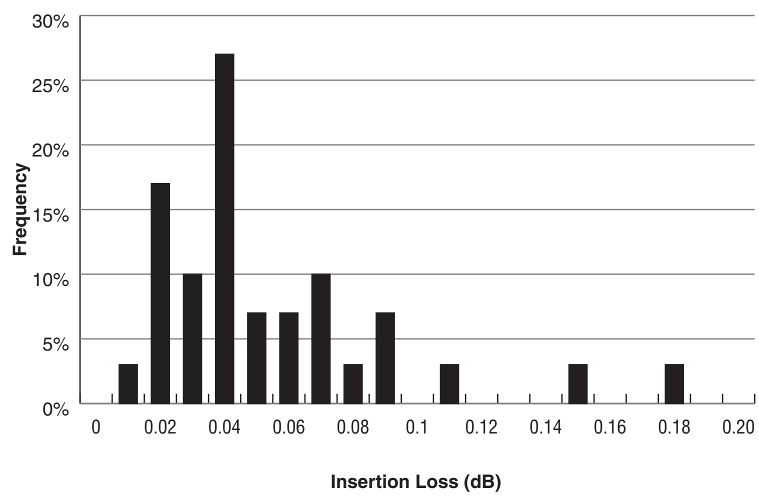
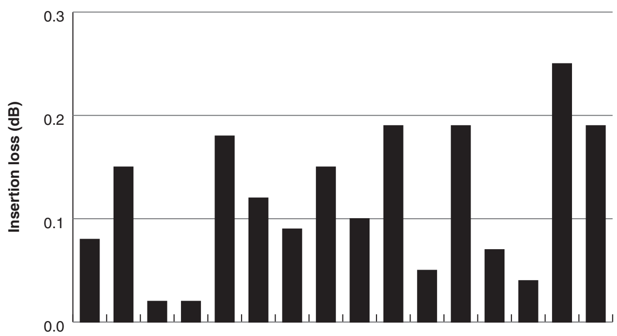


Fig. 10—Insertion loss distribution of Fibrlok splices that were immersed in water for over 21,000 hours (30 months).

5.3 Extended High Humidity, High Temperature

Objective: Determine the effect that extended exposure in a high humidity, high temperature environment has on the performance characteristics of the 3M™ Optical Couplant and the 3M™ Fibrlok™ II Optical Fiber Splices.

The standard test shown in section 4 cycles the splice from -40°C to 80°C with uncontrolled humidity for 100 cycles or 600 hours. Figures 11 and 12 show the loss and reflectance of 16 Fibrlok II 2529 splices after they were exposed to environmental conditions of 85°C and 85% relative humidity for 8,812 hours. The performance data is shown at 1310 nm in Figure 11 and at 1550 nm in Figure 12. The insertion loss and reflectance are excellent at both wavelengths.



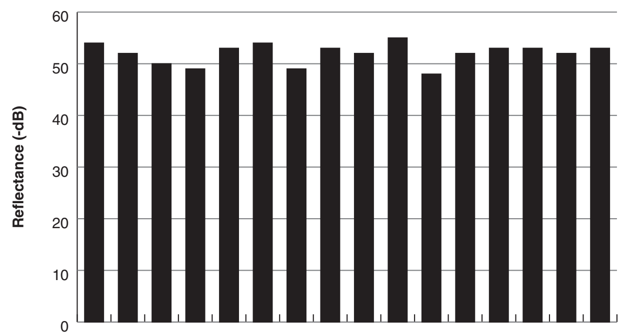
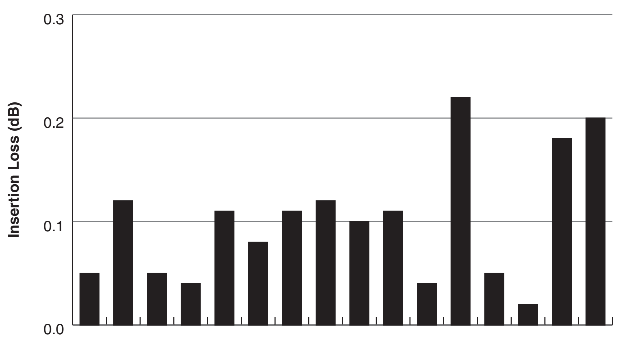


Fig. 11—Loss and reflectance (at 1310 nm) of Fibrlok splices that were exposed to 85% relative humidity at 85°C for 8,812 hours.



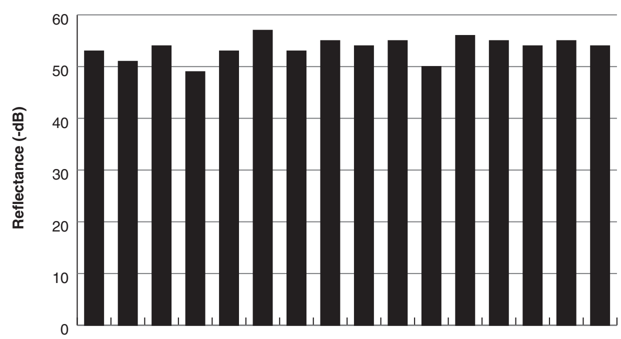


Fig. 12—Loss and reflectance (at 1550 nm) of Fibrlok splices that were exposed to 85% relative humidity at 85°C for 8812 hours.

5.4 Chemical Resistance

Objective: Determine the resistance of the 3M™ Optical Couplant and the 3M™ Fibrlok™ Splicing Systems to industrial chemicals.

The chemical resistance of Fibrlok Splicing Systems was evaluated by immersing fiber pairs joined with Fibrlok splices in the chemicals listed in the following table.

Chemical Solution	Immersion Temperature	Insertion Duration
Sulfuric Acid, 0.2 N	42°C	10 Days
Sodium Hydroxide, 2% by volume	42°C	10 Days
Igepal (detergent)	42°C	10 Days
Salt Water, 5% by weight	42°C	10 Days
Kerosene	23°C	10 Days

The insertion loss of the samples was measured before they were immersed, and again upon completion of the test. Figure 13 shows the change in the insertion loss of the chemical immersion samples. The average change in loss is 0.00 dB.

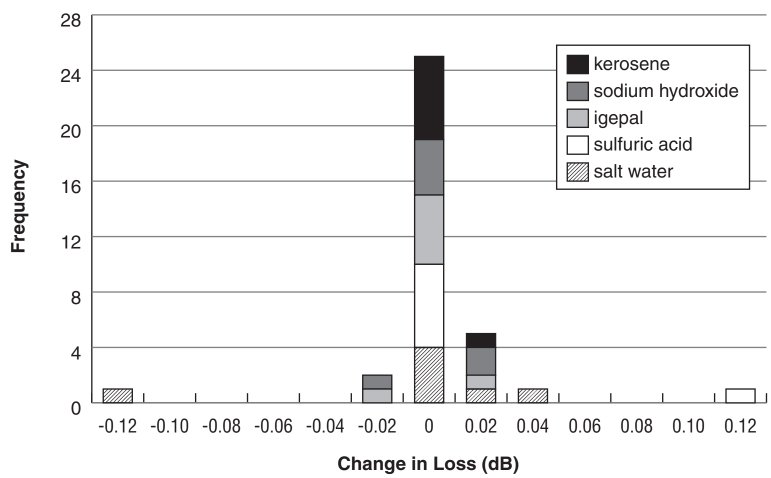


Fig. 13—Change in insertion loss of Fibrlok splices that were immersed in industrial chemicals for ten days.

5.5 Fungus Resistance

Objective: Determine the resistance of 3M™ Fibrlok™ Splices to fungus.

Samples of the Fibrlok splices molded plastic body and of the optical couplant were tested for fungus resistance according to ASTM G21-70. (Inoculated samples were conditioned for 28 days at an incubation temperature of 28°C.) The following table shows the ASTM rating for each of the samples.

Fungus Resistance Test Sample Number	Material Tested	ASTM G21-70 Rating
1	Fibrlok Plastic Body	0
2	Fibrlok Plastic Body	0
3	Fibrlok Plastic Body	0
4	Fibrlok Plastic Body	0
5	Fibrlok Plastic Body	0
—	Control Sample	4
1	Optical Couplant	0
2	Optical Couplant	0
3	Optical Couplant	0
—	Control Sample	4

Both the molded plastic body and the optical couplant samples received a 'Zero' rating when tested to the procedure in ASTM G21-70. This indicates there was no detectable fungus growth on either material.

The control samples tested along with the subject test samples received the maximum rating of four (4), confirming the validity of each test.

5.6 3M™ Fibrlok™ Gigabit Ethernet Performance Test

Objective:

Gigabit Ethernet performance was evaluated by placing 3 Fibrlok splices in series on singlemode fiber. Three thousand feet of fiber separated the first two splices while 100 feet separated the last two splices. The 3 splices were subjected to 2 different phases of environmental tests while 1000Base-LX Ethernet traffic at 95% bandwidth capacity was transmitted through the channel. The first phase consisted of 93 temperature cycles from –10°C to +60°C (1 hr ramp time and 1 hour dwell) with 80% humidity at temperatures above freezing. Immediately after the first phase of environmental testing the temperature range was extended to –40°C to +80°C for seventy-six cycles.

Results:

SmartBits test chassis w/Gigabit ports monitored and recorded the integrity of the data transmission. The Gigabit Ethernet transmit/receive success rate was 100% for the channel that included three Fibrlok splices with square cleaves. A total of 134 trillion bytes were sent and received without error.

5.7 Fibrlok Performance in a 10 Gb/s Network Environment

Objective:

10 Gigabit Ethernet performance was evaluated by placing a Fibrlok splice within a network testbed configuration that was used to perform the testing as shown in Figure 15 below. The test setup uses a C-band (1530–1570 nm) tunable laser, which is modulated to a pseudo-random bit stream from a pattern generator. The data signal is amplified, and travels through 1 km of SMF-28 fiber. During baseline system testing, there is no device under test, and the signal continues on through another 1 km reel of fiber.

At this point, noise is generated and added to the signal to allow the measurement of an optical signal to noise ratio (OSNR) with the optical spectrum analyzer (OSA). The signal, with noise, is then filtered at the correct wavelength, and received at the optical receiver, which then amplifies the signal and sends it to the error detector of the Bit Error Rate tester. The tester compares the received signal to what was sent out by the pattern generator to determine the bit error rate.

Ten different 3M™ Fibrlok™ splices were tested and before each Fibrlok test, a baseline without a Fibrlok splice was also tested. The Power Penalty of the splice is the amount of power lost in the system once the splice is added to the system. To test the Fibrlok splices, we measured the Optical Signal to Noise Ratio (OSNR) required to achieve a fixed BER ($4x10^{-10}$) on the network testbed with and without a Fibrlok splice in place. The measurements were repeated for each splice at each wavelength using 50 GHz channel spacing on the ITU grid.

Power Penalty is defined as the difference in OSNR necessary to maintain the same BER ($4x10^{-10}$) between the baseline measurement and the measurement of the Fibrlok splice. The power penalty that can be attributed to each of the splices was calculated at each wavelength, and is shown in Figure 16 below. As can be seen from the data, the Fibrlok splices tested do not add significantly to the power penalty of the system across the tested wavelengths.

Conclusion:

To the limits of the measurement capability of the test system, in terms of accuracy and repeatability, the addition of Fibrlok splices add no measurable power penalty to the network testbed system across the tested wavelengths.

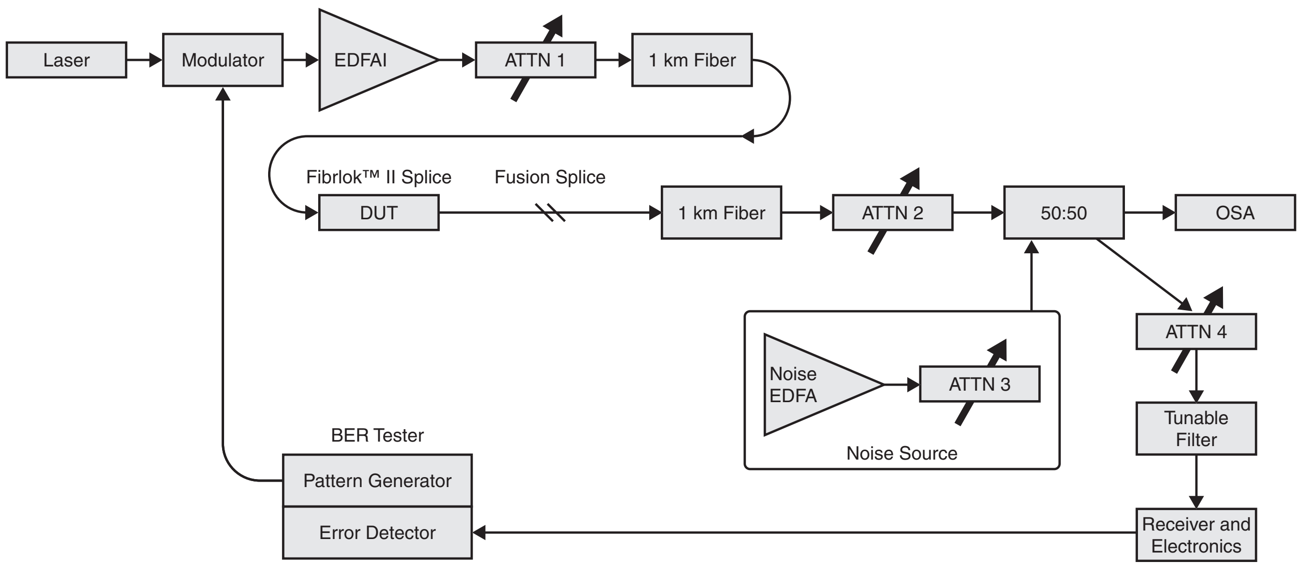


Fig. 15—Network Testbed Configuration for Fibrlok Splice Testing

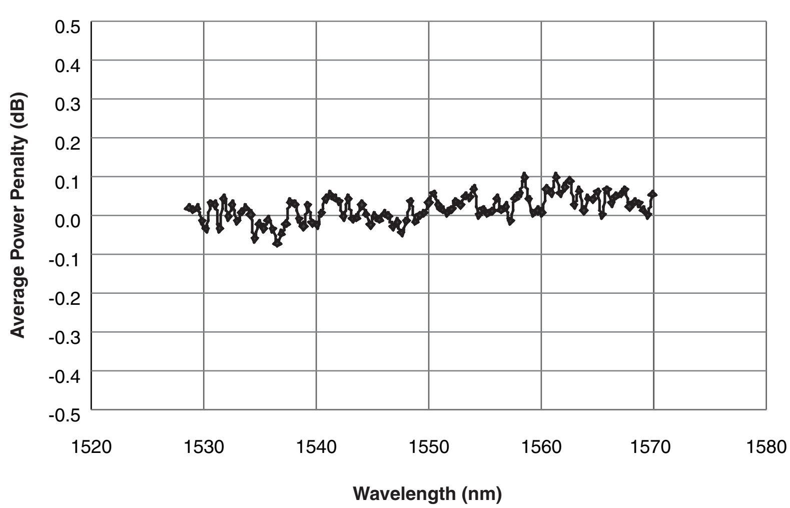


Fig. 16—Average Power Penalty as a Function of Wavelength all Fibrlok II Splices Tested

6.0 Conclusions

This reporting of test results shows that the 3M™ Fibrlok™ II Universal Optical Fiber Splice 2529 has sustained excellent performance throughout rigorous environmental tests.

Tests were performed in environmental conditions referenced in Telcordia 765.

Historic field performance of the splice is also presented, as well as performance data from severe environmental tests, with extended water immersion, extended high humidity and high temperature exposure, chemical immersion, and fungus resistance.

Without exception, the performance of the splice was stable, predictable and excellent, supporting the case that the Fibrlok can be used as a permanent splice.

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