Fiber Design for ITS and Signalization Projects

Welcome to the Fiber Design for ITS and Signalization Projects CBT. Select the start button or press Shift+N on your keyboard to begin.

The purpose of this presentation is to answer a request from the districts to address the general practices of communications design as it relates specifically to fiber optic cable and its application in ITS and signal design. The majority of subject matter discussed today is pulled from the following resources and supplemented by hands-on experience and lessons learned.

Our agenda today is to cover a series of topics that fall under the umbrella of fiber optic cable as it relates to our industry: We will cover general properties of fiber optic cable: what it is, how it works, why we use it, and regulations generally important to us.

We will also cover Fiber design concepts: Layout from high-level, specific conditions, and general regulations or standard practices. Design Plans and their different levels of detail and finally, we'll go over some general examples to help visualize what it is we're dealing with.

We will begin at the basic level of fiber optic cable itself. What is it, how does it work, and why do we use it?

What is fiber optic cable? Basically, it's a very pure glass (i.e., very high index of refraction). The optical fiber itself is called the core. Surrounding the core is the cladding, which is also glass but not as pure (i.e., lower index of refraction than the core). There are other components to the general cable, such as the buffer and jacket. But the primary component of fiber optic cable is the optical fiber.

There are two primary categories of fiber used in our industry: multi-mode and single-mode. The main difference between them is the size of the core. Multi-mode can be anywhere from 50 – 62.5 micrometers in diameter, while single mode is around 9 micrometers. You might think that the large core in multi-mode fiber can carry more data, which makes sense… Well, yes and no. It's true that multi-mode can carry more "modes" or wavelength, but not when it comes to distance and throughput, single mode wins.

Multi-mode fiber's larger core diameter allows for multiple wavelengths to travel along a single optical fiber simultaneously. However, due to angles of reflection and refraction between the core and cladding, signal loss and noise is introduced, which adds attenuation and in turn reduces the overall distance the light wave can travel.

The single mode fiber core only allows one wavelength to travel along a single optical fiber. Because of this, a much focused laser can be used to direct the light wave down a smaller diameter core which allows for all-internal reflection and no refraction into the cladding. Thus, introducing less attenuation so that the light wave can travel much farther.

For the purpose of this presentation, we are going to focus on single mode fiber optic cable…since this is what's used more than 99% of the time. Multimode fiber is still used, but primarily for very short distances or for communications between devices that are in the same room or cabinet.

Fiber optic cable comes in many different configurations. Depending on the application and environment, certain configurations and strengthening or weather-proofing materials may be used.

So, how does it work? Basically, pulses of light are transmitted through a glass medium to send messages from Point A to Point B. These pulses of light are then interpreted as binary ones and zeros by the receiver at the other end.

These ones and zeros are then converted by the receiving device into something we can understand… CCTV video streams, messages on DMS signs, lights on a traffic signal, or whatever application you want.

But why fiber??? Fiber offers extremely low loss over very long distances, with high data throughput, enhanced security measures, and resistance to sources of electro-magnetic interference.

There are a number of important regulations and standard practices related to fiber cable; the most important ones are summarized here to build upon for use in later examples. Those being: Terminology, Color Code, and The Rule of Separating Fiber Optic Cable from everything else.

Some important terminology to know is the difference between the fiber backbone, distribution, drops, and splices/terminations. The Backbone is the main circuit that carries data from multiple network segments, and should be designed with the highest capacity. It is very important that measures are taken to protect the Backbone at all times.

The Distribution circuits branch off of the Backbone and carry data to and from smaller segments of the network. Drop circuits branch off of Distribution circuits and carry data to and from the local equipment. Splices and terminations are basically bridges and endpoints of the FOC itself.

This is the TIA-598-C Standard for "Optical Fiber Cable Color Coding", formerly ANSI/EIA/TIA Standard 598. This color coding scheme is used to identify both fibers and fiber buffers. Also note that not all fiber cables have all of these colors. The Position and Jacket Color depends on the design of the FOC cable itself. Notice that the bottom two examples are both 72-count fiber; however, their designs are different.

Here's an example that shows the connection between the **Black** fiber in the **Blue** buffer and the **Orange** fiber in the **Orange** buffer. The table shows different ways to represent this connection. Notice that both cables are 72-count fiber, but because their designs are different, the **Black** fiber on the left is in Position #8, whereas the **Orange** fiber on the right is in Position #8.

Here are a few things that need to be considered when designing a F.O.N: Minimize exposure to damage, Design with future growth in mind, identifying any existing or potential redundant routes in the network, and know how much signal strength (or loss) the network as a whole can handle to accommodate all of these considerations.

Protecting the Backbone isn't always easy. Underground cables are typically less susceptible to damage than aerial runs or entry points to cabinets and pedestals, but they do get damaged from time to time. The steps to take to help minimize damage to these cables depends on how and where the cable is installed (e.g., directional bore vs. trenching and rural/highway vs. urban/metro).

Conduit provides physical protection from the elements, and some animals, over direct buried fiber. It's more expensive up front, but allows for future expansion without additional construction. During design, you may find that desired locations and buried depths are limited. These restrictions should be taken into consideration to help minimize damage that future projects could cause.

One of the most helpful tools to help minimize damage is accurate as-built drawings. This documentation, coupled with tracer wires, provide locate personnel the ability to properly mark fiber runs. Warning posts and signs, as well as warning tape in the trench, are typically a last-ditch effort to save a cable from the well-known "backhoe fade".

Network capacity is basically "how much traffic (or data) the network can handle". This applies to any given network path or fiber optic link. Keep in mind that Network Capacity is **NOT** a function of the fiber itself, but rather the network hardware that's it's connected to. The price differences between 1Gig, 10Gig, and 100Gig hardware may be large, so we allocate the appropriate capacity based on where it is needed the most.

Earlier we discussed Backbone, Distribution and Drop circuits. Another set of terms for the same thing is often used when discussing capacity. These are Core, Distribution and Access (or edge) respectively.

Think of Network Capacity as a plumbing analogy – sizing typically follows a simple hierarchy. The Core or Backbone should have the largest capacity, followed by distribution, and then access. That being said, with the current prices of 1Gig switches, it may be reasonable to have 1Gig all the way to the edge. It's hard to justify using 100 Megabit switches at the edge when 1Gig switches cost about the same.

At the same time, the price differential between 1G and 10G can be fairly large. We have to balance the network capacity requirements as well as the overall cost. Currently 1Gig is the sweet spot in the market, but this may change over time as technology advances.

Redundancy is probably the number one design concept in communications. We always strive for zero downtime. The only way to achieve that is to build redundancy into every layer of the network, starting with the physical cable.

While fiber is at the top of the communications food chain, it still has many natural enemies - the most common of which is the backhoe. No matter how well you hide it or mark it, the backhoe will still find it on occasion. Along the same lines would be directional boring machines. It takes a little more skill to hit the fiber, but it certainly happens.

Guardrail installation will take out any fiber that is not buried deep enough. And perhaps the most unassuming of these enemies is the rodent. They may be cute, but troubleshooting your cable to find this damage can be very cumbersome.

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So, how can we best protect our network from these fiber predators? By building redundancy into our physical networks…typically in the form of rings. You don't have to use a ring, but it is by far the most common. However, any secondary path will work, but having a physically diverse path is preferred.

This is an example of a redundant ring design with Backbone, Distribution, and Drop circuits. If a backhoe or bore rig finds your network backbone, the network equipment will search for a failover path to restore communications. This is called convergence. We measure the effectiveness or efficiency of the network's convergence by: the time it takes to restore communications, and the amount of data lost during convergence.

Common interruptions to service are: bad jumper cables, bad ports in the switch, bad GBIC (or laser), power outages or damage, and random acts of motorists.

Less Common, but more critical interruptions are: Backbone or Distribution segment cuts –which should re-route the network, and Drop circuit cuts – with this, you lose local network access, but the Backbone and Distribution circuits should still communicate normally.

When designing or reviewing the design of a communications system involving fiber optic interconnects, be sure to consider ways to limit exposure. A common misconception is that the design of a fiber interconnect system between signalized intersections is the same as a copper one. In principle, they are the same since the intent is to provide communications between the cabinets. However, fiber interconnect (as opposed to copper interconnect) is typically just a component of the overall interconnect.

In other words, as copper interconnect is specifically used to communicate between signal cabinets only, a fiber interconnect is usually a small piece of the overall communications traffic that is carried along the FIBER OPTIC NETWORK. As such, it is common to follow a drop cable configuration…

There are three primary categories of loss (also known as attenuation): Distance, Splices, and Connectors. Section 633-3.1.8.1 of FDOT's Standard Specifications for Road and Bridge Construction provides the requirements for testing ALL fibers, end to end, to make sure the appropriate levels of attenuation are realized. NOTE: When designing a FIBER OPTIC NETWORK, you should minimize the number of splices needed AS MUCH AS POSSIBLE. We will touch on this later in this CBT.

Let's look at an example of link loss. Consider a fiber optic network design project that will cover a distance of (5 km), and requires (3 fusion splices), and that the fiber be properly terminated at both ends.

Here's a sample Link Loss Budget spreadsheet with the numbers given plugged in. Given these requirements, the overall link loss budget is between 2.8 and 3.3 dB, depending on the wavelength. For this example, both multi-mode and single mode fiber will work since the link loss budget so low. **However**, keep in mind that the 600 Series of the FDOT Standard

Specifications for Road and Bridge Construction requires single mode fiber since the intent is for outside plant installation and consistency statewide.

Next, we will cover Design Plans, their components, and what should be included in them.

In the Design Plans, there are (6) primary types of detail sheets that are important to us for ITS and signal systems that relate to fiber optic cable These are the: Plan Sheets, Network Block Diagram, Splicing Details (or Splicing Diagram), Port Assignments, Link-loss Budget Details, and Wiring Diagrams. Each of these detail sheets provides insight into how communications will be routed around the FIBER OPTIC NETWORK, and it is very important that you understand this when designing or reviewing a fiber optic network design.

Plan Sheets are a very important part of the Design Plans. There are a lot of details in these plans; however, for the sake of time we will only focus on the items that pertain to the fiber optic cable Our primary focus will be on conduit, pull-boxes, fiber itself, and splicing or termination hardware. We will review the details of each during our Examples section. But for now, we will overview what is typically shown on these plan sheets, and simply point out what is what. These items are: pull-boxes, fiber runs, and splices or terminations.

A Network Block Diagram in essence is the Project Layout Sheet, but specific to the general communications paths of the project. This offers a high-level view of the network topology. It provides general communications information such as backbone, distribution segments, logical routes, and the equipment associated with each drop.

Although this information can be obtained by studying the rest of the Design Plans, it is helpful to have a bird's eye view of the overall network. A quick look at this diagram reveals that there are (5) CCTV cameras associated with this Distribution segment.

The Splice Diagram is where we actually capture the detailed levels of fiber optic cable design. These details show where, and how, the fibers are connected.

Port Assignments take us to the final level of detail with regards to fiber optic cable These details simply identify where each individual fiber is terminated. These details are very helpful for tracing each fiber's path end to end. It's also a helpful for verification during design, and troubleshooting during construction or maintenance.

The Design Plans should include the Fiber Design Plans: Link Budget for ALL communications routes associated with the project.

When designing a FIBER OPTIC NETWORK, you should take into consideration the Failover Link-loss Budget:

1) How far is my fiber path?
2) What does the path entail?, and
3) How much attenuation (or loss) is associated with that path?

Why is this information useful? The allowable loss is used to determine the type and power requirements of the optical transceivers in your fiber optic network devices.

Let's consider the first route in the table, using 1310 nanometers: Looking at the optical specifications for a "typical" 1 Gigabit Small Form-Factor Pluggable / Gigabit Interface Converter for SMF, we see that the transmit power can be anywhere from -9.5 to -3 decibels below 1 miliwatt. <u>**For loss budgets, you should always use the minimum transmit power to help guarantee communications, and account for a certain level of damage that is sure to occur in the future.**</u>

The receiver can detect, AND UNDERTAND (which is very important), a signal as low as -20 decibels. The difference between the minimum transmit or Tx power and the minimum receive or Rx power is a Loss Budget of 10.5 decibels. This is well within our allowable loss of 3.3 decibels @ 1310 nanometer. Therefore, this Gigabit Interface Converter (GBIC) is a good choice.

Another thing to pay attention to is the amount of loss associated with the splices and connections, which is the “Insertion Loss”. The chosen GBIC allows for a total of 6dB of insertion loss. This is important to note because not all losses are the same. Although this GBIC allows for 10.5dB of loss, a mere 7dB due to excessive splices can be an issue. Always keep this in mind.

If the Link-loss Budget is close to the allowable loss of the GBIC, you need to use good engineering judgement to determine whether to stay with that GBIC or upgrade to the next level. Keep in mind that the price difference may be insignificant.

Wiring Diagrams show actual connections of all components at the cabinet or device locations. As you can see in this diagram, wiring other than fiber may be included in this detail.

Finally, we arrive at the Examples portion of the presentation. The major components important to us today are: fiber optic cable, Connection Types (splices and terminations), and Hardware specific to fiber (enclosures, patch panels, etc.), and Infrastructure for fiber (conduit and pull boxes).

NOTE: Some of the examples to come are courtesy of District One’s general training documents that they developed. These slides concisely capture each of the components laid out in our list…, we’ll quickly discuss them and then move on to stage two of this example section.

Section 633 in the FDOT’s Standard Specifications for Road and Bridge Construction covers communication cable, including fiber optic cable Here are a few key subsections to note. The Specifications only reference Single Mode Fiber in the fiber optic cable section, a 12 fibers per buffer is the standard, “unless otherwise shown in the Plans”. This is important to keep in mind.

This is the general layout of the Basis of Payment for fiber optic cable in Section 633. For the Basis of Payment structure, we add additional levels of detail to specify what we want. These details include the: Operation, Location, and Fiber count of the cable. Note that the Basis of Payment structure identifies groups of “ranges” of fiber counts, NOT specific counts. It is very important to identify the specific counts in Pay Item Notes, AND throughout the Design Plans.

Here’s the Basis of Payment structure for fiber connections…not as many options. It’s important to note here that these connections are intended to be used “per fiber”, NOT “per cable”. If the Design Plans show complete splicing for a 72-count fiber optic cable, then the Pay Item quantity should reflect (72), not (1).

Here’s the one for connection hardware…this one has a lot more options to choose from. The picture to the right is of a Splice Enclosure (sometimes referred to as “closure”). This is a hardened device that houses splices and splice trays. The hardened case protects the splices from handling and environmental elements.

In all cases, “pre-terminated” refers to a connector being available at both or either end of the hardware. It is important to note that on all pre-terminated cables, you need to know which type of connector to specify. Otherwise, you won’t be able to connect to anything in the field.

Here are more examples of hardware. There are different options for connectors and patch panels. They MUST match up.

Now we move on to conduit. There were separate specifications and pay items for conduit used for ITS, Signalization, and Lighting, but now they’re all included in Section 630.

An important difference between fiber conduit and other conduits is that standard fiber markers (or route markers) are expected to be included in the pay item by default. This has always been a typical requirement on ITS projects, but may be new to some. The markers are only required for fiber optic cable installations. Don’t forget to include detailed information on what the fiber/route markers say in your general notes and Design Plans.

Here’s an example of the Basis of Payment.

And last but not least, are pull boxes. Section 635 gives some minimum dimensions for your typical applications. Depending on the application, these may be referred to as pull boxes, splice boxes (or vaults), or junction boxes.

There are three major sizes depicted in the Basis of Payment. If the design requires larger sizes, they must be shown in the general notes and Design Plans. If an atypical size is not specified, then the minimum dimensions in the Standards and Specifications will govern.

There are links available for your reference and contact information if you have any questions. That information can be located on the resources page.

This concludes the training on Fiber Design for ITS and Signalization Projects. If you have any questions, please contact the FDOT State Traffic Engineering and Operations Office – TSM&O Program.