

Splicing Efficiency Improvement in Ultra-High Density Fiber Optic Cable

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ABSTRACT

Mass fusion splicing of ribbon fibers has been well established in fiber optic telecommunications deployments for some time, and it offers efficient and cost-effective splicing of high fiber count cables. In recent years, needs for even higher fiber count cables for data center applications have driven the development of new ultra-high density ribbon fiber cable designs to achieve the desired number of fibers within available duct space. These new ribbon fiber cables have successfully met the requirements for high density (with many cables containing 3,456 fibers or more) within an acceptable cable diameter that will fit into existing ducts. However, a new challenge has been encountered with these ultra-high density fiber optic cables. Specifically, it may require several days to prepare, organize, and splice a single high density splice point.

This paper investigates and documents each aspect of the cable joining and the ribbon fiber splicing process of ultra-high density fiber optic cable. This analysis identifies improvements in cable preparation, closure preparation, ribbon fiber preparation, and the mass fusion splicing processes achieved since a previous study was published as a technical paper at the 64th IWCS in 2015.¹ By taking a systems approach to the overall splicing process, it has been possible to improve efficiencies in the cable joining and splicing process to realize additional system cost savings with this technology.

Keywords: Ultra-High Density Fiber Optic Cable; Mass Fusion Splicing; Collapsible Ribbon Cable; Cable Joining; Wrapping Tube Cable; SpiderWeb Ribbon®.

1. INTRODUCTION

The advent of new ultra-high density fiber optic cable has been instrumental in solving a number of network design challenges caused by modern applications of fiber optics in data center applications, dense point-to-point systems, and new access networks. Many of these networks now utilize 1,728 fiber count cables, and some use 3,456 fiber count cables. Even larger 6,912 fiber count cables are now being placed on an initial trial basis.

These large fiber counts create a number of new challenges in constructing and maintaining these networks. In analyzing these challenges, the need for continuous improvements in the overall splicing process has been identified. The splicing process has three distinct sub-processes that can be impacted to improve the total time and cost of placing and joining these ultra-high fiber count cables: (1) cable end preparation or cable entry, (2) closure preparation and ribbon organization within the closure, and (3) the final process of actual mass fusion splicing.

This paper will focus on how each of these steps has been affected by new developments, and what impact this has had on the overall time and cost to join the fibers since 2015.

2. ULTRA-HIGH DENSITY FIBER OPTIC CABLES

2.1 Description of Ultra-High Density Fiber Optic Cables

Ultra-high density fiber optic cables were first introduced to the North American cable market in 2013.² Significant deployments started in 2015 and these deployments facilitated the network cost savings as discussed in the previous study.¹ This new cable technology offers a higher packing density, with more fibers per square millimeter of cable cross section, as compared to traditional ribbon cable designs using encapsulated ribbons.

Since 2015 there have been a number of manufacturers to offer similar cables. The maximum fiber count of these cables in 2015 was 1,728 fibers. Today, cables are commonly offered with up to 3,456 fibers. Cables with 6,912 fibers are in the process of being released by several manufacturers, with initial trial installations taking place as this paper is being published.

There are multiple cable configurations that use a variety of different methods to protect the fiber. Wrapping Tube Cable (WTC) using SpiderWeb Ribbon (SWR®) technology, is one of the technology methods using a “collapsible ribbon” to facilitate high packing density cables.

2.2 Wrapping Tube Cable Design

The Wrapping Tube Cable design is illustrated with a cross-sectional view as seen in *Figure 1—Armored Wrapping Tube Cable Cross-Sectional View* and also in a detailed assembly view seen in *Figure 2—Wrapping Tube Cable Detailed Assembly View*.

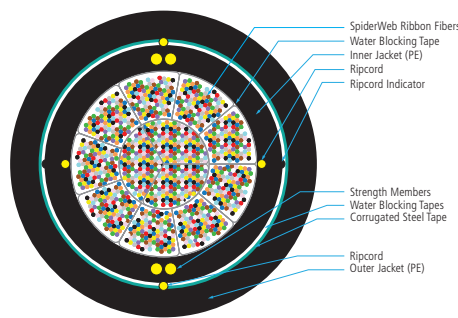


Figure 1—Armored Wrapping Tube Cable Cross-Sectional View

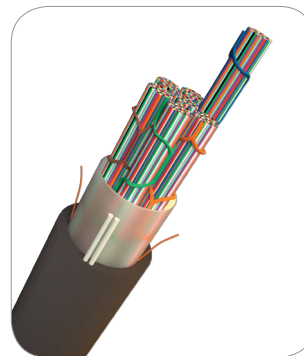


Figure 2—Wrapping Tube Cable Detailed Assembly View

The Wrapping Tube Cable design consists of a core of SpiderWeb Ribbon fibers that are grouped and bundled into binder groups. The bundle groups are wrapped with colored binder tape for easy identification and separation from other bundles.

The fiber core is covered with a longitudinally-applied water blocking tape that creates the wrapping tube core. The wrapping tube core is sheathed with a polyethylene jacket embedded with FRP strength members within the jacket walls.

Ripcords are placed 180-degrees apart under the inner sheath and outer armored sheath for a total of four ripcords. The ripcord locations on the inner sheath are identified with a ripcord indicator ridge that is extruded into the sheath. The indicator ridge allows the installer to identify the ripcord locations on the inner jacket for safe access to a mid-span access point without damaging the fibers.

2.3 SpiderWeb Ribbon

The key technology that allows for this ultra-high density cable design is SpiderWeb Ribbon. SpiderWeb Ribbon is illustrated in *Figure 3—SpiderWeb Ribbon* and consists of 12 fibers that are connected to each other by an intermittent UV-curable resin bond. The intermittent nature of the bond allows for the ribbon to be bunched and collapsed similar to a bundle of loose fibers. It also allows the ribbon to act as either a traditional ribbon for mass fusion splicing or to be easily broken out into individual fibers for single fusion splicing with no need for a special ribbon separation tool.

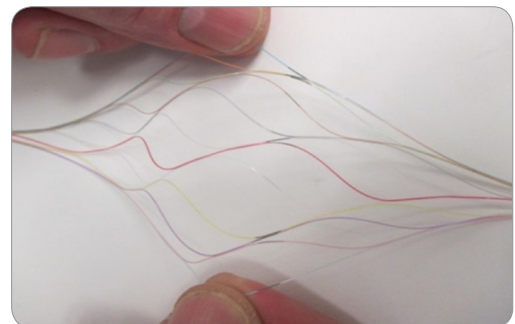


Figure 3—SpiderWeb Ribbon

2.4 SpiderWeb Ribbon Color Code

The SpiderWeb Ribbon uses the industry-recognized fiber color code for individual fiber identification. It is compliant with TIA/EIA 598 D Optical Fiber Cable Color Code, Issue July 2014. The fibers are individually color-coded for identification of fibers one through 12 as shown in *Table 1—SWR Fiber Color Code*. Unique to the SWR color code is that the eighth fiber is clear rather than black. The purpose of this alternative scheme is to ensure the ability to identify the black ring or band marking on the individual eighth fiber (as well as all other fibers) if the ribbon is separated into individual fibers for termination.

Table 1—SWR Fiber Color Code

FIBER NUMBER	FIBER COLOR	FIBER COLOR ABBREVIATION
Fiber 1	BLUE	BL
Fiber 2	ORANGE	OR
Fiber 3	GREEN	GN
Fiber 4	BROWN	BN
Fiber 5	SLATE	SL
Fiber 6	WHITE	WH
Fiber 7	RED	RD
Fiber 8	CLEAR	CL
Fiber 9	YELLOW	YL
Fiber 10	PURPLE	VI
Fiber 11	ROSE	RS
Fiber 12	AQUA	AQ

2.5 SpiderWeb Ribbon Ring Marking

For ease of ribbon identification the SpiderWeb Ribbon is striped or ring-marked with a key code that provides an identification of the ribbon unit. As shown in *Figure 4—SpiderWeb Ribbon Identification Code*, the identification code is based on a series of short and long dashes that provide a permanent identification of the ribbon (as well as individual fibers).

Stripe Ring Mark

Ring marking on each fiber in 12F SpiderWeb Ribbon

SWR No. 1	SWR No. 2	SWR No. 3	SWR No. 4	SWR No. 5	SWR No. 6
■	■■	■■■	■■■■	■■■■■	■■■■■■
SWR No. 7	SWR No. 8	SWR No. 9	SWR No. 10	SWR No. 11	SWR No. 12
■■■■■	■■■■■■	■■■■■■■	■■■■■■■■	■■■■■■■■■	■■■■■■■■■■

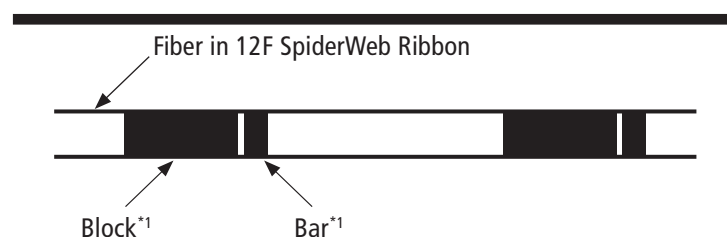


Figure 4—SpiderWeb Ribbon Identification Code

When the SWR has been de-ribbonized for access or single-fusion splicing, the ribbon identification code of short and long dashes stays with the individual fibers, as shown in *Figure 5—De-Ribbonized SpiderWeb Ribbon Identification*. This is key for ribbon identification and individual fiber identification in an access or FTTx solution. With this identification method, the splicing technician does not have to trace the individual fiber back to an undisturbed section of ribbon to identify from which ribbon number the fiber originated. In a traditional flat encapsulated ribbon (in which the 12 fibers are suspended in a ribbon encapsulation matrix that has the ink jet ribbon number printed on the encapsulation), the identification of the ribbon is lost when the ribbon is de-ribbonized for single fiber access because the encapsulation has been removed.



Figure 5—De-Ribbonized SpiderWeb Ribbon Identification

2.6 SpiderWeb Ribbon Binder Grouping

The grouping of the SpiderWeb Ribbon fibers within the colored binders is dependent on the fiber count of the cable. As there are 12 individual ribbon identification bands per *Figure 4*, the maximum base of a grouping is 144 fibers, or 12 ribbons. When the cable fiber count is a maximum of 144 fibers, there is no need for additional band-mark groupings, or separation of groups of ribbons by binder units. Above 144 fibers, the ribbons are organized into binder groups, with each binder group identified by the color of the binder tape. For cables with more than 144 fibers and up to a maximum of 864 fibers, each binder unit contains six ribbons (for a total of 72 fibers). In this case, only the first six stripe-mark identification codes shown in *Figure 4* are required to identify the ribbons within each binder unit. Above 864 fiber cables, the binder groups contain 12 ribbons (144 fiber), and all 12 stripe-mark identification codes are utilized. A cable with 1,728 fibers required 12 binder groups with each containing 12 ribbons (144 fibers). Therefore, the 12 binders are identified by applying the TIA/EIA 598 D Optical Fiber Cable Color Code³ for the binder colors.

In cables with more than 1,728 fibers, the binder groups continue to contain 12 ribbons each (144 fibers). In this case, since more than 12 binder groups are required due to the higher fiber count, binder groups 13 through 24 use a dual-color binder tape. The base color of binders 13 through 24 continues to follow the TIA/EIA 598 D Optical Fiber Cable Color Code, but the second tape of the binder is clear. A summary of the details of the number of ribbons and the size and color of the binder groups (depending on the cable total fiber count) is shown in *Table 2—WTC Cable Binder Color Code*.

Table 2—WTC Binder Color Code

FIBER COUNT	BINDER UNIT (BU)												RING MARKINGS	
144F	No Binder Unit												1-12 Ring Marking	
288F	4 Binder Units	1	2	3	4	5	6							1-6 Ring Marking
432F	6 Binder Units	1	2	3	4	5	6							
576F	8 Binder Units	1	2	3	4	5	6	7	8					
864F	12 Binder Units	1	2	3	4	5	6	7	8	9	10	11	12	
1152F	8 Binder Units	1	2	3	4	5	6	7	8					1-12 Ring Marking
1728F	12 Binder Units	1	2	3	4	5	6	7	8	9	10	11	12	1-12 Ring Marking
3456F	24 Binder Units	1	2	3	4	5	6	7	8	9	10	11	12	1-12 Ring Marking
		13	14	15	16	17	18	19	20	21	22	23	24	1-12 Ring Marking

*For binder units 13-24, the second binder unit is clear

3. ELEMENTS OF THE FIELD SPLICING PROCESS

3.1 Cost Elements of Field Splicing

When investigating the cost of field splicing for ultra-high density fiber optic cable designs, there are three areas of time consumption that correlate to the overall cost of splicing:

- Cable Preparation
- Closure Preparation
- Mass Fusion Splicing

In the previously published study¹, the overall cable joining/splicing time and cost savings for WTC using SWR was compared to single fusion splicing of loose tube cables for a 144 fiber count cable. For larger cables, the total splicing time for WTC containing SWR was compared to ribbon in loose tube cables containing traditional encapsulated matrix 12 fiber ribbons in the tubes. Significant advantages and time savings were found with WTC and SWR in the previous study. This paper focuses on new improvements in the three identified areas of the total cable joining and splicing process, and how these improvements have further reduced the total splicing time and thus reduced the cost associated with joining ultra-high fiber count cables.

3.2 Cable Preparation

Network splicing typically consists of reel-end splicing and/or branch cable splicing. Cable end preparation for network splice applications typically requires removal of 72 to 96 inches (1.84 to 2.44 meters) of cable sheath, depending on the cable closure. The cable preparation time is most impacted by the cable core unbinding, identification of fiber units, and any cleaning and gel removal from the fiber or ribbons.

Cable preparation time on the ultra-high density WTC cable was significantly improved in the initial designs of 2015 relative to traditional ribbon cables. The cable was designed for quick entry and speedy cable preparation. The cable utilizes a dry core design that reduces the cable clean up and strip-back process for both end splicing and mid-cable entry of the cable cores. The tools used in cable entry are the traditional tools used by splicing technicians, as shown in *Figure 6—Industry Standard Tools for Cable Preparation*.

A key product improvement on the WTC is the unique binder identification, made possible by a special binder design. Rather than a helically-wound binder that requires careful unwrapping, the new WTC binder system is comprised of two binder tapes that are edge bonded together intermittently. This allows a bundle of ribbons to pass through the intermittent center of the special binder, as seen in *Figure 7—Edge-Bonded, Color-Coded Binder*. In *Figure 7*, the number 1 Blue binder unit is shown. As previously noted in Section 2.6, in cables with more than 1,728 fibers, binder tapes for binder units 13 through 24 are not a single color. One of the two binder tapes will follow the TIA/EIA 598 D Optical Fiber Cable Color Code³, but it will be edge-bonded to a clear binder tape.

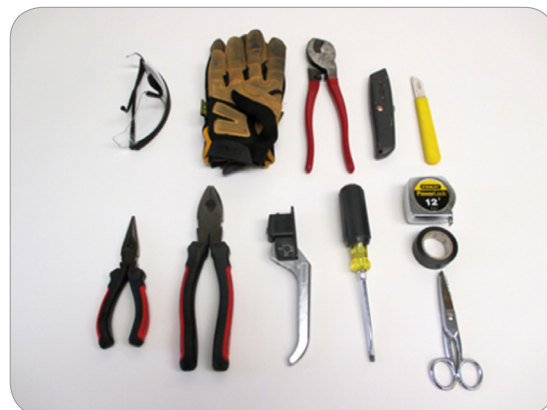


Figure 6—Industry Standard Tools for Cable Preparation

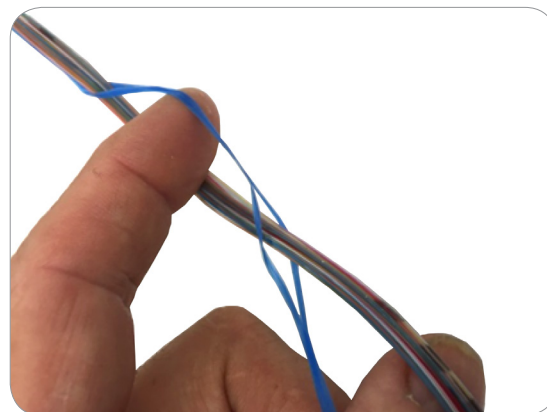


Figure 7—Edge-Bonded, Color-Coded Binder

This binder-group system results in a number of advantages. First and foremost, the removal of the binder does not require helically unwrapping the binder from the fiber-bundle group. The two parts of the binder can be pulled apart and will separate like a zipper. The second advantage is that in a mid-span cable access, the binder can be slipped down away from the fiber-bundle group allowing for access to a specific ribbon number (or a single fiber number within a ribbon) that can be cut in the center and then slipped out of the binder group to facilitate splicing. The binder can then be slipped back into place over the ribbons that do not require mid-span access, thereby maintaining the protection and organization of the remaining ribbons. The final advantage is that the binder protection and organization is maintained all the way from cable entry up to the splice tray, allowing for identification of the binder group at the splice tray. All of these processes or technologies reduce time spent in accessing, organizing, or identifying ribbons and fiber for splicing. Time savings with this binder unit system come to full fruition as the groups of ribbons are organized and routed within the splice closure and into the splice trays. This is explained in the next section.

3.3 Closure Preparation

New generations of splice closures are yielding efficiencies in how WTC is organized and prepared for the mass fusion splicing process. A new organizer basket⁴ eliminates the need for transition tubing to protect the exposed SWR fiber binder groups as they transition from the organizer basket to the individual splice trays. It also provides a channel for routing the SWR binder groups to the splice trays, and fully protects the SWR binder groups. This is accomplished by providing a dedicated splice tray entry area at the opposite end of the closure from the cable entry area, thereby isolating these two areas. These design features result in significant time savings on ultra-high fiber count cables that may have as many as 24 binder groups.

In a conventional scenario, standard practice would require installation of 48 transition tubes over the incoming and outgoing groups of ribbons to protect and organize the ribbons within the closure basket and route the ribbons to the splice trays. This requires a considerable expenditure of time and introduces some danger that a ribbon might be kinked or damaged during this process. In addition, for a ribbon in loose tube cable, the loose tubes must be cut and removed before the more flexible transition tubes can be installed onto each group of ribbons. This is due to the loose tubes within the cable are typically very stiff, and cannot be used for routing the ribbons within the closure. A new closure incorporating the features described above takes full advantage of the benefits of the WTC binder groups and is shown in *Figure 8–New WTC Organizer and Closure System*.

Another new improvement is the SWR binder group retention sleeves for anchoring the SWR binder to the mass fusion splice tray, as shown in *Figure 9–SWR Binder Group Retention Sleeve*. These sleeves are made of a split-foam tube that slips quickly over the SWR binder group and allows a standard small tie-wrap to anchor the SWR binder group to the splice tray.



Figure 8–New WTC Organizer and Closure System

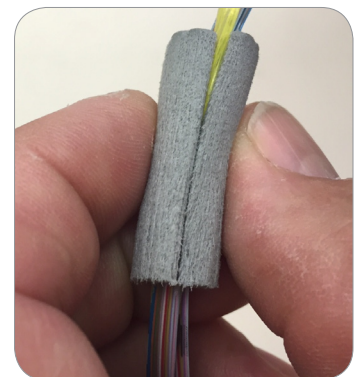


Figure 9–SWR Binder Group Retention Sleeve

3.4 Mass Fusion Splicing

The final area where time and efficiency improvements have been achieved is in the mass fusion splicing process. This area is probably the most significant in time savings improvement relative to the previously published results in 2015. The mass fusion splicing process is broken down into three sections:

- Ribbon Fiber Holders
- Ribbon Stripping, Cleaning, and Cleaving
- Mass Fusion Splicing

With new collapsible ribbons, the fiber holders were found to need improvement in maintaining fiber alignment at the 250 μ m nominal fiber spacing. Mass fusion splicing relies on cladding alignment to splice all 12 fibers simultaneously. New fiber holders have been developed which incorporate 12 grooves at a 250 μ m spacing. This helps ensure that the individual fibers of the SWR maintain such a spacing for easier loading of all fibers into the mass fusion splicer V-grooves. This compensates for the relatively loose structure of the SWR. In addition, the front edge of the fiber holder has been extended in order to maintain alignment of the fibers closer to the fiber entry into the ceramic alignment V-grooves of the mass fusion splicer. These new features have significantly improved the ease with which SWR can be loaded into the splicer V-grooves. With standard legacy fiber holders (which were designed prior to the existence of SWR and other collapsible or web-type ribbons), successfully loading all 12 fibers of the ribbon into the fusion splicer V-grooves was sometimes difficult as compared to conventional encapsulated ribbons. The new fiber holders work very well with SWR containing 250 μ m coated fibers as well as SWR containing smaller 200 μ m coated fibers (which is helpful for achieving even greater cable density and high fiber counts). These fiber holders maintain complete compatibility with legacy encapsulated ribbon designs. The new fiber holders are shown in *Figure 10—New FH-50-12N Fiber Holder*. While the 12 grooves within the fiber holders are very small and difficult to see, the extended nose of the fiber holder has been highlighted.

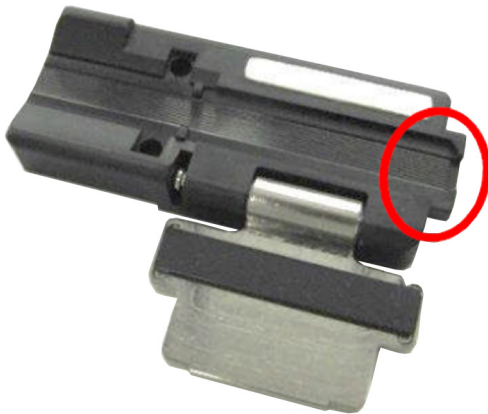


Figure 10—New FH-50-12N Fiber Holder



Figure 11—RS03 Ribbon Thermal Stripper

Further improvements in the preparation of the SWR for the fusion splicing process have been realized by the introduction of a new ribbon thermal stripper. The RS03 thermal stripper (*Figure 11*) has a heating cycle time reduced to 3 seconds, whereas previous versions could require an approximately 15-18 second cycle time for SWR or other collapsible web-type ribbons. Additionally, the new thermal stripper can operate on a self-contained battery that does not pull power from the fusion splicer. This cordless operation eliminates the clutter of the power cord in the work area. This is especially helpful for cable splicing operations where there are such large number of ribbons to be spliced.



Figure 12–Fujikura 70R+ Mass Fusion Splicer

Other significant improvements in the mass fusion splicing time are due to the availability of improved mass fusion splicers. They have continued to evolve and a higher level of automation is now available as compared to 2015 when the original release of the collapsible ribbon technology and original splicing study was completed.¹ The latest generation Fujikura 70R+ is shown in *Figure 12–Fujikura 70R+ Mass Fusion Splicer*.

In the newer 70R and 70R+ splicers, the operating mode can be set such that the wind protector will automatically close after both fiber holders have been inserted into the mass fusion splicing machine, and splicing then commences automatically. In addition, if there are minor offset errors in the alignment of the fiber pairs, the use of the Auto Reloading Function enables the wind protectors to automatically open and close multiple times. Since the fiber clamps are attached to the rear wind protector, automatic opening and closing of the wind protectors causes the splicer’s V-groove clamps to tap on the fibers in order to automatically reduce pre-splice fiber misalignment that may occur due to dust in the splicer V-grooves or on the fiber itself. With previous splicers, manual intervention was required if fiber alignment did not meet the acceptance criteria. The mass fusion splicer also automatically assesses the fibers for debris and the condition of the cleave ends to assure these parameters are within acceptable limits for a successful splice.

After completion of the mass fusion splice and completion of the splice loss estimation, the wind protectors open automatically. The operator then slides the splice protection sleeve over the bare fiber splice region and lowers the completed splice into the splice-protection-sleeve heater oven. The heater closes automatically as the splice is lowered into it, and proceeds with the heat shrink process. When the heat cycle is completed, the heater opens automatically.

The automation of the wind protector and heater opening/closing, as well as the Auto Reloading Function (which is automatically triggered if the splicer detects significant pre-splice fiber misalignment), dramatically reduces the need for the operator to manually manage every aspect of the fusion splicing and splice protection process. Therefore, as the splicing and heat cycle operations are progressing, the operator can focus more time and energy on preparing the next set of ribbons for splicing, or on routing and organizing previously completed splices into the splice tray. This results in significant reductions in overall splicing process time, and is especially helpful in completing mass fusion splicing operations with high-fiber-count cables (with very large numbers of ribbons) in a timely fashion.



Figure 13–CT50 Cleaver

More recently, significant overall mass fusion splicing operational time savings have been achieved via new cleaver technology. A new cleaver has been introduced which incorporates significant improvements. The new CT50 cleaver features Bluetooth® communication capability to link it to either the new Bluetooth-enabled 70R+ mass fusion splicer, or to a cell phone application. Significantly, the rotation of the cleaver blade to a new rotational position (required when the present cleaver blade position becomes worn) can more easily be performed manually by a thumb-wheel on the bottom of the cleaver. This is much faster as compared to previous cleavers in which the fiber shard scrap collector had to be removed from the cleaver prior to blade rotation, blade rotation itself was tedious, and the scrap collector had to be reattached following blade rotation. More importantly, the cleaver blade can be automatically rotated by a motor that is embedded within the cleaver.

With the new Bluetooth communications between the 70R+ splicer and CT50 cleaver, the CT50 cleaver can be linked to the 70R+ (Figure 14). The 70R+ splicer can continuously monitor the cleaver and track the number of cleaves performed at each cleaver-blade-rotation position, while also monitoring the cleaver performance by camera observation of cleave angles and defects. Both the blade usage data and the cleaving performance data can be utilized as criteria to determine when blade rotation is required. The combination of the motorized rotation of the blade position and cleaver status-performance monitoring enables the fusion splicer to manage and command cleaver blade rotation automatically as required, with no need for operator intervention. This totally eliminates periodic splicing process interruptions and delays that are otherwise required in order for the operator to pause splicing activities, and manually rotate the cleaver blade to a new position.



Figure 14—Cleaver Blade Rotation Management by 70R+ Splicer via Bluetooth

Blade life at any cleaver blade rotational position is typically specified to be 1,000 cleaved fibers. Therefore blade rotation may be required after approximated ninety 12-fiber ribbon splices. When we consider ribbon cable with a 3,456 fiber count, splicing requires cleaving 6,912 fibers, and would typically require interrupting splicing operations at least six times in order to manually perform cleaver maintenance. In addition, the human operator must either keep track of the number of cleaves performed since the last cleaver blade rotation, or suffer unplanned interruptions for troubleshooting when cleaving performance degrades and splicer error messages ensue.

With the new system, downtime for cleaver blade rotation maintenance is eliminated, and operation is uninterrupted until blade height adjustment is required. Blade height adjustment is only required once all 16 rotational positions of the cleaver blade have been utilized. The fusion splicer accumulates data for each blade rotational position at each of the of the three blade height positions. By using that data and by tracking degradation of cleaving performance, the software determines when not only blade rotation is required, but also blade height adjustment. When that occurs, the splicer will prompt the operator to raise the blade to the next height position. While this does require a manual action by the operator, it is accomplished very easily and quickly by use of a second thumb-wheel located on the front of the cleaver.

The improvements to the ribbon fiber holders and thermal stripper were documented previously at IWCS.⁵ These improvements have resulted in a ribbon preparation process for SWR that is greatly improved relative to the previous WTC study.¹ The additional benefits of the greater automation of the mass fusion splicer itself, in conjunction with the Bluetooth management of the cleaver, provide further reductions in the fusion splicing process time, as well as the elimination of significant downtime previously required for cleaver maintenance. In particular, linking the cleaver to the splicer results in a mass fusion splicing “system” with synergistic benefits that exceed individual incremental and independent improvements to the splicer or cleaver.

4. SWR MASS FUSION SPLICE COMPARISONS

4.1 Original Mass Fusion Splice Trial of 2015

In 2015, the purpose of the splicing study was to compare the time and motion analysis of SWR mass fusion splicing of WTC versus standard ribbon-in-loose-tube cables (containing conventional encapsulated ribbons) on higher fiber counts. Also, SWR mass fusion splicing was compared to single fiber fusion splicing of loose tube cable for smaller cables containing 144 fibers.

The technicians that were originally used in the 2015 study were experienced in both single fusion splicing and traditional encapsulated matrix ribbon mass fusion splicing. The mass fusion splicer and associated accessories as well as the splice closure were standard products available in 2015. Therefore they had not been optimized to take advantage of the collapsible SWR technology or to compensate for the loose ribbon structure. The details and results of this original study are summarized in *Table 3—Original 2015 Splicing Study*.

Table 3—Original 2015 Splicing Study

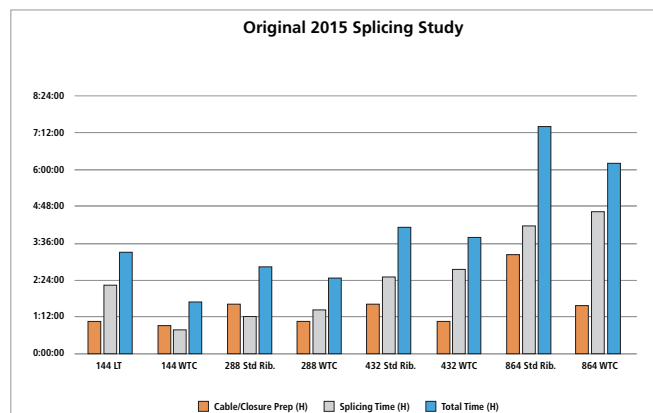
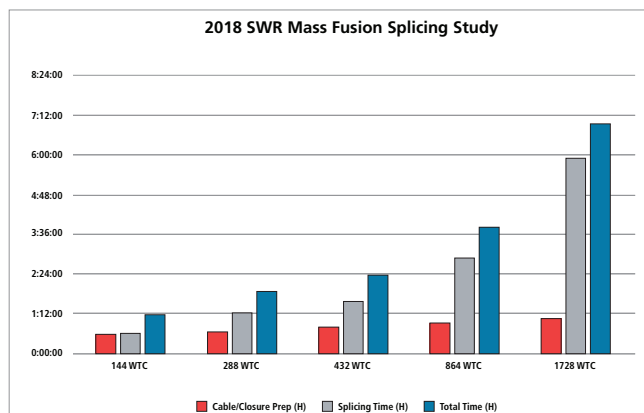


Table 4—2018 SWR Mass Fusion Splicing Study



4.2 New 2018 Mass Fusion Splicing Study

The new 2018 mass fusion splice study is focused on the time savings achieved for collapsible ribbon (SWR) splicing as a result of improvements achieved since the original 2015 study.¹ Fiber counts of 144, 288, 432, 864 and 1,728 cable were examined with a combination of time measurements for cable preparation, closure preparation and mass fusion splicing time for standard reel-end splicing. Some data was extrapolated from lower counts to higher counts.

Data was also collected from end-users in the field to ensure accuracy of the time and motion study. A number of field reports indicated better time for actual field splicing of WTC with SWR than what was measured in the time and motion study. The results of the new study did include the improvements in cable preparation technique, new closure technology, and new mass fusion splicing technology. The results are summarized in *Table 4—2018 SWR Mass Fusion Splicing Study* (above right).

5. SUMMARY AND CONCLUSION

Since the introduction of collapsible ribbon in 2013, the technology has continued to evolve, and installation time and system cost savings continue to improve. Much of this improvement is due to development of related products that are particularly well suited for use in conjunction with collapsible ribbon and ultra-high density fiber optic cable. A comparison of the original 2015 Splicing Study of WTC total splicing time to the recent 2018 WTC Total Splicing Time has yielded a side-by-side comparison chart, *Table 5—2015 WTC Data vs. 2018 WTC Data*. Note that the 1,728F data for 2015 was extrapolated from 864F WTC data. This is because the 1,728F WTC was not released in time for the original 2015 splicing study.

This side-by-side comparison of SWR splicing time from the 2015 study versus the improved times achieved in the 2018 study yield a range of overall SWR splicing time improvement of 24 to 40 percent, depending upon fiber count. This is summarized in *Table 6—Percent Improvement in SWR Splicing Time Since 2015*.

Table 5—2015 WTC Data vs. 2018 WTC Data

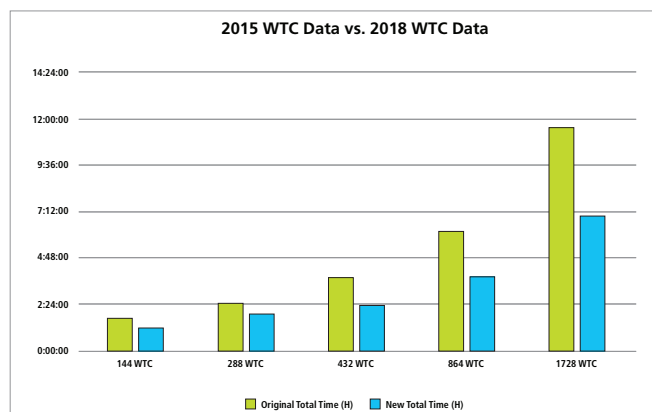
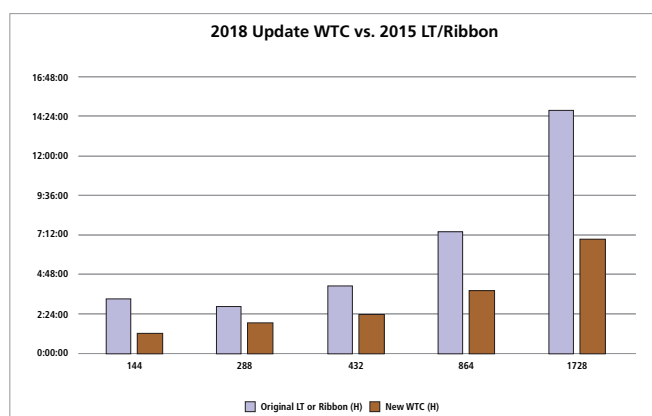


Table 6—Percent Improvement in SWR Splicing Time Since 2015

FIBER/CABLE COUNT	2015 WTC TOTAL TIME (H)	2018 WTC TOTAL TIME (H)	% CHANGE
144 WTC	1:41:47	1:11:35	29.7%
288 WTC	2:28:10	1:53:07	23.7%
432 WTC	3:47:30	2:22:56	37.2%
864 WTC	6:10:52	3:49:03	38.2%
1,728 WTC	11:33:32	6:57:46	39.8%

In *Table 7—2018 Update WTC vs. 2015 LT/Ribbon*, the updated 2018 WTC/SWR splicing time for various cable sizes is compared to the original splicing time data (from the 2015 study) for 144 fiber single-fiber loose tube cable and larger fiber count ribbon in loose tube cables containing conventional encapsulated ribbons.

Table 7—2018 Update WTC vs. 2015 LT/Ribbon



This side-by-side comparison of updated WTC splicing time (from the new 2018 study) vs. the original splicing times for conventional 144 fiber single-fiber loose tube cable and higher fiber count ribbon in loose tube cables (from the 2015 study) yields advantages in WTC/SWR splicing time of 34 to 64 percent vs. the conventional cables. This is summarized in *Table 8—Percent Improvement in SWR Splicing Time vs Traditional LT/Ribbon Since 2015*.

Table 8—Percent Improvement in SWR Mass Splicing Time vs. Traditional LT/Ribbon Since 2015

FIBER/CABLE COUNT	2015 LT OR RIBBON (H)	2018 WTC (H)	% CHANGE
144*	3:17:35	1:11:35	63.8%
288	2:50:10	1:53:07	33.5%
432	4:07:23	2:22:56	42.2%
864	7:23:43	3:49:04	48.4%
1,728	14:47:26	6:57:46	52.9%

*144F is Loose Tube

The introduction of collapsible ribbons such as SWR some years ago represented a paradigm shift in high-density fiber optic cables. While the higher density was valuable in and of itself by providing the opportunity for a much larger number of fibers within restricted duct space, additional benefits were realized in terms of cable joining and total splicing process time, as documented in 2015.

As is the case with many paradigm shifts, full exploitation of such a new technology often requires subsequent related developments. A “systems” approach in which the new technology is analyzed relative to interactions with related technology and products is often beneficial.

In this case, the systems analysis has further extended the splicing time savings of WTC/SWR by developing a splice closure system that takes advantage of the colored binders. This eliminates wasted time normally required to organize groups of ribbons into transportation tubes.

Additionally, the revised ribbon preparation tools such as the new fiber holder and stripping tool have been optimized for the unique characteristics of collapsible SWR to overcome previous craft sensitivity of SWR preparation prior to splicing. The system analysis approach has been applied to the development of the new Bluetooth-connected cleaver and splicer. This has provided total time savings and efficiency benefits greater than would have been achieved by independently developing a new splicer and new cleaver.

Further developments in technology and products related to high density cables and collapsible ribbons will enable realization of additional savings in the total splicing process time in the near future.

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7. AUTHORS

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