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 that enable installers to establish reliable fibre connections in the field that last for a guaranteed 20 years. The ease of use of these new field installable connectors has been greatly enhanced. Installation can take place completely without 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 go away and 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 and are easier to maintain in street cabinets and manholes no electrical energy feed is needed anymore, which amounts to substantial energy savings.

With all that said, one wonders, why not all networks are FTTH today and why so much 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 shout that fibre lines do not transmit properly when installed with tight bends, in a home environment which has many corners. Yes, that argument was true a decade back. But since 2009 when bend insensitive fibres were invented, that technical issue has been resolved.

The supporters of copper networks next shout that optical fibre lines are difficult to connect with high reliability and repeatability of performance using mechanical field connectors. Yes, that 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 towards resolving this issue as well. In this article 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 back haul 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, you name it, everything is hooked up to fibre. Only in the very beginning (when we first connect a tower) 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 that 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 that 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 thousands of other applications and it becomes evident that the demand for bandwidth will skyrocket and fibre is simply 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 that is 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 that 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 30m, not 100m 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 on 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 are highly welcome, because if maintenance teams have to repeatedly drive out and fix problems, the profitability of business is lowered.
The next big hurdle is that the installation process needs to be 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 that he needs to connect a male into a female receptacle. Let us discuss how fibre is deployed presently in contrast.

1.1.1. **Pre-terminated cable- connector assemblies**

With this method typical fibre lengths of let’s say 50m, 100m, 150m are prepared in the fibre factory and connectors are attached on both sides. This has the advantage that everything is carefree for the installer. He gets a package wrapped in plastic and 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 on the building site often the distances are estimated wrongly. This means that there will be no lean supply chain. What you get instead is a constant movement of wrongly ordered cables travelling in between warehouses, some cables being sent back to the factory, others going on the return trip, others somewhere in limbo; all of this delays projects and frustrates managers.

Worse still is that this situation gets more difficult over time and produces enormous waste. Local managers learn from their experience and tend to order longer lengths of cable than actually needed and they tend to 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 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 splice machine (see Picture 1. below) is used to re-join the fibres together.

Picture 1. a Splice machine for the house connect

1.1.2 **Splicing with a machine, on site**

Because of the beforementioned 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 machines and the associated high precision cleaver tool.

Picture 2. A cleaver

. It is true that these fusion splicer machines 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.
These 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 to 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 machine could do the job.

Method	benefit
pre-terminated assemblies	Faster, user friendly, de-skilled work force
Fusion splice on site	more precise
Old field installable connectors	Last resort

2 Field installable fibre connectors

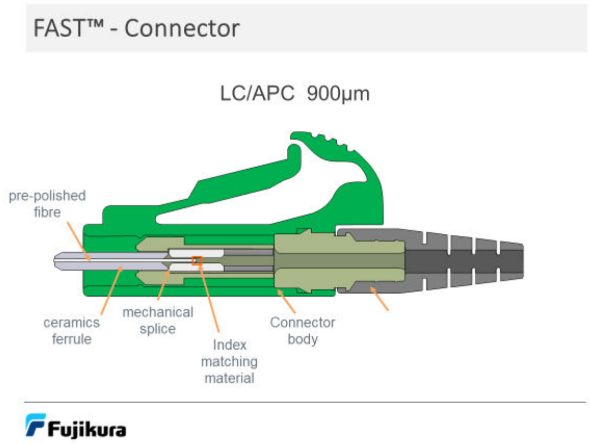
2.1 The old way, when only an Index Matching Gel (IMG) was used

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 that melts the fibres together, as with a splicing machine and no automatic core alignment that takes place. All that is done is a mechanical alignment, a simple physical contact between fibres which is made within a medium which exhibits the same refractive index as the optical fibres themselves this is index matching gel.

In the FAST™ factory a short piece of fibre is cleaved and polished in a ceramic ferrule and positioned into the head of the connector. (See picture 3) It is extremely important that this stub of fibre is of the same fibre type as the inserting fibre, as there would be potentially significant losses caused by 'mode field diameter mismatch' if a single-mode fibre was used with a multi-mode fibre). Only a few quality vendors exist in the world today, 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 microme**tre**, 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.
On the installation site the arriving fibre is prepared, cleaned and cleaved and pushed into the connector. The installer presses on a wedge clamp that sits on the connector body and penetrates the side of the mechanical splice section of the FAST connector, the two fibres are pressed together and pressure maintained during the release of the wedge tool. 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 0,3dB be achieved. Splice machines usually do a better job, but one shall not forget that 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



Picture 3. The inside of the FAST connector

However, in 2019 a disruptive innovation took place in that space. A new product category, the hybrid connector, was invented in Japan, to become a part of the family of FAST™ connectors. What is new here is that there is one more connecting material inside the connector, apart from the index matching gel. This material is applied to the fibre end of the inner 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 FAST™ assembly process. The solid gum has the function to smooth out potential irregularities in the cleave shape between the fibre ends and effectively prevents the ingress of dust and moisture. But not only filling of the cracks is what this magic potion brings to the new connector. It enables an old dream of the fibre designer, it allows to do a trick, which for decades was the toughest nut to crack for the best brains of the fibre industry, the battle against return loss.

Picture 4:

The outward appearance of the FAST connector, the beige component is the wedge clamp.

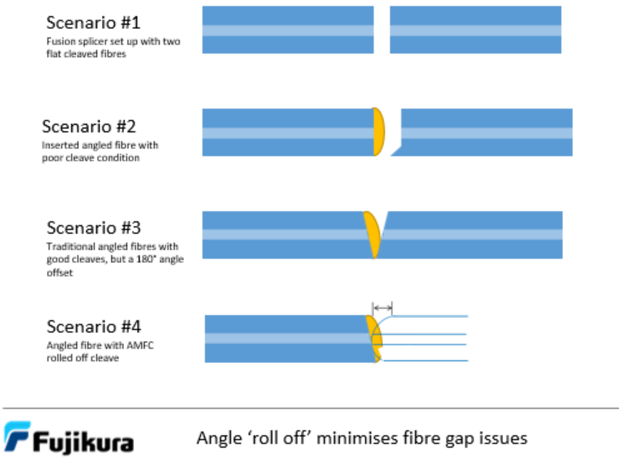
2.3. The double fronted war… or how to battle against two enemies (Insertion Loss and Return Loss)

In order to explain the utmost importance of this, let us return to what we discussed earlier when we spoke about Insertion Loss, vulgarly called optical attenuation. 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 little dust particle, smaller than what we can see with our human eyes on the fibre end face, if it doubles in size, this does impact much stronger than in linear function, it does not impact twice as much, but 4 times as much. So little errors in the installation process snowball quickly and lead to effects which Claude Elwood **Shannon** (*April 30, 1916, † February 24, 2001)"the father of information theory" described as the threshold of noise over signal. Insertion loss is therefore somehow similar to what Georg Simon **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 in the fibre-world is even easier to calculate, 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.

Planners coming from the copper world, inherently have difficulty understanding Return Loss. (Something like RL simply does not exist in the copper world). Adding to the confusion is that 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 RL, when you transmit video, pictures become corrupted or suffer from jitter. And 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 mirror of the target, sort of what you see 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, lasers slowly and gradually go kaput, as their life span is reduced. This is no happy news for network owners, considering that the price tag of these lasers is a couple of hundred thousand dollars each. It is imperative for providers to reduce Return Loss to a maximum.

Today the only known method to reduce Return Loss in field 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 a short distance and with high frequencies such as on FTTH networks.

In theory and in the laboratory all these requirements which the optics demands from us are clear. But try to implement that in the harsh environment of the field and you get what has been the “million dollars” question for 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 degrees 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 the top line of the following image (Picture 5. Scenario #1).



Picture 5. Fibre gaps

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 that cuts in a near perfect angle of 8 degrees. (It has to be noted that these cleavers are very expensive as well. They cost more than double the price of a standard flat angle cleaver, sometimes more than 3000 dollars) But still, angle cutting only one side perfectly does not solve the problem, because having a good Return loss of 60dB is good and keeps your lasers happy, but it means that you have only done half the job, because the Insertion Loss could still be problematic depending on the size of the fibre gap..

Scenario #2

In this scenario, we have two flat cleaved fibres. On the left we have a fibre with ‘solid gum’& on the right we have a fibre with a ‘ripple’. The ‘ripple’ cleave defect is commonly caused when a standard cleave tool’s maintenance and operation guidelines have not been followed; what this simply means is the guidance on blade rotation/height has not been adjusted, the longer the blade rotation & or height is ignored the frequency of a ripple cleave defect increases.

Scenario #3

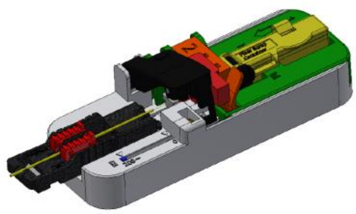
For this example, we have two traditional cleaved fibres with a 180° offset. Previously in this situation with the use of standard IMG, the allowable gap tolerance before an effect to IL can be measured would be 2 microns. Now with the use of solid gum this gap tolerance is increased to 20micron.

Scenario #4

This image shows how we culminate the benefit of our solution of solid gum/IMG and cleave shape. The ‘roll off’ of the angle cleave allows the fibre cores to align closer than before

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 article it takes time to replace vital missing items on the constructions 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 that the FASTCLEAVE™ is being given away for free with every package of 100pcs of FAST PLUS connector. It therefore will be an abundant item on all fibre building sites of the future. No one will get grey hairs if one of them is missing, there will be a replacement FASTCLEAVE™ readily available in the next box.

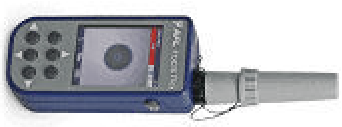


Picture 6: FASTCEAVE™-A (angle cleave tool)-

It has to be highlighted that by using a “cheap” article such as the FASTCLEAVE™ does not mean that there will be a compromise on quality. For example over 1000 blade designs were evaluated and tested to find the optimum design for the FAST PLUS, and with over 10,000 cleaves tested against the current blade design with zero negative cleave conditions (e.g. ripple, mirror, etc) installers can be more confident of about repeatability and reliability of FAST connections. With the new FASTCLEAVE™ the work on the installation site will be no rocket science anymore, no physics doctorate in optics will be needed. Less qualified installers can be employed, the learning curve is steep and short.

3. Recommended additional tools:

According to Cisco a dust particle of 1micron mm size on the 9micron core of a fibre face end can take 1% of the light and 0.05dB loss. A dust particle with a size of 9 micron can completely disrupt data transmission. It should be noted that such dust particles are so small the human eye cannot detect them. It is therefore highly recommended to use an Inspection Scope, when you are working with all optical connectors



Picture 7: Inspection Scope

In order to better control the installation process, also a new generation of handheld OTDR has appeared on the market. See below picture 8. Because when you have a large team of more or less untrained installers, you do want a few specialists to go around the building sites and check on the work being done.

Picture 8: OTDR

4. Conclusion: It is good news for the fibre industry that the three prior methods of connecting fibres, a.) pre- terminated assemblies, b) UPC with fusion splicers and cleavers and c) traditional field installable connectors with traditional cleavers, have now seen the addition of a new method, the FAST method. This new field installable connector is able to fill the air gap between fibre ends with solid gum material as an addition to the existing index matching gel. This solves the issues of high Insertion Loss and low Return Loss of traditional field installable connectors and makes them a good choice for provider in the deployment of fibre networks.