Development of Lightweight Ribbon Cables for Blown Installation

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Abstract

This paper describes the development and application of lightweight ribbon cables optimized for emerging cable architectures and installation techniques, primarily in the metro environment. The new cables are well suited for application in both micro duct systems and into new rights-of-way such as gas lines and sewer ducts.

Keywords

Ribbon; cable; sub-duct; blown cable; air-blowing installation; micro duct; miniaturized duct system.

1. Introduction

Telecommunications service providers face new challenges in the current economic environment. Demand for bandwidth continues to grow, while access to capital has become limited. Fiber is required in the metro and access markets in order to generate revenue from backbone networks that are already complete. Service providers need an economical alternative to the large-scale deployment of dark fiber to ensure that available capital generates maximum revenue. In addition, deployment of optical cables has become increasingly difficult, as governments are increasingly reluctant to allow the installation of new duct systems.

Solutions for these problems are emerging. New low-cost routes to the customer are being developed through existing infrastructure, such as roads, gas lines, and sewers [1][2][3]. Alternatively, miniaturized duct systems, usually called micro ducts, can maximize the usage of existing duct or increase the flexibility of new duct systems. Traditional cables are far from optimum for these new cable routes. In general, the new cable route solutions require smaller cables that make maximum use of resources.

Historically, ribbon cables have been ideal in applications where service providers want to maximize the number of fibers in limited duct space. Ribbon cables containing 432 or more fibers are commonly deployed in metro rings and long distance backbones.

The advantages of central-core ribbon design may also be realized in the design of small cables for metro applications. The inherently high packing density of ribbon units can be utilized to design very dense low fiber count cables. This paper presents the design of dielectric 48-fiber and 72-fiber ribbon cables with fiber packing densities greater than or equal to 1.6 fibers/mm^2. Figure 1, below, is a photograph of the 48-fiber ribbon cable. These cables are appropriate for deployment in both micro duct systems and many new right-of-way systems, including gas lines and sewers.

The new cables will be ideal candidates for deployment in micro duct systems. Micro duct systems have been growing in popularity, primarily in Europe. The use of a micro duct system can reduce the initial capital investment required for a cable route, while leaving room for future capacity growth. We will compare the costs and cash flow of deploying the new small ribbon cables in a micro duct system to the costs associated with conventional cable installation.

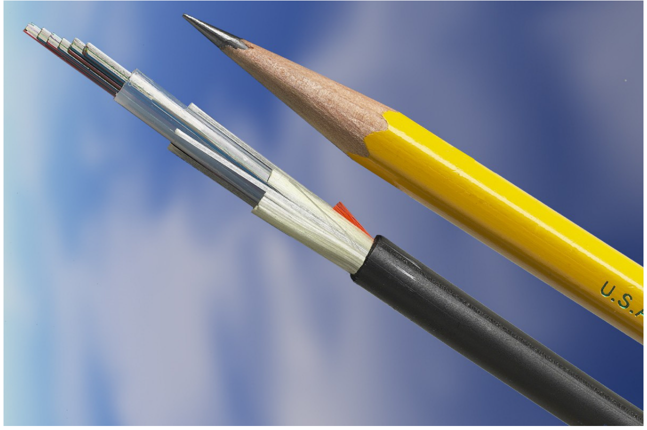

Figure 1. Lightweight 48 Fiber Ribbon Cable

2. Economics of Lightweight Cables

2.1 New Right-Of-Ways

New right-of-ways, such as natural gas and sewer lines, provide an attractive alternative path for optical fiber cables compared to the installation of new duct systems. However, installation of optical cables cannot interfere with the primary functions of these utility systems. As such, sub-ducts installed in gas lines or sewers must necessarily be small. Therefore, small cables will be required in order to utilize the new cable paths.

2.2 Sub-Duct Systems

2.2.1 Economics of Miniaturized Duct Systems

Miniaturized duct systems are attractive in the current economic environment. For a given fiber capacity, a sub-duct cable system utilizing miniaturized ducts can be installed at a lower initial cost, afford greater flexibility for future growth, and provide a greater return on investment in early years of system usage.

To study the economic return of a sub-duct cable system, we will compare the costs of two 288-fiber cable systems of identical length using a simplified model. One system will consist of a single 288-fiber cable. The second system will consist of four sub-ducts, with 72-fiber cables installed in each sub-duct over time.

To make the comparison, we will do the following:

- Calculate the normalized installation cost of the sub-duct systems and a high fiber count cable
- Compare the present economic value of the systems
- Compare revenue streams and return on investment

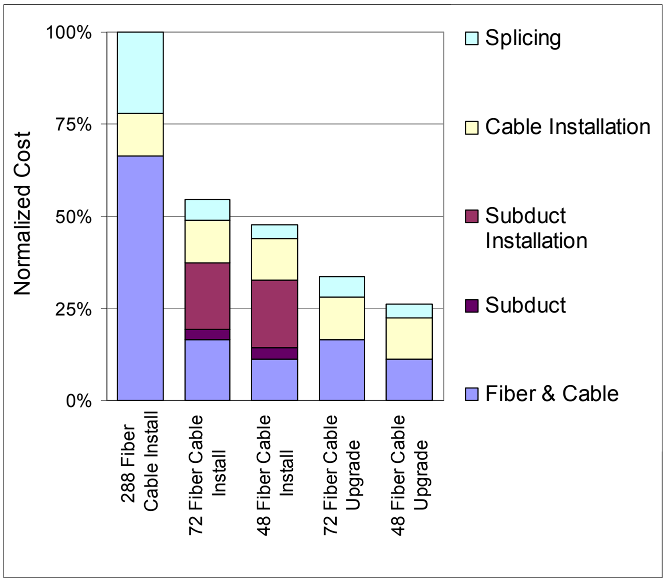

Figure 2. Installation Cost Comparison of Optical Fiber Cables

2.2.2 Initial Costs Figure 2 illustrates the costs of conventional high fiber count cables in comparison to the cost of installing sub-ducts and lightweight cables. An existing 32/40 mm (1.25 in.) cable duct was assumed. The duct has the capacity to hold five – 8/10 mm sub-ducts (48 fiber cables), four – 10/12 mm sub-ducts (72 fiber cables), or a single high fiber-count cable. Cable length was set to 1.5 km. A 288-fiber cable was used as a baseline to normalize costs. Typical North American costs for cabled fiber, cable installation, sub-duct installation, and splicing were used. The cabled cost per fiber was kept constant for all fiber counts. Comparative costs for 48 fiber cables are shown in Figure 2. For simplicity, only 72-fiber cables are used to compare costs in subsequent sections of this paper.

It is obvious that the cost of a lower fiber count cable is lower than the cost of a high fiber count cable. We calculate that the cost of a sub-duct system equipped with a single 72-fiber cable is approximately 54% of the cost of a 288-fiber cable. Three additional upgrades are required to bring the sub-duct system up to the capacity of the 288-fiber cable. After all upgrades, the cost of a 288-fiber sub-duct cable system will be 155% of the cost of a 288-fiber cable installation. Figure 3 uses the normalized costs from Figure 2 to illustrate the *cumulative* cost of the two installation scenarios over time.

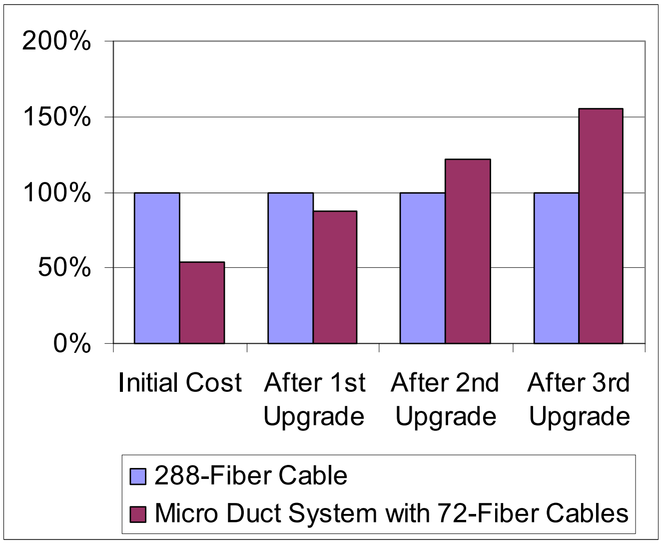

Figure 3. Cumulative Cost of Competing Conventional Cable and Micro Duct Systems

2.2.3 Present Economic Value We can compare the costs of the two systems taking into account the time value of money by looking at the present value of both scenarios illustrated in Figure 3. The equation for the present value of a future sum is given in equation (1).

$$\text{present value } \mathbf{P = F \times (1+i)^{-n}} \qquad (1)$$

where:

P is the Present value at time 0
F is the Future value at time n
i is the **interest** or discount rate
n is the time of a future value F

Note: (1 + i) is raised to the *negative* n power

The relative present value of a micro duct cable system compared to the present value of a 288-fiber cable system using an interest rate of 7% is shown in Table 1. Table 2 illustrates results from calculations at 14%. Looking at the first column of data in Table 1, which uses an interest rate of 7% and an upgrade interval of 1 year, we find that the present value (cost) of the sub-duct cable system is 142% of the cost of the 288-fiber cable.

From Figure 2, we can see that sub-duct installation is a substantial portion of the initial cost of a micro duct cable system. If new duct is required for the route, we could eliminate the cost of a separate sub-duct installation step by using cable duct with integrated sub-duct. For example, when we look at the present value of a micro duct system without the cost of sub-duct installation at an upgrade period of one year, we find that the present value of the micro cable system is 121% of the cost of the equivalent 288-fiber cable.

Table 1. Relative Present Value of 288 Fiber Cable Systems, 7% Interest Rate

Upgrade Period (years)	**1**	**1.5**	**2**	**3**	**5**
72 f Cables with sub-duct installation cost*	142%	137%	132%	122%	107%
72 Fiber Cables no sub-duct installation cost	121%	116%	111%	101%	87%

*System consisting of a single 288-fiber cable = 100%

Table 2. Relative Present Value of 288 Fiber Cable Systems, 14% Interest Rate

Upgrade Period (years)	**1**	**1.5**	**2**	**3**	**5**
72 f Cables with sub-duct installation cost	132%	123%	115%	103%	86%
72 Fiber Cables no sub-duct installation cost	111%	102%	94%	82%	65%

*System consisting of a single 288-fiber cable = 100%

In Table 1 and Table 2, the 100% base line is the cost of blowing a 288-fiber cable into an existing duct. The present value is the sum of present values for the four cable installations spaced out by the upgrade period. A 7% interest rate was used in Table 1 and a 14% rate was used in Table 2. By comparing the two tables, it is obvious that higher interest rates make the sub-duct solution more attractive.

2.2.4 Return on Investment As discussed in the previous section, *installed cost of a sub-duct system is usually higher than the installed cost of a high fiber count cable,* even when taking the time value of money into account. Why should a service provider consider the use of small cables in a sub-duct system instead of installing a high fiber count cable? The answer lies in return on investment (ROI), cash flow, and profit.

In Table 3 we extend our simplified model to compare economic return of a sub-duct system with the return on a conventional 288 fiber cable. Since actual revenue from a system is unknown, we have normalized all numbers. We assume that revenue from the comparable cable systems grows linearly as new cables are installed in the micro duct system. We keep the cost of all system components constant.

Table 3. Economic Return of Sub-Duct System

Time Period		0**n**	1**n**	2**n**	3**n**
Total Investment	288 Fiber Cable	1.0**X**	1.0**X**	1.0**X**	1.0**X**
	Micro Duct System 72 f cable	0.54**X**	0.88**X**	1.21**X**	1.55**X**
Revenue		1**Y**	2**Y**	3**Y**	4**Y**
Return $\left(\frac{\textbf{Revenue}}{\textbf{Investment}}\right)$	288 Fiber cable	1.0 **(Y/X)**	2.0 **(Y/X)**	3.0 **(Y/X)**	4.0 **(Y/X)**
	Micro Duct System 72 f cable	1.9 **(Y/X)**	2.3 **(Y/X)**	2.5 **(Y/X)**	2.6 **(Y/X)**

where:

n is the time interval when upgrades are performed
X is the investment required to install a 288 fiber cable
Y is the revenue realized during the initial period 0**n**

From the table, we can see that the return (modeled as the Revenue divided by the Investment) for the micro duct system is greater than the return on the high fiber count cable until the third expansion. By using the micro duct cable system, we are realizing profits sooner than with the high fiber count system. These immediate profits are realized at the expense of potential future profits as the high fiber count cable reaches its forecast capacity.

2.2.5 Route Distance In the previous four sections, we compared the cost of high fiber count cable to a micro duct architecture assuming that the length of the cable route was identical. Another way to look at the micro duct system is to consider the distance of the routes that can be constructed using a given amount of capital. Compared to traditional installations, the lower initial cost of the micro duct system allows service providers to stretch scarce capital over more cable routes. Based on the simplified model, for the same amount of capital, a service provider may construct a route that is 85% longer using a micro duct architecture.

2.2.6 Conclusions from Economic Modeling The installation of small fiber count cables in sub-ducts and alternative rights-of-way makes economic sense in some circumstances. The following is a summary of the application of standard and lightweight cables:

High fiber count cables and/or heavy-duty cables should be used in the following circumstances:

- When the installation route requires the mechanical protection afforded by traditional cables
- When the capacity demand for a route is projected to grow rapidly

- When the cost of the fiber cable is not significant relative to the installation cost of the system
- When capital is readily available and borrowing costs are low
- Where access for future expansion is difficult (bridges, tunnels)
- When cost per fiber must be minimized

Lightweight cables in micro duct systems are attractive in the following situations:

- The service provider needs to maximize short term return on investment and profitability.
- The service provider needs to shorten planning horizons and maximize flexibility in order to react to growth. The micro duct and small cable system gives flexibility to deploy fibers where needed.
- The service provider anticipates that new fiber designs and technology will reduce the cost of future capacity.

From the economic modeling, we can see that the use of small cables in a sub-duct system can make economic sense.

3. Cable Design

3.1 Lightweight Cable Properties

3.1.1 Required Properties A new lightweight cable design must meet the following requirements in order to be useful in micro-duct installations:

- The cable must have the size, stiffness, and flexibility necessary for installation in a small diameter duct.
- The cable fiber count must be high enough to fit the metro route architecture.
- Sufficient mechanical protection and tensile strength are required for cable installation and for protection of the optical fibers.
- The cable must have acceptable attenuation performance in the expected operating temperature range.

3.1.2 Desired Properties In addition to the minimum requirements for a usable cable, other cable properties are desirable:

- The cable should be dielectric to minimize lightning damage and to provide a safe operating environment for technicians.
- Fibers within the cable should be easily identifiable.
- The cable should not exhibit preferential bending. Preferential bending can make the use of a passive intermediate storage device (fleeting) more difficult. [4]
- The cable should have sufficient tensile strength to be pulled for short distances.
- The cable should have sufficient robustness to be coiled inside a manhole without the protection of a duct.
- Other than tensile strength, the cable should have temperature and mechanical performance comparable to standard outside plant optical fiber cables.

3.2 Cable Description

3.2.1 Central Tube Cable Design Low fiber count central core ribbon cables are an appropriate solution for micro duct systems, due to the inherently high packing density of ribbon units. A central core design also provides for enhanced ruggedness in smaller cables. We can consider the entire cable structure as a robust, reinforced composite tube made up of multiple layers to provide crush resistance and cable flexibility.

In the 48-fiber cable, shown in Figure 4, a 4 mm diameter central tube contains eight 6-fiber ribbons. Six fiber ribbons were chosen to be compatible with a 12-fiber architecture. In the 72-fiber cable, shown in Figure 5, a 5 mm tube contains six 12-fiber ribbons.

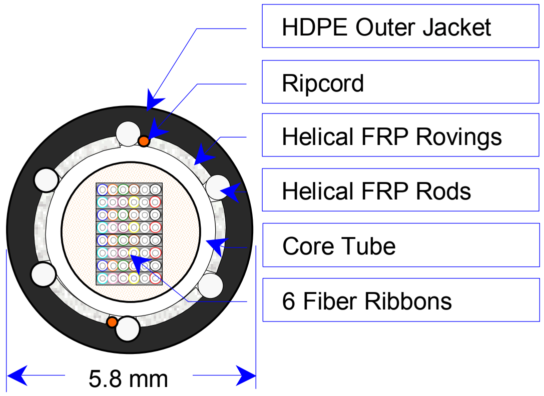

Figure 4. 48 Fiber Ribbon Cable

3.2.2 Ribbon Units Fiber ribbons are a convenient unit structure for small cables designed for simple, low-cost installation. The productivity of mass fusion splicing of ribbons can afford significant time savings during installation. However, the ribbon units in this lightweight cable are also engineered for use in architectures where single fiber management and splicing are desired. Single fiber access is easily accomplished, as the ribbon matrix can be flaked off the fibers without difficulty. [5] Compared to fiber bundles or loose fiber, ribbon units in a central core tube provide compact, easily identifiable fiber groups. In the central core, the ribbons are positioned in sequential order, and can be easily routed within splice trays.

3.2.3 Strength Member System The strength member system is designed as an integral part of the cable structure and is engineered for each core tube size. The strength members are helically wrapped around the core tube. This avoids asymmetrical bending stiffness that can lead to inconsistent coiling in a fleeting device [4]. A minimum of six FRP rods are used to avoid local preferential bending in tight radius turns, which can occur when four or fewer rods are used. As illustrated in Figure 4 and Figure 5, the strength members completely girdle the core tube and are tightly encapsulated by the outer jacket, to reinforce the structure when the cable is subjected to crushing and impact loads.

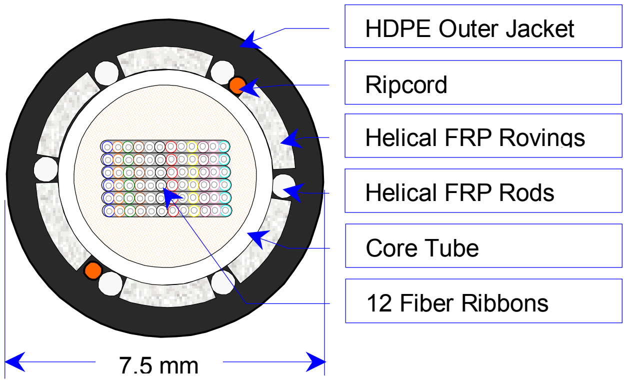

Figure 5. 72 Fiber Ribbon Cable

3.2.4 Outer Jacket Material High-density polyethylene was chosen to provide toughness for the thin jacket section and to provide a low coefficient of friction at high temperatures.

4. Cable Performance

The cable size, tensile strength, and fiber density of the 48 and 72 fiber cables are listed in Table 4.

Table 4. Cable Tensile Strength & Weight

Fiber Count	Fibers per Ribbon	Size (mm)	Fiber Density $\left(\frac{\text{Fibers}}{\text{mm}^2}\right)$	Weight (kg/km)	Tensile Strength	
					W[1]	N
48	6	5.8	1.8	31	2	600
72	12	7.5	1.6	49	2.7	1330

The operating temperature range of the cables is -40°C to +70°C.

A representative sample of test results is presented in Section 5.

5. Test Results

5.1 Test Results Summary

The 48-fiber cable was tested using IEC test methods.

Except for tensile strength, the 72-fiber cable has been tested for conformance to *Bellcore*[2] *GR-20-CORE, Issue 2, 1998* [6] and *ICEA-S-87-640-1999, September 1999* [7].

All test measurements summarized in this paper were made at a wavelength of 1550 nm.

Results are summarized using a box and whisker plot. The whisker represents the range of measurements. The box represents 50% of all points. The line in the white box represents the median value.

5.2 IEC Testing of the 48-Fiber Cable

5.2.1 Environmental Test Results The 48 fiber cable was tested per IEC 60794-1-F1. A summary of the added loss at the last three temperature measurements at -40°C, +70°C, and ambient conditions is shown in Figure 6. The slight elevation at -40°C is the result of elevation in corner fibers.

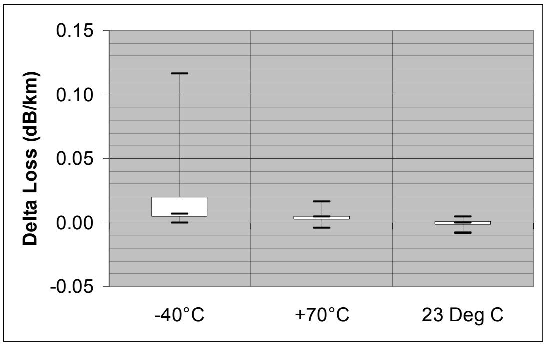

Figure 6. IEC 60794-1-F1 Temperature Cycling, Results for 48-Fiber Cable

5.2.2 Tensile Test Results The tensile performance of the 48-fiber cable was tested per IEC 60794-1-E1 at a tension of 2W, which for this cable is 600N. A summary of the added loss is shown in Figure 7.

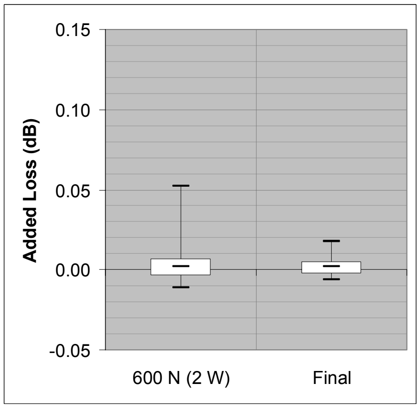

Figure 7. IEC 60794-1-E1 Tensile Performance 48-Fiber Cable

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[1] A cable rated 1W is able to support 1 km of its own weight.

[2] Bellcore is now known as Telcordia Technologies.

5.2.3 Compressive Strength The compressive strength was tested in two places using IEC60794-1-E3 with a load of 1112 N. The added loss was measured with the cable subjected to the long-term load. The Compressive Strength performance of the 72-fiber cable is summarized in Figure 8. The added loss returned to initial values after the test.

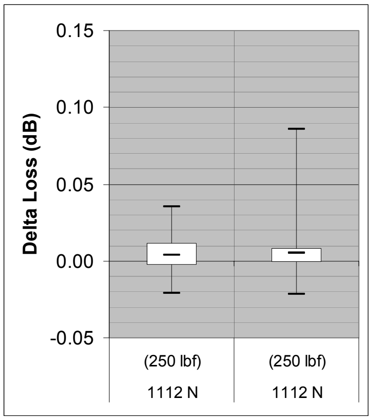

Figure 8. IEC 60794-1-E3 Crush, 48 Fiber Cable, Two Places

5.2.4 Bend Performance The cable was tested per the IEC 60794-1-E6 Repeated Bending test using a 107 mm mandrel. There was no measurable added loss at the end of the test.

The cable was also tested using procedure IEC-60794-1-E11. The cable was wrapped 5 times around a 203 mm mandrel. There was no significant added loss as shown in Figure 9

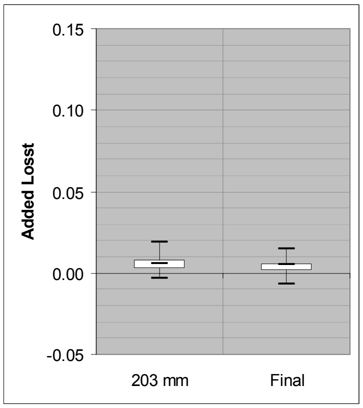

Figure 9. IEC 60794-1-E11 Bend 48 Fiber Cable, 203 mm Mandrel

5.3 Bellcore Testing of 72-Fiber Cable

5.3.1 Bellcore Test Results The 72-fiber cable was tested to the requirements of Bellcore GR-20-CORE, Issue 2 (1998). As described in the subsequent sections, the cable passed all Mechanical and Environmental Requirements except for tensile strength.

5.3.2 Environmental Test Results The 72 fiber cable was tested according to the Temperature Cycling and Cable Aging Tests in Bellcore GR-20. Results are illustrated in Figure 10 and Figure 11.

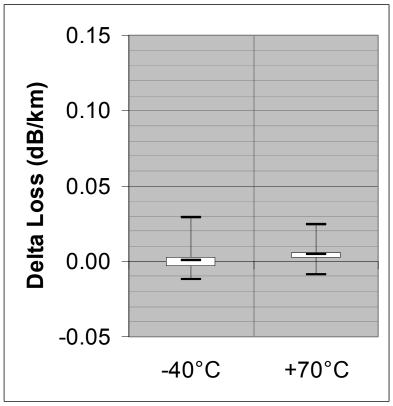

Figure 10. Bellcore GR-20 Temperature Cycling, 72-Fiber Cable

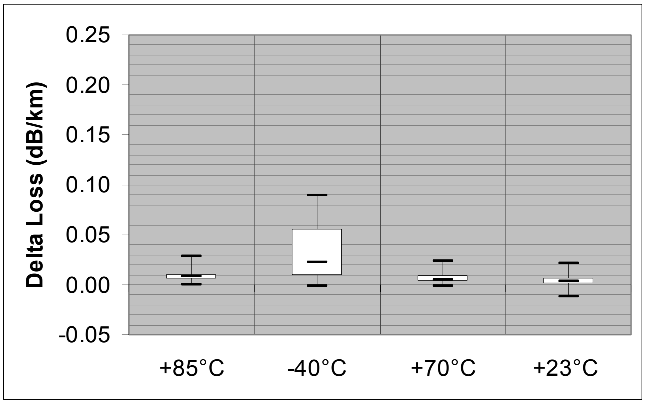

Figure 11. Bellcore GR-20 Cable Aging, 72-Fiber Cable

5.3.3 Tensile Performance The tensile performance of the 72 fibers cable is summarized in Figure 12.

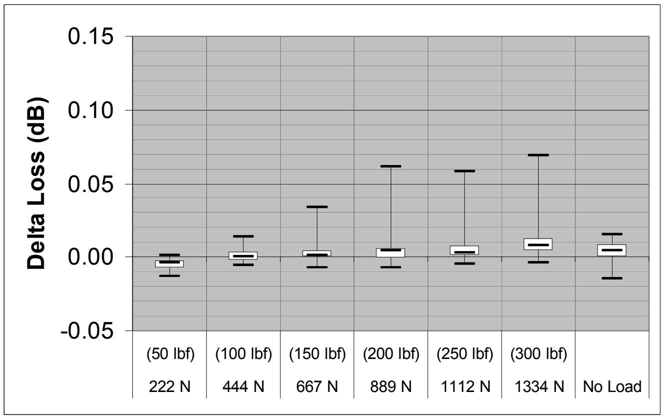

Figure 12. TIA/EIA-455-33A Tensile Load & Bend 72-Fiber Cable

5.3.4 Compressive Strength The compressive strength was tested in two places per Bellcore GR-20, Issue 2 with an incidental load of 220 N/cm, 2200 N total, for 1 minute and a long term load of 110 N/cm, 1100 N total, for 10 minutes. The added loss was measured with the cable subjected to the long-term compressive load. The final measurement after the total compressive load was increased to 440 N/cm and released. The Compressive Strength performance of the 72-fiber cable is summarized in Figure 13.

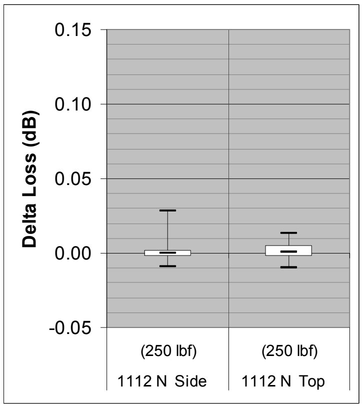

Figure 13. Bellcore GR-20 Compressive Strength Test, 72 Fiber Cable, Two Places

5.3.5 Low and High Temperature Cable Bend. The cable was wrapped 4 times around a 5 in. (127 mm) mandrel at temperatures of -30°C and +60°C per Bellcore GR-20 using FOTP-37. The low and high temperature bend performance of the 72-fiber cable is summarized in Figure 14.

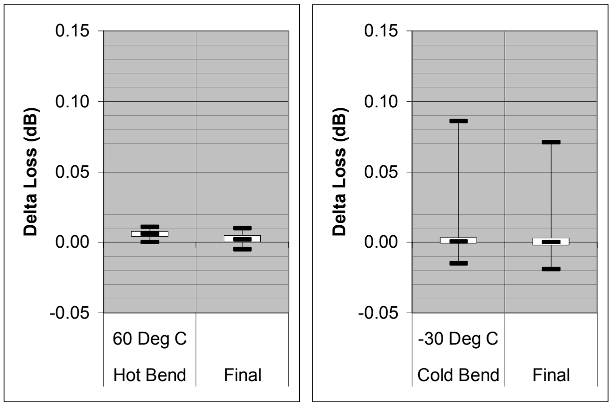

Figure 14. Bellcore GR-20, Low and High Temperature Cable Bend, 5 in (127 mm) Mandrel, 4 Turns, 72 Fiber Cable

5.4 Installation Performance

The 48-fiber cable was tested in a 700m duct trial system designed to simulate a congested inner city environment with numerous bends and rapid changes in elevation. The test route is illustrated in Figure 15. The target was to achieve a blowing distance of 500 m, which represented the maximum distance between access points anticipated by the customer in their network.

A series of trials were conducted comparing different micro-tubes and blowing installation equipment. One major point to note is that no lubricant was used for these trials.

The 500 m target was achieved in all combinations of equipment and tubes. A total distance of 700 m was blown in a time of 10 minutes and 35 seconds. This represented the maximum length of the available test route.

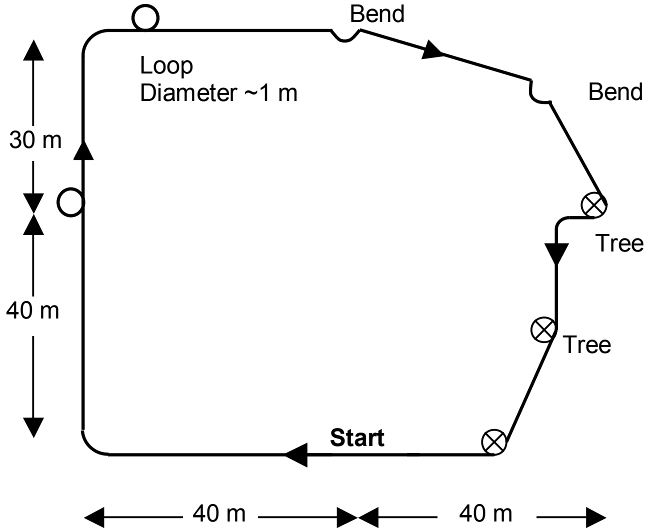

Figure 15. Cable Installation Test Route

The maximum installation distance that may be achieved is dependent upon a variety of factors. These include the blowing equipment, the compressor and the route configuration. Added to this are the different options open to installers with regard to selection of micro-duct designs, i.e. low friction liners incorporated within the tube or the use of lubricants prior to installation. Installation distances greater than 1000 m have been achieved with a maximum distance of 1400 m. This trial was into a duct with a low friction liner and no additional lubricant. Further trials are planned to determine the maximum installation distance that may be achieved.

6. Conclusions

Lightweight dielectric ribbon cables in 48 and 72-fiber versions have been developed. The cables were tested under criteria prevalent in both North America and Europe, and show excellent performance. Characteristic economics have been explored showing the advantages of using these small cable designs in the current economic situation.

7. Acknowledgments

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8. References

[1] J. P. Bonicel, H. Costa-Elias, P. Vertuaux, P. Gaillard, R. Newman, M. Rivard, "A Very Innovative Technology for Right of Way Application", *Proceedings of the 47th International Wire and Cable Symposium*, (1998), pp. 815-824.

[2] P. E. Gregor, L. Kuhn, A. Weiss, "Optical Fiber Cable Links with Gas Pipelines as an Alternative Telecommunications Route Technology", *Proceedings of the 48th International Wire and Cable Symposium*, (1999), pp. 170-175.

[3] J. K. Jeyapalan, "Bridging the Last Mile with Fiber Optic Cables in Sewers", *Proceedings of the 50th International Wire and Cable Symposium*, (2001), pp. 724-731.

[4] M.V. Davies, C. J. Esbester, R. Sutehall, P. Barker, D. F. Bastin, "Advances in Blown Cable Technology: The Development and Life Cycle Analysis of a High Density Fibre Cable," *Proc. 50th International Wire and Cable Symposium,* (2001), pp. 658-665.

[5] K. Konstadinidis, N. W. Sollenberger, S. Siddiqui, K. W. Jackson, J. M. Turnipseed, T. W. Au, R. P. DeFabritis, C. R. Taylor, "UV Color Coatings and Matrix Material for Enhanced Fiber Optic Ribbon Products", *Proceedings of the 46th International Wire and Cable Symposium*, (1997), pp. 274-280.

[6] Bellcore GR-20-CORE, *"Generic Requirements for Optical Fiber and Fiber Optic Cable"*, Issue 2, July 1998.

[7] ICEA-S-87-640-1999, *"Optical Fiber Outside Plant Communications Cable"*, September 1999.

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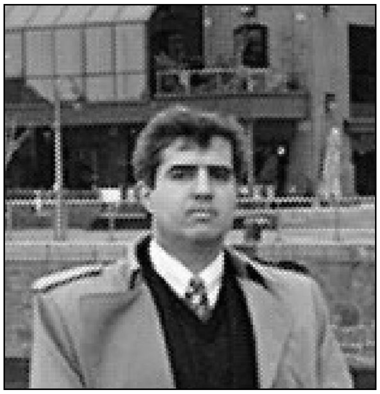

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