Reduced Diameter Fiber Optic Cable Family
Optimized for Bend Insensitive Fiber

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Abstract
Loose tube fiber optic cables continue to be the leader in providing mechanical, thermal, and environmental robustness needed to ensure optical performance in rugged aerial and underground applications. There continues to be a customer need, however, to reduce the size and weight of these cables to get higher fiber density in conduit systems, get higher fiber density in closures, install cables further, and reduce support strength needed for aerial application.

This paper discusses the next generation reduced diameter loose tube cables for use in all standard outside plant applications including FTTH, Distribution, Metro, and Long Haul. These reduced diameter loose tube cables provide additional value to the customer that will be discussed further in this paper. These cables meet the same specifications as the larger diameter industry standard cables, and they contain G.652.D compliant fibers with bend insensitivity. These state-of-the-art bend insensitive fibers offer a wide array of benefits and value to the customer such as a 15 mm bend diameter, less handling sensitivity, and less sensitivity to storage in closures. Paired together, the robust reduced diameter, flexible tube cable designs and the state-of-the-art bend insensitive fibers bring unparalleled performance and value to the customer.

Keywords: Cable; loose tube; size; performance; mid-span access; bend insensitive fiber; reduced diameter.

1. Introduction
Fiber demands are continually increasing, with needs for more and more bandwidth in pre-existing and new constructions. The smaller and lighter the fiber optic cable is for these applications, the more fibers are available in the allotted spaces. This advantage benefits the customer in many ways such as reduced space needed when adding fibers to existing lines, smaller messenger strength needed when lashing the lighter cable, smaller duct space needed for new underground applications, smaller closures needed for new constructions, or more fiber storage in pre-existing closures. The smaller and more flexible the buffer tubes, the greater the advantage to the customer. Smaller buffer tubes have smaller bend radii, greater capacity for storage in manholes, hand-holes and closures, and increased flexibility. The state-of-the-art bend insensitive G.652.D compliant fibers also offer less bend sensitivity in handling and in storage, and a smaller bend diameter. The cable family is offered in a number of sheath options and fiber counts to meet the needs of all standard applications, with many added cost and performance benefits that are currently unmatched in the market.

2. Next Generation Loose Tube Cables
2.1 Loose Tube Cable Design Optimization
The next generation reduced diameter loose tube cable family is offered in fiber counts from 2 to 456 fibers, which is the widest range of loose tube fiber counts offered in the industry today. This cable design contains 2.0 mm outer diameter gel and gel-free buffer tubes using the same material as the current industry standard 2.5 mm buffer tubes. The 2.0 mm tube cable designs range from a 6 position single layer tube core design up to a 38 position triple tube core layer design, with sheath constructions including single jacket dielectric, double jacket dielectric, single jacket single armor, and double jacket single armor. These cables meet the Telcordia GR-20, ICEA-640, RUS/RDUP PE-90, and IEC 60794-3-11 industry specifications, including 20-foot mid-span buffer tube performance. The tube can be accessed in mid-span applications using the current Draka buffer tube access tool.

The 2.0 mm loose tube cable designs have as much as an 18% reduction in cable diameter from the industry standard cable designs, and as much as a 33% reduction in cable weight and volume, as shown in Tables 1, 2, and 3.

Table 1. Comparison of 2.5 mm versus 2.0 mm Tube Designs – Cable Diameter

<table>
<thead>
<tr>
<th>Sheath</th>
<th>Fiber Count</th>
<th>2.5 mm Design</th>
<th>2.0 mm Design</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Jacket</td>
<td>72</td>
<td>10.3</td>
<td>9.5</td>
<td>7.8%</td>
</tr>
<tr>
<td></td>
<td>144</td>
<td>15.4</td>
<td>13.0</td>
<td>15.6%</td>
</tr>
<tr>
<td></td>
<td>288</td>
<td>18.0</td>
<td>14.7</td>
<td>18.3%</td>
</tr>
<tr>
<td></td>
<td>432</td>
<td>20.4</td>
<td>17.8</td>
<td>12.7%</td>
</tr>
<tr>
<td>Single Jacket</td>
<td>72</td>
<td>12.3</td>
<td>11.2</td>
<td>8.9%</td>
</tr>
<tr>
<td>Single Armor</td>
<td>144</td>
<td>17.6</td>
<td>14.8</td>
<td>15.9%</td>
</tr>
<tr>
<td></td>
<td>288</td>
<td>20.1</td>
<td>16.8</td>
<td>16.4%</td>
</tr>
<tr>
<td></td>
<td>432</td>
<td>22.7</td>
<td>19.4</td>
<td>14.5%</td>
</tr>
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</table>

Table 2. Comparison of 2.5 mm versus 2.0 mm Tube Designs – Cable Weight

<table>
<thead>
<tr>
<th>Sheath</th>
<th>Fiber Count</th>
<th>2.5 mm Design</th>
<th>2.0 mm Design</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Jacket</td>
<td>72</td>
<td>81</td>
<td>67</td>
<td>17.3%</td>
</tr>
<tr>
<td></td>
<td>144</td>
<td>174</td>
<td>130</td>
<td>25.3%</td>
</tr>
<tr>
<td></td>
<td>288</td>
<td>240</td>
<td>160</td>
<td>33.3%</td>
</tr>
<tr>
<td></td>
<td>432</td>
<td>306</td>
<td>232</td>
<td>24.2%</td>
</tr>
<tr>
<td>Single Jacket</td>
<td>72</td>
<td>151</td>
<td>133</td>
<td>11.9%</td>
</tr>
<tr>
<td></td>
<td>144</td>
<td>280</td>
<td>227</td>
<td>18.9%</td>
</tr>
<tr>
<td></td>
<td>288</td>
<td>343</td>
<td>269</td>
<td>21.6%</td>
</tr>
<tr>
<td></td>
<td>432</td>
<td>421</td>
<td>337</td>
<td>20.0%</td>
</tr>
</tbody>
</table>
Table 3. Comparison of 2.5 mm versus 2.0 mm Tube Designs – Cable Volume

<table>
<thead>
<tr>
<th>Sheath</th>
<th>Fiber Count</th>
<th>2.5 mm Design</th>
<th>2.0 mm Design</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Jacket</td>
<td>72</td>
<td>83</td>
<td>71</td>
<td>14.9%</td>
</tr>
<tr>
<td></td>
<td>144</td>
<td>186</td>
<td>133</td>
<td>28.7%</td>
</tr>
<tr>
<td></td>
<td>288</td>
<td>254</td>
<td>170</td>
<td>33.3%</td>
</tr>
<tr>
<td></td>
<td>432</td>
<td>327</td>
<td>249</td>
<td>23.9%</td>
</tr>
<tr>
<td>Single Jacket</td>
<td>72</td>
<td>119</td>
<td>99</td>
<td>17.1%</td>
</tr>
<tr>
<td></td>
<td>144</td>
<td>243</td>
<td>172</td>
<td>29.3%</td>
</tr>
<tr>
<td></td>
<td>288</td>
<td>317</td>
<td>222</td>
<td>30.1%</td>
</tr>
<tr>
<td>Single Armor</td>
<td>432</td>
<td>405</td>
<td>296</td>
<td>27.0%</td>
</tr>
</tbody>
</table>

Figures 1 and 2 give a visual comparison of the cable diameter differences between the 2.0 mm tube designs and the 2.5 mm tube designs. Figure 1 shows a direct comparison between the 2.0 mm 288 fiber single jacket cable design and the 2.5 mm 288 fiber single jacket cable design. Note that both of these cables meet the standard outside plant fiber optic cable specifications, yet the 2.0 mm tube design has both improved size and flexibility.

2.2 Fiber Design Optimization

One of the key aspects to ensure the performance of fibers in smaller diameter 2.0 mm loose tube cables is to improve the micro- and macro-bending sensitivity of the fiber to enable proper propagation of the fundamental mode. As such, the fiber is less sensitive to handling and to storage in closures, and allows smaller bend diameters. In addition, micro- and macro-bending losses, which increase with wavelength, need to be controlled to also ensure operation at the highest wavelengths (1625nm). For a given bend radius, bend losses are proportional to the power fraction of the mode that propagates after the radiation caustic. For example, please see Figure 3 showing the radius for which the effective index of the mode intersects the index of the cladding of a tilted profile representing the bent fiber. A traditional way to lower the bending sensitivity is to decrease this power fraction without changing the shape of the power profile. For step-index profiles, this means higher index difference and a smaller diameter or smaller index difference and a larger diameter than those of standard single-mode fibers. This results in a smaller Mode-Field Diameter (MFD) or longer cable cutoff wavelengths, and eventually in bend losses that are not significantly reduced, which is not suitable.

The other and much more efficient way to reduce these losses is to change the shape of the power profile. This can be achieved by adding a negative refractive index trench in the cladding close to the step-index core, as shown in Figure 3. This trench area confines the tail of the fundamental mode without modifying its intrinsic nature. As a result, macro-bend losses can be drastically reduced (factor of ~100 compared to standard single-mode structure) without impacting the MFD or the cutoff wavelength. In this context, the solid single trench concept appears as the most robust option, partly because of its simplicity but also because of its compatibility with industrial manufacturing processes. It also fully preserves all key characteristics of ITU-T G.652.D.
The cabled behavior of such fibers is also of major importance, in particular fiber robustness to cable deformations, that is to say to micro-bends. Several micro-bend-loss measurements were conducted using the fixed-diameter-drum method B of the IEC TR-62221. The all-solid profile-optimized single-mode fiber exhibits much lower micro-bending sensitivities than that of the regular single-mode fiber – with the same 125µm glass diameter, and the same coatings (see Figure 4(a) for regular coating and Figure 4(b) for improved primary coating) and quasi-flat spectra when that of the regular G.652.D is rather steep.

This exceptional feature, attributed to a lower dependence on wavelength of coupling losses and a reduction of the radiation losses, efficiently limits cable loss effects. This opens the door to securing all transmission bands, including the L and U-bands which present the highest exposure to micro-bending effects, inside the final reduced diameter cable.

2.3 Test Results and Performance

The new reduced diameter loose tube cables are designed to meet Telcordia GR-20, ICEA-640, RUS/RDUP PE-90, and IEC 60794-3-11 with equal or better performance than larger industry standard cable designs. The bend insensitive fibers used in these cables are G.652.D compliant.

Figure 5 shows a typical 2 to 72 fiber reduced diameter cable that has been temperature cycled before and after aging, at 1550 nm. As shown in these test results, the 2.0 mm tube design cable performs well within the specification limits for temperature cycling at temperatures as low as -50°C, showing the attenuation variation to be within the noise level of the testing equipment.

Figure 6 displays a typical 456 fiber reduced diameter cable that has been temperature cycled before and after aging, at 1550 nm. Again the test results show the reduced diameter cable attenuation performance in temperature cycling to be within the noise level of the test equipment even in as low as -50°C degree temperatures. Figures 5 and 6 test results show that similar temperature cycling results are attained with the next generation reduced diameter cables for fiber counts ranging from a 2 fiber count cable design to a 456 fiber count cable design. This demonstrates the robust performance of both the smallest and the largest reduced diameter cables in extreme temperature environments. These results are optimal for any fiber optic cable design and are attained regularly with this next generation design family.
fiber strain at a tension load of 600 lbs after a 60 minute hold, and at the residual load of 180 lbs after a 10 minute hold. The measured fiber strains at these loading conditions are well within the maximum fiber strain allowed. Figure 8 shows the fiber attenuation measurements for these same loading conditions. At the 180 pound residual load, there is essentially zero fiber attenuation loss, while the specifications allow up to 0.15 dB individual fiber attenuation loss under these conditions.

These graphs demonstrate the rugged performance attained by even the smallest of the next generation cable designs, while still offering the 2.0 mm flexible buffer tube technology and reduced cable diameters.

Figure 7. Reduced Diameter Cable (72 fiber) Tensile Strain Test Results

Figure 8. Reduced Diameter Cable (72 fibers) Attenuation in Tensile Testing

Figure 9 demonstrates the 20-foot buffer tube mid-span test results for 12 fiber 2.0 mm flexible tubes in both single layer and dual layer cable constructions, at the extreme temperature of -40C. This graph contains a total of 10 test results and is representative of the 2.0 mm tube performance in all next generation cable designs. The mid-span performance demonstrated in this graph is well within the limits allowed by the test. One of the most exciting performance advantages with this next generation design is the consistent and superior mid-span buffer tube performance attained with the state-of-the-art bend insensitive fibers.

Figure 9. Mid-span Testing 20-foot Tube Length 2.0 mm Flexible Buffer Tube

The 2.0 mm buffer tubes were tested beyond the 20-foot mid-span requirement as well. It is not recommended to exceed the maximum specified expressed tube limit of 20 feet, but this testing was done to identify the limits of the next generation cables to find its true capabilities in extreme conditions. The length of the expressed buffer tubes was increased from the standard 20-foot length to the extreme of 40 feet. Figure 10 shows the mid-span test results for these 12 fiber 2.0 mm flexible buffer tubes with 40-foot lengths of expressed tubes at the extreme temperature of -40C. This graph contains 6 different 40-foot long expressed tubes, each containing 12 bend insensitive fibers. As shown in Figure 10, these fibers exhibit exceptional performance in mid-span testing in a 2.0 mm flexible buffer tube, and with twice the maximum specified length of exposed tube at the extreme temperature of -40C. The 40-foot lengths of exposed buffer tube at extreme temperatures have minimal attenuation losses in the next generation, reduced diameter cables.

Figure 10. Mid-span Testing 40-foot Expressed Tube at -40C Temperature Extreme 2.0 mm Flexible Buffer Tube

2.4 Features and Benefits

The next generation, reduced diameter loose tube cables offer savings to the customer in many ways. First, there is a savings in retrofitting cables into pre-existing applications. In duct
applications, the reduced diameter cable requires less duct space. Because the cables require up to 33% less volume in the duct for the same number of fibers, these next generation cables can fit in limited duct space that was not attainable with the same number of fibers in standard cable designs. These cables also require a lower pull force due to the up to 33% reduction in cable weight. These reduced diameter cables allow for more fibers in the same allotted space as a lower count standard design would have allowed, eliminating the need for adding duct capacity. In lashed applications, these new reduced diameter cables put less loading on the messenger and pole line structures, especially during weather load conditions. This is factored into the pole and messenger line design capability. The next generation cables take up less space in closures as well, so more tubes or longer lengths of tubes will fit in pre-existing closures. Figure 11 shows the 2.0 mm flexible tube in a mid-span test pedestal.

Figure 11. Example of Pedestal with Reduced Diameter Tubes

Second, the customer attains significant cost savings in new constructions by using smaller duct sizes (see Figure 12), smaller hand holes, smaller splice closers, more tubes in existing closures, smaller cabinets, smaller reels, decreased freight weight, longer cable length on reels, reduced support strength needed for aerial applications, and lower pull forces.

Figure 12. Next Generation Cable Designs in Reduced Diameter Ducts Including 13mm Micro Duct

Third, the customer gains cost savings in future applications by using this cable design. The reduced diameter cable design allows for more duct space availability for future installations, allowing for more fiber bandwidth to be installed in the same standard duct space. These cables also use less space in closures, allowing for more tubes to be stored later in the same closure.

The next generation, reduced diameter loose tube cables also reduce the carbon footprint of this product line by approximately 13%, compared to the industry standard 2.5 mm loose tube design, which is a benefit to the environment. The cable diameters are up to 18% smaller, allowing cables with up to 456 fibers to be placed into a 1” duct and up to 84 fibers to be placed into a 13 mm duct. This means that up to an 84 fiber standard rugged outside plant cable can fit into a 13 mm duct without any loss in cable performance and strength (see Figure 12).

These next generation cables have a reduced single turn fiber bend radius of 7.5 mm (one mandrel wrap). The 100 turn fiber bend radius specification can be reduced to 20 mm for this bend insensitive fiber. This along with the small tube size and flexible tube material allows the ability to route the fibers and the buffer tubes within the closure down to a bend radius of 20 mm. These reduced cable diameter designs have reduced cable bend radii from the industry standard designs, as well. These cables contain the highly desired flexible buffer tubes with the added benefit of being the smallest size with the most flexible design for a 12 fiber tube. Figure 13 demonstrates the kink resistance of the 2.0 mm flexible tube as compared to the 1.9 mm PBT tube when coiled beyond the minimum specifications.

Figure 13. 2.0 mm Flexible Buffer Tube Bend Diameter as compared to 1.9 mm PBT Tube

These 12 fiber flexible buffer tubes are made with low shrinkage technology and are available with gel filled or gel free water blocking. Figure 14 demonstrates the extremely low shrinkage attained with these next generation 2.0 mm flexible buffer tubes when tested to GR-20 specifications.

Figure 14. GR-20 (4hrs at 95C) Post Extrusion Shrinkage Test 2.0 mm Flexible Buffer Tube
2.5 Fiber Reliability in Small Bends

The probability of a mechanical failure in a population of fibers deployed can be projected, based on known fiber parameters, from the following form of the Power Law Model for Fiber Reliability (IEC 62048).

\[
t_f = \left[ \frac{\beta}{L} \ln \frac{1}{p} + \left( \sigma_p^{m_t} \right)^{1/m_t} \right]^{-1/m_a} \sigma_a^{-m}
\]

where

- \( t_f \) is the projected lifetime, seconds
- \( L \) is the standard fiber length, 1 meter
- \( t_p \) is the proof test effective dwell time
- \( \sigma_p \) is the proof test stress
- \( \sigma_a \) is the stress in service
- \( n \) is the dynamic fatigue stress corrosion factor
- \( m_t \) is the m-value under static fatigue
- \( \beta \) is the parameter related to the estimated population of low stress flaws

\( \beta \) is calculated from:

\[
\beta = \frac{\sigma_p^{m_t} N_p}{n^2}
\]

where the additional parameter, \( N_p \), is the proof test break rate in breaks per meter. All of these parameters are known from characterization testing. Conservative values are used, based on the process parameters and measurements of the global population of fibers produced. The calculated failure probabilities for several small bend radii of individual fibers are shown in Figure 15.

The cable design and application allow for 20mm radius bends for fiber storage in closures. Over a 20 year life the projected failure rate is 0.5 per 10 million full turns of that radius. Occasional bends at smaller radii will still have a near-zero risk. The key factor is the probability of finding an individual flaw in the small surface area of the glass under the maximum bending stress having a characteristic strength close enough to the maximum stress to weaken over time. Over the years, careful studies and attention to the conditions under which the optical fiber is drawn and subsequently processed have considerably reduced the population of larger flaws in the fiber that are susceptible to growth under these deployment strains. This is reflected in historically low proof test break rates, a very shallow slope of the extrinsic region of the Weibull distribution of fiber strength, and virtually zero breaks in the field.

2.6 Customer Trials

A pilot program has been launched in which selected customers have purchased the 2.0 mm tube cable designs for initial cable evaluation purposes. Initial cables have been installed, and additional cables are currently being installed in various applications (see Figures 16 and 17). The smallest 2.0 mm reduced diameter cable has successfully been installed in a blown application, using cable jetting equipment for lengths up to 5100 ft. Customers have remarked that the tubes are more flexible and are being used in small bend applications successfully. Customers are pleased with the smaller size and robustness of these cables. More feedback will be attained as more cables are installed.
3. Conclusion
With increasing demands for greater bandwidth and lower cost installations, the new next generation cable design with state-of-the-art bend insensitive fibers is the ultimate answer to these growing needs. The new next generation reduced diameter cables are up to 33% smaller in volume than the industry standard 2.5 mm loose tube designs while still meeting the same outside plant loose tube performance specifications, including extreme condition buffer tube mid-span testing. Not only do these reduced diameter cables offer smaller sizes and equal performance, they also offer many additional benefits and cost savings to the customer. The advantages of smaller cables, smaller flexible tubes, and more robust fibers are many and include benefits such as higher fiber counts in smaller spaces, smaller cable volume usage, lighter loads on messengers, smaller closures, more fiber in closures, smaller tube bend diameter, smaller fiber bend diameter, easier handling, and lower freight costs. These reduced diameter cables are not only the answer to the growing need for more fiber in smaller spaces, but a next generation solution with added benefits beyond standard designs, all the way down to the fibers themselves.

4. Acknowledgment
Special thanks to the Quality department in Claremont, NC for their dedication to the extensive amount of testing and analysis required for development and qualification of these fiber optic cables.

5. References
[3] RUS/RDUP PE-90 for Fiber Optic Cables

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