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GR-326: STRENGTHENING THE WEAKEST LINK IN MODERN DAY ULTRAFAST OPTICAL NETWORKS

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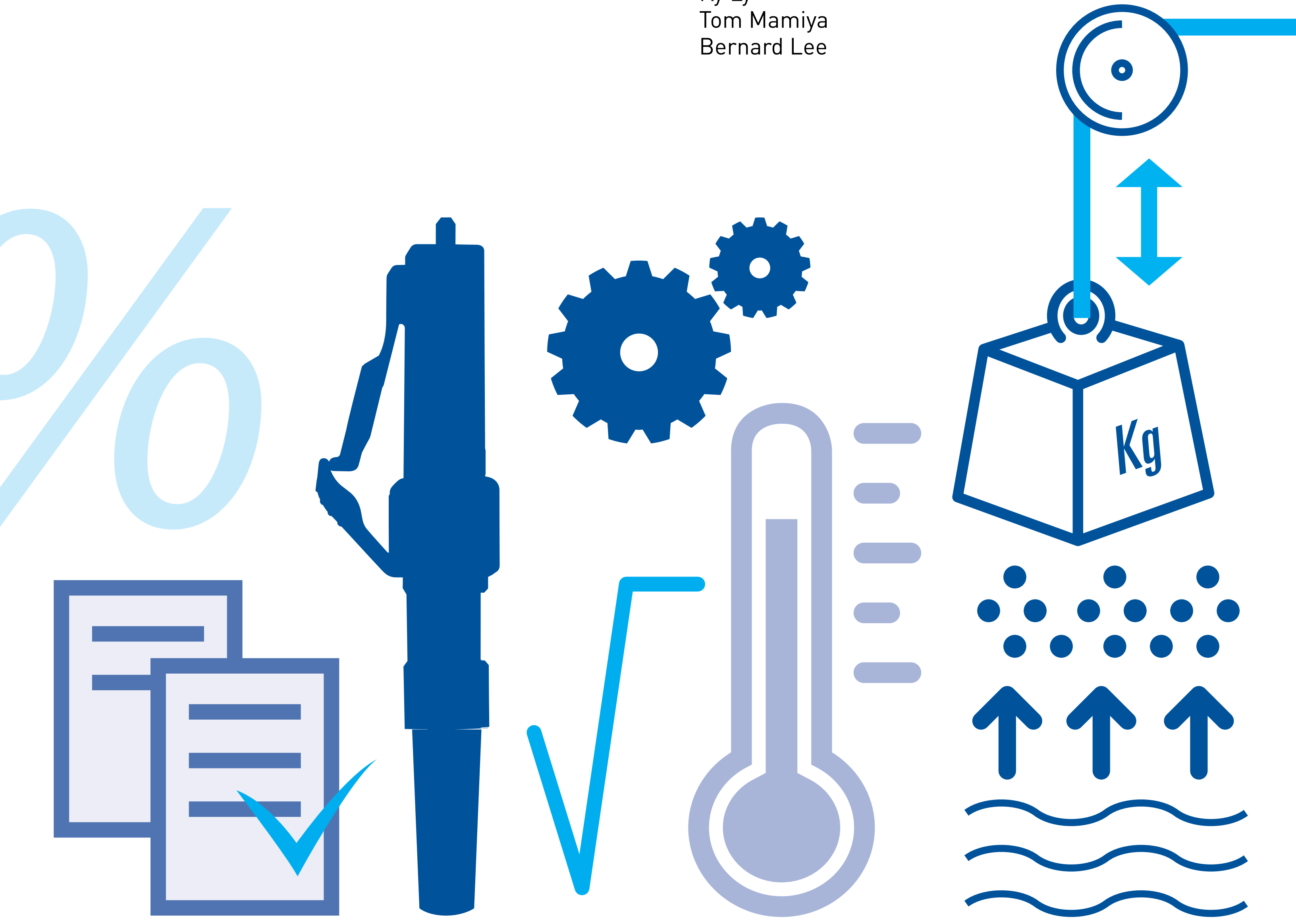

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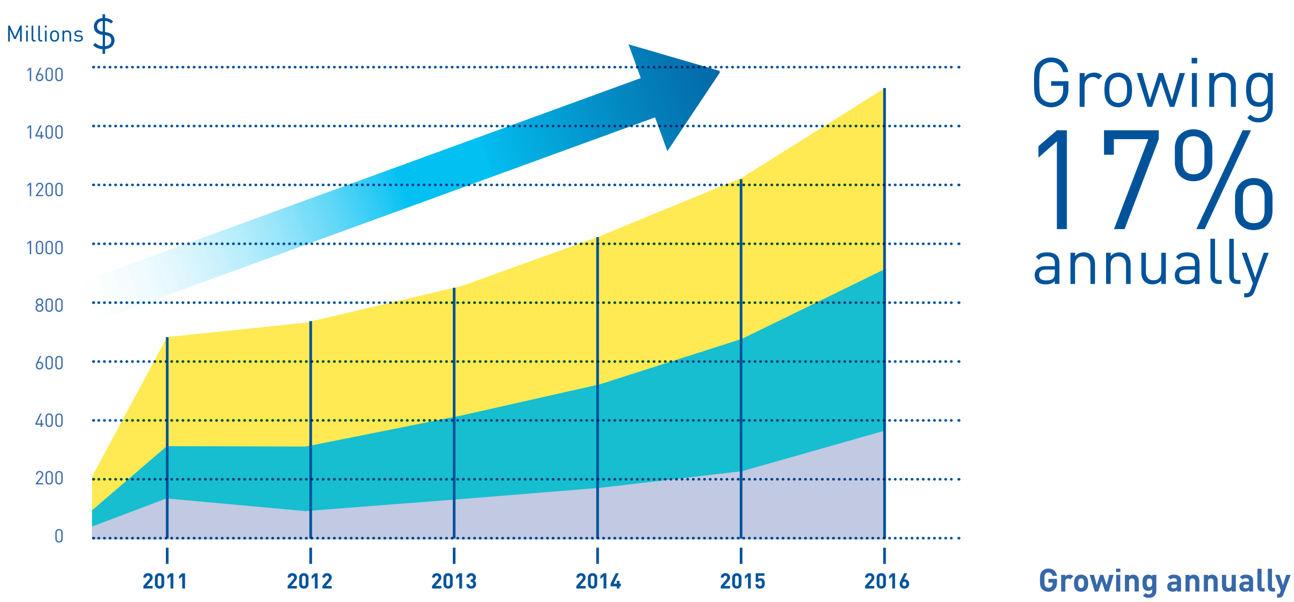
Executive Summary

In 2012, leading market and technology analysts announced their finding which concluded that in 2016, the worldwide consumption volume of connectors and mechanical splices will increase by a factor of 2, reaching over 1.57billion units as compared to the number of 703 million in 2011. The American region led in global market share with 54% in 2011. American consumption is forecast to expand to at an average annual growth rate of 10.8% during the forecast period. The Asia Pacific (APAC) region is forecasted to show the fastest growth with an average annual growth rate of 25 percent (2011-2016). EMEA (Europe, Middle East and Africa) fiber optic connector volume consumption, with 19.5 percent relative market share, trailed the second-place APAC (Asia Pacific) region in 2011. The forecasted trend is shown in **Figure 1.**

As demand for optical connectors increases globally, so does the supply. When one visits trade shows, one will find numerous suppliers offering from basic components to finished cable assembly products. One key fact that end users have discovered in recent years is '***not all connectors are 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 pertinent industry specifications such as the internationally recognized GR-326 standards. This paper describes the relevance of the criteria in 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: Ligthwave Magazine, July 2012



	2011	2012	2013	2014	2015	2016
Americas	380	421	468	519	576	640
Apac	186	233	291	364	455	569
Emea	137	93	125	169	231	365

Growing annually

- 26% Americas
- 25% APAC
- 11% EMEA

Introduction to GR-326: How it all began?

GR-326-CORE (Generic Requirements for Singlemode Optical Connectors and Jumper assemblies) was initially created by Bellcore and continues to evolve as one of the more popular standards in the telecommunications industry. Bell Communications Research, Inc. 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 standard setting arm for the RBOC's. Following a divestiture of the company 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 consistent with the Telecommunications Act of 1996 and it is intended to be the industrial specifications for long haul high-speed applications such as telecommunications and cable TV. There has been a total of four issues of GR-326, initial release, Issue 2 December 1996, Issue 3 September 1999 and the current Issue 4 February 2010. The Telcordia views in any particular release are developed from the expressed needs of the Telcordia Technical Forum (TTF), the TTF is made up from the companies who participated in the development of each new issue. As networks evolve and new products are offered the standards are typically reviewed to see if there are changes that need to be made or criteria added. A good example of this was the addition of four wavelength testing (1310nm, 1490nm, 1550nm, 1625nm) in GR-326 issue 4, this was added because of the heavy use of connectors and cable assemblies in FTTH networks. Field data is also a very important part of the process when determining the need for reissues of the standard. As some of the current networks have been in service for many years, review of FIT (failure in time) rates along with post mortem investigations provide invaluable data about the components long term reliability. When the standards are developed, there are many other industry standards that are referenced. Standards from IEC, TIA/EIA, ASTM, ISO, ITU, UL as well as other Telcordia General Requirement standards are referenced for test procedures, test criteria, intermatebility criteria etc. When these standards are updated, they need to be reviewed to determine if a GR-326 reissue is needed to bring them in line. The purpose for GR-326 is to determine a connector or connector assembly's ability to perform in various operating conditions, and to determine long term reliability. The standard is broken down into 4 main categories (Table 1)

Table 1: List of Main Test Categories

General Requirements	These General requirements cover documentation, packaging, design features, intermateability, product markings and safety
Service Life Testing	A sequence of environmental and mechanical tests that simulate possible conditions the connectors or connector assemblies may be under while in service
Extended Service Life Testing	Various tests intended to determine long term reliability of the connector or connector assemblies. ***Usuava simulated 25 year lifetime***.
Reliability Assurance Program	The program focuses on requirements for the manufacturing process that relate to long term reliability and performance of the finish product. Also includes additional testing to ensure the stability of the manufacturing process

How is a jumper assembly made?

So what should be taken into consideration when choosing a 'good' product? What are the features that one should look for that defines 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 actually making an optical connector assembly and the potential problems that could occur at each of the stages.

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 the steps will result in an inferior jumper assembly***. Each process consists of small steps, and each step requires strict Quality Control of not only the equipment used, but also how each step is carried out. So let us break these processes down into their fundamental steps and see the potential quality issues. For illustration purposes the process described here is the termination of a connector on to a 3mm jacket cable with Kevlar reinforcement.

	Preparation of fibre cable	Termination of fibre cable	Polishing of connector endface
Procedures	1. Stripping of outer cable jacket	1. Inject epoxy and insert fiber	1. Cleave fiber
	2. Trimming of Kevlar fibers to length	2. Crimp Kevlar to back post	2. Remove excess epoxy by hand or machine
	3. Stripping of 900um buffer	3. Crimp outer jacket	3. Polish endface
	4. Clean bare fiber	4. Cure connector in oven	
	5. Check fiber for damage		
	6. Mix two part epoxy		
	7. Degas Epoxy		
	8. Check ferule ID		
Potential Mistakes	Wrong procedures by line operator (e.g. trimmed kevlar length)	Wrong procedures by line operator (e.g. curing stage)	Wrong procedures by line operator (e.g. removal of epoxy)
	Poorly maintain or wrong use of tools	Poorly mainteined or wrong use of tools	Poorly maintain or wrong 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)

Figure 2: Connector termination process and their potential mistakes

Preparation of fiber cable

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

2 **Trimming of Kevlar fibers to length** - This may not seem serious, but long, protruding Kevlar fibers are at best unsightly, but at worst will hinder the correct fitting of the strain relief boot. The result is insufficient mechanical support when a jumper assembly of any significant length is left to dangle. Insufficient mechanical support in these circumstances will result in fiber stress and/or breakage.

3 **Stripping of 900um buffer** - At this stage, damage to the fiber may not be visible to the naked eye or even seem superficial, but will cause performance degradation or in the worst case scenario cause complete loss of transmission. Nevertheless, through the Extended Humidity Test, any defects to the fiber during stripping will be detected. The stripper used must be sharp and its internal diameter (ID) tight enough to remove not only the 900um buffer, but also the acrylate coating around the fiber. However, the ID cannot be so tight as to score or scratch the fiber. Close 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 10mm of buffer should be removed at any one time. Attempting to remove more will result in over bending, causing micro and macro bending induced stress on the fiber. Such damage at this stage will result in poor performance, but in the worst case will cause fiber breakage during the epoxy curing process later on.

4 **Clean bare fiber** to ensure acrylate coating has been removed. When this thin coating of acrylate isn't completely removed it is impossible to insert the fiber into the ferrule. Trying to do so will invariably result in fiber breakage and a wasted connector.

5 **Check for fiber damage** - A four direction fiber bend check should be performed to check for fiber damage or breakage during the buffer removal process. If the fiber was scored or cracked it will break. It's important to check fiber damage at this stage before insertion into the ferrule to minimize fiber breakage during the curing process.

6 **Mix the two part epoxy** - Two-part epoxies such as Epo-Tek 353ND are commonly used to bind the fiber inside the ferrule. Some manufacturers have taken steps to lower their cost by the use of glue or standard epoxy from hardware stores instead of the proper epoxy compound which will result in premature failure of the connectors (usually within months). Hence why one must always avoid such inferior products. Poorly mixed epoxy will result in poor adhesion and or lower glass transition operating temperatures and, as a result, the fiber will piston, varying the fiber height in relation to the ferrule surface. Excessive fiber protrusion will lead to fiber damage.

7 **Degas to ensure epoxy is free of air bubbles** - Once mixed, the epoxy will have tiny air bubbles trapped inside it, and removal of these air bubbles is essential. Air bubbles inside the epoxy will expand under the temperatures it's exposed to during curing; this will result in stress on the fiber, or in the worst case fiber breakage. In either case, IL performance will suffer.

8 **Check ferrule ID is clear of any obstruction** - An obvious but sometimes overlooked step. Anything inside the ferrule that obstructs the insertion of a fiber will result in wasted preparation time as mentioned is the steps above. Although not a critical step, it will possibly highlight an issue with a vendor's ferrule or connector and help maintain productivity.

Termination

1 **Inject epoxy & Insert Fiber** - Whether this is performed manually or automatically, care must be taken to not inject too much epoxy. Failure to control the amount of epoxy injected will cause an over flow of epoxy, which can result in blockage of the curing oven connector receptacles, polishing fixture receptacles and, of course, the seizing of connector mechanics. All of which are time consuming and expensive to rectify. Care must always be taken to avoid stubbing the fiber or to attempt to insert the fiber too quickly. Doing may result in fiber breakage.

2 **Crimp Kevlar to back post -** Crimping must be performed with a crimp tool set to the correct torque. The crimp die must also be of the correct size and shape, usually round or hexagonal, and must be in good condition. If the die size is too large or worn and the torque set too low, the resulting crimp will not hold the Kevlar and connector back post together securely enough to provide sufficient tensile load protection. If however, the die is too small or torque set too high, it's possible the back post can be crushed, damaging the fiber inside. Also, the Kevlar must be evenly place around the back post. If the Kevlar is not placed around evenly, it will significantly reduce the retention strength.

3 **Crimp outer jacket** - Same die size and shape concerns as mention for Kevlar crimping, as well as the same concern regarding the appropriate torque setting. Over crimping here will cause damage to the fiber.

4 **Cure connector in oven** - Care must be taken when placing the connector into the curing oven. Stubbing the fiber protruding from the ferrule may cause the fiber to break. Even if the fiber only partially breaks, it may potentially be cracked further down the fiber. This essentially renders the termination useless and would require re-termination with a fresh connector, wasting time and resources.

Polishing

1 **Cleave fiber** - When cleaving, the cleave point should be as close to the epoxy as possible, and performed with one clean cut. Excessive force and any pushing action should be avoided to prevent fiber cracking. Also the blade of the cleaver must be properly maintain and sharp enough. Fibers should be periodically checked under a microscope to ensure the cleaver blade is working properly.

2 **Remove epoxy by hand or by machine** - This should be performed at low speed with low pressure to prevent cracking the fiber.

3 **Polish using a suitable machine and procedure** - Polishing isn't just to make the ferrule end face nice and clean. Polishing is the final and crucial part of jumper assembly termination. Polishing defines the geometric parameters of the ferrule end face, parameters that affect connectivity and performance. 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?

Many have asked "what is the cost benefit of using a GR-326CORE certified connector". In comparison a GR-326CORE connector may be double the price of a similar looking non GR-326-Core product. Thus one must consider the network in totality and not just the cost of one component itself. Also, one has to move away from the concept of reducing the initial Capital Expenditure cost (CAPEX) to the concept of reducing Total Cost of Ownership which takes into account the potential maintenance costs in the near future. Hence, the authors have made a model based on standard FTTH networks and cost analysis provided by the FTTH Council Europe.

Based on a typical 1:32 PON network with 10 connectors from the OLT to the ONT and assuming the cost per homes connect is US$1,000/home, the difference in cost per Homes Connect is less than 1% of the total homes connect cost when using a GR-326CORE certified versus a non-GR-326CORE connector. 1% of US$1000 equals US$10/home connect. Nevertheless, from a CAPEX point of view, the use of the non-GR-326 connectors is still a saving although it is only US$10/home (approximately the price of a large pizza).

Nonetheless, GR-326CORE does provides an assurance in reliability unmatched by the other non-compliant connectors. An average cost of replacing a faulty connector is approximately US$50/connector. If a network operator takes into account that within the 20 years the FTTH network's lifetime, if a mere 2%, or 1 in 50 connectors fail, it will already render the use of GR-326CORE connectors to be more cost effective than using a non-compliant product. This saving does not include losses in terms of:

• Revenue due to down time (e.g. Video on Demand, voice calls, etc)

• Penalty due to service disruption (Service Level Agreement penalty)

• Customer confidence

In **Figure 3**, we have compared a 20-year Total Cost of Ownership between the uses of GR-326CORE versus non-GR-326CORE connectors. The analysis clearly shows that although initial CAPEX is less for non-GR326CORE case but in the span of 20 years, the average cost (repair of faulty connectors and loss of revenue) will be 2x the cost of using a GR-326CORE certified connector. The additional 1% per home pass for using a GR-326CORE certified connector is definitely a worthwhile assurance by any experienced network operator.

Figure 3

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

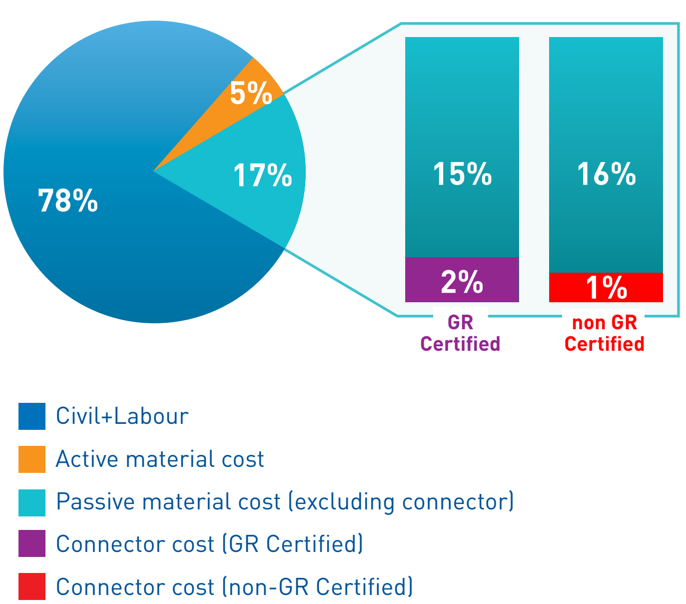
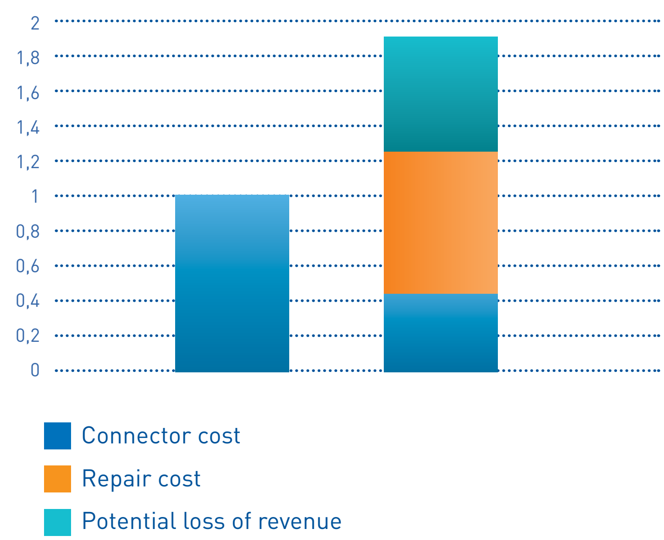


Figure 4

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



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

The GR-326-CORE test is one of the most comprehensive testing methodologies which will not only test the product's material and manufacturing precision but also the quality of workmanship. A full test will take a minimum of 2000hrs with multiple tests running in parallel. As mentioned earlier, the GR-326-CORE test is divided into two main tests (i.e. Service Life Tests & Extended Service Life Tests). In the majority of cases, when a sample is requested, a 'golden sample' will be provided which will most definitely pass all tests with flying colors. Hence, one should always ask for a **GR-326-CORE compliance certificate** which is issued to manufacturers whom has passed the GR-326 compliance test at **any accredited 3rd party test laboratory in the world.**

Service Life Test

The function of the Service Life test is to ***simulate the stresses a connector may experience during its lifetime***. The test is divided into two sections namely the Environmental Test & Mechanical Tests. The Environmental Tests are **NOT ONLY** performed to ensure the jumper assemblies will be able to withstand prolonged exposure to 85°C or temperature fluctuations of up to 125°C but also to accelerate the effects of aging on jumper assemblies. Details of each of the 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 stress 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 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 (75° to -40°) over the course of three hours. Heavy stresses 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 procedures are not optimal, this can lead fiber cracks or breakage.
Humidity Aging	Humidity aging is designed to introduce moisture into the connector and to determine the effect that the moisture has on the samples. This test is performed at the 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 by the water acting as an optical intermediary. The purpose is to achieve heavy condensation, so as to simulate a worse-case condition that may occur in outside plant applications.
Dry-out Step	The product is exposed to a drying step at 75 degrees Celsius for 24 hours before the Post-Condensation Thermal Cycle is performed. 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 previously performed. 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), and these changes can potentially affect the loss and/or reflectance of the connector.

There are several mechanical tests (Figure 6) required to be performed once the aging is complete. These include: Flex Testing, Twist Testing, Proof Testing, Impact Testing, Vibration Testing, Durability, and Transmission with an Applied Load. Again, details of each of the test are explained in Table 3.

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

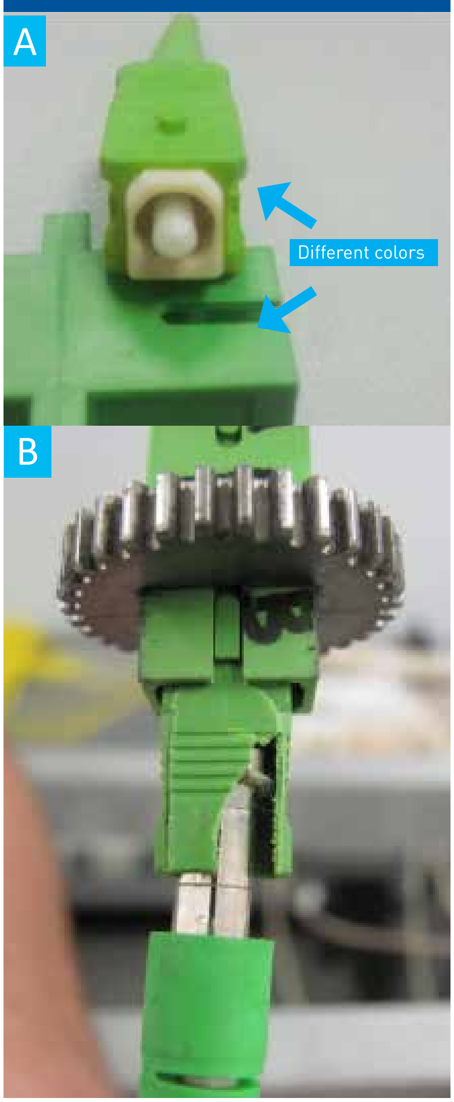


TABLE 3 – Mechanical Tests

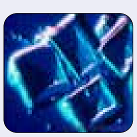
Vibration Test	In a vibration test, the products being tested are mounted to a "shaker." By stressing the connectors in this fashion, the test will reveal whether high frequencies of vibration induce performance change in the connectors being tested. The test is conducted on three axis for two hours per axis at an amplitude of 1.52mm with the frequency sweeping continuously from 10 and 55 Hz at a rate of 45Hz per minute.
Flex Test	The purpose of performing the flex test is to simulate stresses on the terminated cable and mated connector that could be incurred over the life of the connector. The boot, in particular, is important in this test, as it serves as one of the main points of strain relief. Thus, if the materials in the boot are inadequate, the boot may not function as intended. In addition, this will confirm that the fiber will not become uncoupled from the connector under such circumstances.
Twist Test	The twist test puts a rotational strain on the fiber, which tests the strength by which it is coupled with the connector. In addition, the adequacy of the crimp will also be tested. This, like the flex test, will help to 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. Should the jumper assembly receive a sudden tug after installation, this test ensures that the jumper assembly will neither break nor pull out of the adapter.
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, as well as the 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 have incurred 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 the bottom of the fixture, approximately 1.5m from the horizontal plane that the connector will be dropped from. The connector contacts the cinderblock, and 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 6ft) so as to simulate what a user in the field might encounter when standing in front of a telecom rack. The test can potentially reveal any problems with the design and/or material flaws in the connector, such as any part of the latching mechanism that may be heavily strained or flawed by 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 Life, Humidity, and Thermal Cycle. These tests, which run for at least 2000 hours each (83 days), are further studies in the life of the connector across a range of service environments. Testing is non-sequential, so there is no cumulative effect. 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.

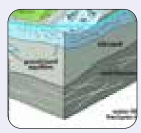
Dust can seriously impair optical performance. Particles that contaminate endface can block optical signals and induce loss. Whether or not the dust particles find an exposed path to a ferrule endface is largely a matter of probability. Over time, dust particles will find their way to the optical connection 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 endface to additional risk of contamination. This test involves intense exposure to a dust of specified size particles in order to determine if there is a risk of any particle finding its way to the ferrule endfaces.



Salt Fog (referred to as Salt Spray) is performed to guarantee the performance of the jumper assembly in free breathing enclosures near the ocean. This test involves exposing the connector to a high concentration of Sodium Chloride (NaCl) over an extended period. After the test, optical testing is performed, followed by a visual inspection to confirm that there is no evidence of corrosion on the materials.

The **Airborne Contaminants** test is designed to guarantee the performance and material stability of connectors in outdoor applications with high concentrations of pollution. The test repeatedly exposes mated and unmated connectors to various gases and inspects the connector not only optically, but also performing the same visual examination as in the Salt Fog test. An assortment of volatile gases is used in a small chamber for 20 days to simulate prolonged exposure to these elements.

The materials are also verified in the **Immersion/Corrosion test**. This test has no optical requirements, but instead involves a prolonged submersion in uncontaminated water. This test, like Dust, Salt Fog, and Airborne Contaminants, involves both mated and unmated connectors. Mated connectors are checked for ferrule deformation by measuring the Radius of Curvature before and after the test, and comparing the values. If the ferrule is not geometrically stable during this test, it could be an indication of a flaw in the zirconia material used in the ferrule. Unmated connectors are checked for Fiber Dissolution, which involves checking to see if the fiber core has not 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 is strictly to verify the materials involved, and uses de-ionized or distilled water. Connectors deployed in underground environments are much more likely to be exposed to contaminated mediums 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, as well as biological mediums. 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, Kevlar Placement, 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, there are manufacturers all over the world whom are still not GR-326 compliant and have been selling their products in the market posing as similar quality as those who have taken the effort to comply to the standards. This section of the whitepaper would like to share some of the case studies where non-compliant products have failed and has affected the service providers' network.

Dimension Defect

Connector dimensional non-compliance can result in engagement and disengagement force issues, but just as seriously, they ***may not fit into industry standard test equipment***. Figure 5A shows an SC APC connector unable to fit into a Data-Pixel interferometer chuck, due to an inner housing that is wider than that specified by international standards. Figure 5B shows a ferrule lodge into the adapter and unable to be removed as the dimension of the adapter was too small. Eventually, the ferrule broke off from the connector body.

Material Defect

Use of substandard materials can result in discoloration, distortion and mechanical malfunction when put through environmental testing. Discoloration as shown in Figure 6A is not of great concern, but distortion and mechanical failure is as seen in Figure 6B. Figure 7 shows the worst case scenario of SC adapters melting during damp heat testing. Note that in the same photograph, the GR-326 compliant connectors attached to the adapter were not affected by the testing and retained its integrity.

Workmanship Defect

Due to improper crimp ring placement during crimping, the upper most FC connector in Figure 8 exhibited cable retention pull force well below the requirements specified GR-326. More seriously shown in Figure 9A & 9B, where there is a gap between the ferrule and the flange during the termination process. If the gap is too big, that place becomes an air pocket which will, during expansion at higher temperature, exert pressure on the fiber thus causing the fiber to break (Figure 9C). A sample of a good connector can be seen in Figure 9D.

Figure 5: Non-compliant to standard dimension could cause **A)** Fitting mismatch or even **B)** Damage during operations

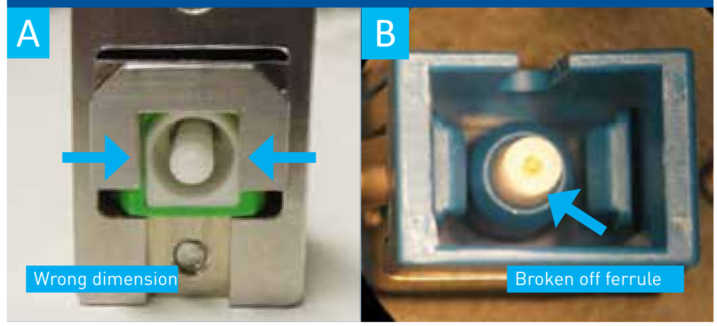


Figure 7: Sub-standard Material unable to withstand environmental test

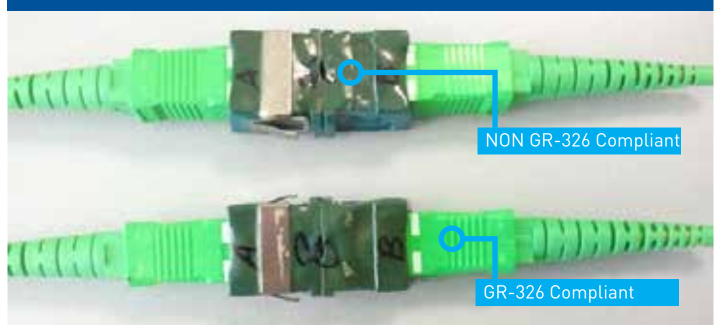


Figure 8: Improper crimp ring placement during crimping

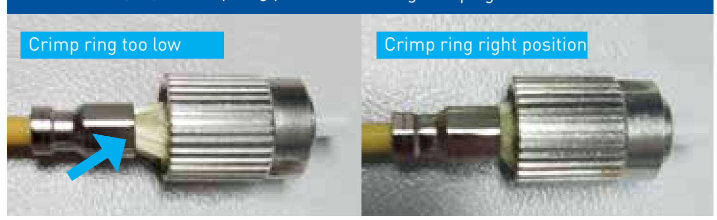
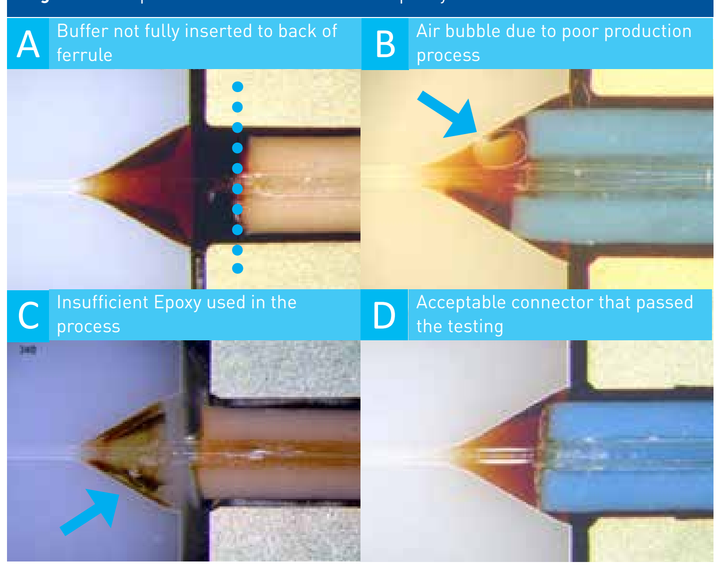


Figure 9: Samples of connector terminations quality



Summary

Jumper assembly reliability is guaranteed not only by using quality components and manufacturing processes and equipment, but also by adherence to a successful Quality Assurance program. While jumper assemblies themselves are typically tested 100% for insertion loss and return loss, there are many other factors that need to be monitored to ensure the quality of the jumper assembly. One of the most important factors is the epoxy. Epoxies typically have a limited shelf life and working life, or "pot life." Most epoxies used in fiber optic terminations are two-part epoxies and, while they cure at elevated temperatures, preliminary cross-linking will begin upon mixing. Once this has started, the viscosity of the epoxy can begin to change, making application more difficult over time. Mixing two-part epoxies introduces trapped air, or "bubbles", which is 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.

Many of the tools used in jumper assembly production also has periodic maintenance and a limited tool life. This includes all stripping, cleaving and crimping tools. Most stripping tools, whether they are hand tools or automated machines, can be damaged by the components of the cable, most notably the aramid yarn strength members. When a cleaving tool wears out and a clean score is not made, it is almost impossible to detect during manufacturing. However, the result could be non-uniform fiber breakage during cleaving, which can result in either breaking or cracking the fiber below the ferrule endface.

In conclusion, the integrity of the incoming materials and manufacturing processes, once specified, needs to adhere by all the appropriate guidelines and procedures. The importance of these materials not only has a strong influence on product reliability, but also on product performance. ***GR-326 CORE is that assurance of performance and reliability.***

GR 326
COMPLIANT

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Biography

Zack Forman joined Resolute Technologies in June of 2012. Since then, he has been performing environmental and mechanical testing in accordance with GR-326, and has assisted in a number of projects since then. Currently, he serves as a fiber optic lab technician under Sean Grenon.

Ky 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 Hamamatsu 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 and is a member of the Verizon FOC program. 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 joined SENKO Advanced Components (Australia) Pty Ltd in 2011 as the R&D Director. Prior to joining SENKO, Bernard was working at Telekom Malaysia (TM) R&D from 2003 till 2009. In 2010, Bernard was transferred to Telekom Malaysia's (TM) Head Office as the Assistant General Manager for the Group Business Strategy where he oversees the company's business direction on fixed and wireless broadband and applications. Bernard has published various technical papers, including international journals, conference papers and also white papers on high-speed communications systems and networks especially on IP based communications and high speed communications semiconductor devices. Currently, Bernard holds the Vice President position of the Asia Pacific FTTH Council.

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