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GR-326: Strengthening the weakest link in modern day Ultrafast Optical Networks

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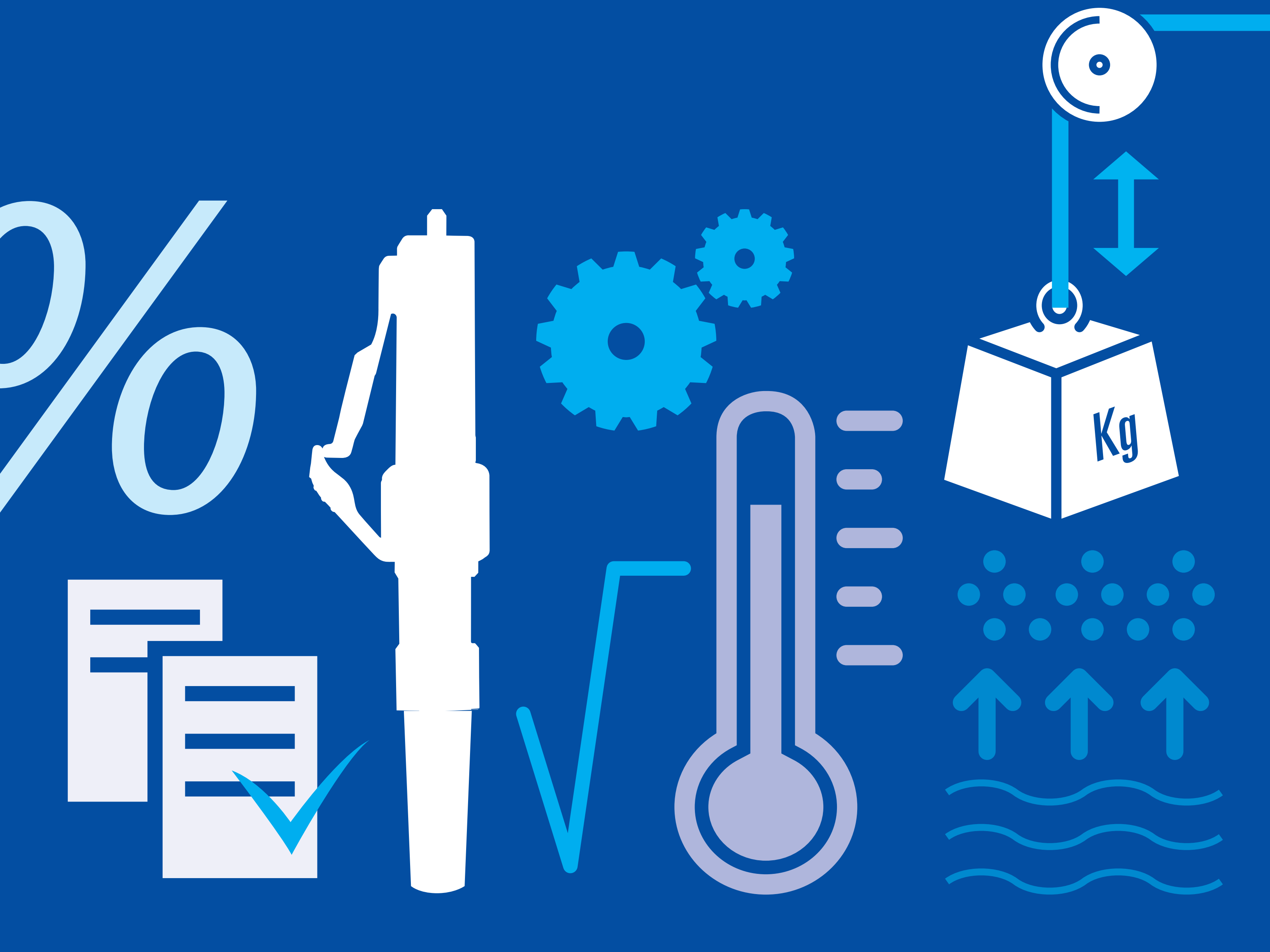

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GR-326: Strengthening the weakest link in modern day Ultrafast Optical Networks

Contents

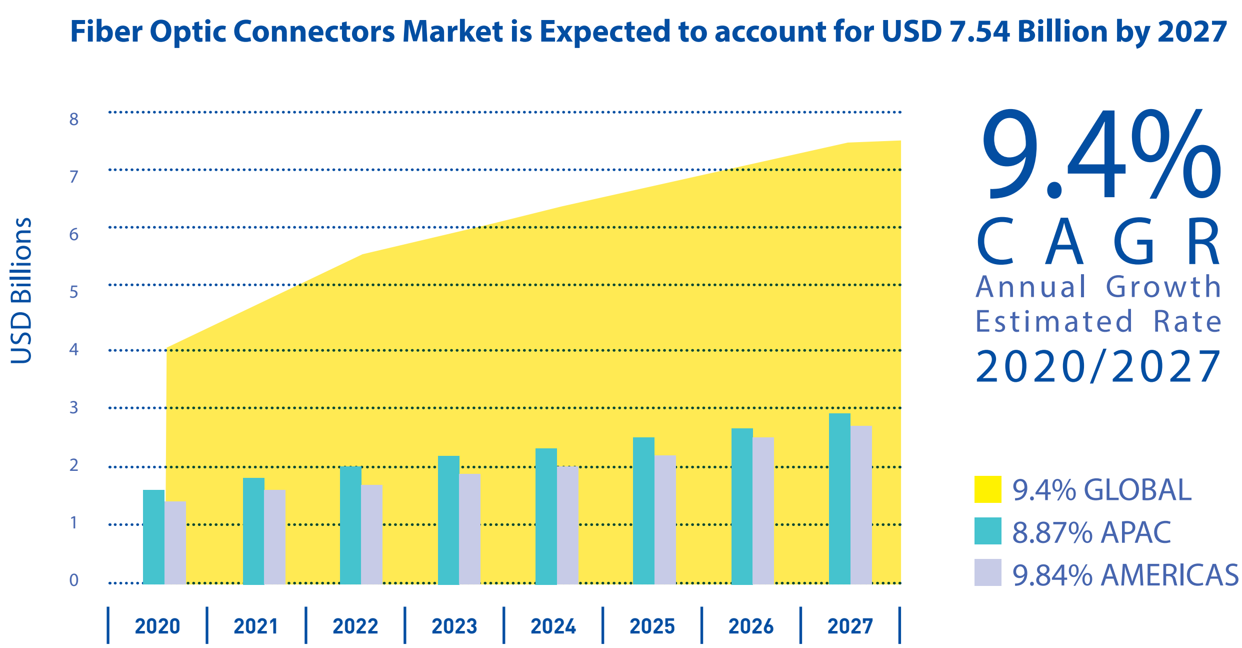
Executive Summary

The global market for fiber optic connectors is expected to nearly double from $4.0 billion to $7.5 billion, at compound annual growth estimated rate (CAGR) between 8.6% and 9.4%, for the period of 2020 - 2027. The Asia-Pacific market (APAC) for fiber optic connectors is estimated to grow from $1.6 billion to $2.9 billion, at a CAGR of 8.87%, for the period of 2020 - 2027. The Americas market for fiber optic connectors is estimated to grow from $1.4 billion to $2.7 billion, at a CAGR of 9.84%, for the period of 2020 - 2027. These estimates were reported in May 2021 by research conducted for Business Wire News. The forecasted trend is shown in **Figure 1.**

Growth in the global fiber optic connectors market is driven by a demand for higher bandwidth, the rapid adoption of fiber optic technologies (including the commercialization of 5G networks), the expansion of telecommunication services, increased government funding for network infrastructure, decreased fiber optic installation/equipment costs, and an increased market for optical systems. Fiber optic connectors connect transceivers with optical fibers for numerous applications. Today, connectors enable the application of optical technologies, such as lasers for medical applications (ex: endoscopy), which permits less invasive diagnoses and treatments of illnesses. Use of connectors also drives high power lasers for industrial applications. Connectors are used in laser-guided weapon systems and commercial vehicles. However, the original market for fiber optic connectors remains the largest by a significant margin.

As global demand for optical connectors increases, so does supply. When one visits trade shows, one will find numerous suppliers offering basic components to finished cable assembly products. One key fact that end users have discovered in recent years is that **'not all connectors are created equal'**. The quality, reliability, and performance of optical components and cable assembly products, such as patch cords, are assured by selecting the best components and by terminating and polishing with the best equipment and procedures. These components and procedures must assure that the jumper assemblies meet or exceed the requirements of all relevant industry specifications, such as the internationally recognized GR-326 standard. This paper describes the relevance of such criteria with the applicable industry specifications, as well as the importance of the physical parameters and how they relate to the performance of the jumper assembly.

Figure 1 Increase in Global Demand for Fiber Optic Connectors — Source: Data Bridge Market Research 2020



Introduction to GR-326

GR-326-CORE (Generic Requirements for Single-mode Optical Connectors and Jumper assemblies) was initially established by Bellcore and continues to evolve as one of the more popular standards in the telecommunications industry. Bell Communications Research, or Bellcore, was established in the early 1980's by the Regional Bell Operating Companies (RBOC'S) upon their separation from AT&T. Bellcore served as the research and development, training, and standards setting arm for the RBOC's. Following a divestiture in 1996, Bellcore was officially renamed Telcordia Technologies in 1999. In 2012, Telcordia was acquired by Ericsson.

GR-326-CORE was written as part of Telcordia's General Requirement series to be compliant with the Telecommunications Act of 1996 and was intended to be the industry standard for long haul high-speed applications, such as telecommunications and cable TV. There have been a total of four issues of GR-326; its initial release, Issue 2 from December 1996, Issue 3 from September 1999, and the current issue (4) from February 2010. Telcordia's standards for any particular release were developed from the expressed needs of the Telcordia Technical Forum (TTF).

The TTF is comprised of companies that participated in the development of each issue. The standards are typically reviewed to see if any changes need to be made and/or criteria added when networks evolve and new products are offered. The most recent update to GR-326 (issue 4) includes optical testing at additional wavelengths of 1490 nm and 1625 nm to certify performance at the limits of current fiber optic networks, such as Gigabit Passive Optical Network (GPON). Field data is also important in determining the need for reissuing any standard. With some networks in service for many years, review of failure in time (FIT) rates and post-mortem investigations provides invaluable data about the long term reliability of components. When the GR-326 standards are established, many other industry standards are referenced(from IEC, TIA/EIA, ASTM, ISO, ITU, and UL, as well as other Telcordia General Requirement standards), for test procedures, test criteria, intermateability criteria, etc. When any of these standards are updated, they need to be reviewed to determine if a GR- 326 reissue is necessary to maintain accuracy. The purpose of GR-326 is to determine a connector or connector assembly's ability to perform under various operating conditions and to evaluate long term reliability. The standard is broken down into 4 main categories **(Table 1)**.

Table 1: List of Main Test Categories

General Requirements	General requirements cover documentation, packaging, design features, intermateability, product markings, and safety.
Service Life Testing	A sequence of environmental and mechanical tests that simulate conditions the connectors or connector assemblies may experience while in service.
Extended Service Life Testing	Various tests intended to the long-term reliability of the connector or connector assemblies. **These tests are designed to simulate a lifetime service of 25 years.**
Reliability Assurance Program	Focuses on the manufacturing requirements for long-term reliability and performance of the finished product. Also includes additional test ing to ensure consistency with the manufacturing process.

How is a jumper assembly made?

What should be taken into consideration when choosing a 'good' product? What are the features that define the quality of any connector or jumper assembly? In order to appreciate the significance of a standard compliant product, one must first understand the process of making an optical connector assembly and the potential problems that could occur at each stage.

There are three main processes in the termination of a jumper, **Preparation, Termination, and Polishing (Figure 2), and a total of 15 steps where negligence at any one of these will result in an inferior jumper assembly**. Each process consists of small steps and each step requires strict Quality Control of equipment use and how each step is performed. For illustration purposes, the process described here includes the fundamental steps and potential quality issues in the termination of a connector onto a 3 mm jacket cable with Aramid yarn reinforcement.

Figure 2: Connector termination process and potential quality issues

Preparation of fibre cable	Termination of fibre cable	Polishing of connector end-face	
1. Strip the outer cable jacket	1. Inject epoxy and insert fiber	1. Cleave the fiber	Procedures
2. Trim the aramid yarn to length	2. Crimp aramid yarn to back post	2. Remove excess epoxy (by hand or machine)	
3. Strip the 900 µm buffer	3. Crimp the outer jacket	3. Polish end-face	
4. Clean the bare fiber	4. Cure the connector in an oven		
5. Check for fiber damage			
6. Mix the two-part epoxy			
7. Degas the epoxy			
8. Check the ferrule ID			
Incorrect procedure by line operator (e.g. trimmed aramid yarn length	Incorrect procedure by line operator (e.g. curing stage)	Incorrect procedure by line operator (e.g. removal of epoxy)	Potential Issues
Poorly maintained or incorrect use of tools	Poorly maintained or incorrect use of tools	Poorly maintained or incorrect use of tools (e.g. cleaver)	
Low quality or inappropriate material (e.g. epoxy)	Low quality or inappropriate material (e.g. epoxy)	Low quality or inappropriate material (e.g. polishing films)	

Preparation of fiber cable

1 Strip the outer cable jacket - Using a suitable jacket stripper, the outer jacket is removed without damaging the 900 µm buffered fiber inside. The stripper blade must be sharp and of the appropriate inner diameter to not damage the 900 µm buffered fiber inside. Even though the fiber is protected by a 900 µm buffer, there's a high possibility of damage to the fiber if the buffer is pinched or kinked.

2 Trim the aramid yarn to length - Long, protruding aramid yarns could hinder the proper fit of the strain relief boot. This results in insufficient mechanical support when a jumper assembly of any significant length is left to dangle, which could lead to fiber stress and/or breakage.

3 Strip the 900 µm buffer - Damage to the fiber at this stage may not be visible to the naked eye (or even under magnification), but could result in performance degradation and even a complete loss of transmission. Nevertheless, any fiber damage introduced during stripping is detected via the Extended Humidity Test. The stripper used must be sharp and its internal diameter (ID) narrow enough to remove not only the 900 µm buffer, but also the acrylate coating around the fiber. However, the ID cannot be so narrow as to score or scratch the fiber. Particular attention must also be paid to the length of buffer to be removed, especially in the case of tight-buffered fiber. When using unheated strippers, no more than 10 mm of buffer should be removed at any one time. Attempting to remove more may result in over bending, causing micro and macro bending-induced stresses on the fiber. Such damage will result in poor performance and possibly cause fiber breakage during the epoxy curing process later on.

4 Clean the bare fiber to ensure that the acrylate coating residue and finger oils have been removed. The debris may cause fiber breakage and a wasted connector. The oily fiber surface may prevent/impede epoxy binding.

5 Check for fiber damage - A four-direction fiber bend check should be performed to check for fiber damage or breakage from the buffer removal process. If the fiber had been scored or cracked, it will inevitably break. It is important to check for fiber damage before insertion into the ferrule to minimize fiber breakage during the curing process.

6 Mix the two-part epoxy - Two-part epoxies, such as Senko S-123, are commonly used to bind the fiber inside the ferrule. Some manufacturers employ cost-saving measures by using glue or standard "hardware store" epoxy. However, using such inferior products, instead of the proper epoxy compound, will result in premature connector failure (usually within months). Poorly mixed epoxy results in poor adhesion and/or lower glass transition operating temperatures, causing the fiber to piston, and thus varying the fiber height in relation to the ferrule surface. Excessive fiber protrusion leads to fiber damage.

7 Degas the epoxy - Once mixed, the epoxy will have tiny air bubbles trapped inside. Removal of these air bubbles is essential. Expansion of these air bubbles during exposure to curing temperatures will result in fiber stress and possibly breakage. Either way, IL performance will suffer.

8 Check the ferrule ID - Although not a critical step, checking that the ferrule ID is devoid of any obstructions improves process efficiency by identifying ferrule and/or connector issues early. Anything obstructing fiber insertion will impede valuable preparation time vendor's ferrule or connector and help maintain productivity.

Termination

1 Inject epoxy & insert fiber - Whether performed manually or automatically, care must be taken not to inject too much epoxy. Failure to control the amount of epoxy injected will cause epoxy overflow, which may result in blockage of the curing oven connector receptacles, polishing fixture receptacles, and locking connector springs. As such, automation is preferred for consistent epoxy application inside the connectors. The automated epoxy station is a precision dispensing system that applies accurate and consistent amounts of epoxies used in the connectors.

2 Crimp aramid yarn to back post - Crimping must be performed with a crimp tool set to the correct torque. The crimp die must also have the correct size, shape (usually round or hexagonal), and be in good condition. If the die size is too large or worn, and/or the torque is set too low, the resulting crimp will not hold the aramid yarn and connector back post together securely enough to provide sufficient tensile load protection. However, if the die is too small and/or the torque is set too high, it is possible for the back post to be crushed, thus damaging the fiber inside. In addition, the aramid yarn must be placed evenly around the back post; otherwise, retention strength will be significantly reduced.

3 Crimp the outer jacket - Refer to the section on "Crimp aramid yarn to back post" for the importance of proper torque settings and die size/shape. Over crimping will cause damage to the fiber.

4 Cure the connector in an oven - Care must be taken when placing the connector into a curing oven. Accidentally stubbing a fiber that is protruding from the ferrule may cause the fiber to break. Even with a partial breakage, the fiber may be potentially cracked further down its length. This renders the termination useless and would require re-termination with a fresh connector, wasting precious time and resources. Additionally, a proper curing schedule must be followed to achieve a high glass transition temperature.

Polishing

1 Cleave the fiber - Cleaving should be performed with one clean cut and be as close to the epoxy bead as possible. Excess force and any pushing action should be avoided to prevent the fiber from cracking. The blade of the cleaver must be sharp and properly maintained. Automated mechanical and laser-based cleavers are preferred over manual ones because they eliminate human error.

2 Remove excess epoxy (by hand or machine) - This should be performed at low speed and low pressure to prevent cracking of the fiber.

3 Polish end-face - Polishing is crucial and the final part of jumper assembly termination. Polishing defines the geometric parameters of the ferrule end-face, which affect connectivity, performance, and reliability. Critical parameters such as apex offset, fiber protrusion, end-face radius, and end-face quality are created and controlled through polishing.

Cost benefit of using GR-326 CORE connectors

What is the cost benefit of using a GR-326 CORE certified connector? At potentially double the price of competing non-GR-326 CORE products, one must evaluate network life in the long run and not just single component costs. Although reducing initial Capital Expenditure costs (CAPEX) is important, it may pale in comparison to the savings achieved from reducing the Total Cost of Ownership, which considers future maintenance costs. Hence, the authors have developed a model based on standard FTTH networks and cost analysis provided by the FTTH Council Europe.

The savings in using non-GR-326 connectors is only ~$10 USD/home from a CAPEX standpoint. This calculation is based on a typical 1:32 GPON network with 10 connectors from the Optical Line Terminal (OLT) to the Optical Network Terminal (ONT) at an estimated connection cost of $1000 USD/home. Deploying a GR-326 CORE certified versus a non-GR-326 CORE connector is an additional expenditure of less than 1% of the total home connection cost; 1% of $1000 USD = $10 USD/home.

GR-326 CORE certified connectors are the most cost-effective long-term solution. The assurance in reliability of certified GR-326 CORE connectors is unmatched by their non-compliant counterparts. The average cost of replacing a faulty connector is ~$50 USD. GR-326 CORE connectors will already be more cost-effective if a mere 2% (1 in 50) of non-compliant connectors fail within 20 years of an FTTH network's lifetime. This does not account for additional savings in the prevention of: a) revenue losses due to down time (ex: Video on Demand, voice calls, etc.), b) service disruption penalties (i.e. service level agreement penalty), and c) a reduction in customer confidence.

Deploying a GR-326 CORE certified connector could yield 100% in lifetime cost savings. Depicted is a comparison of the cost analysis (figure 3) and 20-year Total Cost of Ownership (figure 4) between GR-326 CORE and non-GR-326 CORE connectors. Although the initial CAPEX is less for a non-GR-326 connector, the average lifetime cost (i.e. faulty connector repair, loss of revenue, etc.) will be 2X that of using a GR-326 CORE certified connector. The additional 1% expense per home pass for deploying a GR-326 CORE certified connector is a worthwhile investment for any network operator.

Figure 3

Cost analysis of GR-326 CORE vs non-GR-326 CORE connectors

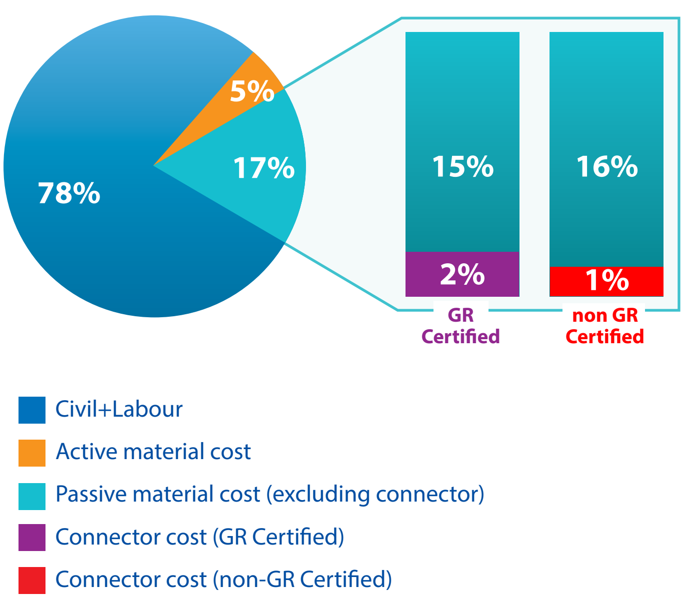
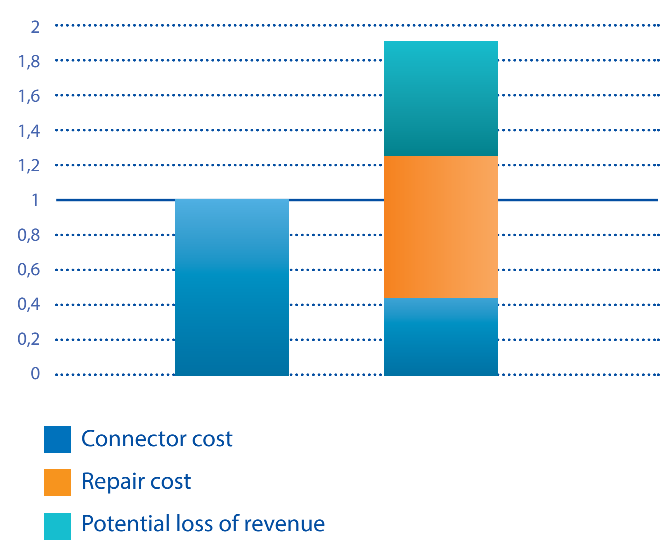


Figure 4

Total Cost of Ownership Comparison between GR-326 CORE vs non-GR-326 CORE Connectors



GR-326 CORE testing: What does it involve and what does it guarantee?

The GR-326 CORE test is one of the most comprehensive testing methodologies used in assessing a product's material and manufacturing precision, and quality of workmanship. A full test requires a minimum of 4 months with multiple tests running in parallel. The GR-326-CORE test is divided into two main categories: Service Life Tests and Extended Service Life Tests. In many cases, when a sample is requested, a 'golden sample' will be provided that will most likely pass all tests. Hence, one should always ask for a **GR-326-CORE compliance certificate** issued to a manufacturer from an **accredited 3rd party test laboratory**.

Service Life Test

The function of the Service Life test is to **simulate the stressors a connector may experience during its lifetime**. The Service Life test consists of two categories: Environmental and Mechanical Tests. The Environmental Tests are **NOT ONLY** performed to ensure that jumper assemblies can withstand prolonged exposures to extreme temperatures and extreme temperature fluctuations, but also to simulate the effects of aging. Details of each environmental test are explained in **Table 2.**

TABLE 2 – Environmental Tests

Thermal Aging	The Thermal Age Test is considered the least extreme of the environmental tests in terms of stressors applied and is intended to simulate and accelerate the processes that may occur during shipping and storage of the product. Connectors are subjected to a temperate of 85 degrees Celsius with uncontrolled humidity for a duration of 7 days, with measurements taken before and after testing.
Thermal Cycle	During thermal cycling the temperature fluctuates over an expansive range, subjecting the product to extreme heat and cold. Thermal cycling involves changing the ambient temperature of the connector by 115 degrees Celsius (from 75°C to -40°C) over the course of three hours. Stressors and strains will be applied to each of the materials in the product. This test will also expose any weaknesses in the termination. If the design and/or procedures are suboptimal, this can lead to fiber cracks and/or breakage.
Humidity Aging	Humidity aging is designed to introduce moisture into the connector and to determine the effect that moisture has on the samples. This test is performed at an elevated temperature of 75 degrees Celsius for 7 days, while the connectors are exposed to 95% RH (relative humidity).
Humidity/ Condensation Cycle	Humidity/Condensation cycling is performed in order to determine the effect that water has on the connector when a rapid transition in moisture occurs. This can cause water molecules to freeze or evaporate within the connector assemblies, potentially exposing "gaps" in the physical contact between connectors within an adapter. This phenomenon may have previously been masked with the water acting as an optical intermediary. The purpose is to achieve heavy condensation to simulate a worst case scenario that may occur with external plant applications.
Dry-out Step	The product is exposed to a drying step of 75 degrees Celsius for 24 hours before the Post-Condensation Thermal Cycle. The purpose is to remove any moisture that may remain from the previously performed Humidity/Condensation Cycling.
Post Condensation Thermal Cycle	This is identical to the Thermal Cycle that was performed previously. The changes that may occur in the connector during Humidity/ Condensation cycling are often revealed once the condensation is removed (as is the purpose of the 'Dry-Out' step). These changes can potentially affect the loss and/or reflectance of the connector.

There are several mechanical tests (**Figure 6**) that are performed once aging is complete. These tests include: Vibration, Flex, Twist, Proof, Transmission with Applied Load, Impact, and Durability. Details of each mechanical test are explained in **Table 3**.

Figure 6: Sub-standard material causes
A) discoloration of components
B) structural defect

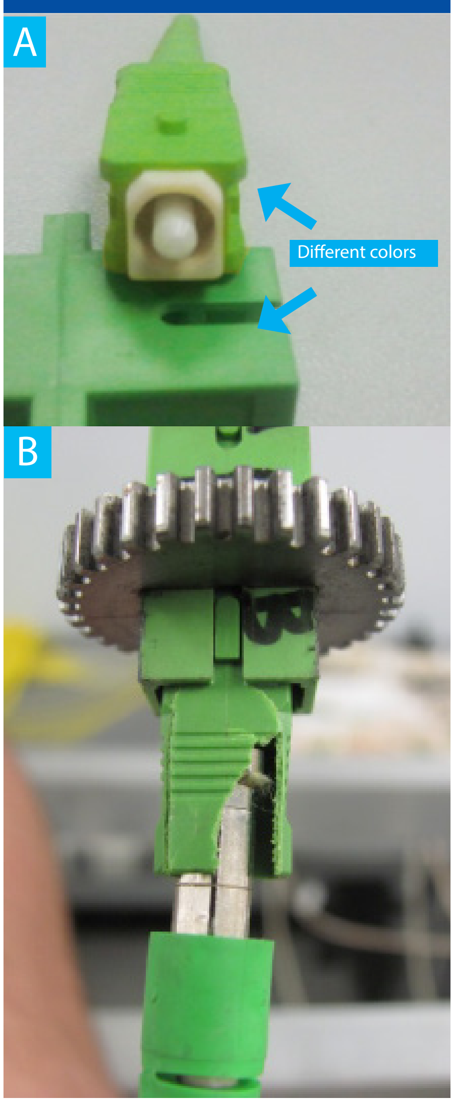


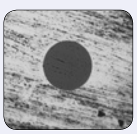
TABLE 3 – Mechanical Tests

Vibration Test	In the vibration test, the products being tested are mounted to a "shaker". By stressing the connectors in this fashion, the test will reveal whether high vibration frequencies induce performance changes in the connectors. The test is conducted on three axes, for two hours per axis, at an amplitude of 1.52 mm, with the frequency sweeping continuously from 10 and 55 Hz at a rate of 45 Hz per minute.
Flex Test	The purpose of performing the flex test is to simulate stressors that could be incurred by the terminated cable and mated connector during their lifetimes. The boot is important in this test because it serves as one of the main points of strain relief. Thus, the boot may not function as intended if the materials in the boot are inadequate. In addition, this will assess whether the fiber will remain coupled to the connector under such circumstances.
Twist Test	The twist test induces rotational strain on the fiber, which tests the strength by which it is coupled to the connector. In addition, the adequacy of the crimp will also be tested. Like the flex test, this will help identify weaknesses in the termination process.
Proof Test	Proof Testing ensures the strength of the latching mechanism of the connector, as well as the crimp during the termination process. This test ensures that the jumper assembly will neither break nor pull out of the adapter should it receive a sudden tug after installation.
TWAL **(Transmission With Applied Load)**	TWAL testing will stress the samples by applying different weights at multiple angles. The series of weights used depends on the media type of the cordage, cable size, and the connector's form factor. Small Form Factor connectors are subject to a more extensive range of measurements. *Note: Live measurements are made while the samples are under stress; this is done to reflect any degradation in transmission that might occur while the product is stressed in the field.
Impact Test	Impact Testing is performed to verify that the connectors are not damaged when they are dropped. A cinderblock is mounted to a fixture approximately 1.5 m below the horizontal plane from which the connector will be dropped. The connector is dropped, striking the cinderblock; the process is repeated 8 times.
Durability Test	Durability testing is designed to simulate the repeated use of a connector. This test involves repetitively inserting (200 times) the connector into an adapter. This is done at different heights (3 ft., 4.5 ft., and 6 ft) to simulate what a user in the field might encounter when standing in front of a telecom rack. This test can potentially reveal any problems with the design and/or material defects in the connector, such as any part of the latching mechanism that may be heavily strained or flawed from frequent use.

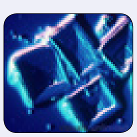
Extended Service Life Test

The criteria for connector and jumper assembly extended service life testing are exclusive to GR-326-CORE. The testing includes exposure to a variety of environments, including additional **Environmental Testing** and **Exposure Testing**. The additional Environmental Tests include extended versions of the Thermal Aging, Humidity Aging, and Thermal Cycle tests. These tests, which run for at least 2000 hours each (83 days), are further studies into the life of a connector across a diverse range of service environments. Testing is non-sequential, so there are no cumulative effects. The Exposure Tests include Dust, Salt Fog, Airborne Contaminants, Ground Water Immersion, and Immersion/Corrosion.

During the extended Environmental Testing, many of the extruded compounds used in jacketing and buffering will shrink after exposure to elevated temperatures, which can cause micro bending in the glass fibers and induce excessive loss.



Dust can seriously impair optical performance. Particles that contaminate end-faces can block optical signals and induce signal loss. Whether or not the dust particles find an exposed path to a ferrule end-face is largely a matter of probability. Over time, dust particles will find their way to the optical connection if it is possible. While the dust particles are not difficult to remove, the cleaning process involves disconnecting the connector, which not only stops the transmission, but also exposes the end-face to additional contamination risks. This test involves intense exposure to specifically sized dust particles to determine if there is a risk of any particle finding its way to the ferrule end-faces.

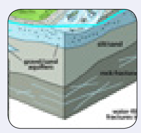


Salt Fog (also referred to as Salt Spray) simulates the performance of jumper assemblies in free breathing enclosures by the ocean. This test involves exposing the connector to a high concentration of Sodium Chloride (NaCl) over an extended period. The test is followed by optical testing and a visual inspection to evaluate whether there is corrosion on the materials.

The **Airborne Contaminants** test simulates the performance and material stability of connectors in outdoor applications with high concentrations of pollutants.

The test exposes mated and unmated connectors repeatedly to various gases, followed by optical testing and a visual inspection similar to that in the Salt Fog test. An assortment of volatile gases is applied to a small chamber for 20 days to simulate prolonged exposure to these elements.

Materials are also assessed in the **Immersion/Corrosion test**. This test has no optical requirements, but rather involves a prolonged submersion in uncontaminated water. This test, like the Dust, Salt Fog, and Airborne Contaminants tests, involves both mated and unmated connectors. Mated connectors are checked for ferrule deformation by comparing the Radius of Curvature before and after the test. If the ferrule does not remain geometrically stable during this test, it could indicate a flaw in the zirconia material used in the ferrule. Unmated connectors are checked for Fiber Dissolution, which involves verifying whether the fiber core has recessed too far into the fiber cladding.



The final exposure test is **Groundwater Immersion**. This test verifies the ability of the product to withstand underground applications. The Immersion/Corrosion test strictly verifies the materials involved using de-ionized or distilled water. Connectors deployed in underground environments are much more likely to be exposed to contaminated media if their enclosures fail. During this test, the connector is exposed to a variety of chemicals found in sewage treatment and agricultural fertilization, among other applications. These chemicals include ammonia, detergent, chlorine, and fuel. Presence of these chemicals can have a detrimental effect on the materials comprising the connector and adapter, reducing optical performance.

In summary, the ***Key Product Features*** that we look at when determining short and long-term reliability are:

1. **Materials:** Plastics (Flammability rating of V1 or better in accordance with UL94, Fungus rating of 0 per ASTM G21-96), Metals, Metallic Plated Surfaces (Corrosion, Salt Spray), Zirconia Grade (Extended Humidity Aging).

2. **Termination Process**: Cleanliness, Epoxy Type, Proper Preparation and Application of Epoxy, Curing Time, Curing Temperature, Correct Crimp Sizes and Pressure, Cable Component Strip Lengths, Aramid Yarn Placement, and Polishing.

3. **Intermatebility**: Critical Dimensions in accordance with applicable TIA/EIA FOCIS Standards.

Connector Defects: Case Studies

The adoption of GR-326-CORE standard is an assurance of not only the performance, but also the reliability of the product. Nevertheless, many manufacturers remain non-compliant and market their products to be of similar quality to those that are GR-326 compliant. This section of the whitepaper shares some of the case studies where non-compliant products have failed and negatively affected the service providers' network.

Dimensional Defects

Connector dimensional non-compliance can result in engagement and disengagement force issues, but just as seriously, **may not fit into industry standard test equipment**. Figure 6A shows an SC APC connector that is unable to fit into an interferometric equipment chuck due to an inner housing that is wider than that specified by international standards. Figure 6B shows a ferrule that was lodged into an adapter because the dimensions of the adapter were too small. The ferrule eventually broke off from the connector body.

Material Defects

Use of substandard materials can result in discoloration, distortion, and mechanical malfunction subjected to environmental testing. Discoloration, as shown at the bottom of Figure 7, is not of great concern, but distortion and mechanical failure are, as seen at the top of Figure 7. Figure 7 shows the worst-case scenario of SC adapters melting during Thermal Aging tests. Note that the GR-326 compliant connectors attached to the adapter retained their integrity during testing.

Workmanship Defects

Due to improper crimp ring placement during crimping, the FC connector on the left in Figure 8 exhibited a cable retention pull force well below the requirements specified in GR-326. More seriously, as observed in Figures 9A, there is a gap between the buffer and the flange during the termination process. If the gap is too large it will become an air pocket as shown in Figure 9B, which will, during expansion at higher temperatures, exert pressure on the fiber and cause it to break (see Figure 9C). An example of a good connector can be seen in Figure 9D.

Figure 6: Non-compliance to standard dimensions can cause **A)** Fitting mismatch or even **B)** Damage during operation.

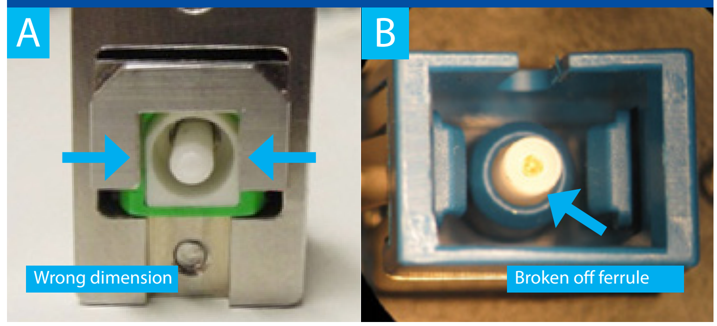


Figure 7: Sub-standard Materials are unable to withstand environmental testing

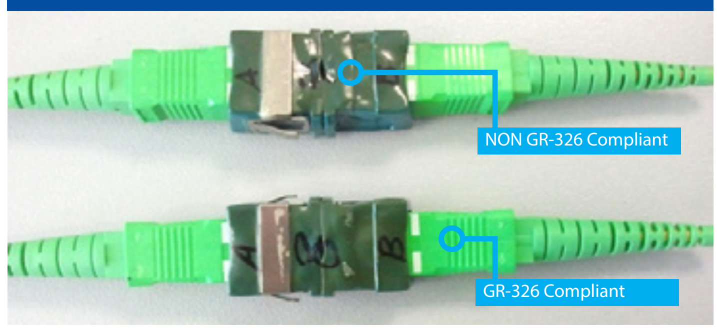
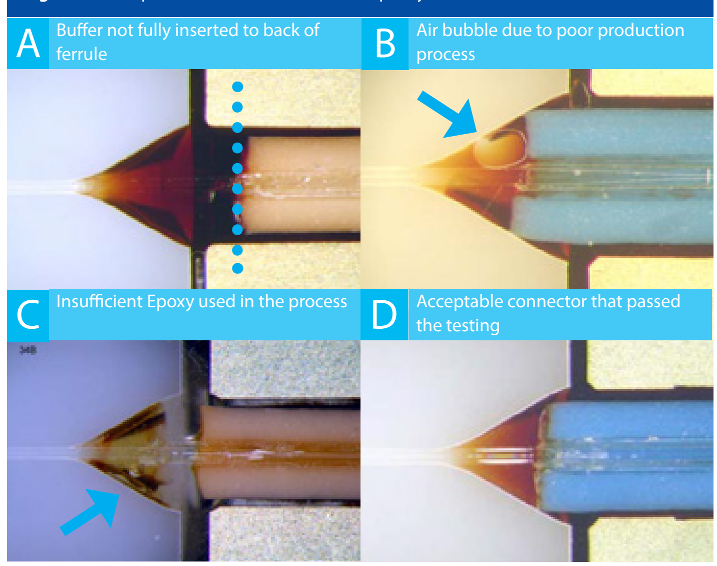


Figure 8: Improper crimp ring placement during crimping

Figure 9: Examples of connector termination quality



Summary

Jumper assembly reliability is not only guaranteed by using quality components and manufacturing processes and equipment, but also by adhering to a successful Quality Assurance program. While jumper assemblies themselves are typically tested 100% for insertion loss and return loss, many other factors need to be monitored to ensure the long term quality of the jumper assembly. One of the most important factors is the epoxy. Epoxies typically have a limited shelf life and working life and must be cured at elevated temperatures. Mixing two-part epoxies introduces trapped air, or "bubbles", which can be then injected into the connector. This trapped air introduces inconsistency in the cured epoxy, leading to a high risk of mechanical failure. The trapped air, or bubble count, must be minimized. If the fiber is improperly bonded inside the ferrule, the fiber will move with pressure from environmental changes. The amount of movement indicates how well the epoxy is bonding the glass fiber to the ceramic ferrule and whether the epoxy is properly cured. Therefore, it's important to follow a proper protocol with selecting the right epoxies, eliminating the bubbles after mixing it using degassing techniques in a centrifuge and following a proper curing schedule to achieve the required glass transition temperatures.

Many of the tools used in jumper assembly production also have a limited working life. This applies to all stripping, cleaving, and crimping tools. Most stripping tools, whether they are hand tools or automated machines, can be damaged and require inspection, calibration, and maintenance. When a cleaving tool is worn out and a clean score is not made, it is almost impossible to detect during manufacturing. This could result in non-uniform fiber breakage during cleaving, which can lead to either breaking or cracking the fiber below the ferrule end-face. Fiber Optic termination process using a range of tools: precision fiber strippers, kevlar shears, crimpers, scribes, epoxy curing ovens and automated polishers. They all need to be calibrated and be on a regular maintenance schedule to help with successful terminations.

The compliance to GR-326-CORE starts with a quality licensed connector from a reputable manufacturer that is designed to applicable standards. Also, when requesting connectors or an assembly product that is "compliant to GR-326 CORE", it is important to understand the level of compliance. Has full compliance to every requirement in the GR-326 been achieved by the manufacturer? Or have only a portion of the GR-326 CORE set of requirements been deemed satisfactory, such as end-face geometry or proof pull test only. In conclusion, the integrity of the incoming materials and manufacturing processes, once established, need to adhere to all of the appropriate guidelines and procedures. **GR-326 CORE is an assurance of quality, performance and reliability.**

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Biography

Andrei Vankov, is an Application Engineer at SENKO Advanced Components. He received his BS from Thomas Edison State College and his MSEE from Pennsylvania State University. He began his career in 1993 at Sumitomo Electric Lightwave Corp as a Fiber Optic Manufacturing Engineer where he worked on active and passive components using Kaizen methods in Yokohama, Japan. As a Senior Optical Design Engineer in Franklin, MA (founded as Advanced Interconnect) Andrei Vankov developed various passive optical components and packaging integration to meet Telcordia industry standards. He designed optical interconnects, including optical backplanes (MTP, HBMT, PHD, OGI), and a fiber optic SMPTE compatible Broadcast Connector for HD applications. In 2013-2020 Andrei worked at Nokia division Radio Frequency Systems (RFS) where he provided leadership for a LTE RAN launch project team. He was responsible for engineering, design and cost estimating of fiber optic builds for microwave and cell tower projects, defining design criteria and completing initial planning and cost estimates of fiber optic projects in North America. Andrei holds a number of US and European Patents in fiber optics interconnect technology.

Emmanuel Kolczynski, is an Application Engineering Manager at SENKO Advanced Components. He is from Ottawa, Canada where he attended Carleton University and completed his Bachelor of Engineering, with a focus in Electrical. He began his fiber optic career with JGR Optics Inc. in 2013 as an Application Engineer, helping companies globally with production processes and various testing needs. He eventually became a Product Line Manager to help guide the company business direction by making strategic decisions based on market trends and planning a future road map. At SENKO, Emmanuel applies his fiber optic knowledge and expertise to help with the design, testing, and release of critical interconnect technology for use in a constantly evolving market. He is currently a member of the Telecommunications Industry Association (TIA) to follow the latest in industry standardizations and developments. Emmanuel has a passion for technology and being able to reach the fullest potential through constant innovation and developments

Ky Ly is currently the Senior Staff Engineer at SENKO Shenzhen where he joined since 2007. Prior to joining SENKO, Ky spent 3 years working as an engineer at Hamamatsu Photonics KK, as part of their Intelligent Vision Systems research team. Then, he was responsible for tests/experimentation and camera control software development. Prior to Hama- matsu Photonics Ky worked as an engineer at Panasonic for 7 ½ years in their European mobile phone division based in the UK. Responsible for programming of automated SMT laser inspection machines and quality data feedback.

Sean Grenon joined Resolute Technologies in November 2008 as the Regional Lab Manager. Resolute Technologies is an independent test facility with a focus on passive optical components and specializing in GR-326 testing for fiber optic connectors and cable assemblies. Sean has been involved in many Telcordia Technical Forums (TTF) for various standards. Prior to joining Resolute Sean was the Verizon FOC Program and Lab Manager for Curtis Strauss from 2007 to 2008. Before joining Curtis Straus, from 2000 to 2007 Sean held various positions at Fiber Optic Network Solutions. Sean worked in Manufacturing Engineering, Research and Development before starting the Reliability and FTTH Design Verification programs for FONS.

Tomoyuki (Tom) Mamiya joined SENKO Japan in July 1999, and then joined SENKO Advanced Components in the United States from Japan to manage all global engineering efforts as an Engineering Manager in February 2000. Tom worked in various engineering and product development positions before being promoted to Global Vice President of Engineering in 2006. Tom went back to SENKO Japan in 2010 to be responsible for all engineering activities in Japan.

Prior to joining SENKO, Tom had worked for fiber optic component and equipment manufacturing company in Japan for more than 5 years as R&D engineer. Tom held over 10 patents in fiber optic component field in world-widely, in the US, Europe, Japan, and Taiwan.

Dr. Bernard Lee is currently the Director of Technology & Innovation at SENKO Advanced Components. He started his career in optical communications when he was a Senior Research Office for the European Union IST project known as DAVID in 2000. In 2003, he joined Telekom Malaysia R&D where he has held various technical and management positions there including the Head of Photonic Network Research and also Head of Innovation and Communications. Bernard then joined the parent company, Telekom Malaysia (TM) in 2010 as the Assistant General Manager at the Group Business Strategy Division. Bernard is also an Expert at the International Electrotechnical Commission (IEC), a Chartered Engineer (CEng) accredited by the Engineering Council of UK, a Professional Engineer (PEng) registered with the Board of Engineers Malaysia and also a BICSI Registered Communications Distribution Designer (RCDD).

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