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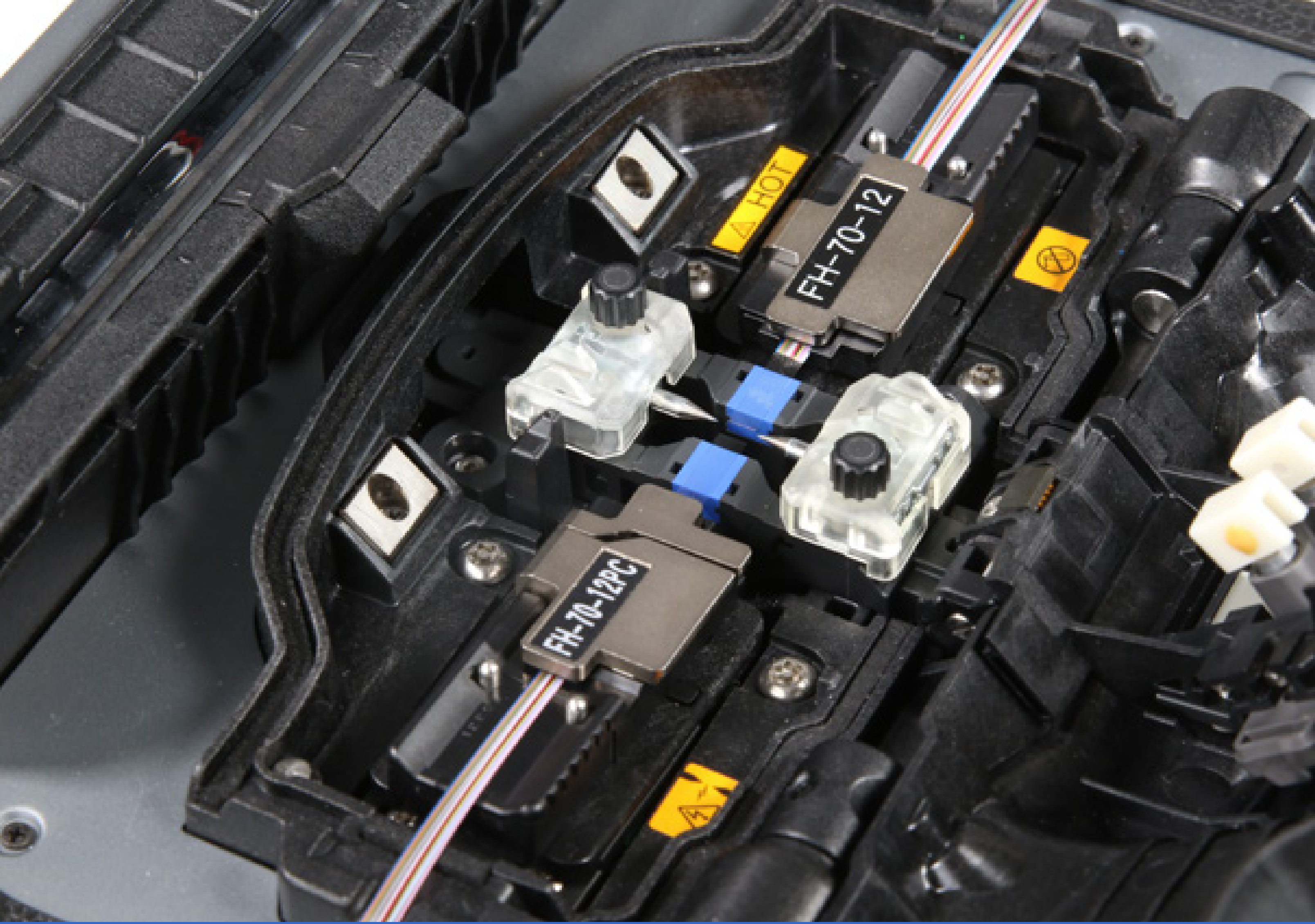

Smart Infrastructure is Driving Forward the Physical Layer and Smart Installation Equipment

By Lucas Mays

Smart devices, such as mobile phones, tablets, cars, and entire homes, are plentiful. A well-designed smart device or application in the business to business (B2B) world enables more confident, efficient, and cost-effective decision making with less room for error. It also provides data for either manual or automatic proactive action to avoid detrimental failures (i.e., achieve more with less). A plethora of supporting smart technologies to deliver smart applications for these devices are being introduced. The ICT world is one of these supporting areas, driving infrastructure and supporting equipment toward smart use-cases to align with quickly evolving needs. The ICT industry is in a unique position to deliver entire smart systems due to its role in building an interconnected web of data that these smart applications and devices require.

DEFINITION OF KEY TERMS

The word "smart" when used as an adjective has vague applications. The term has become colloquial and deviated from its original definition, which is sometimes utilized as a buzzword to spin-up public interest and appeal. What is the correct use? It is not commonly known that the term "SMART" is an acronym for Self-Monitoring Analysis and Reporting Technology. This definition will be used for the discussion of smart as it pertains to applications, infrastructure, and splicing technology; the primary focus will be on the latter two. This original acronym is not all encompassing of product features deemed smart by today's standards, but such deviations are worth noting. However, features or capabilities that do not meet the original definition at a minimum are not considered "smart."

Infrastructure is a broad term describing many categories of underlying structures that support current and future ways of life (e.g., roads, bridges, power grids, water, waste, and broadband). A smart infrastructure has the ability to self-monitor and report data for either manual or automatic decision making, improving network efficiency, lowering cost of ownership, and mitigating critical errors. This definition, however, does not depict smart infrastructure clearly either. Why?

The answer is that its exact definition is still maturing and, like many industry-wide terms, may possess a myriad of diverse meanings. Smart infrastructure is currently defined and discussed as a unique union between physical and digital infrastructures. As an example, some smart cities include the use of sensing and control systems to traffic lights, so the Department of Transportation (DOT) of a municipality can establish real-time, automatic traffic flow decision making at intersections with regard to rush hour changes, emergency responders, city events, and construction related detours.

Various impact metrics could then be generated based on this new variable at the government's control, such as improvements to commute times, emission levels, and automotive accident rates. This is only one example, but countless like it are possible as current smart infrastructure ideas are implemented and new ones created. Figure 1 illustrates a smart intersection.

ICT INDUSTRY STIMULI

The Rural Digital Opportunity Fund (RDOF), an incentive program from the United States Federal Communications Commission (FCC) to stimulate network builds for broadband equitable access, in conjunction with the more recent $1.2 trillion USD bipartisan infrastructure bill, have catalyzed smart infrastructure discussion as nationwide deployments are in various stages—from funding application, distribution, network design, planning, or building construction. Internet access is now regarded as a critical utility and, likewise, the supporting infrastructure. Therefore, the ICT industry is receiving significant funding from these bills.

These investments have directly and indirectly stimulated network builds. Not all networks qualify for federal funding (e.g., wireless 5G), but the bullish outlook on the industry overall is driving private and telecommunication network expansion. Although money is currently plentiful, this industry is cyclic, and data communications infrastructure is a significant investment. Designing and building networks to meet today's needs are not sufficient. Planning for 15 or 20 years of bandwidth growth is preferred to avoid wasting time and money spent on new infrastructure. As smart applications, such as autonomous vehicles, smart homes, delivery drones, emergency response systems, advanced medical procedures, biometric monitoring, and other smart technologies advance in capability, the amount of data required to support them is astronomically higher than the current infrastructure can supply.

FIGURE 1: A smart city intersection.

In addition, demand for low latency requirements will continue to increase, since an autonomous vehicle must make decisions in milliseconds to avoid fatal collisions. These trends are only some of the drivers to introduce "smart" into infrastructure. Network operators are always looking for differentiators to offer existing subscribers to gain market share. In recent years, Managed Wi-Fi is an example of this, and its feature set continues to develop. Managed Wi-Fi offers a premium customer experience from which smart infrastructure can further benefit, as well as enterprise, municipal, and residential consumers. The backbone for smart infrastructure systems require significant ICT physical layer investments to transport data from one application to the next.

ICT infrastructure, installation, and repair equipment are growing smarter to support these open system interconnect (OSI) applications. The physical medium for passive infrastructure (e.g., optical fiber) is not experiencing high volumes of innovation with the exception of some of the packaging, deployment, and equipment required to install and maintain.

One often forgotten aspect of ICT construction that has experienced much innovation is the fusion splicing of optical fiber responsible for connecting the multitude of segments comprising a network. It is a crucial process that enables the ability to light-up new and repair existing networks. Fusion splicers have evolved to meet modern demands of the cable, connectivity, and optical fiber upon which traditional and smart infrastructures are built. Installers, designers, and project managers must be aware of the passive infrastructure advancements and the subsequent capabilities of the fusion splicer handling these innovations. Installers will lose competitive positioning if continued learning and adapting are not prioritized. Missed deadlines, costly installs, and rework are sure to follow if ignored.

Expandability, flexibility, and accessibility (EFA) are key requirements of physical infrastructure.

PHYSICAL LAYER ADVANCEMENTS SUPPORTING SMART INFRASTRUCTURE

The OSI model describes seven layers of communications for computer systems on a network. The first of these seven is the physical layer, defined as the physical medium that the raw bit streams are transmitted across. This includes components, such as cable, wireless, and connectivity that actively or passively transmit data traffic. This physical layer has been shifting from primarily copper-based to fiber-based in the outside plant (OSP) for many years.

What began as limited fiber deployments in major telecommunications networks are now commonplace as optical fiber penetrates further into greenfield and brownfield deployments. The progression of ICT infrastructure over the last 50 years and exponential acceleration of data demands have culminated into significant deployment challenges from a capacity perspective, especially in metropolitan or high-density environments.

Expandability, flexibility, and accessibility (EFA) are key requirements of physical infrastructure. Expandability, so there is room to grow in the physical layer; flexibility, so unexpected, changing applications can be serviced; and accessibility, so the first two can be achieved in a cost-effective and timely manner.

Trenching new underground pathways in cities or building aerial real estate for optical fiber cable is not a simple or inexpensive task. Maximizing existing and future-proofing new pathways are of key importance to avoid inflated costs for network builds. High fiber count and high-density cable designs have proliferated the fiber optic industry as these needs have been made apparent. Traditional loose-tube cable designs are not capable of the density required for compatibility with congested pathways. Underground ducts considered at maximum capacity with prior cable designs can accept additional cable using new high-density designs.

Traditional loose-tube cable designs are also not suited to scale with the increasing capacity requirements of telecommunication backbone and hyperscale applications. Fiber optic cables with 6,912 fiber counts are in active, hyperscale networks. Even larger fiber count cables are being discussed. The outer diameter and weight of traditional loose-tube cables at these fiber counts would make their utilization uneconomical. The lighter weight, smaller diameter, and unique design of these new cables are even supporting blown cable installations at significantly longer distances, notably lessening the effort, time, and cost compared with pulling cable. Figure 2 shows the fiber count comparison of the new high-density cable (left) versus traditional loose-tube cable (right).

FIGURE 2: New cable density possibilities.

The EFA requirements of the physical layer for smart infrastructure are apparent with these optical fiber developments, benefiting both the network operator and installer. The benefits of air-blown friendly cable designs are not limited to high fiber count cables. The 144 count fibers and below are offered across many manufacturers and generate similar savings in smaller bandwidth networks as well. Adhering to cable solutions that align with EFA objectives set up networks for current and future success to a greater degree than previous generations of optical fiber cable.

Connectivity is a fitting term for one of the final pieces of the physical layer, given that ICT infrastructure is the connection from one application, system, or device to another. The options for this final step of connecting the many links of an ICT network have increased as data applications and their need for versatility have increased. Furthermore, EFA remains a fitting motto for best practices of connectivity design for future-proofed optical fiber networks. Pre-terminated cables, fusion splice-on connectors (SOCs), mechanical splice connectors, and fusion splicing directly to preassembled panels, boxes, or terminals are the typical options offered by optical fiber and connector manufacturers.

Each method has its pros and cons and can be application dependent. Pre-terminated cables are the simplest and quickest to install. Pre-terminated cables are often the preferred method of connection within a telecom closet, patch panel, or short in-building runs of existing construction. There is a cost premium for pre-terminated cables but not outweighed by the labor involved for other termination methods. Multiple dwelling unit (MDU) activation is also a popular application for pre-terminated cables. The runs are generally single fiber, fixed distance, and the optical loss penalty is not meaningful compared to the enhanced speed of deployment when the networks are designed with this penalty in mind.

The SOCs have risen in popularity significantly, replacing mechanical splice connectors in many cases. The primary benefits of a fusion SOC over mechanical connectors are significantly reduced optical loss and increased field reliability. Fiber enclosure panel repair work that connects low fiber count drops to a premise and small indoor telecommunications enclosures, commonly called wall boxes, are popular applications for both types of connectors.

The cost barrier for fusion SOCs has dramatically decreased as the prices for handheld fusion splicers with active cladding have decreased due to healthy competition and technology maturation. Temperature cycling, physical strain, moisture, and particle ingress are more problematic for mechanical connectors. Due to much lower optical loss, fusion SOCs have a clear advantage in outdoor environments. If the link loss requirements are low or numerous devices exist in the network, pressuring the overall budget, fusion SOCs reclaim their advantage otherwise lost with a mechanical connector.

Lower cost per connector with no fusion splicer required remains the primary benefit of mechanical connectors. Arguments for each aligning with EFA can be made, but splicing to pre-assembled connectors is the best answer if this were a multiple-choice question.

The common term in the industry is cassette. Industry standards refer to this component as a module; the terms module and cassette are synonymous. These cassette options offer clear expandability, flexibility, and accessibility features for enabling smart infrastructure success. The LGX-118 is an industry standard form factor for optical fiber enclosure adapter panels and cassettes. It is also a bulky form factor, consuming greater rack real-estate when compared to the high-density form factors.

The density translates to future expandability with the same or less space used in an LGX-118 footprint, which may have only met the needs of the present. The housing and cassette design are modular, meaning future changes to the network can be handled by swapping individual cassettes or inserting new cassettes if the housing was ordered partially populated. Tap, xWDM, patch, fanout, conversion, splice, as well as other methods are available cassette options.

The swappable nature of the cassettes within the housings reduces housing obsolescence risk. Future cassette designs for changing or introducing new network applications maintain backwards compatibility with the housing. The cassette exchange or addition is completed from the housing in most cases, providing accessibility. Pre-terminated, plug-and-play, and fusion spliced cassettes appear to be favored based on current industry adoption. Multiple vendors have published time study data touting these benefits from a labor time-savings cost perspective. The main con of the cassette system is the requirement of rack and panel space. This solution is not yet adapted for wall or din-rail mounted termination, but these developments may come with further adoption of this technology as fiber counts rise. Figure 3 shows various proprietary form factor cassettes/modules.

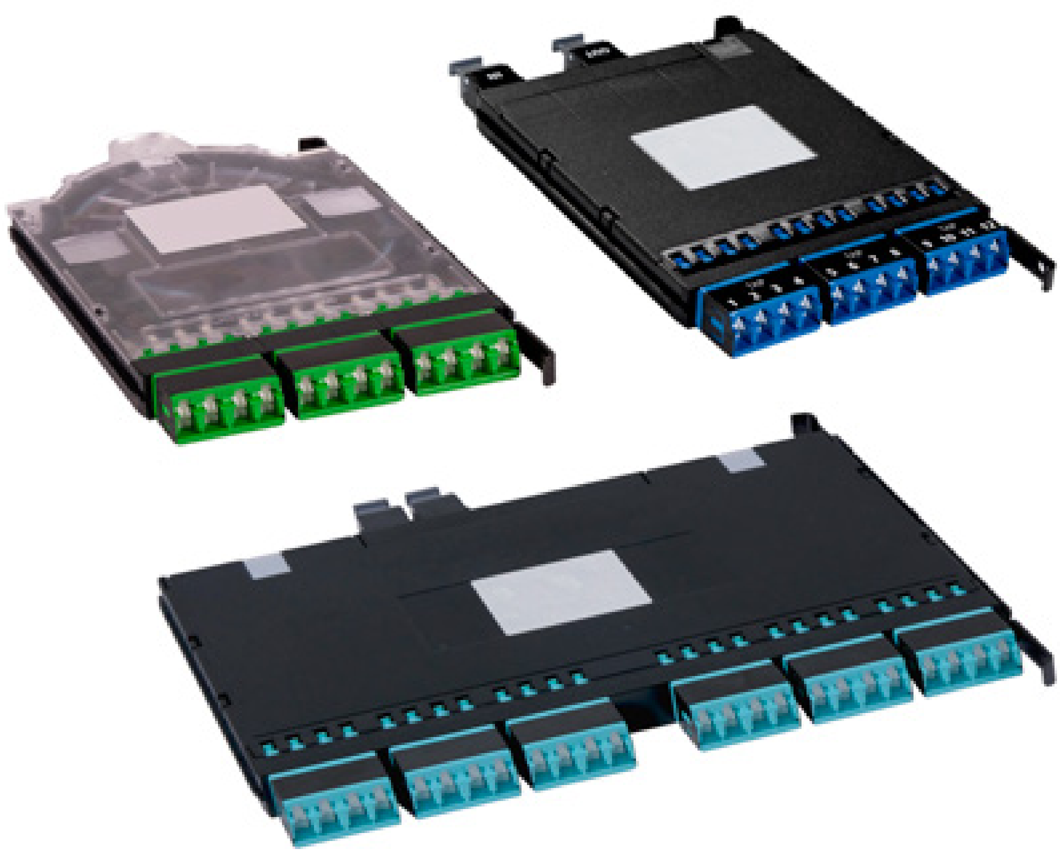

FIGURE 3: Proprietary form factor cassettes.

EFA SMART FUSION SPLICERS

As cable and connectivity advance to meet and exceed the needs of smart infrastructure, mass fusion splicers (sometimes referred to as ribbon splicers) compliment these innovations with the same EFA benefits. Many fusion splicing technicians are leery of ribbon splicing due to unfamiliarity, poor cleaning practices, or local consensus. Some newer mass fusion splicers on the market offer exchangeable V-grooves, which is not an easy feat technically.

The V-grooves of a fusion splicer are responsible for retention of the optical fiber during precision alignment via internal motors directed by image processing algorithms. Removing and installing new V-grooves with precision alignment of each fiber maintained is vital for the fusion splicer to achieve low splice losses.

Ribbon splicers with removable V-grooves allow for faster, more thorough cleaning, and job continuation in minutes without halting, regardless of cleanliness, poor cleaning practices, or unavoidable environmental characteristics. Additionally, as 200 micron (µm) ribbon fibers grow in prevalence to serve higher density needs, new V-grooves and fiber holders are required to seamlessly splice these fibers to themselves and existing 250 µm ribbons. A fusion splicer that is capable of application flexibility by exchanging V-grooves ensures job continuity and future-proofing as smaller pitched ribbon fibers develop. Singlemode fibers with 80 µm cladding and 160 µm fiber coating for telecommunications applications are now available.

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Research and development of these fibers in a ribbon format is ongoing and require new V-grooves for a successful fusion splice, if exchangeable V-grooves are not part of the machine's design. A fusion splicing chassis with modular V-grooves ensures EFA in fiber network construction if or when optical fiber ribbon changes fiber counts, pitch, or fiber type.

While EFA capabilities in the physical layer strongly support smart infrastructure, the physical layer does not then acquire the "smart" label per the definition provided. Given the role of the physical layer, it is not entirely practical or feasible to integrate smart into the fiber itself. However, the tools used to install or repair the physical layer can be smart if designed as such. One example of smart fiber equipment supporting the physical layer for smart infrastructure is the modern fusion splicer. Figure 4 shows the exchangeable V-grooves.

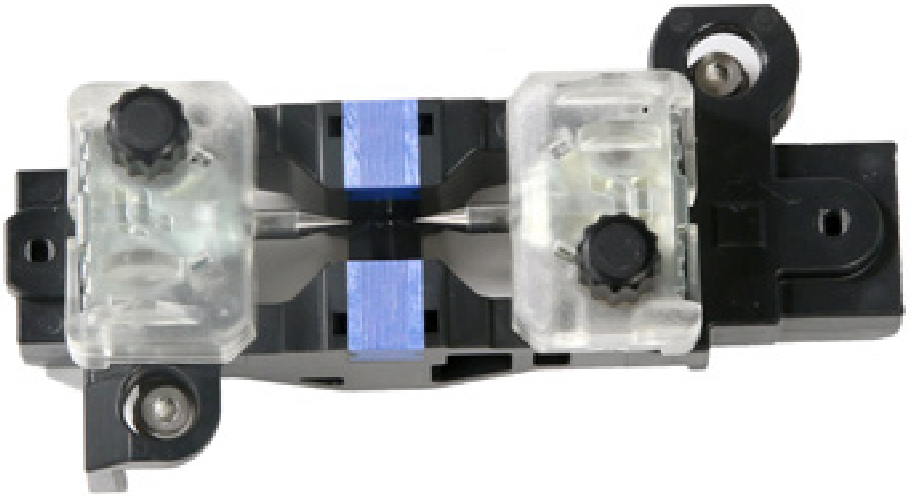

FIGURE 4: Exchangeable fusion splicer V-grooves.

Fusion splicing machines have evolved significantly since their commercial introduction to the Japanese market in 1979. Those who fusion spliced in the 1980s lived through the painstaking, cumbersome, and error-prone process of fusion splicing. For those without this hands-on familiarity, Figure 5 may help visualize the painstaking process.

The fusion splicer in Figure 5 is one of the earliest generations of fusion technology. This splicer had no cameras, no image processing, no optimized splice modes, no sensors, no motors, no arc calibration, no automated function, and no bells or whistles. A microscope was required to view the fibers and using mechanical precision stages, the fibers were moved by hand into position for fusion splicing.

FIGURE 5: The 1st generation fusion splicer.

Once manually aligned, a separate button was pressed to start the arc, and fibers manually moved again to touch in order to create a joint while heated. There was no loss estimation capability, so testing was the only method to confirm a passing fusion splice. Although much to be desired, it provided the basic function required for permanently joining two optical fibers with acceptable splice loss. Even with an inefficient process, compared to today's standard, it was much less expensive, less wasteful, and faster than installing new cable.

Optical fiber cable had not yet proliferated telecommunication networks as it has today. When fusion splicing was introduced, fiber optic cable was limited to the core layer of OSP telecommunications networks. The fiber rings in these early wireline networks had very few fiber counts (24 or less) and were not fusion spliced at many locations before tiering down further with copper. Early implementation of fiber in Ethernet networks followed the same methodology. As fiber was trialed and performance in real-world deployments scrutinized, the benefits of fiber began to be recognized. This drove further adoption of optical fiber as a preferred medium, and innovations to remove pain points followed.

Fusion splicing has evolved into a smart capable technology. Not all fusion splicers on the market fall into the smart category, but some manufacturers have introduced features which match the EFA acronym. For example, management of fusion splicer accessories, namely the fiber cleaver, was solely on the technician to manage blade rotations to ensure quality fiber cleaves. Solutions now exist for automatic blade rotations based on the condition of the cleaved fiber seen by the fusion splicer's zoom-capable camera(s) and automatically reports the condition to the operator. Self-monitoring analysis and reporting are present in this newer capability.

Another example is self-splice optimization. Some fusion splicers can identify the ITU classification of the fiber in the machine, set arc parameters based on the optimal conditions for the fiber, and self-optimize arc conditions when larger cleave angles are present, which historically cause poor splices. With self-splice optimization, splicing technicians can achieve low splice loss despite the fiber preparation quality.

Additional advancements are ongoing, specifically to tie fusion splicing data to cloud-based reporting for close-out packages that installers deliver to their customers for proof of network build and quality. Time stamps, GPS location, photos of the splice location and conditions, estimated splice loss, and pre-splice fiber conditions are some of the information available for upload to the cloud for reporting. This capability does not meet the "smart" definition but provides beneficial data for network construction quality and status. This is one of the newest capabilities on the market and, thus far, the primary benefactors appear to be the installers managing the status of their construction against key deadlines.

The key takeaway from the advent of smart fusion splicing features and cloud reporting is that installation equipment is performing key job functions technicians were required to monitor.

Any experienced fusion splicing technician knows the numerous steps and detailed tasks that require management to light-up and repair a network correctly. Modern installation equipment aims to take more off management's shoulders, so mental capacity is allocated to higher priorities. This is especially important as the so-called Great Resignation, caused by the pandemic, has ushered a newer generation of technicians. In addition, government stimulus for broadband equity is driving companies to quickly recruit new hires whose project deadlines outweigh training.

Stories of new fiber technicians without prior experience being handed fusion splicers, alongside many and various kinds of fiber tools, on their first day on the job and expected to successfully work on fiber networks are more commonplace than ever. Doing more with less is a common theme today, so machines and tools that support this need are crucial.

FURTHER INNOVATION AND CONCLUSION

Further innovations are destined for the physical and higher communications layers, especially for the optical fiber infrastructure and the machines and tools that support its installation and maintenance. Hollow core fiber (HCF) and multi-core fiber (MCF) are examples of major fiber innovations with promising results for the ICT industry. The HCF is already deployed in some high-frequency trading networks, and aggregate data transmission testing using MCF has been published. The HCF transmits signals at the speed of light in a vacuum, which provides significant time benefits over long distances.

The MCF offers unmatched signal density through its unique spatial division multiplexing strategy of multiple waveguides or singlemode cores within a single strand of optical fiber. Fusion splicing of these fibers has been tested and proven. However, other technologies, such as active transceivers friendly to MCF, need further development before a full solution offering is possible. New connector types, cable types, sensing systems, active components, and other smart technologies are in development, as many companies heavily invest in research and development activities to further advance the ICT industry as it supports the connectivity of smart infrastructure.

Only a few examples of smart infrastructure and the supporting cast have been discussed. The possibilities are nearly limitless as a new generation of communications speeds and latency are emerging. This fundamental layer promises exciting and unseen possibilities as industries that utilize ICT technologies develop smart infrastructures and smart applications. As a network designer, planner, or installer, staying abreast of industry trends is necessary to keep up with the competition and to get ahead. More importantly, continued learning and usage of the innovations discussed will better serve humanity's progress from the prominent position the ICT industry holds.

Fusion splicing has evolved into a smart capable technology.

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