Passive Optical Components in Harsh Environments

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This paper will discuss the importance of quality passive fiber optic components in a harsh environment. It will focus on the importance of environmental testing and certification of components used in an outside plant fiber optic network. It will also point out how high quality, dependable reliability and consistent performance are key factors to designing and maintaining a passive fiber optic outside plant network. Industry standards and manufacturing practices covered by the Telcordia GR-326, GR-1209 and GR-1221 testing procedures will be examined.

The value of passive optical components, led by fiber optic cable assemblies in harsh environments reached $711 million in 2015. Transmitter/receiver units held a 43% percent share of total components consumption in 2015. The total use of fiber optic components used in all harsh environment applications is forecast to increase at an average annual growth rate of 14.6 % from $1.3 billion in 2015 to $2.6 billion in 2020.

Historically, the market value of harsh environment fiber optic components and devices has been dominated by military/aerospace-qualified components, with a 68% share back in 2010. It is forecasted that the military/aerospace application's market share will decrease over the forecast period (2015-2020). However, it is expected that glass-based optical fiber will increase in opportunity in commercial/industrial applications and the Telecom and Wireless market.

What is a Passive Optical Network?

First of all, let's understand the meaning of a Passive Optical Network (PON). PON is a fiber telecommunications network that uses point-to-multipoint fiber in which unpowered optical splitters are used to enable a single optical fiber to serve multiple end-points. A PON consists of an Optical Line Terminal (OLT) at the service provider's central office and a number of Optical Network Units (ONUs) or Optical Network Terminals (ONTs), at the end user. A PON reduces the amount of fiber and central office equipment required when compared to point-to-point architectures. A passive optical network is a form of fiber-optic access network, but can also be found in the form of a Full Service Access Network (FSAN). In most cases, downstream signals are distributed using fiber optic splitters to multiple users. Upstream signals are combined using a multiple access protocol, typically using Time Division Multiple Access (TDMA). Wave Division Multiplexing (WDM) PON is also a variation used in Passive Optical Networks. PONs provide higher bandwidth and better security than traditional copper based access networks.

WDM PON

Separating signals into multiple wavelengths WDM-PON can increase the capacity of what can be transmitted through a Passive Optical Network. Sending separate CWDM and DWDM wavelengths to specific Optical Network Units (ONUs) allows for multiple virtual PON's. This design can co-exist on the same physical infrastructure as standard PON. This has been proven to work well for Multi Dwelling Units (MDU's) and business class locations. Unfortunately, there is no common industry standard for WDM-PON.

Passive Optical Network Design

When designing Passive Optical Networks, fiber optic splitters are a key component to a successful Fiber to the "X" (FTTX) network. Starting with a single fiber at the central office and splitting it 8x, 16x, 32x, 64x (and some have even gone as far as splitting it 128 times) allows you to reach numerous customers while keeping your fiber cable plant costs down and central office footprint to a minimum, when compared to true point to point architecture. Whether you want to run BPON, GPON, 10GEPON or the Next Gen PON, the Passive Optical Networks will need to use fiber optic splitters and potentially WDM's in the harsh outside plant environment.

Prior to FTTX deployments, the majority of all Optical Components were installed in controlled environment buildings and enclosures. These can be expensive to operate and maintain. However, pushing the splitters further out into the fiber network helps to eliminate the amount of fiber panels needed at the central office and reduce the overall foot print. The splitters that are typically deployed in a PON design use equal split ratio Planar Lightwave Circuits known as PLC Splitters. The optical input power is distributed uniformly across all output ports. Splitters with non-uniform split ratios, known as concatenated or tree splitters, are also available, however, these types of splitters are usually custom-made and cost a premium.

Due to the highly controlled processes and sometimes proprietary materials used in manufacturing optical components, they are able to be installed in most outside plant applications. Passive components can be deployed above grade in pedestals and below grade in splice closures or terminals in vaults, mounted on poles, hung in aerial closures and in outdoor enclosures on the exterior of a building. In an OSP environment they could see extreme temperatures depending on their geographic location. Whether they are deployed in the hot desert of Arizona and Mexico where it can reach 120f/49c degrees and higher, or in Alaska where temperatures can go below -40f/-40c, passive optical components need to be able to perform optically and mechanically in these extreme elements. Another element to worry about is rapid temperature change. Imagine waking up in the morning at 7:30 a.m. with the temperature at a frigid -4 degrees. You bundle up and go outside and just two minutes later you notice that the frigid air is not quite so frigid anymore. You look at your thermometer and the temperature has shot up to 45 degrees. That's right, a temperature increase of 49 degrees in just a few minutes! Hold on, there is more to this story. After the temperature climbs all the way to up to 54 degrees by 9 a.m., it then quickly drops down 58 degrees in 27 minutes to -4 degrees again. Sounds impossible, but it's not. This actually happened in Spearfish, S.D. back on January 22, 1943. This is rather an extreme example and certainly not typical. However a quick temperature change can cause a catastrophic failure to inferior optical components. This is why it is so important to do your research and investigate the quality and reliability of the optical components that will be used in an outside plant fiber optic network.

One thing to look for when it comes to high quality and reliable components is accreditation and certification to known testing plans. Some of the most trusted testing plans for fiber optic components come from Telcordia Generic Requirements (GR). These are complete testing plans for specific products such as fiber optic cable, optical components and fiber terminations. The GR’s are intended for users or purchasers, and manufacturers, suppliers, or vendors of singlemode fiber optic products. Users and purchasers of these products may include telecommunications service providers and telecommunications equipment manufacturers. These GR’s provide guidance about features that are necessary or desirable for such products, and presents performance criteria that these products should meet.

GR Test Plans

Generic Requirements for fiber optic cables fall under GR-20 and GR-409. Fiber optic cable terminations fall under the GR-326 test plan. Optical components such as splitters, WDM, CWDM, DWDM and Circulators (to name a few) all fall under GR-1209 and GR-1221. Some of the requirements within each GR can refer to other GR specs with in the documents. For instance within the GR-326 requirement you must use a cable that is GR-20 and/or GR-409 certified to be fully compliant. Just as in GR-1209 and GR-1221 you must use fiber that is GR-20/GR-409 compliant, along with any terminations used in conjunction with optical component are expected to be GR-326 compliant. All Telcordia Generic Requirements depend heavily on accepted national and international standards activities such as International Electrotechnical Commissions (IEC), International Telecommunication Union (ITU), Insulated Cable Engineers Association (ICEA) and the Telecommunications Industry Association (TIA).

Quality Fiber Optic Cable

When designing a quality network it is important to start with a quality fiber optic cable. Verifying that it has been put through the complete GR-20 and/or GR-409 test plan and has also been fully documented and reported to have passed all the objectives or requirements within the test plan. Some of the important requirements within

GR-20 and GR-409 are cable construction, cable markings & packaging, cable materials, jacket requirements, mechanical requirements, environmental requirements, electrical protection requirements and optical performance requirements. For an outside plant fiber network, all requirements are important. The mechanical, environmental and optical performance focus is on areas that can be most affected by extreme temperatures.

Reliable Fiber Optic Termination

Along with using a quality fiber optic cable, verifying the reliability of the termination on that cable is not something you want to overlook. Termination of fiber optic connectors on to fiber optic cable has become a very important part of the outside plant fiber optic network. As noted in the Passive Optical Network (PON) design, more and more components are being deployed in the field in uncontrolled environments that will see extreme temperatures along with rapid temperature change. It is not unlikely for the temperatures inside of some enclosures, such as an above ground pedestal or an aerial terminal, to be 10 to 20 degrees hotter or even cooler than the outside air. Telcordia GR-326 refers to the requirements for singlemode optical connectors and jumper assemblies. This covers multi-fiber cables that could be terminated directly in a cross connect cabinet, or inside of a Smarterminal or pedestal. It would also include the simplex and duplex patchcord jumper assemblies that are used in outdoor closures, at an ONT or when terminated on an optical component like a splitter or WDM.

To achieve a reliable fiber optic termination there are two main factors that contribute to a quality termination. One is the connector components themselves and the other is a controlled repeatable termination process.

Another important factor is the intermateability of a connector. This assures that the product purchased from one vendor will function satisfactorily when intermated with a product manufactured by another supplier. The verification is basic dimensional requirements. It does not however determine the use of specific designs or materials.

Key Factors to Quality Fiber Optic Terminations

Listed below are details to keep in mind when selecting quality connectors for fiber optic terminations.

- **Ferrule**

  Quality Zirconia ceramic material, precision tolerances with tight concentricity for improved fiber core alignment keeping insertion loss to a minimum, high strength and durability for repeated matings, resistant to aging and chemicals, high pull out force from holder.

- **Ferrule Holder**

  Non-corrosive material resistant to salt spray and chemicals, tight tolerance, high ferrule pull out force.

- **Spring**

  Consistent spring force that meet the conditional limits specified by the TIA/EIA FOCIS documents, non-corrosive material resistant to salt spray and chemicals.

- **Housings**

  Non-corrosive metal and plastic materials resistant to salt spray and chemicals especially ones found in the Immersion/Corrosion test in GR-326 4.4.4.5.

- **Strain Relief and Boots**

Reliable high strength strain relief pull out force of fiber and jacket retention, bend limiting boot, non-corrosive metal and plastic materials resistant to salt spray and chemicals, especially ones found in the Immersion/Corrosion test in GR-326 4.4.4.5.

The termination process is also a very important factor to meet all requirements in the GR-326 test plan. Below lists some important factors in terminating fiber optic connectors.

- **Cleanliness**

  The cleanliness of the materials, tools, workspace and handling of the fiber are all very important. Contamination during the process reduces consistency and repeatability of the process.

- **Cable Preparation and Stripping**

  Using high quality cable preparation and fiber striping tools can help to eliminate the chance of fractures to the fiber unseen by the human eye. A nick to the cladding of the glass can later become a large fracture causing the fiber to potentially break. This would typically show up during the GR-326 thermal cycle test. The temperature cycle reaching -40c to +85c for 21 cycles over 168 hours will stress the fiber and most likely cause fiber damage or catastrophic failure. Another important detail is the cable and fiber strip length. There needs to be the right ratio of fiber length to Kevlar length for that specific connector. If the fiber is prepped short with excess slack of Kevlar this could allow the jacket to pull back from the connector putting all the stress on the fiber itself and possibly breaking it.

- **Epoxy Curing**

  The Epoxy that is used can make or break a quality termination suitable for outside plant applications. The slightest foreign chemical or particles on the glass fiber or inside the ferrule can reduce the adhesion properties of the epoxy to the fiber and the ID of the ferrule. That is why cleanliness is so important as noted earlier. If the adhesion bond between the glass and ferrule are not adequate the fiber could move in relation to the ferrule during temperature cycling. This goes for connectors in the field as well. As they are subjected to extreme temperatures, and due to the expansion and contraction of the different materials, fiber can pull back from the end face causing increased insertion loss or reflections. Another issue that is often over looked are air bubbles or epoxy voids inside the ferrule and ferrule holder when the fiber is terminated into the ferrule. A bubble or pocket of air near the back of the ferrule where the fiber is inserted can create havoc on a fiber termination. As temperatures increase or decrease, the air pocket puts stress on the fiber due to the indifferences of expansion and contraction of the ferrule to fiber potentially causing insertion loss or a possible catastrophic fiber break failure. Using premixed, degassed, frozen epoxy can help to reduce the chances of this happening.

- **Cable Strain Relief**

  One of the most common failures for mechanical testing is not having enough cable strain relief to the connector. During the vibration, flex, twist, impact and proof tests in GR-326 this is where the strain relief will be subjected to some stringent tests. This will determine if the cable jacket that is supposed to be secured to the connector is adequate. If the strain relief starts to fail, it will work its way out of the back of the connector and can expose the fiber itself, or worse, the Kevlar can slip out from the crimp and then all the force is then applied to the fiber itself. During the proof test, a 15lbs weight is hung on the jacketed cable that is terminated into the connector under test, if the Kevlar pulls out of the crimp typically you'll have a catastrophic fiber breakage due to the required weight applied during this test. As mentioned earlier in the cable preparation and stripping section, strip length is important for good strain relief. Too much slack on the Kevlar could allow the cable to pull back on the connector putting all of the strain on the fiber before the Kevlar slack starts to take on the load. This will most likely cause the termination to fail.

Termination of fiber optic cable in a controlled, manufactured environment is strongly recommended. Terminating fiber in the field will not allow for the cleanliness and control of process that is required for a high quality termination. Factory terminated assemblies and pre-terminated optical components is the safe way to go when deploying OSP networks. Using a "plug and play" design will help to eliminate failures due to termination or component failure in extreme environments.

Quality Passive Optical Components

When it comes to Passive Optical Components Telcordia GR-1209 & GR-1221 are the requirements that should be followed. As mentioned earlier, the fiber used in optical components should be GR-20 and/or GR-409 certified. If the optical component will have connectors on it then the terminations are expected to be GR-326 certified. When testing optical components that are terminated with connectors they are expected to go through the full GR-1209 & GR-1221 requirements with the terminations included. This will subject the complete assembly to the temperature extremes of the test requirements. The fiber and the fiber jacketing will need to handle these temperatures while being monitored and tested at the temperature extremes. This is why using quality fiber, reliable connector components and a controlled termination process with passive optical components is important when deploying them in an OSP environment.

GR-1209 Requirements

GR-1209 environmental and mechanical requirements are designed to demonstrate the short term operational performance of passive optical components and were chosen to be compatible with those specified in GR-1221-CORE, which is used to demonstrate the long-term reliability of components. This is done to minimize the use of two different sets of samples to accomplish short-term performance and long-term reliability evaluations.

Key Factors to Quality Passive Optical Components

- **Insertion Loss**

  When it comes to splitters and WDM's there can be significant amount of light loss or power loss as compared to the fiber itself or the terminations used on fiber cables. Typical singlemode cable has a dB/km loss of 0.35dB at 1310nm and 0.25dB at 1550nm. Typical connectors have a loss of 0.35dB, however there is one company that will guarantee a maximum insertion loss of 0.20dB per connector with a typical loss of 0.15dB. Using premium optical components with premium low loss terminations will reduce your total insertion loss budget and allow you to extend the fiber network further.

- **Return Loss**

  Optical Return Loss is the % of power reflected back from a particular point in a light path. It is measured as a negative decibel (dB). Reflections can be caused by any impurities in the core or cladding, micro-bends or macro-bends and any splices or terminations. A quality optical component should have minimal return loss.

- **Uniformity**

  Uniformity is the maximum insertion loss difference between one input or common port and all the outputs ports. The tighter the uniformity the better. This helps to ensure that the transmission power at each output port is within a specified range. This will allow for simpler network design.

Optical splitters deployed for a WDM PON system have additional performance criteria such as Optical Bandpass, Wavelength Isolation, Wavelength Stability, Directivity and Polarization Dependent Wavelength (PDW). More information on the additional criteria can be found in the Telcordia GR-1209 & 1221 documents.

GR-1221 Requirements

The requirements for GR-1221 outline environmental and mechanical test requirements to ensure long term operational performance. Listed below are some of the reliability test requirements and the importance for compliance.

- **Mechanical Integrity**

  When it comes to Mechanical Integrity, there are four main tests: Mechanical Shock, Vibration, Thermal Shock and Fiber Integrity. These tests are designed to ensure reliable optical performance when subjected to common conditions during storage, transportation and installation.

- **Endurance**

  Optical Endurance has seven main tests which are the High Temperature Storage (Dry), High Temperature Storage (Damp), Low Temperature Storage, Temperature Cycling, Cyclic Moisture Resistance, Airborne Contaminants, Water Immersion and Salt-Fog. The tests simulate an accelerated aging effect to expose the component to weaknesses that may come about during the estimated lifetime of an optical component. The moisture coupled with the thermal cycle temperature levels will have an effect within the optical component, especially the epoxy which provides a high level of structural integrity to the waveguide chip, ferrule and filter adhesion in the final package.

Stay Away From Imitators

When it comes to designing an optical network and selecting the components that will be used during the build… do your homework and make sure you are selecting high quality, reliable components. Would you buy a Rolex watch from some back alley store or on an internet site that sells everything under the sun at a fraction of the price? My gut feeling is the watch would probably be an imitation. Stay away from imitations! There are quality suppliers of optical components, but there are even more suppliers that are not so good. They use lesser quality components and have not made the investment to do the testing or taken the time to truly qualify the complete assembly. They most likely do not maintain the high level of consistency or repeatability in their processes, which is required when the component will be used in a harsh environment. There are a lot of manufactures that claim they have been tested to or are compliant to GR-1209 & 1221, but the truth is in the reports, or in some of their cases, lack of reports. If an optical component was to fail in the field this would cause unexpected outages and could affect numerous customers at once. It would then require high level technicians to troubleshoot and repair/replace the failed components creating unexpected expenses that were not budgeted for. ***The less expensive component that has not been fully qualified will most likely cost more in repairs in the long run***.

Summary

Passive Optical Networks can reduce fiber optic network build costs by pushing the optical components further into the OSP network, eliminating the need for climate controlled hubs using electricity to power them. All components must be able to handle the harsh environments and extreme temperatures of an OSP network. Selecting high quality, reliable, tested components is the only way to ensure the performance and dependability needed in today's market.

References

1. Telcordia GR-1209-CORE, "Generic Requirements for Passive Optical Components", Issue 4, September 2010

2. Telcordia GR-1221-CORE, " Generic Reliability Assurance Requirements for Passive Optical Components", Issue 3, September 2010

3. Telcordia GR-326-CORE, "Generic Requirements for Singlemode Optical Connectors and Jumper Assemblies", Issue 4, February 2010

4. Telcordia GR-20-CORE, "Generic Requirements for Optical Fiber and Optical Fiber Cable", Issue 4 July 2013

5. Telcordia GR-409-CORE, "Generic Requirements for Indoor Fiber Optic Cable", Issue 2, November 2008