APPLICATION SPECIFIC SOLUTIONS FOR FTTx BLOWN FIBER SYSTEMS

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Abstract

As optical fiber for broadband access is deployed closer to both consumer and business customers, strategies for matching fiber deployment to expected customer demand are critical for access providers. Use of blowable cabled-fiber units and microduct systems are offered as one cost effective solution. Product types for several specific applications are presented.

1. Introduction

The past five years have seen an enormous investment in long haul fiber capacity by the telecommunications industry. Looking forward, the main areas of future fiber investment will be in metro rings and, increasingly, in FTTx applications to connect both household and enterprise customers to broadband services. Installation of this "last mile" of fiber has been slow due to the high cost of this installation per customer served and the corresponding uncertainty of securing any increased revenue from each customer. A novel approach to this challenge is the concept of "fiber on demand". This approach involves the pre-installation of a multi-microduct system and then the subsequent, incremental installation of fiber based on individual customer demand.

To support this "fiber on demand" approach in last mile builds, a fiber cable product must allow the installation of just a few fibers at a time. Further, the cable product needs to take up the smallest amount of the service provider's right-of-way (i.e., fit in the smallest microduct) so that there is plenty of space to add fiber for future customers. Based on these requirements and the need to serve residential and enterprise customers, blown cabled fiber products are designed to be scalable, usually from 2 to 12 fibers. OFS has developed and markets several cabled fiber products – two product lines will be presented in this paper. Both products are designed to fit in the smallest commercial microducts over distances up to one kilometer.

One type of cabled fiber unit packages the fibers in a polyolefin tube that is specifically designed for easy fiber access, and to minimize friction between its outer surface and the inner duct wall so as to optimize installation performance. This type of solution has been field tested successfully in duct routes that are representative of the paths encountered in the "last mile"

A second cable product leverages the technology used to make optical fiber ribbons. The UV curable acrylates are used to coat and bundle optical fibers into small cable units, ideal for the smallest right-of-ways including fiber-in-gas installations. Further, the coating provides mechanical protection while still allowing easy access to the fibers.

2. Performance Considerations for Blown Fiber Units

2.1 Typical Fiber & Duct Counts and Sizes

As described above, the deployment of fiber units is done in a phased approach. First a duct system is installed and then at a later time fiber is blown through the duct to the customer. The advantage of this approach is that fiber deployment is initiated by a customer request for broadband service, maximizing ROI for the service provider. Additional advantages that have been advertised are that latest generation fiber, or fiber meeting customer data requirements can be installed in a "custom" fashion and that this conduit can be upgraded in the future by removing installed fiber and replacing with newer products. This FTTx approach requires consideration of both the fiber unit and the duct it will be installed within. A key feature of this arrangement is that the fiber unit will be designed to impart some environmental protection and structure to a set of fibers, but will ultimately be protected from the environment by the duct system. Thus, any design effort must consider the fiber unit, the duct system and the interaction between the two.

Fiber units themselves have been normally seen with fiber counts ranging from 2 to 12 fibers and will typically have an outside diameter of between 1. and 1.5 millimeters. Units containing only 2 fibers can typically be used to deliver service to a single customer in duplex fashion, with one send and one receive. Alternatively, actual deployments have seen this strategy used with a 4-fiber unit, with the extra fibers available for quick response to service problems. At the high end of fiber counts, an example for 12 fiber units is where drops are required in a building that will ultimately service a large customer or multiple customers within a defined area, say a floor of a multi-story building. More detail on specific designs for these fiber units will be given in later sections.

Duct systems for blowable fiber units are commercially available and have been designed to optimize blowing distances and provide additional protection from the ambient environment. Typically a number of ducts will be packed together and jacketed much the same way as an optical cable without the fiber. The hollow plastic ducts are sized to allow the fiber unit to be blown into the duct freely, and the inner surface of the duct is designed to minimize sliding friction and static buildup with the fiber unit. Although no standards for duct inside and outside diameters have been set, commercial de facto standards are emerging. A list of available duct sizes with inner and outer diameters and maximum recommended fiber unit diameters is given in Table 1.

Table 1: Available Duct Sizes and Feasible Fiber Counts for Installation

Duct OD	Duct ID	Fiber Unit OD	Microcable OD	Fibers
12 mm	10 mm	---	7.5 mm	to 72
10 mm	8 mm	---	5.8 mm	to 48
7 mm	5.5 mm	3 mm	---	to 24
5 mm	3.5 mm	1 mm - 1.6 mm	---	to 12
4 mm	2.5 mm	1 mm	---	to 4
3 mm	2.1 mm	1 mm	---	to 4
4 mm	2 mm	1 mm	---	to 4

2.2 Mechanical and Frictional Properties of Fiber Units

The key fiber unit mechanical design issues are unit stiffness and elasticity, unit robustness and surface friction. Although the blown unit is effectively pulled into the duct by an air stream during installation, there are circumstances under which compressive axial forces can occur, and hence the possibility of buckling the fiber unit. Buckling can cause jams in the duct and possible damage to the fiber being installed.

A fiber unit must also be able to bend around corners as typical installations will contain bends. Thus the unit bending stiffness must be sufficiently high to minimize the risk of buckling, but not so high as to impede cornering during installation. Blown fiber units do not utilize strength members as do traditional fiber cables, and therefore the entire unit stiffness is achieved through the intrinsic stiffness of the fibers themselves, as well as the materials coating the fibers. Here the small cross-sectional geometry of the fiber unit plays a favorable role in achieving a balance between flexibility and stiffness.

Another key fiber unit property is its surface characteristics. The goal is to maximize viscous air drag on the fiber unit and minimize friction with the duct. As mentioned before, the duct inner surface is optimized for low friction with the fiber unit during installation. The fiber unit itself is also designed to minimize sliding friction with the duct. This allows for blowing distances great enough to make this system practical for a wide range of installation situations. Typically the materials that make up the outer coating of the fiber unit will be modified to reduce their friction coefficient with the duct surface. There are a number of technical routes that can be taken to achieve this. Two specific methods will be described later in this paper.

2.3 Optical and Environmental Requirements

As this technology is relatively new, optical and environmental requirements for blown fiber units are heavily customer dependent. There has been one detailed specification [1] for a fiber unit design deployed in the UK. Other than this, no definitive specification in the standards bodies has been decided upon. Given this, it is clear that these units will need to meet specifications widely accepted for fiber employed in traditional cables. Although it might be argued that the duct system provides some environmental protection, the intrinsic optical properties for these units must meet customer requirements after installation. Below we will briefly discuss some of the optical and environmental requirements for these products. Specific capabilities of the two design embodiments described in this work will be given in later sections.

Any fiber unit design must meet customer requirements. The loss budget for a particular situation will vary, however loss requirements for single mode fibers in the 1310 nm and 1550 nm windows will typically be ≤ 0.35 dB/km and ≤ 0.25 dB/km respectively. We have seen much customer requirements for products as high as 0.50 dB/km at 1310 nm and 0.50 dB/km at 1550 nm, highlighting the fact that installation spans are around 1 km. In addition to room temperature results, there will usually be temperature cycling requirements. Standard GR-20 calls out less than 0.05 dB/km added loss for 90% of fibers tested and less than 0.15 dB/km for all fibers tested for a - 40°C and + 70°C temperature range. CW1574 calls out a less strenuous temperature cycling (- 10°C to + 60°C), indicating that users of this technology have seen a reduced vulnerability of these units after installation in ducts.

In addition to basic attenuation requirements, specifications call out loss limits for a variety of situations where the fiber unit is subjected to mechanical tensile or compression (crush resistance) loading. These requirements point out that although an ideal installation leaves the fiber unit free from any stresses, in actual installations service providers desire to have some safety margins on attenuation.

Finally, the unit must be robust to the presence of gases or liquids (water) in the duct. CW1574 calls out a stringent water immersion requirement where added losses must be less than 0.07 dB/km after 2000 hours in room temperature water. GR-20 does not address blown fiber explicitly, but does require any optical product to be water blocked. Clearly any fiber unit design must account for the unintended presence of water in a duct. In the area of gases, a special case will be addressed in Section 4 where the unit design must be robust to these environments.

2.4 Installation Issues

The key parameters when installing fiber units in ducts are blowing distance and time. Ideally the fiber unit should be capable of being blown for at least a kilometer, and preferably more. At the same time, installation speed should be such that installing to these lengths does not require an inordinate amount of time. Typical installation speeds are in the 25 to 45 meters per minute range under an air pressure of 10 bar.

The difficulty in designing for these parameters lies in the fact that installation layouts can vary widely. In the simplest case the unit would be installed in a straight, level section of duct. In actual conditions, the number and radius of turns the unit will be required to make will be significant. We have attempted to develop understanding of how well a particular fiber unit design will perform under practical installation conditions through empirical data gathered on simulated installation and lab routes, and the development of predictive models. We have collected blowing data on our fiber unit designs on two actual test routes similar to that shown in Figure 1 and designated Rt I and Rt II below. Rt I, the serpentine track consists of 50 meter straight sections and 180 degree turns at 0.5 meters in diameter. Rt II consists of sections of duct which can be joined together in various configurations and lengths. Both of these tracks are designed to mimic installations that might be seen in the field.

Another set of laboratory type routes, designated Rt III and Rt IV in Figure 1 below, have been used to measure fiber unit blowing capability. Rt III consists of a 500 meter length of duct wound around a 0.5 meter hub or drum. Rt IV contains an inner and outer route with multiple laps of duct. The outer track has a turning radius of 0.5 meters, while the inner track has a more severe turning radius of 0.25 meters. Both tracks are intended to correlate with actual conditions so product testing can be carried out without requiring field trials.

Given equivalent inlet air pressure and exit flow rate the dominating factors determining how a specific fiber unit design will perform are the number, angle and radius of the turns in the route. Consequently, we have developed a model that accounts for these factors in two parameters. The first is tortuosity and the second is the minimum bend radius in the track. The tortuosity T is the length-weighted average value of curvature for a given path. The value of tortuosity is that it provides a measure of the challenge a path layout presents to a blowing installation. Evaluations of actual installation paths and “standard” routes can be used to design a laboratory test bed for experimenting with blown unit prototypes prior to testing in the field.

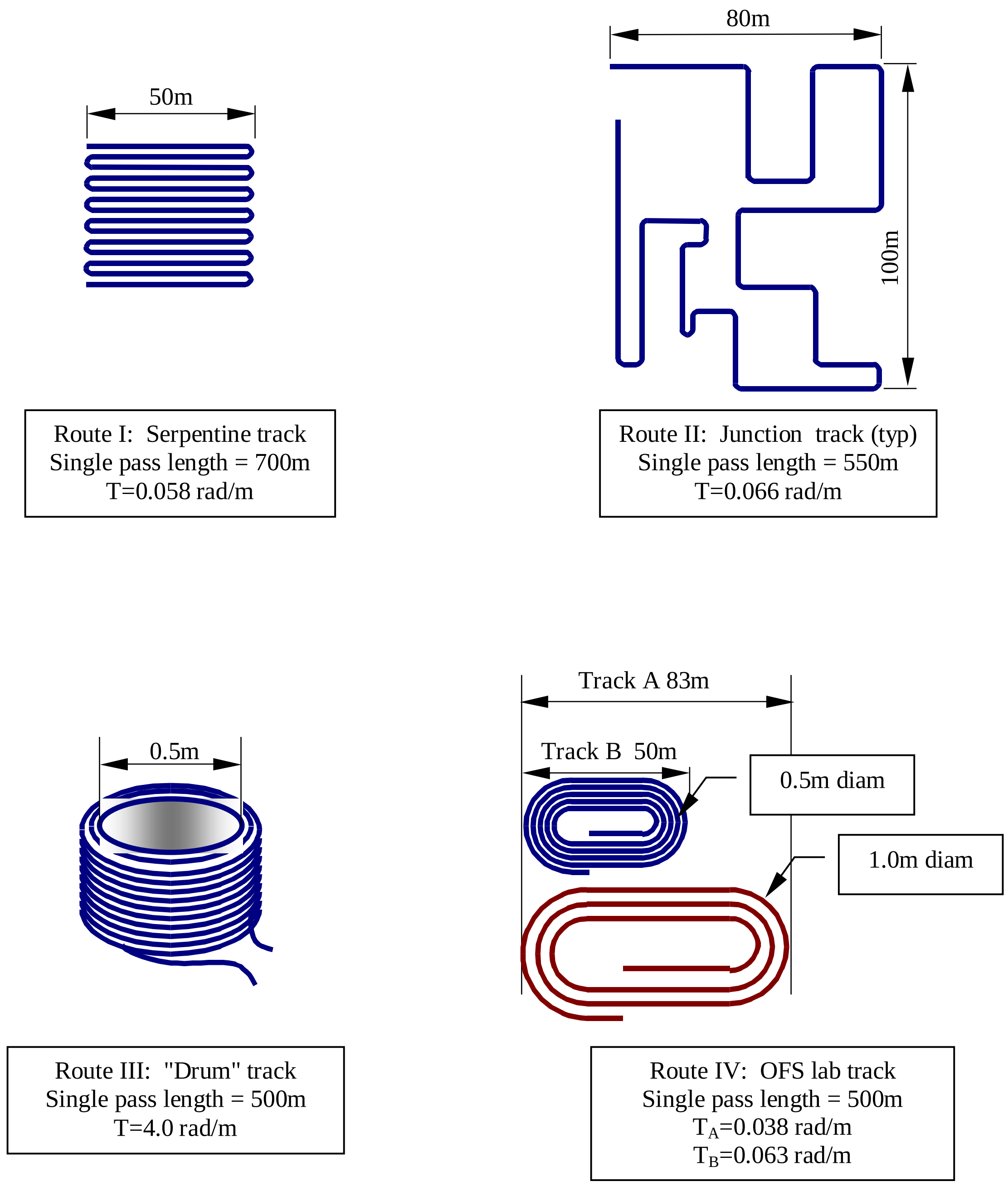

Figure 1: Field (Rt I and Rt II) and OFS Lab (Rt III and Rt IV) Test Tracks

Tortuosity has the following properties:

- Like curvature, it has units of radians per length.
- It is bounded by the maximum and minimum curvatures found along the length considered.
- Different path lengths and different path geometries may have the same tortuosity.
- Tortuosity treats all curvature as a non-negative quantity. In other words, while “crookedness” may vary along a path, it always accumulates and never cancels. Otherwise, antisymmetric curves such as S-bends would have zero tortuosity like a straight line.

Straight line $y = mx + b$: $T = 0$ for all lengths

Circular arc $x^2 + y^2 = r^2$: $T = \frac{1}{r}$ for all arclengths and subtended angles

Sinusoid $y = A \cdot \sin 2\pi \frac{x}{L}$: $T \approx \left(2.8\frac{A}{L}\right)^4 - \left(4.4\frac{A}{L}\right)^3 + \left(5.3\frac{A}{L}\right)^2$

General $y = f(x)$: $T = \frac{1}{L}\int_{x=0}^{x=L} \frac{|f''|}{1+(f')^2}dx$

The process of a blowing installation involves geometry, energy, mechanics, thermodynamics, and aerodynamics. Tortuosity captures only part of the geometric considerations. The sequence of curvature variation is transparent to tortuosity. For example, a straight path with a coiled section has the same tortuosity if the coiled section is located at either end or anywhere in between. Thus, it may make sense to also calculate the moment of tortuosity with respect to the blowing point. Tortuosity does not distinguish between planar paths and ones with elevation variation. A horizontal straight line and a vertical straight line both have zero tortuosity, but a unit can be blown further on the horizontal path.

Because tortuosity is an "average" value, it is imperative that the minimum radius of curvature encountered also be included in evaluating a path's geometry. On a practical level, the tortuosity of real-world pathways may be approximated by the number of right angle turns *n* and the total path length *L*. These approximations assume that the "straight" portions are truly straight, i.e. zero curvature sections.

$$T_{practical} = \frac{\pi}{2}\frac{n}{L}$$

Given this analysis, values for tortuosity and minimum bend radius for each track described above are given in Table 2 below. It can be seen that the OFS Lab Rt IV track closely mimics field track conditions the OFS Lab Rt III is a severe test of a fiber unit design's blowing ability. However, the attractiveness of this route is its small footprint and repeatability in a controlled set up. Our experience suggests that units that perform well on 500m of Rt III should perform well in typical 1km field installations. Thus, we have a high degree of confidence that any design performing well on Routes III and IV will perform well in the field.

Table 2: Tortuosity (T) and Minimum Bend Radius for Different Test Routes

Track	Tortuosity (rad/m)	Min Bend Radius (M)
Rt I	0.058	0.25
Rt II	0.066	0.2
Rt III	~ 4.0	0.25
Rt IV	0.038 (A) - 0.063 (B)	0.5 (A) - 0.25 (B)

2.5 Section Summary

Having discussed the general form of fiber units and the ducts they are installed in, requirements for mechanical and optical properties and methods to evaluate their blowing performance, we will now turn our attention to specific fiber unit solutions developed for this technology. In the next section we will describe a robust fiber unit designed for a wide range of blowing applications and give performance data. In the following section we will give the same treatment to an acrylate based fiber unit.

3. Polyolefin Tube Fiber Units – XpressTube® FX Cable™

The first embodiment of a fiber unit developed at OFS is based on a gel-filled polyolefin tube. The key feature of this economical design is that up to 12 fibers can be placed in a small 1.6 mm OD tube. Examples of available fiber counts are shown in Figure 2.

3.1 Unit Design Features

In this design the ingress of water is prevented by a water blocking gel. Because of the small size of the blown tube, the amount of gel utilized is minimal making it a virtually dry tube. The simplicity of the flexible polyolefin tube inherently provides easy entry and no ripcord is needed. End and midspan access is easily done with wire strippers without damaging the optical fibers. Additional design features of this unit include:

- Twelve unique tube colors available to identify different fiber types
- Message and length printing available
- Profiled exterior for low friction
- Tensile strength: 20N
- Minimum bend radius: 36 mm

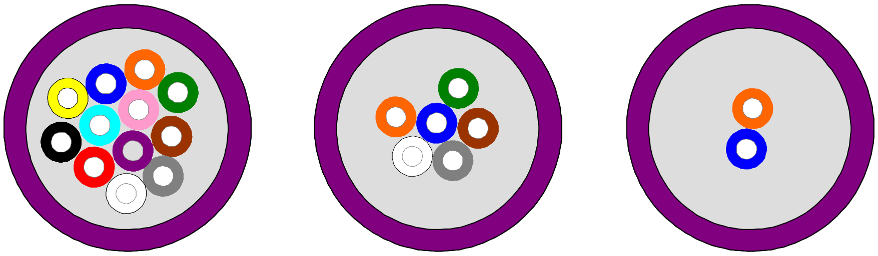

Figure 2: Gel filled polyolefin tubes with different fiber counts

3.2 Unit Performance Data

This fiber unit was designed to comply with the following mechanical requirements specified by IEC standards at 1550 nm: tensile performance IEC 794-1E1, flexing IEC 60794-1-2-E11A, and crush IEC 60794-1-2-E3. Table 3 below summarizes the requirements.

Table 3: Performance Specifications for Fiber Unit

Test	Test Method(s)	Test Parameters	Requirements (Testing at 1550nm)
Tensile Performance	EN 187000 A1/501 IEC 794-1-E1	22N load, 10 minutes	Fiber strain = 0.4% during test
Flex	IEC 60794-1-2-E11A	Bend diameter ≤ 40x cable diameter, 4 turns, 10 cycles	Attenuation change ≤ 0.05 dB after test
Crush	IEC 60794-1-2-E3	100 mm plate, 100N load, 1 minute, 2 tests at different places	Attenuation change ≤ 0.1 dB during test Attenuation change ≤ 0.05 dB after test
		100 mm plate, 500N, 1 minute, 2 tests at different places	No broken fibers
Temperature Cycle	IEC 60794-1-2-F1 (3 cycles)	Normal temp = 20ºC Low temp. = -40ºC High temp. = 60ºC	Absolute attenuation < 0.5 dB/km during test Attenuation change ≤ 0.1 dB after test

Tests of blowing performance for this unit have been conducted using field test routes similar to Route IV described above. The results for these trials are shown in Figure 3.

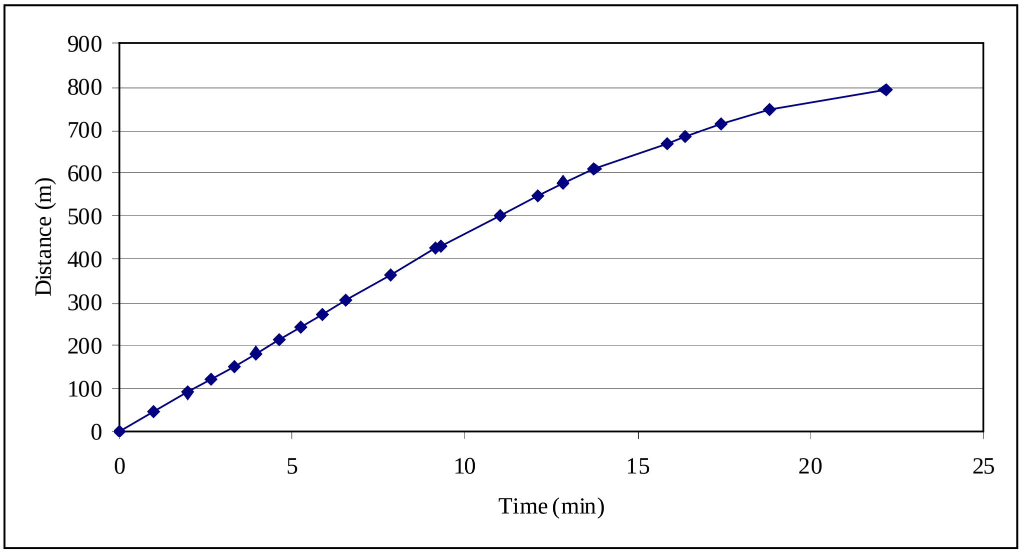

Figure 3: Blowing Distance vs Time for 12-fiber Polyolefin unit

It is seen from the graph that uninterrupted blowing distances to 800 meters have been achieved in less than 25 minutes. Additional testing on a serpentine track similar to Rt I has shown this unit capable of being blown for distances greater than 1 kilometer without intermediate blowing points. In actual field applications, installation lengths of multiple kilometers have been achieved with successive intermediate blowing points.

3.3 Future Development

Ongoing development work for XpressTube® FX™ fiber units will be in the areas of optimization of the units at specific fiber counts and the incorporation of multimode fiber into the product line. In fiber count optimization, a smaller diameter is being qualified for counts less than 6 fibers, and work is being done on a 24-fiber unit. Finally, platform work is being conducted to develop totally dry (no filling gel) units.

4. Acrylate Fiber Units – AccuBreeze™ FX Cable Units™

The use of UV curable acrylate materials in the manufacture of fiber and fiber optic ribbons is well-established technology in the fiber industry. Use of UV curable matrix materials has been common in the manufacture of fiber optic ribbons where an array of fibers is coated with a single thin layer or multiple layers of matrix materials. Such constructions permit easy access to individual fibers either in end access or in mid-span access. Use of UV curable acrylate materials permits very high processing speeds for ease in consistently achieving small cross-sections with tight tolerances. A further advantage is that the construction is totally dry (without any filling compound) which is preferred by the crafts in the field. These attributes make it extremely attractive to extend UV acrylate technology to blown fiber units [2]. In some ways, such a unit can be referred to as a circular ribbon structure.

4.1 Unit Design Features

Figure 4 shows typical constructions of such a unit with fiber counts ranging from 2 through 12. Both the loose fiber options and the ribbon options are shown.

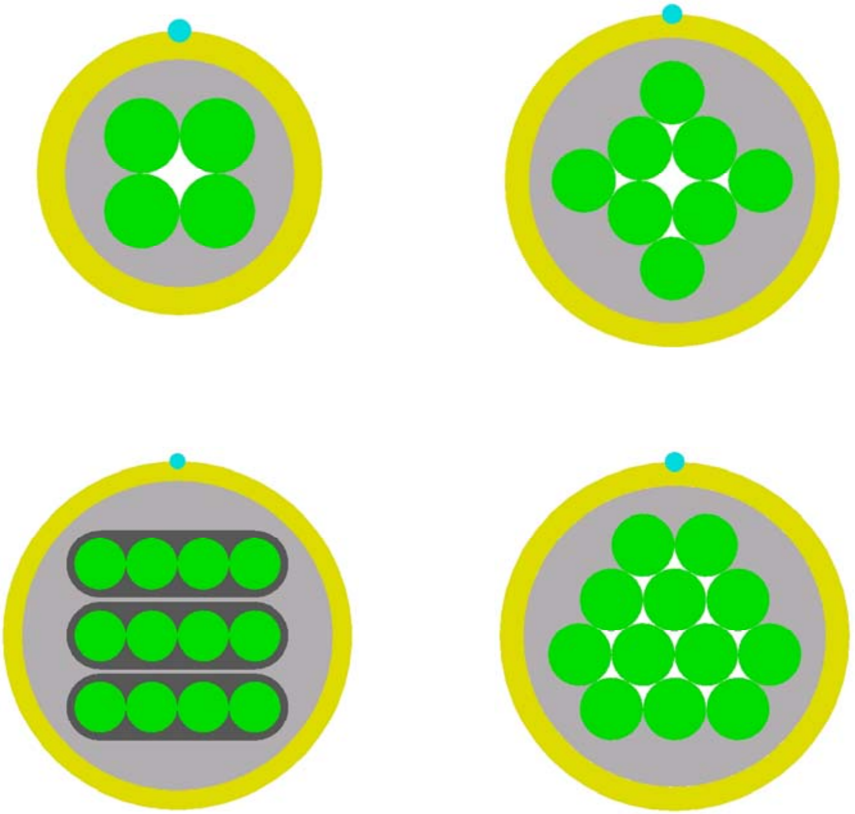

Figure 4: Acrylate Fiber Units from 4-fiber to 12-fiber Counts

The units consist of a soft inner layer encasing the fibers or ribbons, followed by a tougher outer skin. The outer surface may be modified to achieve desired installation attributes. The undercoat is typically a low modulus matrix material buffering the fibers against microbend losses under environmental conditions; the overcoat is a high modulus matrix material to withstand the rigors of the installation and to provide robustness to the overall unit. The surface of such a unit may be modified to achieve the desired installation properties. Use of partially embedded micro-spheres is one such technique documented in the literature [3]. These micro-spheres are typically 60-150 microns in diameter and can be either hollow or solid glass beads. These glass beads alter the surface properties to enhance viscous air drag of the unit and reduce the friction between the duct and the unit during installation. The fibers in these units are typically accessed by using fiber pairs as ripcords to strip off the matrix materials.

In 2-fiber units where only one fiber pair is present, a separate ripcord such as a yarn or monofilament is required to avoid breaking the fibers during access. Fiber unit performance greatly depends on the various design and processing parameters such as:

- Thickness of the various layers
- Mechanical properties of the inner/outer matrix layers
- Glass bead diameter and its distribution
- Uniformity of application and the depth of penetration of the glass beads
- Unit weight/stiffness/axisymmetry
- Processing conditions
- Surface roughness characteristics

These parameters must be carefully optimized to achieve a unit with good handling and installation properties. The design of such a unit should typically support installation lengths of 1 to 1.5km in a single blowing trial under various field conditions with commercial blowing apparatus.

4.2 Unit Performance Data

Below we present a key set of performance data for a 4-fiber unit as described above. This unit has been developed at OFS and is commercially available. The blowing performance for this unit is shown in Figure 5. The blowing tests were performed using the Route IV track described in Section 2. It can be seen from the graph that blowing distances can be realized to 1200 meters in under 45 minutes (the blowing time limited by the installation equipment maximum speed of 35 meters per minute). This represents excellent performance for this type of fiber unit.

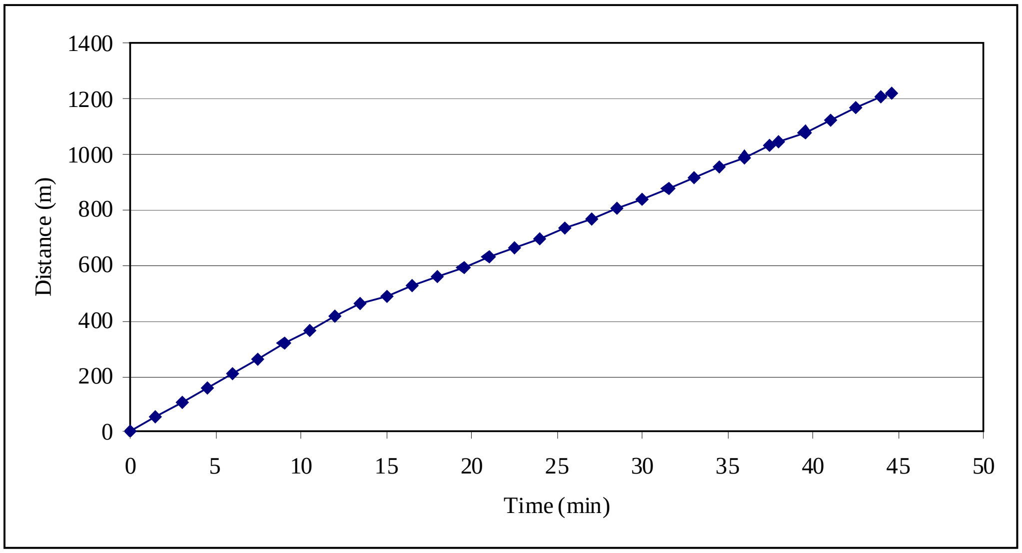

Figure 5: Blowing Distance vs Time for 4-fiber Acrylate Unit

This unit has been designed for compliance with CW1574. Additionally, the unit displays good robustness to attenuation during more extreme temperature cycling. In Table 4 below added loss values after a 24-hour soak at -40°C show that the unit is capable of meeting the GR-20 requirement for added loss of ≤ 0.05 dB/km.

Table 4: Added Loss in dB/km for 4-fiber Unit at - 40°C

	1310 nm	**1550 nm**	**1625 nm**
Avg	-0.006	0.001	0.017
Max	-0.004	0.009	0.041

4.3 Future Development

A promising application for deployment of these types of fiber units is being developed at OFS. Natural gas utilities are considering using their installed lines to provide broadband service to existing customers. In the “last mile” these utilities require a very small unit optimized for fiber counts blow sis. Further, the essentially “solid” and dry construction of AccuBreeze™ FX cable units™ is beneficial.

In these unique right-of-way applications, additional requirements become important, including performance when exposed to contaminants in the gas and material performance in the pressurized gas environment. In such applications, use of glass beads is not recommended to prevent any glass beads from coming loose and clogging up the valves and seals. OFS is actively working with a vendor of this installation technology.

5. Summary

In this work we have reviewed a new approach for fiber deployment in FTTx applications, where fiber units are blown into pre-installed duct systems. This approach has the advantage that fiber can be installed “on demand”, greatly reducing the up front costs for network installation, thus allowing service providers to realize much faster ROI for fiber deployment.

It was shown that the design of the fiber units themselves must be carefully optimized to give adequate blowing distance and speed, while minimizing environmental effects on fiber attenuation. Key elements of fiber unit design were identified. These include unit size and stiffness, and the choice of materials to minimize optical attenuation and surface friction. Significant treatment was given to the understanding of how the physical conformation of installation routes affects blowing performance, and a quantitative method for comparing different routes was presented.

Two design alternatives; XpressTube® FX cable™ and AccuBreeze™ FX cable units™ developed by OFS were presented. The first was based on a gel-filled polyolefin tube and the second on a totally dry UV curable acrylate system. Both units were shown to meet standard optical performance criteria. Test results were presented to show that both fiber unit families display excellent blowing performance, with blowing lengths greater than 1 kilometer and total installation times limited only by the maximum speed of the installation equipment used.

6. Acknowledgements

Phil Barker of BT exact Technologies
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Sherman & Reilly

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