Fiber Optic Fusion Splicing—Two Technologies Compared

By Todd Norton and Joseph Geary

When fiber optic cables are installed or repaired, splicing is by far the most common method of joining any two fibers together. Whether fusion or mechanical splicing is used, the goal is to join the tips of the two fibers together, end-to-end, in a permanent manner. The most important criteria for a good fiber splice is low insertion loss (the amount of light lost at the junction, relative to what would cross if the fiber were continuous), back reflection from any features in the junction, and the stability of the splice over an extended time at normally varying ambient temperature.

The two basic methods of splicing are mechanical and fusion. Mechanical splices use a support structure, such as a precision capillary, to accept the two fibers and support them in lateral alignment with each other. When the fiber faces are properly aligned in contact with each other in the capillary, they are clamped or glued in place. This method has the advantage of using relatively low-cost tools. However, the splice modules tend to cost substantially more than the reinforcements used on fusion splices, and both the insertion loss and the back reflection values tend to be substantially higher. Furthermore, mechanical splices tend to be much less tolerant of wide temperature variations and other environmental stresses. They are usually used where the total number of splices is not large and the performance specifications are relaxed.

Fusion splicing is the method preferred by most installers. This approach generally uses an electric arc to soften the ends of the two glass fibers, at high temperature, while they are in contact with each other and are being pushed slightly together. The two fibers are actually fused together. When a fusion splice is properly made, the joint is virtually indistinguishable from an uncut fiber. Both the insertion loss and the back reflection values are normally extremely low, and the splice, when properly protected, is very durable under environmental stresses. Top-of-the line fusion splicers are highly automated, incorporating x-y-z alignment of the two fibers, microprocessor control of the fusion process, programs optimized for particular fibers, and the automatic estimation of the insertion loss after the splice is completed. After the fusion splice is completed, a simple protective reinforcement is usually applied to ease handling and storage of the spliced fiber.

We recently compared the two most common methods of automatic fiber optic fusion splicing: Local Injection/Detection (LID) and the Profile Alignment System (PAS). We studied two different automatic arc fusion fiber optic splicers. These were the Orionics/Aurora Model FW310 and the Fujikura FSM-20CS. The FW310 is a LID splicer and the FSM-20CS is a PAS splicer.

To begin the study, each instrument was used to splice a Corning 1521 single-mode fiber 75 times. Data for each splice were recorded and tabulated. The test setup is described in the EIA Standard Interconnection Device Insertion Loss Test (EIA-455-34) Method A (see Figs. 1a and b). The instruments were judged based on their performance in achieving and estimating low-loss splices on single-mode fibers. In addition, certain advantages and disadvantages of each instrument were noted, mostly in the area of ease of use or operator friendliness.

Setting a Baseline

To assure accuracy of all data, the baseline was corrected to remove any daily fluctuations. This was achieved by leaving the last splice from the previous day intact overnight; the new day's baseline was determined by using the previous day's baseline and splice loss. This procedure was done daily and was successful in eliminating day-to-day fluctuations.

Fiber Preparation

To splice fiber efficiently, it must be properly prepared. This was done in the same manner for each instrument to eliminate any possible

FIGURE 1 A

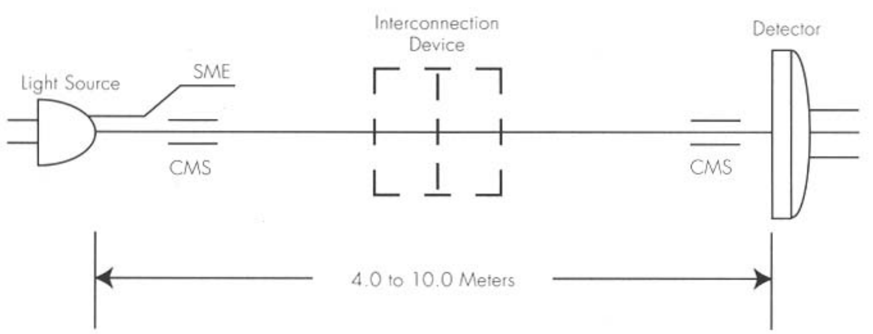
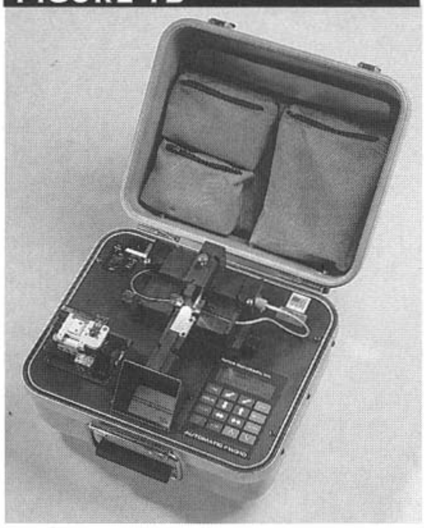


FIGURE 1 B



Fiber optic fusion splicer.

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skewing of results. Using built-in cleavers, the scribe and break technique was used to prepare the fiber for splicing. In this technique, an extremely sharp blade (typically diamond or carbide) is used to very slightly score the fiber, or induce a slight defect. Then the fiber is pulled under controlled conditions. With proper combination of scribe and tension, the fiber will break very cleanly at the location of the defect, with a flat featureless end surface virtually perpendicular to its long axis.

TABLE 1

ORIONICS **AURORA** **FW310**

Splice #	Estimate Loss (dB)	Circuit Loss (dB)	Alignment Time (sec)	Gap Length	Estimate Error (dB)
1	0.02	0.03	42	28	0.01
2	0.01	0.04	46	28	0.03
3	0.08	0.02	49	32	-0.06
4	0.01	0.01	46	27	0.00
5	0.04	0.00	41	30	-0.04
6	0.00	0.00	53	26	0.00
7	0.03	0.04	63	29	0.01
8	0.02	0.07	52	30	0.05
9	0.05	0.05	53	27	0.00
10	0.06	0.01	57	28	-0.05
11	0.01	0.00	48	28	-0.01
12	0.07	0.01	44	24	-0.06
13	0.03	0.04	47	23	0.01
14	0.02	0.03	39	28	0.01
15	0.00	0.02	43	25	0.02
16	0.00	0.00	52	25	0.00
17	0.01	0.02	44	27	0.01
18	0.01	0.02	43	24	0.01
19	0.08	0.05	50	26	-0.03
20	0.03	0.04	41	27	0.01
21	0.03	0.04	38	25	0.01
22	0.02	0.02	50	26	0.00
23	0.02	0.02	31	28	0.00
24	0.03	0.00	54	24	-0.03
25	0.03	0.02	40	25	-0.01
26	0.03	0.03	45	29	0.00
27	0.00	0.00	42	24	0.00
28	0.04	0.04	35	23	0.00
29	0.02	0.00	38	23	-0.02
30	0.05	0.02	46	26	-0.03
31	0.05	0.02	49	24	-0.03
32	0.02	0.00	51	24	-0.02
33	0.06	0.00	39	23	-0.06
34	0.03	0.01	46	24	-0.02
35	0.03	0.03	42	24	0.00
36	0.02	0.02	37	24	0.00
37	0.02	0.02	47	25	0.00
38	0.04	0.02	36	23	-0.02
39	0.02	0.03	42	22	0.01
40	0.03	0.03	38	25	0.00
41	0.00	0.01	46	22	0.01
42	0.03	0.01	47	25	-0.02
43	0.03	0.01	46	26	-0.02
44	0.02	0.02	44	27	0.00
45	0.02	0.01	43	25	-0.01
46	0.05	0.01	40	29	-0.04
47	0.06	0.04	39	29	-0.02
48	0.01	0.01	59	26	0.00
49	0.03	0.00	44	26	-0.03
50	0.01	0.01	45	26	0.00
51	0.05	0.01	48	25	-0.04
52	0.00	0.00	51	25	0.00
53	0.04	0.00	50	24	-0.04
54	0.00	0.00	46	23	0.00
55	0.01	0.01	43	25	0.00
56	0.00	0.00	53	23	0.00
57	0.02	0.01	48	23	-0.01
58	0.01	0.00	38	27	-0.01
59	0.02	0.00	46	26	-0.02
60	0.02	0.02	46	24	0.00
61	0.06	0.03	45	23	-0.03
62	0.03	0.02	60	23	-0.01
63	0.01	0.00	44	23	-0.01
64	0.03	0.03	41	24	0.00
65	0.04	0.03	41	25	-0.01
66	0.03	0.01	49	25	-0.02
67	0.01	0.01	46	26	0.00
68	0.01	0.01	48	22	0.00
69	0.00	0.00	48	26	0.00
70	0.02	0.01	41	22	-0.01
71	0.01	0.01	44	26	0.00
72	0.02	0.01	48	23	-0.01
73	0.00	0.00	46	24	0.00
74	0.01	0.01	45	27	0.00
75	0.02	0.01	48	22	-0.01
AVERAGE:	0.02533	0.01653	45.53333	25.33333	-0.00880

TABLE 2

FUJIKURA **FSM-20CS**

Splice #	Estimate Loss (dB)	Circuit Loss (dB)	ARC Count	Alignment Time (sec)	Estimate Error (dB)
1	0.03	0.07	773	71	0.04
2	0.02	0.06	774	78	0.04
3	0.17	11.39	775	78	11.22
4	0.02	0.00	776	72	-0.02
5	0.04	0.00	777	79	-0.04
6	0.03	0.00	778	79	-0.03
7	0.03	0.00	779	71	-0.03
8	0.03	0.02	780	70	-0.01
9	0.02	0.02	781	79	0.00
10	0.02	0.04	782	76	0.02
11	0.02	0.03	783	74	0.01
12	0.02	0.02	784	78	0.00
13	0.02	0.02	785	77	0.00
14	0.10	0.10	786	71	0.00
15	0.02	0.01	787	81	-0.01
16	0.03	0.09	788	76	0.06
17	0.02	0.04	789	81	0.02
18	0.02	0.03	790	78	0.01
19	0.05	0.04	791	78	-0.01
20	0.02	0.01	792	77	-0.01
21	0.04	0.03	793	74	-0.01
22	0.04	0.06	794	74	0.02
23	0.02	0.02	795	81	0.00
24	0.02	0.00	796	72	-0.02
25	0.02	0.01	797	74	-0.01
26	0.03	0.04	798	75	0.01
27	0.02	0.03	799	74	0.01
28	0.02	0.02	800	68	0.00
29	0.03	0.06	801	71	0.03
30	0.03	0.06	802	73	0.03
31	0.02	0.05	803	69	0.03
32	0.02	0.04	804	69	0.02
33	0.02	0.03	805	70	0.01
34	0.03	0.03	806	68	0.00
35	0.03	0.16	807	73	0.13
36	0.03	0.02	808	79	-0.01
37	0.03	0.09	809	69	0.06
38	0.03	0.08	810	74	0.05
39	0.02	0.05	811	71	0.03
40	0.02	0.06	812	74	0.04
41	0.03	0.04	813	71	0.01
42	0.02	0.03	814	70	0.01
43	0.05	0.05	815	79	0.00
44	0.02	0.00	816	77	-0.02
45	0.04	0.02	817	71	-0.02
46	0.02	0.03	818	77	0.01
47	0.02	0.02	819	74	0.00
48	0.04	0.04	820	72	0.00
49	0.02	0.02	821	71	0.00
50	0.04	0.06	822	73	0.02
51	0.02	0.01	823	71	-0.01
52	0.02	0.01	824	79	-0.01
53	0.02	0.01	825	74	-0.01
54	0.02	0.01	826	71	-0.01
55	0.02	0.02	827	79	0.00
56	0.02	0.02	828	80	0.00
57	0.02	0.02	829	86	0.00
58	0.02	0.02	830	70	0.00
59	0.02	0.00	831	65	-0.02
60	0.02	0.01	832	62	-0.01
61	0.02	0.00	833	67	-0.02
62	0.02	0.01	834	74	-0.01
63	0.02	0.00	835	79	-0.02
64	0.02	0.01	836	73	-0.01
65	0.02	0.00	837	71	-0.02
66	0.04	0.01	838	70	-0.03
67	0.02	0.00	839	79	-0.02
68	0.02	0.00	840	72	-0.02
69	0.03	0.00	841	78	-0.03
70	0.04	0.00	842	73	-0.04
71	0.02	0.10	843	71	0.08
72	0.02	0.00	844	74	-0.02
73	0.02	0.02	845	72	0.00
74	0.02	0.00	846	68	-0.02
75	0.03	0.04	847	73	0.01
AVERAGE:	0.02622	0.02932		73.83784	0.00311

FIGURE 2

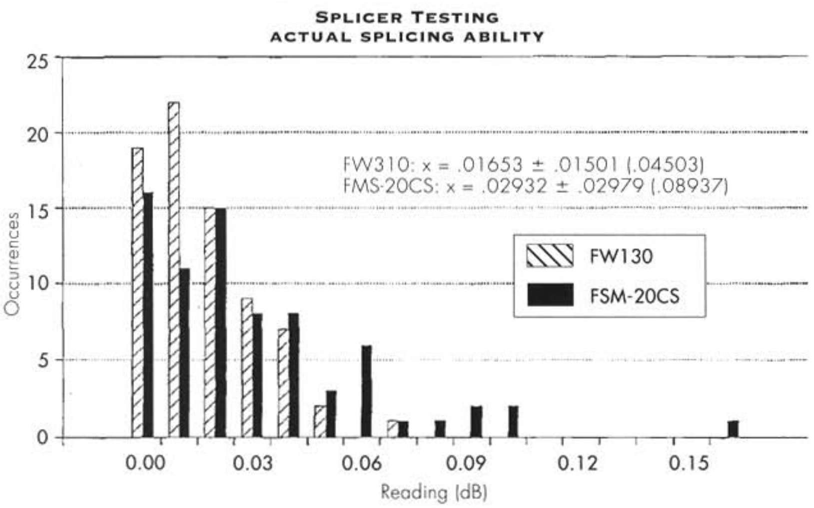


TABLE 3

HISTOGRAM DATA

ACTUAL SPLICING ABILITY

READING (dB)	OCCURRENCES: FW310	FSM20CS
0.00	19	16
0.01	22	11
0.02	15	15
0.03	9	8
0.04	7	8
0.05	2	3
0.06	0	6
0.07	1	1
0.08	0	1
0.09	0	2
0.10	0	2
0.11	0	0
0.12	0	0
0.13	0	0
0.14	0	0
0.15	0	0
0.16	0	1
Other	None	1

ABILITY TO ACHIEVE LOW-LOSS SPLICE

Seventy-five splices were made with each instrument, and optical power data were compiled in two tables, one for each instrument (see Tables 1 and 2). From the data, each splicer's ability to make low loss splices can be determined. For the purposes of this study, the insertion loss is defined as the difference between the transmitted power after the splice and the power before the fiber was broken (baseline). This value is assumed to be the actual loss occurring across the splice and is error-free. Since many splices were made in any one day, the baseline power was measured at the beginning of the day, using an unbroken fiber. The insertion losses achieved by each machine provide a vital measure of its performance, relative both to other machines and to other methods of splicing. Tables 1 and 2 include the calculations of insertion loss for all splices made with both machines.

The average and standard deviation of the circuit loss column in each table is directly related to the respective instruments' splicing ability. The data are further detailed in Figure 2 and Table 3. Figure 2, a histogram of the data in Table 3, plots the number of times a given reading occurred for one instrument against the reading that occurred. In the graph, the two instruments' splicing abilities can be viewed reading by reading. This allows one to make a direct comparison immediately between the two. Also on the graph are the average loss per splice and the standard deviation from this value with the limit of error recorded in parentheses.

While detailed data are available on the results of this phase, it is evident that the LID splicer is more capable of making a low-loss splice as compared to the PAS splicer. For example, the loss per splice averaged 0.017 dB for the LID splicer—about half the average loss of the PAS splicer at 0.029 dB. Also, the LID splicer's standard deviation from this average value (0.015 dB) is one half the deviation for the PAS splicer (0.030 dB). Therefore, the LID splicer is better—by a factor of 2—at achieving a low-loss splice than the PAS splicer.

ESTIMATION OF SPLICE LOSS

Another performance parameter of interest is each instrument's ability to estimate the loss of a given splice. The value of this estimation capability is determined by taking the insertion loss as determined by the power meter reading minus the baseline (insertion loss value) and subtracting from it the instrument-estimated loss on a splice-by-splice basis. This allows a column of estimated error values to be tabulated, and the results are shown in Tables 1 and 2 in the columns titled "estimate error."

The data for estimate error are further accumulated in Figure 3. The LID splicer averaged an estimated error of −0.0088 dB, which means that it more often overestimates the loss of the splice. This is opposed to the PAS splicer average of +0.0031 dB, which means it more often underestimates a splice's loss. The magnitude of these values demonstrates both instruments' ability to accurately estimate a given splice. Both instruments' estimations deviate on average less than .01 dB from the actual splice loss. However, these numbers can be deceiving because a value of zero as the average could mean that the resulting curve is just centered about the y-axis.

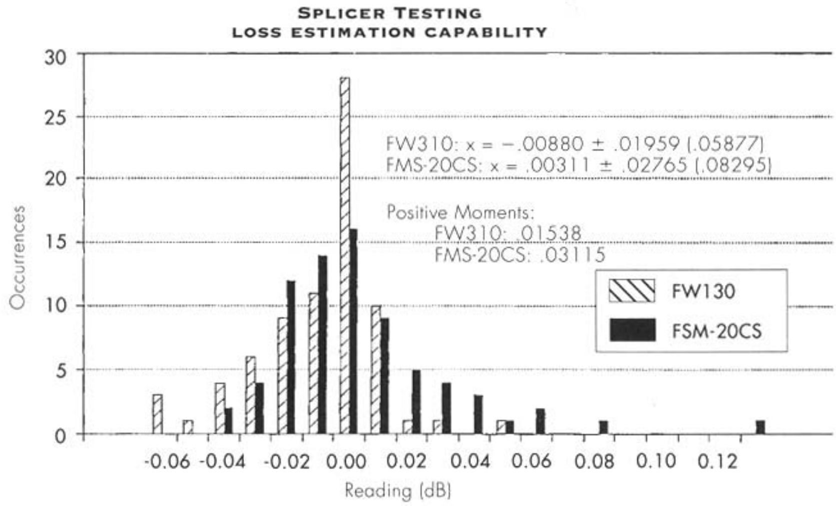
Other useful information, such as the positive moment, can be derived from the data. Since underestimation of the loss could be detrimental, the positive moment for each instrument is calculated. The larger the positive moment the more often an instrument would underestimate a splice loss value. Positive moment is a statistical measure of the tendency of the data to deviate from a reference value. In this case, it is the mean of the deviations of the actual losses from the loss estimates. Thus, if the data show a positive moment of 0.02, on average the actual loss of any splice is typically 0.02 dB higher than the corresponding estimated made by the machine. The larger the positive moment, the more likely it is that a splice is more lossy than the machine says it is. In some cases, it could mean that splices are accepted—based on a machine estimate—which are actually out of spec.

For the LID splicer the positive moment is 0.01538, while for the PAS splicer it is 0.03115. The value for the LID splicer is twice as good, and the LID splicer had one half as many underestimations as the PAS splicer.

Splice Time

The time it takes to splice the fiber ends is another important factor in splicer performance. Since the PAS splicer does not display the time necessary for splicing, a separate watch was used to record this information. The LID splicer does display the time and its output was tabulated. The LID splicer splices a fiber in approximately 45 seconds, while the PAS splicer takes approximately 75 seconds (see Tables 1 and 2). This time difference of 30 seconds is significant. After splicing 120 times, the LID splicer would have saved one hour compared with the PAS splicer.

FIGURE 3



Conclusions

Some of the operating characteristics of the PAS splicer are independent of operator control and, thus, cannot be enhanced by inherent capabilities present in the instrument. By contrast, the LID splicer's shortcomings can be almost completely eliminated under the control of an experienced operator. The LID splicer produces splices that are twice as good as the PAS splicer. In addition, the LID splicer, on average, estimates splice loss about twice as well as the PAS splicer. The LID splicer not only is better at splicing and estimating on average, it also has a smaller standard deviation in this area. This shows the greater consistency of the LID splicer. In addition to these qualities, the LID splicer completes its splices approximately 30 seconds faster than the PAS splicer. The LID splicer has the added advantages that it can be used to splice and estimate multi-mode fibers. The LID splicer does not have any quirks that would introduce possible erroneous splices into a system. In general, the LID splicer is easier to use and more efficient than the PAS splicer.

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LID vs. PAS splicing: Advantages and disadvantages

Results of this study provided many clear distinctions between the two fusion splicing techniques.

Advantages of LID splicer

- Automatic splicing sequence may be interrupted at any time, such as when cleaning arc must be fired repeatedly to remove all dirt.
- Fiber alignment and loss estimation for both single-mode and multi-mode fibers may be achieved using core-to-core light alignment of the built-in light source and detector.

Advantages of PAS splicer

- Rotating screen permits ease of viewing in any position.
- V-groove loading technique speeds and simplifies splicing.
- Auto-gapping mechanism places fiber ends at preset distance apart before auto-aligning sequence is initiated.
- Tensile strength of fiber is automatically tested using in-line proof procedure.
- Integral heat shrinking unit is available for splice protection jackets.

Disadvantages of LID splicer

- Fixed display restricts operator viewing angle.
- Fibers must be bent to inject and detect the light necessary for alignment. If the fiber is not loaded correctly, it can be snipped by the door mechanism, which then requires a new splicing sequence.

Disadvantages of PAS splicer

- A noisy fan must run continuously to prevent overheating.
- LCD view screen is difficult to see under bright light conditions—especially under bright sunlight.
- Separate cleaver is inconvenient, requiring too many pieces to move in and out of position near the end of the fibers.
- Multi-mode fiber splice loss estimation is not provided; for single-mode fiber, estimated losses are not shown below 0.02 dB, even if the actual loss is in this range.
- Too much unnecessary data is provided for output, causing required data to be "hidden" and easily missed.
- Loud beeping sounds during splicing are annoying.
- Cover lid for the arc and splicing area can pinch the fiber, causing it to snap. When the lid is left open, splicer resets until it is closed; the splicer will not function with the cover open.
- Lack of operator control of the cleaning arc can lead to dirty fiber ends prior to splicing. Fusion of dust particles between fiber ends can create large splicing losses.
- To further exacerbate inaccurate loss estimations, bubbles can appear in the core or cladding near the core after fusing and are not accounted for in the splice loss estimation. Actual loss can be substantially higher than estimated loss, providing a false sense of splice quality.