Conduit Pathway Advantages Relative to Distributed Acoustic Sensing

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Introduction

This document is designed to be a resource for systems integration companies and end-users of Distributed Acoustic Sensing (DAS) who are either considering installation of fiber optic cable for new projects (greenfield) or use of such cables in conduit for existing installations (brownfield). Whereas companies specializing in provision of DAS technology have been implementing commercial high-quality systems in conduit for many years, there has been little effort to validate that there is negligible performance impact to a commercial grade DAS installation with proper conduit selection. As a member of the Fiber Optic Sensing Association (FOSA) and as the global leader in permanent conduit pathways for datacom and other applications, Dura-Line is aware of this gap in industry knowledge. Thus, Dura-Line has embarked upon both experimentation and aggregation of information to demonstrate the advantages of the use of conduit pathways to users of DAS technology. The advantages can be realized by conventional datacom network providers and installers, as well as end-users of DAS technology in a wide variety of vertical markets and applications, with demonstrated support of acoustic performance.

About Dura-Line

Dura-Line's mission is to create what connects us by providing state-of-the-art quality products designed for both protection and also fast, safe installation of communication networks and power cables. Dura-Line products support a wide range of markets, including telecommunications, enterprise networking, energy, and transportation, as well as solutions and services which enable reliable communication by supporting the design, construction, and operation of these pathways. In addition, Orbia, as Dura-Line's parent company, is a purpose-driven company tackling complex challenges across the globe. Our businesses serve customers in the name of advancing human life. Orbia focuses on food growth, water management, infrastructure development, data access, and health advancement with a portfolio of brands operating in 41 countries.

Conduit

BRIEF HISTORY OF CONDUIT NETWORK SYSTEMS

In the early to mid-1980s, tremendous growth occurred in the deployment of fiber optic cables, linking major metropolitan areas. Fiber optic cables were quickly becoming the technology of choice for streaming huge amounts of voice, video, and data. These cables were installed in very long lengths, up to 30,000 feet, with the goal of using as few splice points as possible to minimize signal attenuation. Because of the more fragile qualities of these long, thin strings of glass, individually no thicker than a strand of human hair, they needed more protection and different handling procedures than traditional jacketed metallic cables. There was an immediate need for a conduit system that offers improved installation efficiencies and cable protection.

Existing conduit network systems typically were 3.5 to 6 inches in diameter to accommodate the very large diameter of copper cables that filled the duct banks. As copper cables were being replaced with fiber optic cables, which are much smaller in diameter, smaller high-density polyethylene (HDPE) conduits ranging from 1 to 1.25 inches were pulled into the vacated conduit, creating multiple pathways to be used for initial and future fiber optic cable placement and for redundancies if a cable got damaged. This new method of deployment using MicroDucts in existing pathways was called “innerducts” and is still used today. Additionally, now conduit suppliers offer bundled MicroDucts under one oversheath for ease of placement and to maximize fiber count in limited underground and aerial spaces. Multiple variations of standard HDPE conduit and bundled HDPE MicroDucts are available. The installation methods and tools are the same for both.

In addition to traditional trenching, over the years newer installation methods also evolved to minimize the above and below ground surface damage, restoration requirements, and disruption to traffic: plowing, horizontal directional drilling (HDD), and MicroTrenching.

Conduit is not all created equal, and the selected conduit is determined by the type and dimensions of fiber cable you need. Conduit has an inner diameter and an outer diameter; the standard is to refer to the outer diameter when describing the conduit. It is recommended to not fill each conduit subduct more than about 65-70 percent full of fiber cables. This space is necessary to jet, or pull, the fiber through the conduit without damaging the fiber. As fiber technology continues to evolve, it will continue to get smaller. Microfiber cables can fit many strands of fiber in small diameter conduit. MicroTechnology continues to improve. For decades, conduit has been the preferred manner of installing fiber cable underground and now even in aerial applications.

Advantages of Conduit

Many of us are likely unfamiliar with the advantages of using conduit, so it's helpful to review some of the main reasons why conduit is used routinely as an integral part of a datacom system using fiber optic cables.

INSTALLATION ADVANTAGES

- It is easier to install, as it can be put in section by section between access points, with the fiber cable later air-assisted and pushed or pulled in as a continuous run.
- It is also easier to handle unexpected changes in the route, such as having to go around an obstacle as compared to directly placing fiber cable.
- The continuous run of fiber cable can help reduce the cost of splice points and improve the fiber loss budget for the total system.
- The conduit itself can be locatable, which allows the fiber cable to be constructed with only non-conductive dielectric materials and thus also enables easier fiber access.

PROTECTION OF FIBER

- The conduit provides mechanical protection of the fiber cable both during installation of the fiber cable AND over the entire life of the fiber cable.
- Typically, direct buried fiber cables require additional design enhancements to withstand environmental conditions, whereas the conduit can provide that environmental, tensile and crush protection itself. This enables the fiber density to increase significantly for a given outer diameter cable. We see that with the smaller and smaller high-density MicroCables.

PERMANENT PATHWAY

- Conduit provides for an always-present pathway for upgrades and changes whenever you need to make them. For example, you can:
    1. remove and change out a fiber cable that is damaged
    2. swap out with improved technology
    3. simply use the additional empty conduits for increasing capacity
    4. re-route the conduit pathway if there is a change in route

- The "Dig Once" legislation stresses the importance of burying conduit once, with the possibility to add new cables, upgrade existing ones, and increase capacity. By planning for the future via installing extra permanent pathways, the networks are able to adapt to changes more quickly.

COMMUNICATION NEEDS

- It could be for telecommunications, cameras, data transfer, security and many others.

REVENUE OPPORTUNITY

- There is a financial opportunity that network and right-of-way owners are realizing and planning for whereby empty pathways can be used to grant access to difficult right-of-ways or be leased to carriers.

By installing multiple MicroDucts, we can take full advantage of the new high-density MicroCables that fiber cable providers are shrinking and improving year over year.
It is important to realize that there are different types of conduits suited for different purposes:

- In a more traditional system, 1, 2 or 3 standard conduits could be installed together. However, the outside diameter of these conventional ducts is often quite large compared to the smaller outer diameter of MicroDucts now available. While these larger dimensions, perhaps 1.5 inches or 2 inches in diameter, are still used in the industry, they were developed at a time when fiber cables were of much larger diameter with lower fiber density. Since typically only one cable is placed per duct, they actually limit the number of fiber cables that can be placed in a right-of-way.
- Smaller diameter MicroDucts are designed to take advantage of the advances of higher fiber density MicroCables that have much smaller outer diameter. Amazingly, there are 288 and 432 fiber cable diameters on the market on the order of 7 to 10mm, so by sizing the MicroDucts for better space utilization, you can achieve much greater overall fiber density in any right-of-way space.
- Dura-Line manufactures FuturePath, which is smaller MicroDucts that are packaged together under one sheath. There are combinations of FuturePath all the way from 2-MicroDucts, under a single sheath to 24 MicroDucts under a single sheath. Other configurations have mixed sizes of MicroDucts to accommodate both smaller and larger diameter cables.

A well-engineered plan will ensure the application can achieve benefits well in excess of the costs of the plan and the conduit network system deployment. As one example for highway road applications, the U.S. DOT's Intelligent Transportation Systems Joint Program Office estimates the average cost of deploying fiber-optic cable is about $27,000 per mile.

According to the Federal Highway Administration, 90 percent of that cost is when the work requires significant excavation of the roadway. And generally, the actual cost of the conduit network systems is only approximately three percent of the overall project costs.

Distributed Acoustic Sensing in Conduit

Distributed acoustic sensing (DAS) is one type of fiber optic sensing that provides intelligence for a range of markets and applications. It monitors, detects, and classifies acoustic vibration patterns. Small changes are identified from pulse to pulse and by changes in the interferometric signal. The combination of sensing technology with conduit pathway technology is increasing in vertical markets like security and asset integrity, pipelines and smart city applications. In consort with Dig Once policies, installing sensor technology gives more peace of mind regarding the integrity of the cable and can save thousands of dollars from early detections of potential issues.

Optical fiber sensing interrogator companies have been installing commercial sensing systems in conduit for many years and the use is now increasing. Information from several market leading companies has indicated that approximately 50 percent of existing sensing systems are comprised of fiber cables installed within conduit pathways. The multiple reasons for installing the fiber cable in conduit pathways were detailed earlier in this paper, and include tremendous added protection, easier installation, flexibility for changes, repairs, and technology upgrades, as well as added capacity for additional use and monetization. When it comes to distributed acoustic sensing, however, an additional reason is that commercially deployed & highly sensitive systems still work extremely well in conduit.

In an effort to provide the technical community a quantitative validation of the commercial viability of DAS sensing in conduit, Dura-Line collaborated with industry leading optical fiber manufacturer OFS and a leading sensing solution interrogator company Fotech to devise a clever experiment and answer questions that included the following:

- Is standard telecom-grade fiber well suited for DAS installations?
- How does cable design impact DAS performance?
- Can modern state-of-the art and installation-friendly smaller conduits, called MicroDucts, be used for DAS commercially with little to no downside?

While the conclusions from this study can certainly be extrapolated to many of the earlier mentioned markets, the initial market focus was to examine results related to:

- The Security and Asset Integrity Market
- The Pipeline Market
- Emerging Smart City applications

To provide the appropriate stimuli or "events" that were to be detected and monitored, the experiment was designed to include:

- Manual excavation

- People walking
- Leak simulation for both gas and liquid based for buried pipelines

The first results of this experimental effort can be viewed in a FOSA webinar presented to the global community on Feb. 10, 2020, entitled "Breakthrough Research on Distributed Acoustic Sensing (DAS) for Third-Party Intrusion (TPI) monitoring." The webinar presenting the results can be found at https://www.fiberopticsensing.org/p/cm/ld/fid=734&tid=310&sid=3074 and https://www.youtube.com/watch?v=BKhZbpwUofc

The experiments used a novel cable design which was able to directly compare both cable construction and fiber type. Conventional datacom cable was compared relative to enhanced backscatter fiber, and a less acoustically coupled inner construction was compared to a more acoustically coupled inner construction. The MicroConduit chosen used varying levels of inner diameter cable spacing in an attempt to examine this parameter. Finally, the commercial distributed acoustic sensing interrogator system was designed to operate in both an intensity mode and with quantitative phase based mode. All configurations were run with one optical pathway in series via a continuous optical fiber loop designed within the Dura-Line Fiber Optic Sensing test facility to normalize the results. This enabled simultaneous interrogation of all the sensing fiber in all the installed conditions. Third party intrusion testing consisting of both controlled impact and duration of excavation by manual pickaxe and also walking at fixed locations perpendicular to the fiber pathway. For the excavation part of the experiment, perpendicular offsets ranged from 5 to 100 meters and the optical fiber length was varied from 2 kilometers to 50 kilometers.

The data was carefully evaluated by first determination of the "noise" component of the signal to noise (SNR) calculation, and then the SNR was evaluated for each fiber, cable, and installation condition. This resulted in elaborate 2-dimensional plots which characterized the SNR relative to perpendicular offset for each optical fiber path length. The reader is highly encouraged to review these SNR/Offset comparisons within the linked webinar. Through establishment of a commercially conservative SNR threshold of 6dB, FoTech was able to infer commercially acceptable ranges for all conditions. For very short optical path lengths, quite amazing results were demonstrated, such as commercially viable excavation detection at a perpendicular distance as great as 100 meters from the fiber with 2 kilometers optical path length in conduit. Additional results suggested detection at 20 meters perpendicular offset from the fiber at the full optical path distance of 50 kilometers for all conditions, including the use of conduit. The sensitivity impact of using conduit relative to buried fiber cable was extremely low and in the range 0.7 to 1.6 dB. It should be noted that this type of total system sensitivity is more than adequate for perimeter security and/or border applications. Finally, the advantages of using an enhance backscatter fiber, when

warranted, were noted in that the SNR was significantly improved at the longer optical path lengths.

Primary overall conclusions from this innovative research were that there is negligible and acceptable impact of commercial detection capabilities in using the Dura-Line conduit relative to fiber cable buried without the use of conduit. The acoustic signal to noise ratio (SNR) for the fiber cable tested in conduit was more than adequate to provide a reliable and commercially viable signal as attested to by the expertise of Dr. Peter Hayward of Fotech. As a result, the use of Dura-Line MicroDuct conduit provides comparable sensing performance that applies across the board relative to traditional datacom fiber designs, and one may conclude that a comprehensive total solution system including fiber, cable, conduit, and a high-end sensing interrogator & software combination enables commercially acceptable TPI performance, such as that desired for multiple market applications such as perimeter and/or border security.

Summary

Conduit offers many advantages above and beyond simple direct burial of fiber optic cable and for that reason has been and continues to grow in popularity as the preferred best-in-class installation technology for datacom optical fiber cables. Now, based on research that concludes the commercial viability of distributed acoustic sensing in conduit, the sensing industry can enjoy the same robust conduit pathway benefits and advantages with highly sensitive commercial DAS implementation.

Additional Resources

Fiber Optic Sensing Association

"Breakthrough Research on Distributed Acoustic Sensing (DAS) for Third-Party Intrusion (TPI) monitoring, https://www.fiberopticsensing.org/p/cm/ld/fid=734&tid=310&sid=3074 (https://www.youtube.com/watch?v=BKhZbpwUofc)

CTC Technology & Energy

Technical Guide to Dig Once Policies (April 2017)
[DROPBOX LINK] http://www.ctcnet.us/wp-content/uploads/2017/05/CTC-White-Paper-Dig-Once-20170414.pdf

FTTH Council

Dig Once, Dig Smart
[DROPBOX LINK] https://www.ncbroadband.gov/wp-content/uploads/2018/01/FTTHCouncil-DigOnceDigSmart11.pdf

Plastic Pipe

Chapter 14 Duct and Conduit
[DROPBOX LINK] https://plasticpipe.org/pdf/chapter14.pdf

United States Department of Transportation, Federal Highway Administration, Office of Policy and Governmental Affairs

Successful Practices of Broadband Deployment in Highway Rights of Way: Summary Paper May 2013
[DROPBOX LINK] https://www.fhwa.dot.gov/policy/otps/successprac.cfm