FIBER OPTIC CABLE CONSTRUCTION AND INSTALLATION

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ABSTRACT

Once the decision has been made to utilize fiber optics as the medium for communications transmission, the next question is in what form should the fiber be cabled (loose tube versus tight buffer), and how should it be installed. The application for both loose tube cables and tight buffered cables is addressed. Also, considerations for direct buried, duct, and aerial installations will be described. In addition, the differences in the two primary fiber manufacturing methods will be discussed. The concern is to insure the correct cable construction and installation are combined to provide the fiber with the necessary long term reliability beginning with the rigors of installation through the cyclic changes caused by its permanent environment.

INTRODUCTION

Fiber optic cable is being utilized by cable television companies to carry signals from sattelite downlinks to headend; headend to headend; headend to hub; and potentially deeper into the cascading system. Some of the reasons for using for fiber optics are 1) reduction of amplifiers in the cascade, 2) elimination of signal leakage, 3) lower maintenance costs, 4) higher reliability 5) increased bandwidth/ channel capacity. The method of cable installation and the corresponding cable construction are critical to insure, as a minimum, the standard 15-year life expected by most cable TV companies is achieved.

In numerous communication industries, fiber optics have been utilized consistently and successfully for the past 10-15 years. Most manufacturers will discuss cable life in terms of 20-40 years. The inherent properties of the fiber optic glass are such that, if properly cabled and installed, the product life could be in excess of 20-40 years. The limiting factors are the materials used to house the fiber and the external stresses that may be applied during manufacturing, installation and under environmental loading.

The vast majority of cable TV applications will call for singlemode (as opposed to multimode) fiber due to its low loss and high bandwidth/channel capacity characteristics. A short description of the two most common methods of singlemode fiber manufacturing will be followed by a description of loose tube cables and tight buffered cables, and a discussion on the application of each. The final area of discussion is methods of installation with special emphasis on self-supporting aerial cables. The reason for emphasis on the self supporting aerial method is its unique combination of being one of the fastest and least expensive methods of installation while also being the most demanding on the fiber optic cable, based on environmental loading.

SINGLEMODE FIBER MANUFACTURING

There are several methods of manufacturing high quality optical fibers. For the sake of argument, "high quality" fibers will be defined as singlemode fibers with attenuation less than or equal to 0.5dB/km at 1300nm and 1550nm, bandwidth in excess of 2GHz•km at 1300nm, and dispersion less than or equal to 3.5 ps/nm•km from 1285nm to 1330nm and typically 17 ps/nm•km from 1500 to 1550nm.

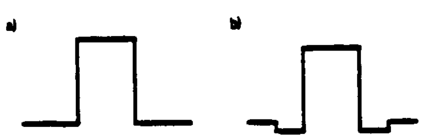
The two primary methods used for manufacturing the fibers are Outside Vapor Deposition (OVD) and Inside Vapor Deposition (IVD). Simplistically, vapor phase despositon is a method of doping fused silica glass with metallic halides in order to establish a desired refractive index profile. The refractive index profile depicts the change in the refractive index across the fiber to include the core, the core cladding interface, and the cladding. The refractive index is the ratio of the speed of light in a vacuum to the speed of light in the glass. For light to propogate properly in a singlemode fiber, the refractive index of the core glass must be slightly greater than the refractive index of cladding glass at their interface. The net result is what is referred to as a step-index profile.

Figure 1 shows the profiles associated with the OVD and IVD processes. The matched cladding index profile is the result of a fiber manufactured by the OVD process. The depressed cladding index profile is the result of a fiber manufactured by the IVD process. Both processes produce fibers that perform equally well. The primary reason for the depressed clad profile associated with the IVD process is to overcome the difficulties associated with this manufacturing

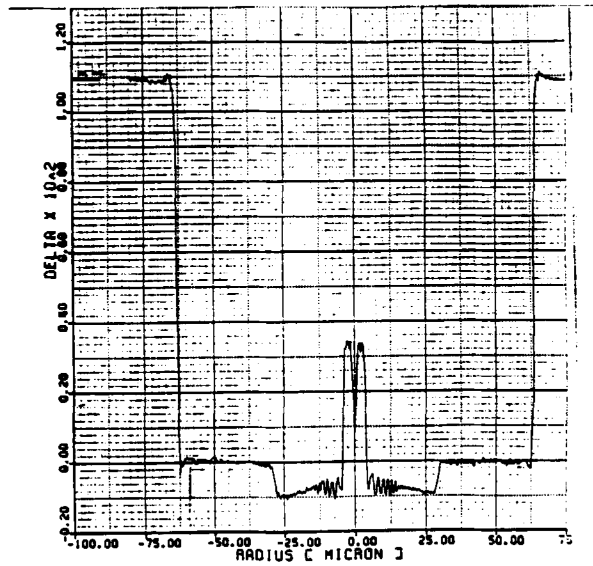
Figure 1.

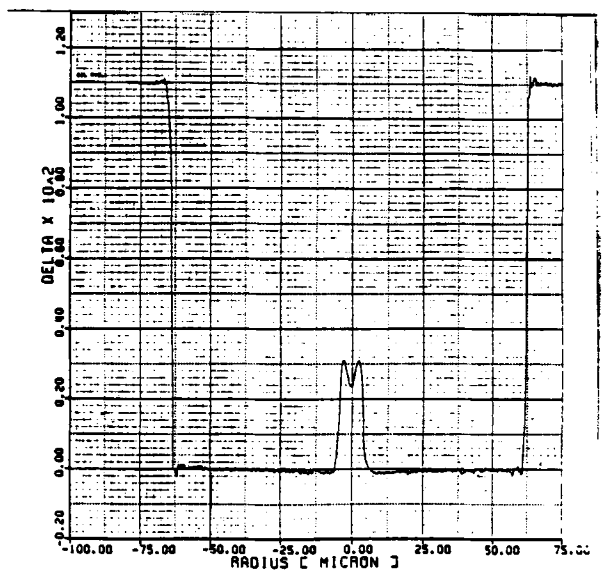
a Standard step index profile (simple step index or matched cladding)

b Step index profile with reduced refractive index in the cladding (depressed cladding)



process in maintaining the uniform refractive index profile critical to quality performance. Figure 2A shows an actual refractive index profile of a depressed clad singlemode fiber. Figure 2B shows an actual refractive index profile of a matched clad singlemode fiber.





The key element regarding fiber is how it will perform once cabled and installed. Bending losses and strain applied to the fiber can degrade its performance and life expectancy. Corning Glass Works, a major fiber manufacturer holding patents for both the OVD and IVD processes, recommends a minimum bend diameter for the fiber of 50mm. At bend diameters below 50mm, there is potential for substantially decreased expected fiber life. At bend diameters of 50mm and above, the loss associated with the bend is negligable for both matched and depressed clad fibers with slightly superior performance of the matched clad over the depressed clad for bend diameters encountered in typical splice trays (60-80mm).

Regarding fiber strain, Corning Glass Works states that a fiber can withstand strain up to one-third of its proof test, long term, without degrading its expected life. The typical proof test after manufacturing is 50 kpsi for fibers intended for loose tube construction and 100 kpsi for fibers intended for tight buffered construction.

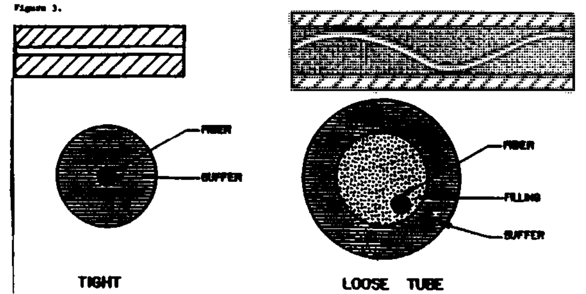
LOOSE TUBE AND TIGHT BUFFERED CABLES

CONSTRUCTION AND APPLICATION

The difference between loose tube and tight buffered cables is the basic premise of how the fiber should be treated regarding strain. A tight buffered design accepts the fact that some amount of strain will be coupled to the fiber during manufacturing, installation, and due to environmental exposure. It makes the further assumption that the strain will not degrade the long term optical performance of the fiber. A loose tube design makes the assumption that the best way to assure maximum performance of the fiber over time is by isolating it from the majority of strain associated with manufacturing, installation, and environmental conditions.

Figure 3 depicts the buffering techniques applied to the fiber by tight buffer and loose tube designs. As shown, the loose tube design provides a percentage of fiber overlength relative to the loose buffer tube and decouples the fiber from the buffering material, whereas the tight buffer design does not.

Figure 3.



BUFFERING TECHNIQUES

The reasons for decoupling the fiber from its buffer is to isolate the fiber from the strain associated with expansion and constraction of the cable components, and the strain induced during installation. In a loose tube design, the fiber or fibers in the individual tubes are given the freedom to remain in a strain-free state relative to the other cable components. This is particularly important when the cable is to be placed in a non-environmentally controlled environment (i.e. outdoors).

Generally, fiber optic cable manufacturers with the capability of manufacturing both loose tube and tight buffered cables will specify the loose tube cables for use in outdoor applications to include direct buried, duct and aerial installations. In aerial applications, it is particularly important to utilize the loose tube design due to temperature cycling, ice loading, and wind loading. The tight buffered cables are normally specified for use indoors in environmentally controlled areas. Siecor Corporation, a major manufacturer of fiber optic cables, can also recommend a new tight buffered cable design for use outdoors, in ducts, buried below the frost line for short haul applications.

Numerous other cable construction issues such as jacket material, types of armoring, buffer tube materials, etc. could also be discussed at this point. However, this paper will not address them because they are not directly fundamental to the concern of fiber strain versus fiber life, nor particularly important to installation techniques.

CABLE INSTALLATION

Three broad terms capture the types of installations utilized for the outdoor placement of fiber optic cables. They are 1) duct installations, 2) buried installations, and 3) aerial installations. The methods, techniques, and equipment utilized for the installations would be extremely difficult if not impossible to list. However, upon inspection it is clear that by following a few fundamental guidelines, the installation of fiber optic cable in any application is analagous to the installation of coaxial cable. In fact, the size, weight, and flexibility of fiber optic cable should make cable installation faster, easier and less expensive to install.

Duct Installations

Fiber optic cables can be pulled into ducts and innerducts using conventional cable techniques with minor modifications. The two most important guidelines to follow are 1) to not exceed the cable manufacturer's specified maximum pulling tension and and 2) do not exceed the manufacturer's specified bending radius. The industry standard for maximum tension on fiber optic cable is 600 lbs. during installation. This number can be increased or decreased by the cable manufacturer as requried. Generally, the minimum bending radius for a cable during installation, under tension, is 15 to 20 times the diameter of the cable.

In order to pull a cable through a duct, the cable is typically attached to a pulling eye by its strength member(s). The strength of the cable should not necessarily be confused with the central member. Some manufacturers rely wholly or in part on the central member for strength. However, the most commonly used cables utilize aramid yarns applied over the cable core and directly under the jacket as the primary cable strength member. The pulling eye is composed of a wire mesh pulling grip, a kevlar tie-off loop, and is attached to the pulling rope or winch line via a swivel. The purpose of the swivel is to allow the rope to rotate naturally without twisting the fiber optic cable.

In order to reduce friction and increase pull lengths, a pulling lubricant compatible with the particular cable sheath may be utilized. At all times, the pulling tension being applied to the cable should be monitored to insure maximum tension is not exceeded. The distance a cable can be pulled in one direction can be increased by utilizing figure-8 techniques (backfeeding or center pulls).

As an example, if the intent is to pull in a four km reel of cable and after 2km the maximum tension is reached, the cable can be pulled out of the duct at the nearest manhole back from the point of maximum tension and layed on the ground in large figure-8 loops. (The purpose of the figure-8 is to allow for easy handling of the cable and to prevent kinking.) Once all of the cable is formed into a figure-8, it is turned over so that the pulling eye of the cable is on top. The pull can then continue through the duct from this new starting point. In some cases, it may be necessary to hand assist the cable at an intermediate manhole in order to reduce the tension enough to pull the cable out of the manhole to form the figure-8.

Center-pulling of cable can be performed as an alternative to backfeeding for long cable lengths. This technique involves the placement of the reel near the center of the duct run to be pulled. The cable is pulled in one direction to a predesignated splice point. The remaining cable is unreeled, figure-eighted on the ground, and pulled in the opposite direction.

It is conceivable that with proper "housekeeping" either technique could allow cable pulls of 4-6km of continuous cable. Some manufacturers are capable of manufacturing singlemode cables up to 12km in length without fiber splices.

It is recommended that in manholes, flexible conduit be utilized to house and protect the cable. Enough conduit should be used to allow it to be secured to the manhole wall and extend approximately one meter into the duct on each side. Enough cable slack must be left in each manhole for this purpose also.

Buried Installation

The cable utilized for a buried installation would be the same as that used in a duct with the exception that it would be housed in innerduct or, more commonly, it would contain its own armoring such as a corrugated steel tape. The purpose of the armor is to protect the cable against rodent attack and potential crushing forces. The cable is typically buried at depths of 30-48 inches in utilizing a conventional cable laying plow. Depending on the ruggedness of the cable, many manufacturers do allow their cables to be installed with vibratory plows. A warning tape may be buried along with, or above the fiber optic cable for the purpose of forewarning ground excavators.

Trenching is an alternative method for burying fiber optic cable. For short distances, it may prove to be more economical than plowing.

In the event the soil is particularly rocky and there is a concern about cable damage, it would be wise to prepare the area prior to installation. In the case of plowed cable, the ground can be pre-ripped. In the case of trenching, the trench can first be backfilled with approximately one foot of sand.

Aerial Installations

As indicated earlier, aerial installations tend to subject the cable to its harshest environmental conditions over time. This is due to several environmental factors. First, temperature cycling will occur which may cause dissimilar movement between the fiber optic cable and its host supporting messenger. Second, for heavy ice and wind loading areas, seasonal loads of 1/2 inch radial ice with 40mph winds can be anticipated. Third, areas of heavy wind load can produce wind loading up to or in excess of 110mph. In all cases, these factors will place increased stress and strain on the fiber optic cable. If properly designed and installed, a loose tube cable design can insure the fibers remain in a relatively stress-free state eliminating concerns of reduced service life.

As with a duct installation, the two rules of thumb to follow when installing fiber optic cable aerially are: 1) do not exceed the maximum pulling tension and 2) do not exceed the minimum bend radius as specified by the cable manufacturer. The construction of the cable will normally be the same as a cable used in a duct installation.

A minority of users opt to install an armored cable aerially. In some cases, it is for ease of inventory and in a few cases, it is as a precaution against squirrel or rodent damage. Other customers may opt to utilize an all-dielectric cable due to its non-conductive properties and associated concern regarding lightning damage.

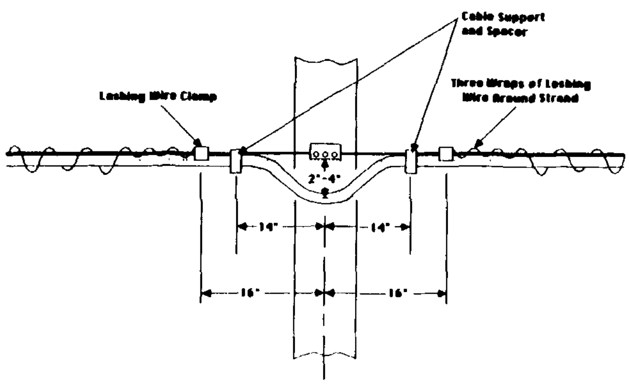
The most common aerial installation involves lashing the cable to a dedicated steel messenger utilizing standard lashing techniques. Either a "pull-in" or "drive off" method may be used. Because of the reduced "make ready time," the drive off method is quicker and more economical. Again, it is critical that the recommended minimum bend radius and maximum tensions as specified by the cable manufacturer are followed. It is critical that the aerial cable blocks and cable guide are large enough to insure the cable's minimum bend radius is not violated. For short spans, one-quarter inch extra-high-strength steel wire messenger has become fairly standard.

Overlashing the cable to existing plant is also an option. In this case, all procedures are the same as with a dedicated messenger. For installation, again, the keys are maximum pulling tension and minimum bend radius. In an overlashing situation, the fiber optic cable is coupled to the copper cable which can sustain more strain than the fiber optic cable. In most cases, the design engineer should consult with the cable manufacturer to discuss the variables which determine the fiber optic cable strain involved in an overlashed situation. The design engineer should also take into consideration the additional potential load to the existing cable and structure just as he/she would in the case of overlashing copper cables.

In the case of dedicated and overlashed aerial installations, most manufacturers suggest that drip loops be left at each pole to allow for expansion of the messenger. The loops are generally 2 to 4 inches below the lashing wire, depending on cable size, with the limiting factor being minimum cable bend radius. The lashing line is clamped to the pole and spacers are generally used.

Siecor

Recommended Drip Loop for Aerial Siecor Fiber Optic Cable



Another method of aerial installation which is growing in popularity is the use of self-supporting cables. The primary reason is ease of installation and significant time/labor savings. When compared to installing a dedicated messenger and lashing a fiber optic cable, a self-supporting system will normally be more economical. In addition, newer designs provide superior relief for the fiber from environmental forces.

To install a self-supporting cable, the same procedures would be followed that are utilized for installing a messenger. Again, tension and bend radius are limiting factors. The Rated Breaking Strength (RBS) of most self-supporting cables runs from 4000 lbs. to 35,000 lbs. The recommended RBS should be specified by the manufacturer based on span length, maximum sag allowed, and ice and wind loading. The recommended installation tension will vary, but will generally be between 10-20% of RBS. As with previously described procedures, if a pulling rope is used as with the "pull-in" method, a swivel should be placed between the pulling rope and fiber optic cable.

The key elements to a self-supporting cable design are 1) ease of installation, 2) a strain-free fiber environment under worst case loading, 3) no effect on the fiber by hardware attachments, 4) resistance to wind induced vibration and 5) the flexibility to preplan the cable construction to accomodate overlashing in the future, if requested.

The three most common self-supporting cable designs satisfy these requirements to greater or lesser degrees. The designs are figure-8, concentric or circular, and pre-stranded or helically wrapped. Of the three, the pre-stranded most completely satisfies the above stated parameters.

The figure-8 design consists of a fiber optic cable clipped or bonded to a messenger. The messenger is normally poly coated and can be fiberglass reinforced plastic (FRP), steel, or aramid yarn. The FRP designs are most common. The figure-8 typically installs easily, but due to the rigid messengers commonly used, may pose handling problems. The fact that there is a physical coupling between the messenger and cable reduces the effectiveness of maintaining the fibers in a strain-free environment. Loads applied to the messenger will be mechanically coupled to the fiber optic cable. Since the cable has a separate messenger, hardware can be attached without the danger of compressive forces applied to the fiber optic cable. The cable design also exhibits resistance to wind forces because the disimilar harmonic motions of the messenger and cable will help to dampen wind induced movement.

The concentric or circular design is simply a standard aerial cable with an increased rated breaking strength and crush resistance. The strength of these cables is found in layers of aramid yarn. By increasing the cross sectional area of aramid yarn, the manufacturer can design a cable capable of aerial installation without an external messenger. These designs provide the lightest weight, most flexible design for installation. The disadvantage is the reduced ability to isolate the fibers from strain during tensioning and under load. Also, hardware must be applied directly to the fiber optic cable increasing the possiblity of placing compressive stress on the fibers. Because of the circular construction, dampeners may be required in some cases to reduce wind induced vibration.

The pre-stranded or helically wrapped design utilizes a poly jacketed messenger with a fiber optic cable stranded around the messenger. The stranding process is zero torque so as not to induce a twist to the fiber optic cable during manufacturing. The messenger is normally a poly jacketed aramid yarn to give the cable low elasticity, high strength, and flexibility for handling. The pre-stranded design incorporates all of the positive points associated with a figure-8, the greater ease of handling found with the concentric, and reduces the mechanical coupling of strain from the messenger to the fiber optic cable because there is no physical bonding.

In all cases, the manufacturer should supply the user with sag/tension information for specific applications. This information should include installation sag and tension, horizontal displacement and vertical sag under worst case loading, and tension under worst case loading. In addition, the manufacturer should be able to guarantee the system will not see any increased attenuation under worst case loading conditions.

To be able to overlash the system in the future, the manufacturer needs to plan for the increased cross-sectional area and weight during the installation design. Both the concentric and pre-stranded designs are capable of being overlashed. The profile of some figure-8 cables may preclude the ability to overlash.

Summary and Conclusions

Reliability of fiber optics has been proven over the last 10-15 years in several communications industries. In order to insure the same success and long term reliability is acheived in the Cable Television Industry, it is important that the design of the cable match the application. Reduction or elimination of fiber strain over time is an essential element to insuring expected life cycles are achieved.

If properly cabled, both matched clad singlemode glass and depressed clad singlemode glass will meet or exceed performance expectations. By utilizing cable constructions compatible with the installation technique specified, the Cable Television Industry will benefit from the reliability, long life, and superior performance afforded by fiber optic cable systems. Acceptance of fiber optic cable as a viable transportation medium for transmission of Cable T.V. signals has occurred.

References

For additional related information, refer to the following publications:

1. G. Mahlke and P. Goessing, Fiber Optic Cables. New York: John Wiley and Sans Limited, 1987.

2. J. Palais, Fiber Optic Communications. Englewood Cliffs, New Jersey: Prentice Hall, Inc. 1984.

3. AMP, Designer's Guide to Fiber Optics. Harrisburg, Pennsylvania: AMP, Inc. 1982.