

The Benefit of Field-installable Connectors for Fibre Build-out

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As a consequence of growing demand for ruggedized fibre connections, new solutions have been recently developed which enable installers to establish reliable fibre connections in the field to last for a guaranteed 20 years. The ease of use of field-installable connectors has been greatly enhanced. Installation can take place completely without bulky tools and no polishing is needed. All standard requirements for insertion loss and return loss are fulfilled.

1. INTRODUCTION

By using fibre on the last mile and in-house, networks can be substantially improved. Copper and coax cables were okay for reduced bandwidth and when only large download and little upload was required. But in the new world of symmetrical Gigabit and powerful streaming platforms, copper and coax need to be replaced by fibre from end to end as soon as possible. Networks built with pure fibre have a much better noise/signal ratio, cover larger distances and are safer from an IT security standpoint. Fibres allow for very small signal latencies, are not affected by EMI, have no scrap value and are therefore less prone to be stolen. Compared to legacy copper cable networks, fibre cables are both lighter and easier to transport, whilst allowing for greater energy efficiency for data transmission. Fibre is easier to maintain in street cabinets and manholes and no electrical energy feed is needed. This amounts to substantial energy savings.

With all that said, one wonders, why all networks are not Fibre-to-the-Home (FTTH) today and why so much Fibre-to-the-Curb (FTTC) is still surviving. In many countries low fibre penetration still persists. Fibre deployment is slow in coming and the question needs to be raised "Why is this still the case?" The supporters of copper networks often say fibre lines do not transmit properly when installed with tight bends, in a home environment which has many corners. Yes, this argument was only true a decade back. Since 2009 when bend-insensitive fibres were invented, this technical issue has been resolved.

The supporters of copper networks next say optical fibre lines are difficult to connect with high reliability and repeatability of performance using mechanical field connectors. Yes, this argument was also true over a decade ago. However, there have been continuous developments made to these products and the most significant advancements have culminated in the FAST PLUS, the new generation of field-installable fibre connectors which have made significant advancements toward resolving this issue. In this paper, we will describe why this revolutionary new development will surely create grid parity for fibre and bring about a breakthrough for fibre on the last mile.

1.1 Use Cases

There is another kick to this story, which is not only will fibre replace the existing copper, but also fibre networks themselves will grow on their own account. The big driver for this is 5G. For the layman this sounds surprising; but when we speak of "wireless" networks, of course, only the interface between subscribers and the antennas are wireless. Most of a 5G network, especially the backhaul, is done with single-mode fibres, which is due to huge increases in data traffic which are expected to be transmitted. Artificial intelligence, Big Data, IoT, to name a few, everything is hooked up to fibre. Only in the very beginning (when a tower is first connected) is it admissible to organize the backhaul via wireless to another tower. (Often this is done initially not for technical reasons, but because the permits for the right-of-way for fibre deployment have not been granted. So for the interim wireless is used.) But this kind of "wireless backhaul" needs to be temporary, because, once the cells fill up with subscribers and traffic goes up, fibre needs to take over the job to guarantee stable connections to all customers.

Every new mobile standard essentially means the data volume goes up by a factor of 40. This was the case when 3G became 4G in 2012 and it will be the case when 4G will become 5G in 2020. Add to this the transmission requirements of very low latency for autonomous driving,

robotics and other applications and it becomes evident – the demand for bandwidth will skyrocket. Fibre is the only medium to do the job. In Telecoms, as in other market segments of the IT industry, such as data centres, single-mode fibre is the new kid on the block taking over the business. The norms which allow 40 GB/s over copper have been around for five years, but not a single vendor of transceivers has jumped onto the bandwagon, so no copper-based transceivers beyond 10 GB/s have appeared yet. And it is doubtful this will ever happen. Copper is quickly dying out. This is clearly seen, where only shielded copper cables are allowed that may not stretch over more than 30 m, not 100 m as before. Full fibre networks are the only viable way to connect house entry points and devices like Small Cells, Base Stations, Cameras, Edge Computing Data Centres, etc.

The question this article is concerned about is how this hook up will be achieved in detail. We have to bear in mind that extremely tough conditions exist in the outdoor environment. Therefore ruggedized components are needed to overcome issues caused by water ingress, frost, heat, dust, salt, chemicals and vibrations. Telecom components are generally designed with a minimum service lifespan of 20 years. Everything that makes the component live longer in the outdoor environment is highly welcome. If maintenance teams have to repeatedly drive out and fix problems, the profitability of business is lowered.

Also the installation process needs to be more user friendly. The fibre industry of the past has suffered from being too complex. In every country there are multiple connector types, acronyms and naming conventions, cryptic, confusing and error prone. Compare this to copper, where the RJ45 connector is used globally. All the installer needs to know is to connect a male into a female receptacle. Let's discuss how fibre is deployed presently in contrast.

1.1.1 Pre-terminated Cable – Connector Assemblies

With this method typical fibre lengths (of 50 m, 100 m, 150 m) are prepared in the fibre factory and connectors are attached on both sides. This has the advantage that everything is carefree for the installer – the package is wrapped in plastic and he plugs it in at designated spots. Everything is easy. In the factory, dust-free connections can be assured and good attenuation values guaranteed.

The drawback of this method is that often the distances are estimated wrongly on the building site. This means there will be no lean supply chain. What happens instead is a constant movement of wrongly ordered cables travelling in between warehouses. Some cables will be sent back to the factory, others go on the return trip, others stay somewhere in limbo; all of this delays projects and frustrates managers.

Worse still, this situation gets more difficult over time and produces enormous waste. Local managers learn from the experience and, after a time, tend to order longer lengths of cable than actually needed and will get more creative in deploying overlengths. From their point of view, this is justified. They want to be on the safe side. When they see excess of cable, they wrap it around and hide it somewhere behind a panel in a basement. Or with aerial cables, they hang those extra lengths somewhere on a pole. All is better than shipping the cable back and delaying the execution of the work.

Often entrance ways into houses are too narrow and go around too many corners. The result is the cable needs to be cut to remove the excess and a fusion splicer (Figure 1) is used to rejoin the fibres together.



Figure 1–Fusion splicer for connecting cable in the house

1.1.2 Splicing with a Machine, On-Site

Because of the aforementioned reasons, many providers do not allow pre-terminated cable assemblies. However, they can only implement such a rule if they have enough skilled installers and enough capital to equip all of them with fusion splicers and the associated high-precision fibre cleaver tool.

It is true – these fusion splicers get better and less expensive every year; but still it is an effort to train installers to an effective level and bring these skilled teams into operation. It remains doubtful, if with the sheer volume of fibre projects, it will be affordable to get these tools to all teams. The same problem of complicated supply chain applies here – splice machines break down, get stolen, need maintenance, need new electrodes or software updates. Sometimes there is not enough physical space in basements to work with a bulky splice machine. For these situations, the field-installable fibre connector was developed. These early connector designs were considered as a quick fix, often for a repair and as a last resort.

Early versions had to be epoxy polished, and this took time and skill. Frequently, more experienced installers had to return to the site to do a “proper” splice and replace the “quick” fix of the field-installable connector. To sum up, this way to connect fibres was only used when neither pre-terminated assemblies nor splice machines were available to do the job.



Figure 2–Fibre Cleaver

Table 1

METHOD	BENEFIT
Pre-terminated assemblies	Faster, user friendly, de-skilled work force
Fusion splice on-site	More precise
Epoxy polish field-installable connectors	Last resort

2. FIELD-INSTALLABLE FIBRE CONNECTORS

2.1 The old way, when only an Index Matching Gel (IMG) was used

The general principle of all field-installable fibre connectors is that there is a mechanical splice performed inside the connector. There is no electrical arc to melt the fibres together as with a splicing machine and no automatic core alignment takes place. Only a mechanical alignment is done, a simple physical contact between fibres, which is made within a medium called index matching gel. This gel exhibits the same refractive index as the optical fibres. This technology is used in the Fujikura FASTConnect® field-installable connector.

In the factory, a short piece of fibre is cleaved and polished in a ceramic ferrule and positioned into the head of the FASTConnect (See Figure 3). It is important that this stub of fibre is of the same fibre type as the customer installed fibre, as there would be potentially significant losses caused by ‘mode field diameter mismatch’ if a single-mode fibre was used with a multimode fibre. Only a few quality vendors exist in the world today for this style of mechanical field-installable connector because the challenge of aligning ferrules and fibres is a tough one. If there is gap between the two, (when we speak of “gap” we mean an error tolerance of 0.5% of 9 micrometre, which is microscopic) light will propagate out of this construction. Only a near perfect drilling hole in the ceramic ferrule and excellent concentricity of the fibre will do the job.

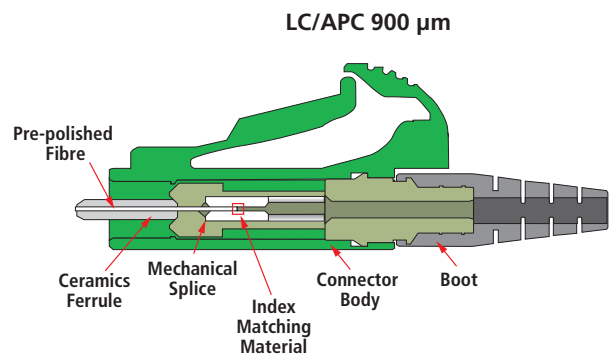


Figure 3–Inside of the FASTConnect

On the installation site the arriving fibre is stripped, cleaned, cleaved and inserted into the connector. A wedge clamp which sits on the connector body has two wedges which penetrate the inner mechanical body of the connector to open the body for insertion of the fibre. The installer squeezes on the wedge clamp once fibre insertion is complete to release the wedges from the body of the connector. This release action allows the mechanical splice to clamp down and grip the fibres and hold them in place for the lifetime of the product.

Only with a methodical approach to the assembly process (using high quality tooling) could attenuation values of insertion loss below 0.3 dB be achieved. Splice machines typically do a better job, but one shall not forget not only the typical 0.02 dB of the splice loss needs to be added to the attenuation budget when using a splice machine, but also the loss of the attached connector. In the past in order to save a few cents, purchase departments tended to buy very low-cost connectors for this purpose, and this gave the market of field-installable connectors as a whole a bad reputation. These very low-cost connectors were rightfully considered to be unreliable.

2.2 The New Hybrid Field-installable Connector

However, in 2019 a disruptive innovation took place in this space. A new product category, the hybrid connector, was invented in Japan, to become a part of the family of FASTConnect field-installable connectors. What is new here is one more connecting material inside the connector, apart from the index matching gel. This material is applied to the fibre end of the factory installed fibre stub inside the connector, and it is called **“Solid Gum” index matching** material. It is of a higher viscosity than the standard IMG, and it is directly applied and adhered to the fibre end. The “solid gum” serves as a cushion or airbag, protecting the fibre from excess force during the fibre insertion stage of the FASTConnect assembly process. The solid gum serves the function to smooth out potential irregularities in the cleave shape between the fibre ends and effectively prevents the ingress of dust and moisture. Filling the cracks is not the only magic potion this gum brings to the new connector. The gum also solves an old problem, which for the decades has been one of the hardest solutions to crack for some of the best brains in the fibre industry: the battle against return loss (RL).



Figure 4—FAST PLUS Connector

2.3 The double-fronted war...or how to battle against two enemies (Insertion Loss and Return Loss)

In order to explain the utmost importance of this, let us return to what we discussed earlier when we spoke about Insertion Loss (IL). Whenever we propagate laser light through fibre, we encounter two main enemies, the first one is Insertion loss, which is measured in additive decibel in logarithmic function (dB). This means if we have a dust particle, smaller than what we can see with the human eye on the fibre end-face, a loss will be caused – but if this particle doubles in size, the impact to loss will be four times as much. Therefore, little errors in the installation process snowball quickly and lead to effects which Claude Shannon (*April 30, 1916, † February 24, 2001) described as the threshold of noise over signal. Insertion loss is therefore similar to what Georg Ohm (* 16. März 1789, † 6. Juli 1854) described as electrical resistance on copper wires, a weakening of the signal over distance. Planners can deal with this. It is something they understand from the copper world, and is even easier to calculate in the fibre world. Here, attenuation numbers add up nicely, and can be predicted with utmost precision. This is not copper transmission where every neighbouring active copper line, running adjacent the transmitting copper cable can interfere with the signal.

On the other hand, planners, coming from the copper world, inherently have difficulty understanding Return Loss (RL) as it simply does not exist in the copper world. Adding to the confusion is Return Loss is also measured in dB in logarithmic function, but unlike Insertion Loss, the higher the number of dB in Return Loss you have, the better this is for your transmission. If you have less than 35 dB Return Loss, when you transmit video, pictures become corrupted or suffer from jitter. If you have less than 10 dB Return Loss over a short distance and you pump in light from a laser with high frequency, you will damage the expensive source lasers. The source laser will take a hit from the back reflection of the receiving target, sort of similar to what is seen in science fiction movies, when a mirror is put up and the laser weapon of the attacker explodes. In the telecom world, it does not happen as dramatically, but lasers slowly and gradually go kaput. Their life span is reduced over time. This is no happy

news for network owners, considering the price tag of these lasers is a couple of hundred thousand dollars each. It is imperative for providers to maximize Return Loss.

Today, the only known method to reduce Return Loss in connections is to cut an angle into the fibre end-face. Now, when the laser light hits the tilted “mirror” of the fibre end-face, you have effectively prevented it to propagate the laser light back to the light source in a straight line. By detracting the laser light into the cladding glass, you prevent it to do harm to your laser. It is especially important to do that when you are operating over short distances and with high frequencies such as in FTTH networks.

In theory and in the laboratory, all these requirements which the optics demands from us are clear. But try to implement this in the harsh environment of the field and you get what has been the “million dollar” question in the fibre industry for decades. How to find a practicable solution to the APC dilemma? How to make the circle square and defend both enemies, IL and RL, at the same time? In order to understand what a tough challenge this is, just consider the following. If you cut a fibre with a normal cleaver, you usually get a straight 90 degree angle down. Now this cut is perfect for the mating of fibres with a light arc, the domain of the splice machine. When the fibre cores are melted together with the help of a splice machine, this is exactly what happens. This is the optimized mode for cleavers and splicers to work together, as you can see in Figure 5, Scenario #1 at right.

In order to defeat Return Loss, a small number of specialized cleaver manufacturers have appeared on the market. There are only a few because it is a challenge to produce a cleaver which cuts in a near perfect angle of 8 degrees repeatably, while also being affordable (most angled cleavers cost more than \$3,000). Still, angle cutting only one side perfectly does not solve the problem, because having a good RL of 60 dB is good and keeps your lasers happy, but it means you have only done half the job, because the Insertion Loss could still be problematic depending on the size of the fibre gap.

An angled cleaver does not solve the issue of RL for most mechanical connectors as the factory installed fibre stub is typically a flat cleave. Mating an 8 degree cleave to the flat factory stub would cause issues as a gap would form between the two fibres. This is also true when mating any irregular field cleaved stubs to the factory stub. The solid gum on the end of the factory stub helps close this gap and minimize RL issues created by the following scenarios.

In Figure 5, Scenario #1, we have two flat cleaved fibres. On the left is a fibre with ‘solid gum’ and on the right is a fibre with a “ripple.” The ripple cleave defect is commonly caused when the maintenance and operation guidelines for a standard cleave tool have not been followed. This simply means that the guidance on blade rotation/height has not been adjusted, the longer the blade rotation and or height is ignored the frequency of a ripple cleave defect increases.

Figure 5, Scenario #3 has two traditional cleaved fibres with a 180 degree offset. Previously in this situation with the use of standard IMG, the allowable gap tolerance before an effect to IL can be measured would be 2 micron. Now with the use of solid gum this gap tolerance is increased to 20 micron.

Finally, Figure 5, Scenario #4 shows how to culminate the benefit of the solution of solid gum/IMG and cleave shape. The ‘roll off’ of the angle cleave allows the fibre cores to align closer than before.

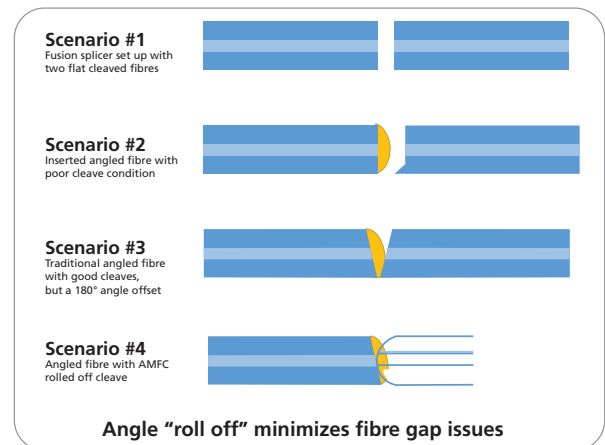


Figure 5–Fibre gaps

2.4 The FAST Cleaver

In the effort to create more ease of use for the installer, the development of the FASTCLEAVE™ was an important milestone. As described earlier, loss or damage of a traditional cleaver is not only a financial loss of an asset, but even more damaging because of the interruption of work it automatically entails. As described throughout this paper, it takes time to replace vital missing items on the construction site, be it a wrong assembly, a broken part on a splice machine or on a cleaver. In extreme cases, arrival of replacements can take days or even weeks. It is a relief for the project manager the FASTCLEAVE is being given away for free with every package of 100 pieces of FAST PLUS connectors. It therefore will be an abundant item on all fibre building sites in the future. No one will worry if one of them is missing. There will be a replacement FASTCLEAVE readily available in the next box.

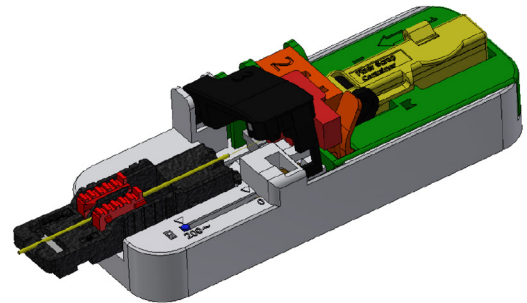


Figure 6–FASTCLEAVE (angle cleave tool)

It has to be highlighted that using a “cheap” article such as the FASTCLEAVE does not mean there will be a compromise on quality. For example, over 1,000 blade designs were evaluated and tested to find the optimum design for the FAST PLUS. With over 10,000 cleaves also tested against the current blade design with zero negative cleave conditions (e.g. ripple, mirror, etc), installers can be more confident about repeatability and reliability of FAST connections. Minimum training will now be required prior to installation on site with the fast and easy learning curve presented with the introduction of the FASTCLEAVE alongside the FAST PLUS connector.

3. RECOMMENDED ADDITIONAL TOOLS

A dust particle of 1 micron on the 9 micron core of a fibre end-face can take 1% of the light and 0.05 dB loss. A dust particle of 9 micron can therefore completely disrupt data transmission. It should again be noted – such dust particles are so small the human eye cannot detect them. It is therefore recommended to use an Inspection Scope (Figure 7 below) when you are working with optical connectors.



Figure 7–Inspection Scope



Figure 8–Handheld OTDR

In order to better control the installation process, a new generation of handheld OTDRs (Figure 8 above) has appeared on the market. Because when you have a large team with some untrained installers, you do want a few specialists to go around the building sites and check on the work being done.

4. CONCLUSION

It is good news for the fibre industry that these three prior methods of connecting fibres:

- Pre-terminated assemblies
- UPC with fusion splicers and cleavers
- Traditional FASTConnect field-installable connectors with traditional cleavers

have now seen the addition of a new method, the FAST PLUS method. In this new field-installable connector, the air gap between fibre ends is filled with solid gum material as addition to the existing index matching gel. This solves the issues of high Insertion Loss and low Return Loss of traditional field-installable connectors.