288 Fiber Ultra-High Fiber Density Micro-Duct Cable with Extreme Operating Performance

Justin Quinn
AFL
Duncan, SC
+1-864-486-7073 · justin.quinn@aflglobal.com

Olaf Storaasli
Dura-Line
Knoxville, TN
+1-630-402-0015 · olaf.storaasli@duraline.com

Abstract

A common means for deploying fiber optic cable is by jetting (sometimes referred to as blowing) the cable into installed ducts. To support these deployments, cable designs must be optimized for installation. For example, a general rule of thumb is the cable outer diameter (OD) should be less than 80% of the duct inner diameter (ID). Therefore, in order to maximize the number of fibers that can be installed in a given duct, the fiber density—the ratio of optical fibers to the cable cross-sectional area—must be maximized. However, the cable design must be sufficient to protect the fibers during installation and operation.

This paper will introduce an innovative, ultra-high density micro-duct cable having a 10.4mm OD and containing 288 fibers. The cable is designed to withstand an installation tensile load exceeding 300 lbs and for operational temperatures between -40°C and 70°C. Test results of various fiber types will be presented. Additionally the paper will discuss results of a field trial where the cable was installed in a micro-duct with a 13mm ID.

Keywords: Micro-duct; Micro-duct Cable; Fiber Density; SPIDERWEB™ Ribbon; MiniJet; Cable Installation Performance; Mid-span Access

1. Introduction

Fiber optic cables are designed to protect optical fibers from external forces during installation and throughout the life of the cable. Historically, Outside Plant (OSP) Cable—cable intended for use in an outdoor environment—has been designed to meet the stringent mechanical and environmental requirements of Telcordia Technology's GR-20-CORE, *Generic Requirements for Optical Fiber and Optical Fiber Cable*, and the Insulated Cable Engineer Association's ANSI/ICEA S-87-640, *Standard for Optical Fiber Outside Plant Communications Cables*.

OSP cables are most commonly installed aerially or buried underground. Cables intended for aerial installation are typically constructed of all-dielectric components while cables intended for underground installation routinely contain a metallic armor under the outer sheath to offer additional protection to the fibers. Regardless, both types of construction are subjected to the same mechanical and environmental requirements during product qualification. While some special handling is required during installation, these constructions are quite robust and limit the forces that are applied directly to the optical fibers.

As fiber networks continue to grow and expand, particularly in urban locations and rough terrain, OSP cables are often installed in conduit or ducts. In particular, micro-ducts—factory bundled ducts with multiple pathways as shown in Figure 1—are advantageous because they facilitate future expansion since only the cable currently needed is installed. Additionally, the micro-ducts provide additional protection to the fibers, further insulating them from external forces.

Figure 1. 7-Way Micro-Duct

GR-20-CORE recognizes the micro-duct cable type and indicates that the small size of the micro-duct cables results in generally lower tensile strength, crush resistance, and the like [1]. However, the robust construction described in this paper is designed to prevent damage that could occur during installation and operation, while still providing ultra-high fiber density.

2. Traditional OSP Cables

While OSP cable constructions may vary, two common types include loose tube (LT) and central tube cables. In both constructions, fibers are enclosed within a buffer tube. Both constructions use rigid and/or non-rigid strength members to provide tensile strength, and an outer sheath provides additional protection to the buffered fiber.

2.1 OSP Loose Tube Cables

Loose tube cables typically contain 12 or 24 fibers per buffer tube, and multiple tubes are stranded together, over a rigid strength member, with a reverse oscillating lay (ROL). In addition to mechanical protection, the buffer tubes serve to separate groups of fibers for easy identification in splice boxes. The ROL allows for simple mid-span access to the fibers and creates a fiber strain free window so that strain on the fibers is much less than the cable elongation at the rated installation load.

2.2 OSP Central Tube Cables

Central tube cables contain a single buffer tube and often include more than 24 fibers per tube. Fiber groups are commonly identified with colored threads or ring marks. Alternatively, ribbonized fibers may be used in central tube constructions. Strength members are applied over the tube and/or embedded in the cable sheath. Mid-span access to the fibers can be achieved, but is more difficult than with loose tube cables. Further, since the cable has little or no fiber strain free window, additional strength members are needed or the cable tensile rating may be reduced.

3. OSP Micro-Duct Cables

3.1 Traditional Micro-Duct Cables

The use of cable ducts and eventually micro-ducts began expanding in the 1980s. The common approach was to reduce the size of components by reducing free space and wall thickness, and eliminating the metallic armor. As shown in Figure 2 below, these changes resulted in a diameter reduction of 56% for 72 fiber constructions, and an increase in fiber density from 0.5f/mm^2 to 2.4f/mm^2.

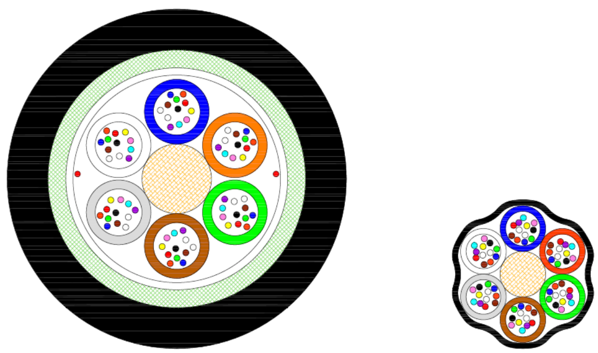

Figure 2. OSP Cables with 72 Fibers

Conversely, the tensile rating for the cable was reduced from 2,670N to 667N, the compression resistance was reduced from 440N/cm to 100N/cm and the minimum operating temperature was limited to -30°C.

3.2 Micro-duct Fiber Units

Thin-walled, reduced-diameter buffer tubes allow a significant reduction in cable diameter, but they can be prone to kinking when expressed and coiled in enclosures. To overcome this issue, alternate cable constructions were developed with micro-modules—thin-walled sub-units made of lower modulus, thermoplastic elastomers that are less likely to kink when coiled. The small diameter and thin walled micro-modules allow for increased fiber density over traditional micro-duct cables. However micro-modules and micro-duct fiber units offer minimal protection to the optical fibers. Moreover, the tensile rating and compression resistance of these cables may be reduced even more, and operating temperature may be further limited [2].

4. Robust Micro-Duct Cables with Extreme Performance

In many applications, the most likely opportunity for cable damage occurs during installation. Cables are pulled off of the reel, flexed around bends, twisted, and even occasionally stepped on. Since these same opportunities for damage exist during the installation of micro-duct cables, robust micro-duct cables have been designed to withstand these forces [3]. Similar to traditional micro-duct cables, robust micro-duct cables contain reduced-diameter buffer tubes; however, the tubes are designed and produced to be more kink resistant.

4.1 Ultra-High Fiber Density Construction

In some instances, duct space is limited, but high fiber counts are needed. To create the ultra-high fiber density construction, a cable has been designed by combining the ROL strand of a loose tube cable with the high fiber density of a central tube construction, thus reducing the size of the cable components.

The ultra-high density construction utilizes a buffer tube containing 48, 250µm fibers. As shown in Figure 3, the fiber density of this tube is 6.4f/mm^2 where the fiber density of four micro-modules, each containing 12 fibers, is 4.0f/mm^2. Additionally, Figure 4 shows the compression resistance of different buffer tubes, relative to traditional OSP LT buffer tubes.

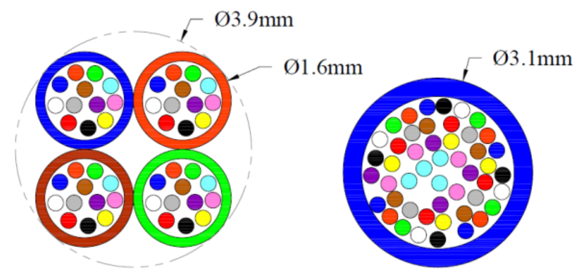

Figure 3. Micro-Modules vs. Ultra-High Fiber Density Buffer Tube

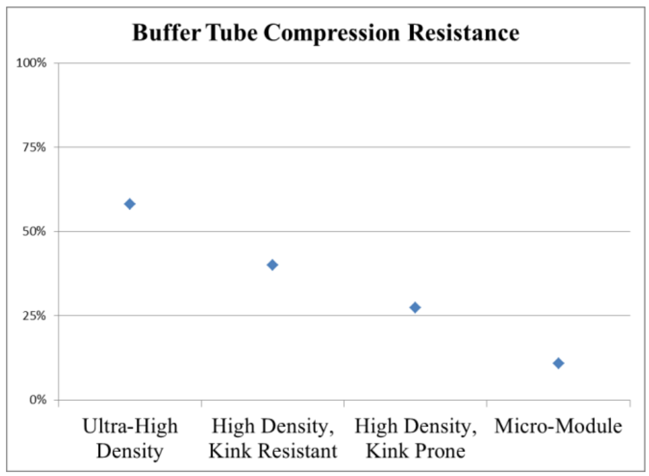

Figure 4. Buffer Tube Compression Resistance

Fiber identification is achieved by color coding as described in ANSI/TIA-598-D, where groups of 12 fibers are contained within color-coded threads. Alternatively, fibers may be ring marked. Additional development work is underway with SPIDERWEB™ Ribbon (SWR™). Unlike traditional ribbon, SWR contains intermittently bonded fibers that can be rolled or formed into a compact bundle to allow for tight packing [4] and [5].

To construct the 288 fiber construction, six of the ultra-high fiber density buffer tubes are stranded over a central strength member (CSM) with a ROL. This, along with the robustness of the tubes, allows for the extended tensile rating, along with the ability to access buffer tubes and fibers in midspan applications. An outer jacket is then applied over the core, providing a final cable OD of 10.4mm.

4.2 Ultra-High Fiber Density Cable Testing

Cable qualification testing was performed on 48 live fibers per GR-20-CORE and IEC 60794-5-10. Table 1 below describes the four different fiber types that were evaluated.

Table 1. Fiber Types Included in Qualification Test Cable

Fiber	Type
“A”	ITU-T G.652.D
“B”	ITU-T G.652.D
“C”	ITU-T G.652.D*
“D”	ITU-T G.657.A1

* Bend performance exceeds ITU-T G.657.A1 requirements

4.2.1 Mechanical Testing. Figure 5 shows the tensile performance of the test cable. The measured fiber strain is below the measured cable strain, confirming the fiber strain free window. All of the fibers exhibited ≤0.2dB power loss at the 600 lbs load and no measureable power loss was recorded in any fiber when the load was reduced to 180 lbs.

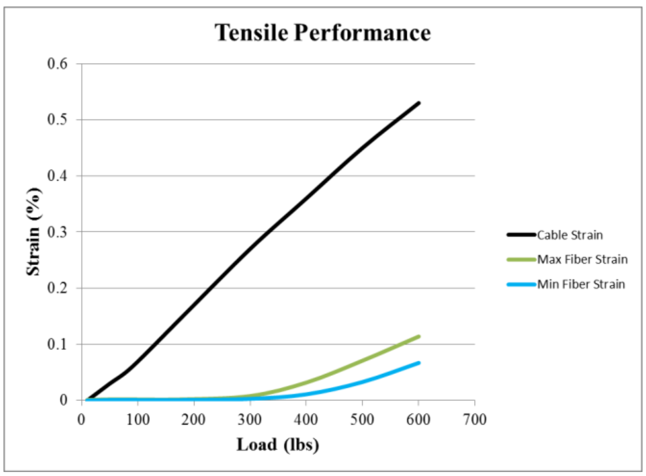

Figure 5. Cable Tensile Performance

Table 2 shows the results of crush testing using a 990N load, the same load used to evaluate OSP LT cables. Note that IEC 60794-5-10 requires a 500N load. Results include the maximum and average power loss by fiber type while the cable is under the crush load, and after the crush load has been released.

Table 2. Cable Crush Test Results

Fiber	Under Load		Load Released	
	Maximum	Average	Maximum	Average
A	0.04dB	0.02dB	0.04dB	0.01dB
B	0.05dB	0.02dB	0.01dB	0.00dB
C	0.02dB	0.00dB	0.01dB	0.00dB
D	0.02dB	0.01dB	0.00dB	0.00dB

Similarly, cable impact testing was performed using 4.4J and two impacts at three locations, the same energy and impacts used to evaluate OSP LT cables. Note that IEC 60794-5-10 requires 1J and one impact at three locations. The residual power loss was ≤0.1dB for all four fiber types.

As shown in Figure 6, the buffer tube kink diameter for the ultra-high fiber density tube is slightly higher than the traditional OSP LT buffer tube, but much less than 100mm.

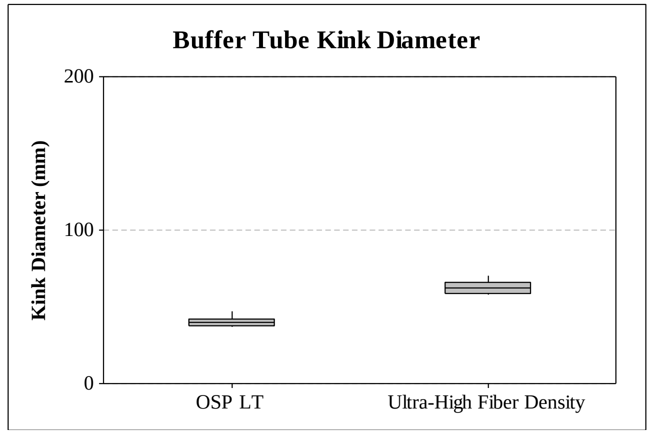

Figure 6. Buffer Tube Kink Diameter Comparison

4.2.2 Environmental Testing. Results of the cable temperature cycling are presented in Figure 7 and results of the cable temperature cycling after heat aging at 85°C for 168 hours are presented in Figure 8.

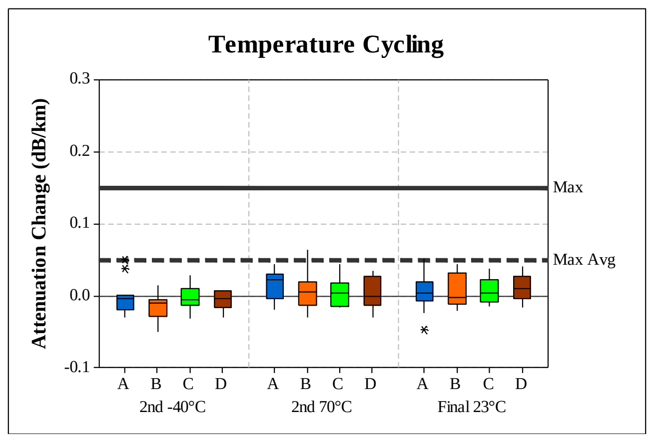

Figure 7. Cable Temperature Cycling

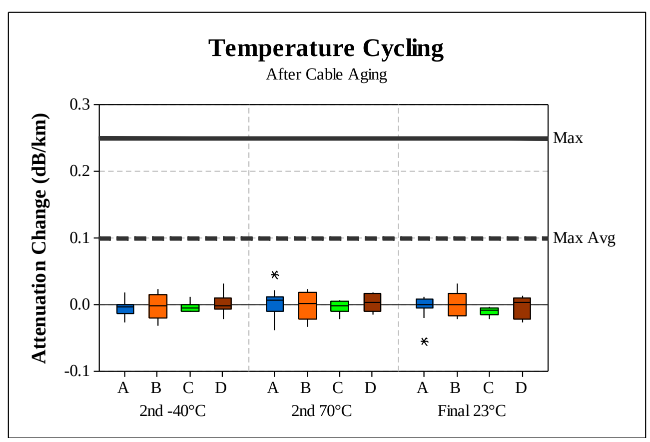

Figure 8. Cable Temperature Cycling after Cable Aging

To evaluate mid-span buffer tube performance, 4.9m of buffer tubes were expressed from the ultra-high fiber density cable and stored in a LightGuard® 350XL Splice Closure. As shown in Figure 9, this commercially available closure is designed for large count fiber splicing [6].

Figure 9. LightGuard 350XL Fiber Optic Splice Closure

The cable and stored buffer tubes were conditioned per FOTP-244 and the results from the second cold cycle are shown in Figure 10. Notice that fiber types A and B only meet the optical requirements at -20°C, but the bend-insensitive fiber types, fibers C and D, meet the optical requirements of GR-20-CORE at -40°C. As commonly seen with ITU-T G652.D fibers, the power loss in type A and B fibers is directly related to the MAC value.

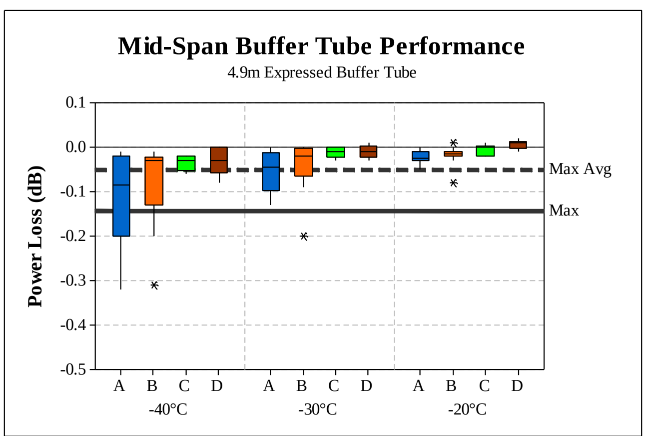

Figure 10. Mid-Span Buffer Tube Performance

After the mid-span buffer tube performance test, the buffer tubes were inspected for damage. No signs of breaks, cracks, blisters, kinking or excessive discoloration were observed.

4.2.3 Installation Performance Testing. The installation performance test was conducted in a 7-Way FuturePath™ duct. This duct consists of seven 16mm (OD) x 13mm (ID) micro-ducts. Note that the ratio of the ultra-high fiber density cable OD (10.4mm) to the micro-duct ID (13mm) is 80%. As shown in Figure 11, the 284m length of duct was installed and the elevation change between the ends of the duct was 7.2m. Four micro-ducts were connected in series so that the total path length was 1136m, and the loops where the micro-ducts were connected were 1.5m in diameter.

Figure 11. Installation Test Track

Prior to performing the installation performance test, the micro-duct route verification test was completed. As described in IEC 60794-1-21, Method E23, a plastic sphere with the same OD as the test cable was successfully blown through the path, confirming the path was free from obstructions. Subsequently, a sponge coated with lubricant was blown through the path.

The jetting apparatus selected for the installation performance test was a Plumett Minijet®. Figure 12 shows the pneumatic jetting device that is intended for cables with OD ≤16mm with a recommended maximum install speed of 100m/min [7].

Figure 12. Plumett Minijet®

The Minijet® was connected to the 13mm ID micro-duct and the installation test was started. During the test, the outside temperature was 28°C with 65% relative humidity. The cable was jetted through the 1136m path in 21 minutes with a maximum air pressure of 1.0MPa, meeting installation performance expectations.

4.3 Fiber Access with Ultra-High Density Buffer Tube

Similar to traditional OSP and Micro-duct cable, fiber access is achieved by first removing the outer sheath and string binders, and unwrapping the buffer tubes as shown in Figure 13. Note that the appropriate access length is documented in the instructions for the selected pedestal or closure.

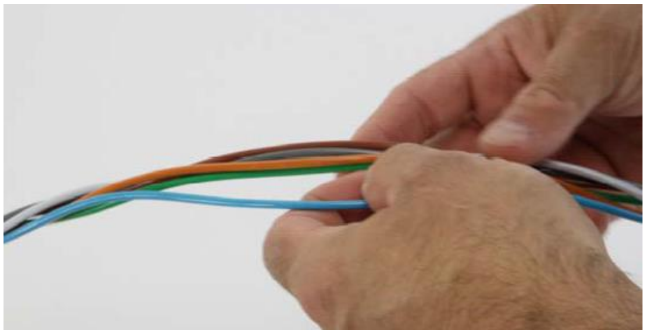

Figure 13. Core Access

4.3.1 Mid-span Access. Using a MS-6 Mid-Span Slitter made by Jonard Tools, score the tube and separate into two halves as shown in Figure 14. Ring cut the tube near the split and remove the buffer tube.

Figure 14. Buffer Tube Access

Separate the four bundled groups of 12 fibers; each group is contained within two counter helical color-coded threads as shown in Figure 15.

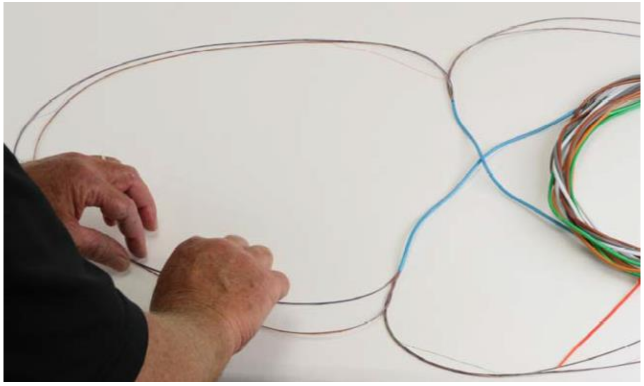

Figure 15. Fiber Bundle Access

Next, anchor the buffer tube in the splicing tray, clean and coil the non-accessed binder groups, and remove the string binders from the group to be accessed as shown in Figure 16. Finally, clean and prepare the fibers for splicing.

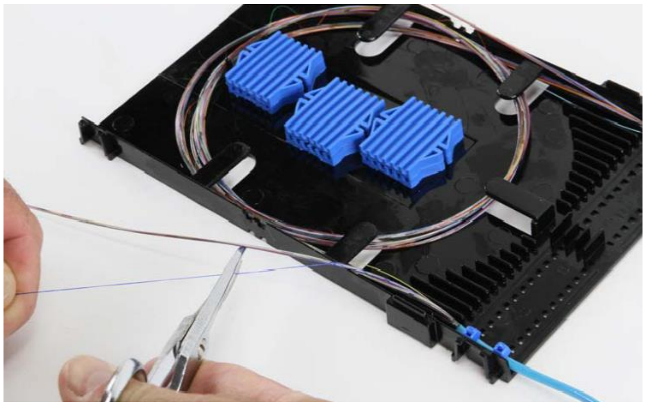

Figure 16. Fiber Bundle Storage and Fiber Access

4.3.2 End Access. Using a ring cutting tool, score, and then remove the buffer tube, exposing the fiber bundles. Separate the four bundled groups of 12 fibers; each group is contained within two counter helical color-coded threads. Load the buffer tubes into splitters and route the bundles of fiber into furcation tubes as shown in Figure 17. Finally, clean and prepare the fibers for splicing.

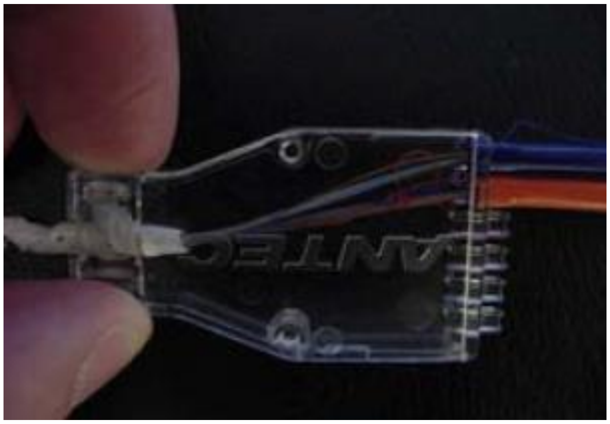

Figure 17. Fiber Routing and End Access

4.4 Additional Fiber Density Increase with 200µm Fibers

By applying the same design criteria used for the ultra-high fiber density cable, with 200µm fibers, the buffer tube OD is reduced to 2.5mm and the OD for a 288 fiber cable is reduced to 8.7mm.

5. Conclusions

The ultra-high fiber density cable that was presented is capable of withstanding tensile loads in excess of 300 pounds and operating at temperatures from -40°C to 70°C. Utilizing a robust, ultra-high fiber density buffer tube, the construction minimizes the risk of fiber damage during installation and throughout the life of the cable. With bend-insensitive fiber, the cable is suitable for mid-span buffer tube access. Furthermore, the installation performance testing indicates excellent jetting properties. Considering all of the data presented, the 288 fiber ultra-high density cable demonstrates extreme operating performance, and meets or exceeds industry standards for micro-duct cables.

6. Acknowledgments

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7. References

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8. Pictures of Authors

Justin Quinn is a Product Development Engineer for Cable Systems at AFL. He earned a Bachelor of Science in Mechanical Engineering from Clemson University in 2000, and began his career in fiber optics that year. In his current role, Justin is responsible for development of micro-duct, OSP loose tube, ADSS and premise cables. Prior to joining AFL in 2012, Justin held various process and development engineering roles with Alcatel and Draka Communications. Justin has been granted eight U.S. patents and has authored multiple IWCS papers.

Olaf Storaasli is the Eastern Enterprise Sales Manager at Dura-Line. He holds a Bachelor of Science in Mechanical Engineering from Virginia Tech, a Master of Science in Aerospace Engineering from Old Dominion University and a MBA in Global Business from Lenoir-Rhyne University. Olaf has 15+ years of experience in fiber optics from various roles in R&D, Application Engineering, Product Management, Marketing and Sales. Olaf has been granted 10 U.S. patents and has authored numerous IWCS and industry papers, including many on micro cables.