White Paper

Splicer Alignment Technologies—
The Technical and Data-Driven Differentiators

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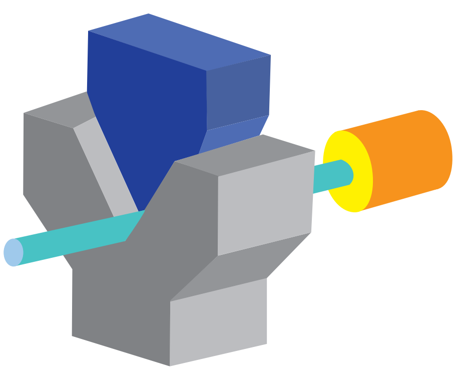
Fusion splicers were once a "black magic" piece of equipment, where a lot of specialized R&D was obvious and the technology required to splice fiber was appreciated. Initially, fusion splicing belonged to a limited community with only a few major fiber optic companies possessing this technological capability. What has changed from then to now? Namely, time and money. As it became obvious this product line was profitable, naturally, the technology was reverse engineered by others. As with many profitable, ground-breaking products, the followers disrupted the market with price as their primary weapon, claiming to offer the same quality for less. The products are aesthetically pleasing, the companies providing them market savvy, but lacking the most important aspect: technical know-how. This natural competitive progression has circulated a lot of incorrect information, making navigating the splicer landscape increasingly difficult for customers, especially for newcomers to the industry. In response, this white paper aims to resolve this inherent challenge by educating the industry on the different splicer technologies, using technical and data differentiators as opposed to marketing verbiage. This knowledge will then enable readers to choose the splicer and supplier that best meet their needs.

The three main categories of fusion splicer, regardless of fiber count, are sorted by their alignment technology, i.e. the method and mechanisms used to align the fibers to one another. The general definitions are below, but will be expounded upon in this paper. In addition to defining these categories in more detail, you will see the common applications they serve and the pros/cons of each type.

1) **Fixed V-groove(s) –** Immovable V-grooves aligned with one another that act as passive guides for bringing fibers into linear alignment with one another.
2) **Active Cladding Alignment –** Independent, movable V-groove(s) capable of actively aligning two fibers to each other at various locations in the X/Y plane based on cladding edge detection.
3) **Active Core Alignment –** The same V-groove system as active cladding alignment, but instead of cladding edge detection, the splicer clearly identifies the fiber core's location and aligns the two fibers based on this information.

Fixed V-groove

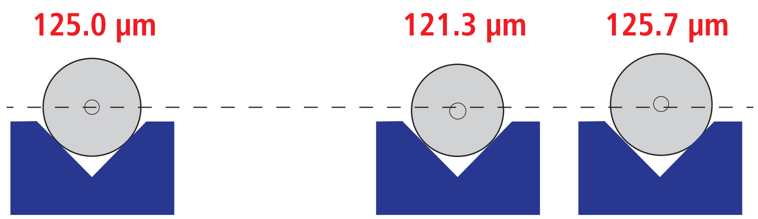
The name fixed V-groove is fairly self-explanatory in understanding how this method works. A high precision "V-shaped" wedge is cut into a ceramic block, serving as a controlled surface for the fiber to rest. Once a fiber is placed in the V-groove in a splicer, a top surface – embedded in the wind protector – is closed on the fiber so contact is made at three distinct points to the fiber's surface. This retention method restricts degrees of freedom in undesired directions. This allows the fiber to be easily moved linearly for aligning and fusing to an opposing fiber.



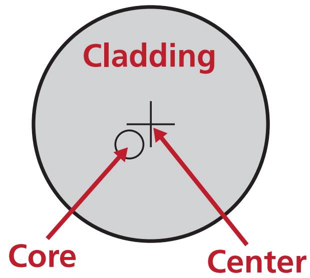
The V-groove method of passively aligning two fibers was the basis for the first generations of fusion splicers and is used in a wide array of fiber alignment applications today. The fixed V-groove method is now applied to low-end single fiber splicers and mass fusion splicers. Mass fusion splicing is the technical term for splicing multiple fibers in a single heat cycle. These mass fusion splicers are capable of splicing from 1-12 fibers at the same time and are used for splicing ribbon fibers in high-density cable applications primarily. The existing single fiber fixed V-groove machines are most commonly used as small field-portable units suitable for FTTx and other ending network segments.

Typically, passive component (which splices are seen as from a network architecture standpoint) loss criteria at the tail-end of a network is much looser than at the core, spine, or trunk segments of said network. With this category of splicer being unable to actively align the fibers, since the V-grooves are fixed, higher losses on average are imminent due to the following pain points:

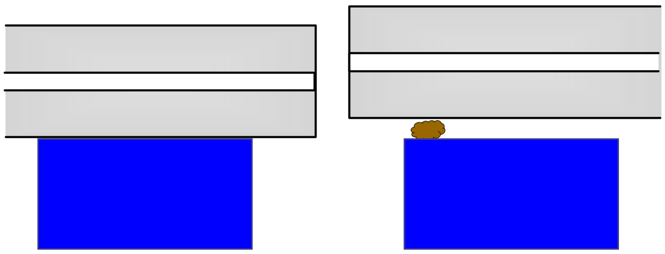
1) **Cladding diameter variation –** range of cladding diameters allowed in fiber manufacturing which causes fiber cores to sit at varying heights within the V-grooves. The illustration below represents the maximum and minimum diameters for fiber manufacturers today. There is a 1.4 µm offset possible by cladding diameter variation alone, which causes 0.33 dB loss on average with standard single-mode fiber.



2) **Core/Cladding concentricity error –** deviation of core and cladding central axes locations from one another causes the cores to be offset from one another, even if the claddings are the same diameter and aligned perfectly. The maximum allowed variation of this characteristic for fiber manufacturing today is 0.5 µm. If two fibers at this limit are brought together, a total core offset of 1.0 µm is possible.



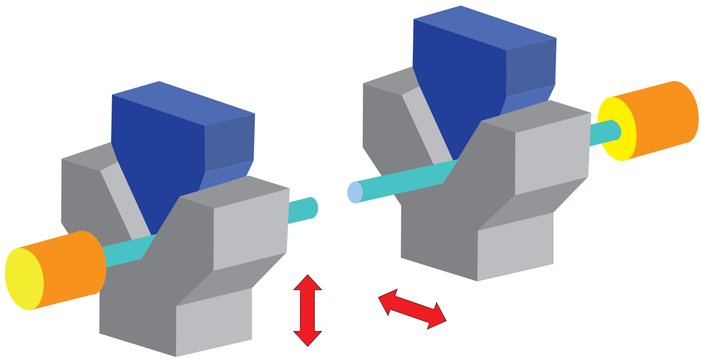
3) **Dirt or coating debris in V-grooves –** since the V-grooves are fixed, an object that inhibits the fiber from resting flat against the V-groove walls will cause fiber misalignments. This is obviously not a fiber issue, but is a common problem for splicers used in outdoor (and sometimes indoor) environments or when thorough fiber cleaning is not observed.



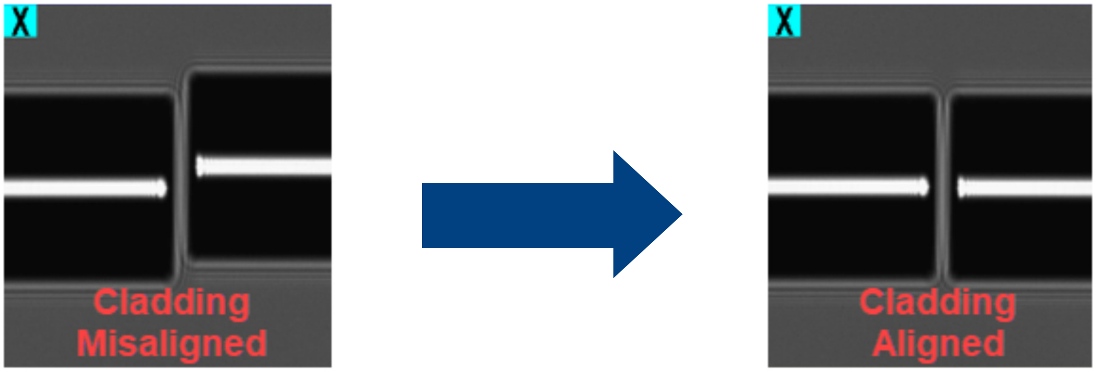
This alignment method was simpler to develop and cheaper to produce than the active alignment counterparts. Fixed V-groove splicers can provide sufficient results when – loss criteria are relaxed, you are splicing good quality fiber, and your V-groove's cleanliness is maintained – which is why these splicers are still around today. However, these requirements can be restrictive and hard to control which led splicer manufacturers to develop higher-end solutions to combat these pain points.

Active Cladding Alignment

As stated previously, the active cladding alignment method utilizes the same V-groove and retention system, but takes alignment a step further with motorized movement of the V-grooves. The "active" designation refers to the V-grooves that have independent electric motors which allow for travel in the X and Y directions.



As stated in the name, the two fiber claddings are aligned to one another which is achieved via image processing. The V-groove movement is controlled by numerous software algorithms based on the fiber's movement on-screen, making viewing the fiber and identifying the cladding edges the crux for alignment. This is not an incredibly difficult task for anyone experienced in image processing, since the splicer is only applying basic boundary conditions within the camera field of view. The splicer identifies the cladding edges, and then moves the V-groove motors until the corresponding edges are aligned to one another.



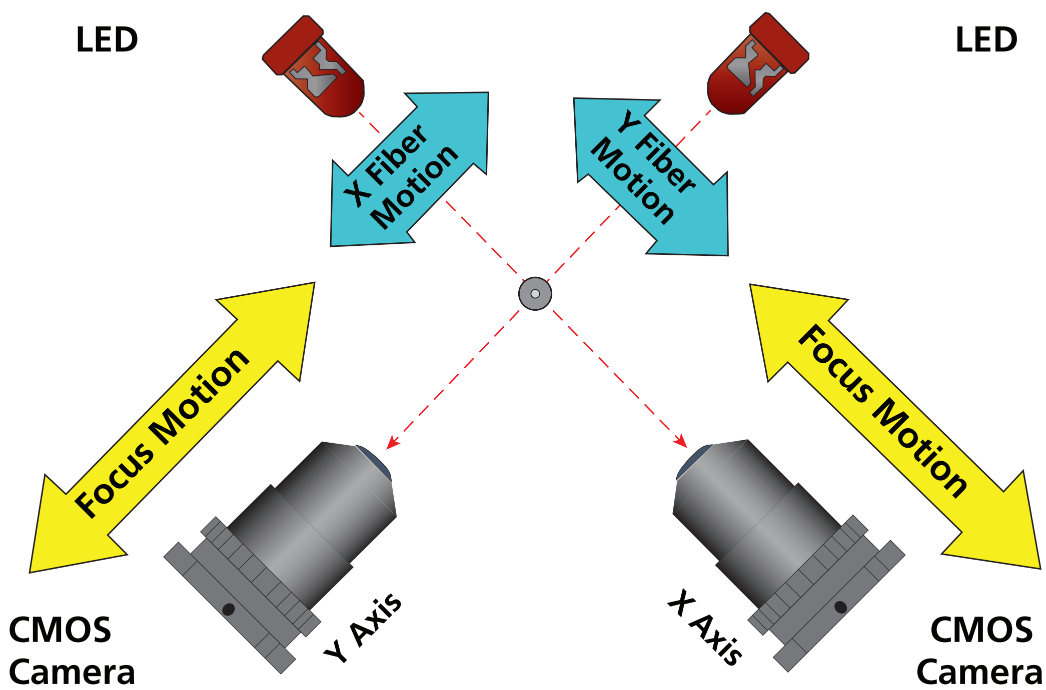
Fusion splicers, which utilize movable V-grooves to provide active alignment of the fiber cladding, are more craft-friendly than fixed V-groove splicers. The movable V-grooves eliminate the pre-splice cladding misalignments that may be the result of cladding diameter variations, dirt or coating debris in the V-grooves, or a combination of the two. Despite the advantages and technical differences, the cost delta between fixed V-groove and active cladding alignment splicers is not substantial. The low cost delta is primarily attributed to decreased material cost over the years, and that fixed V-groove and active cladding alignment splicers use the same low grade optical system. In fact, the cost difference, improved ease-of-use, and increased field robustness have led some suppliers to consider eliminating fixed V-groove single fiber splicers as a category altogether. In addition, a new sub category of these active cladding alignment splicers has been introduced that use warm splice image (WSI) technology to offer loss estimation based on core observation while fusing even though only the cladding can be observed and aligned prior to splicing. You can see AFL's white paper, "Splice Loss Estimation with the Fujikura 41S Fusion Splicer" for more details on this technology.

The aforementioned core/cladding concentricity error pain point is unresolved with active cladding alignment and therein lies a major drawback to this category of splicer. Fibers vary in quality from manufacturer to manufacturer and vary based on age. Poorer quality and older fiber will have a larger core/cladding concentricity error, making your splices inherently prone to higher losses due to higher core offsets. Fibers also vary by type, same as splicers, but the list of fiber types is much longer. The implications of varying fiber specifications will be discussed shortly, but important to note is that active cladding alignment splicers cannot identify different fiber types nor automatically compensate for the variances in splice parameters that different classifications of fiber require.

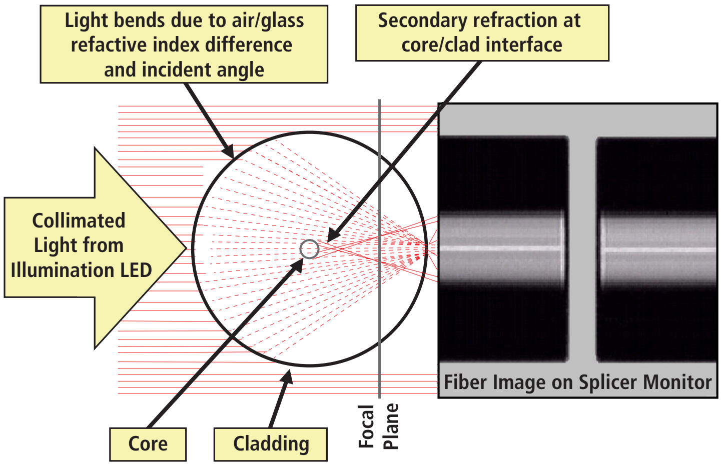
Active Core Alignment

Active core alignment splicers utilize movable V-grooves, the same as active cladding alignment splicers, but have a completely different method of aligning the two fibers with these movable V-grooves. Two fibers in a core alignment splicer are considered "aligned" when the fiber cores are positioned such that, after splicing, a single continuous fiber core results. The splicer knows alignment is achieved by usage of a sophisticated imaging and image processing system. The imaging and alignment process in splicers today, both core and cladding alignment, are based on a Profile Alignment System (PAS) which is essentially a 2D profile image of a fiber. Accomplishing a core alignment splice requires data collection and manipulation of multiple PAS images, whereas cladding alignment is a much simpler process as was previously described.

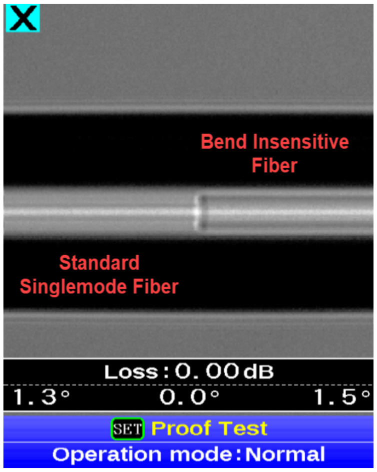
Both core and cladding alignment PAS makes use of two collimated backlights shone through the fiber onto two CMOS cameras placed in perpendicular fields of view. From this point, the first obvious distinguishing factor of a core alignment PAS splicer from a cladding alignment splicer lies in the components comprising the optical system. Core alignment optics require higher resolution, magnification, lens quality, and the ability to change focal planes. The image below represents the hardware setup for core alignment:



The backlight is refracted through the fiber to produce a Brightness Intensity Profile (BIP) on each camera. The cameras are observing and collecting data from the different BIPs as the cameras move through the various focal positions. Software algorithms looking for the clearest fiber core image are controlling the camera motors, and decide the final positions of the cameras. This is the same process any splicer advertised as core alignment goes through, since it is easy to observe and likewise reverse engineer. The remaining steps of the core alignment process are all programming based. There are a number of proprietary image smoothing techniques, and specific fiber knowledge used to identify the actual location of the fiber core within the bright band of a PAS image. A common misconception is that by using this hardware setup alone, core alignment can be achieved.



As was hinted at previously, the various classifications of fibers play a role in splice loss. The differing fiber types are a result of the array of applications within fiber data communication: long haul networks, undersea cables, FTTx, and high-density networks, to name a few. The requirements of these applications, likewise, can contrast starkly, so standard single-mode fiber does not always meet the need. Manufacturers have met these demands by altering the optical behavior of fiber with different physical constructions. For example, unique dopant materials and concentrations, geometric sizes and structures, and manufacturing techniques are ways these fiber specifications are met. When it comes to splicing, each fiber type looks different in a PAS image, so the core locations cannot be algorithmically detected in the same ways. The photo at right helps illustrate this point. Also, the varying dopant materials and concentrations cause the fibers to react to the same amount of heat differently, i.e. different dopants melt at different rates. If you do not know what fiber you are going to be splicing, having a core alignment splicer that can automatically detect these differences is highly beneficial for painless, quality work.



While it is impossible to assess a splicer's programming for finding a fiber core, it is possible to analyze splice loss data of differing fiber combinations and of fiber with poor core/cladding concentricity. Fibers with poor core/cladding concentricity require much larger degrees of alignment correction to achieve core alignment, therefore low splice loss. A cladding alignment splicer used on high core offset fibers will produce higher losses on average, whereas a core alignment splicer will maintain low losses regardless of core position within the cladding. The same rule follows with different fiber combinations that require different core finding techniques.

An internal study was conducted to compare splice loss performance of fibers with various core/cladding concentricity values with fiber types commonly found in today's telecommunication and enterprise networks. Mid (0.35 µm – 0.5 µm) and high (0.9 µm) core offset test groups with different fiber classifications were used to simulate splices in these networks. These core offset values were chosen to reflect common splices encountered with high core/cladding concentricity error embedded fiber, and high core/cladding concentricity error modern fiber. The table below outlines the test groups:

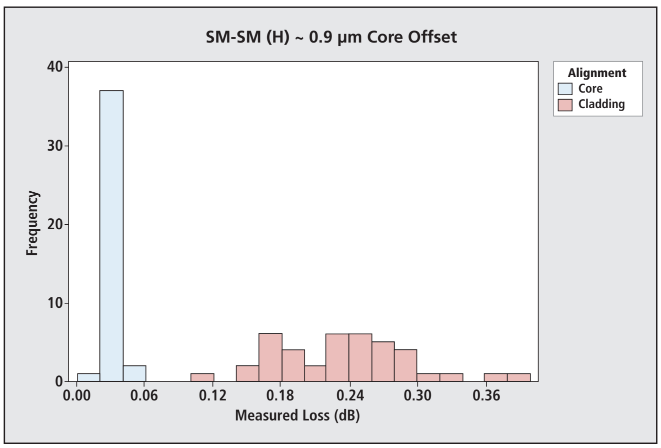
SPLICER ALIGNMENT TECHNOLOGY TESTING		
FIBER TYPE	**GROUP**	**CORE OFFSET**
G.652.D - G.652.D (SM-SM)	SM-SM (H)	~ 0.9 µm
	SM-SM (M)	~ 0.37 µm
G.652.D - G.657.A1 (SM-BIF)	SM-BIF (H)	~ 0.9 µm
	SM-BIF (M)	~ 0.48 µm

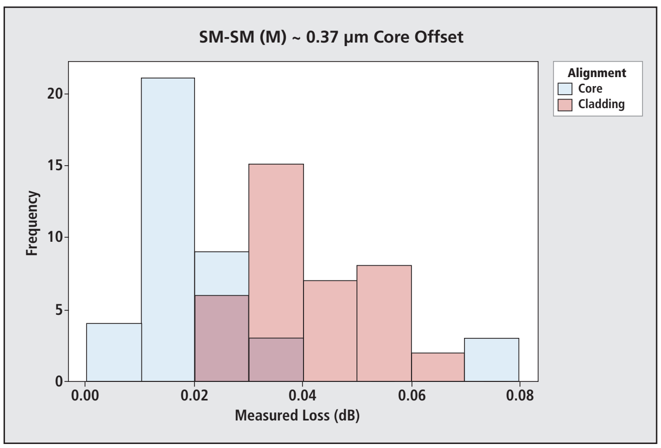
SM – Standard Single-mode Fiber

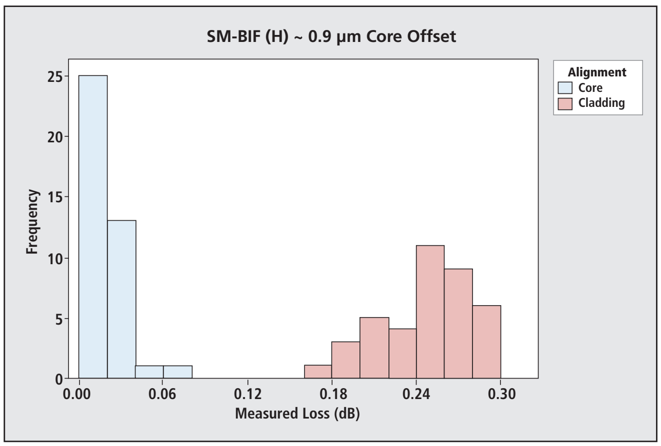
BIF – Bend-insensitive Fiber

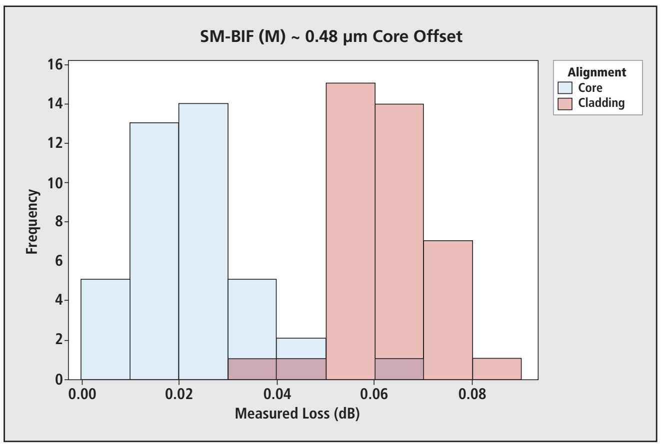
Core Offset – The average offset between the fiber cores when the claddings are aligned. Therefore, the offset the splicer has to compensate for when aligning.

The loss data was acquired using a light source and power meter at the 1310 nm wavelength. The fibers were fusion spliced with multiple Fujikura core and cladding alignment splicers – to avoid a sample mean outlier from a high or low performing splicer. A specialty cleaver was used to maintain cleave angles of ≤ 0.5°, so splice loss values would be the result of core detection and alignment only. The findings are presented below:









CORE ALIGNMENT				
	SM-SM (H)	SM-SM (M)	SM-BIF (H)	SM-BIF (M)
AVERAGE	0.025	0.017	0.015	0.018
ST. DEV.	0.006	0.017	0.011	0.012

CLADDING ALIGNMENT				
	SM-SM (H)	SM-SM (M)	SM-BIF (H)	SM-BIF (M)
AVERAGE	0.23	0.036	0.243	0.057
ST. DEV.	0.06	0.012	0.033	0.01

The core alignment splice loss averages are fairly consistent from group to group with a range of 0.015-0.025 dB, but the cladding alignment averages range from 0.036-0.243 dB. The changing from high to low core/cladding concentricity splices introduces some variability even with core alignment splices, but the variation seen is mostly influenced by other fiber characteristics – e.g. MFD mismatch, manufacturing techniques, and different dopant concentrations. The high and low values in these groups are negligible for modern network requirements, so regardless of fiber quality or type, low loss is assured. The broader distributions in the cladding alignment data indicate that splices can fall out of loss specifications with appreciable frequency, causing excess network loss. This high loss will appear on an OTDR trace leading to splice rework, but if no trace is run, the customer network can suffer.

The bottom line is this category of splicer will provide the most consistent loss in every splicing situation, ensuring your quality of work is secure in either core or last leg network segments. The results of this study also insinuate potential for using this class of splicer in optical component manufacturing. Optoelectronic devices can require splicing – depending on the design – and the results here validate many electronics manufacturers who make core alignment splices to ensure low power consumption within their modules. The downside of this class of splicer is, of course, cost. Whether or not this premium is seen as an investment or expense is up to the buyer based on their needs. The knowledge gained from this data collection and analysis should help buyers make a more informed decision either way.

Tying It Together

The continued mixing of splicer manufacturers from all over the world, using various technical terms, marketing strategies, price points, and differentiators has made finding the right splicer a more difficult task. This presentation of the different splicer technologies aims to educate readers to choose the splicer and manufacturer that are right for them. Knowing the technical and loss performance differentiators should give you the tools required to do exactly that. As was presented, knowing the fiber types, quality, and age are key pieces of information in deciding whether or not a category of splicer will meet the loss requirements set by you or your customer. Also, knowing whether or not a splicer performs as advertised is crucial in ensuring a return on your investment.

When looking to upgrade, or if you're new to splicing, ask your sales point-of-contact for proof of loss performance in different splicing applications or a splicing demo in your environment. If your point-of-contact doesn't have this information, they should be able to connect you with a technical person in their organization who does. AFL collected this data and wrote this paper to place that information at your fingertips, and assure you that when purchasing a Fujikura splicer you will get what you pay for — a high-quality product, the technical know-how and exceptional service.

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