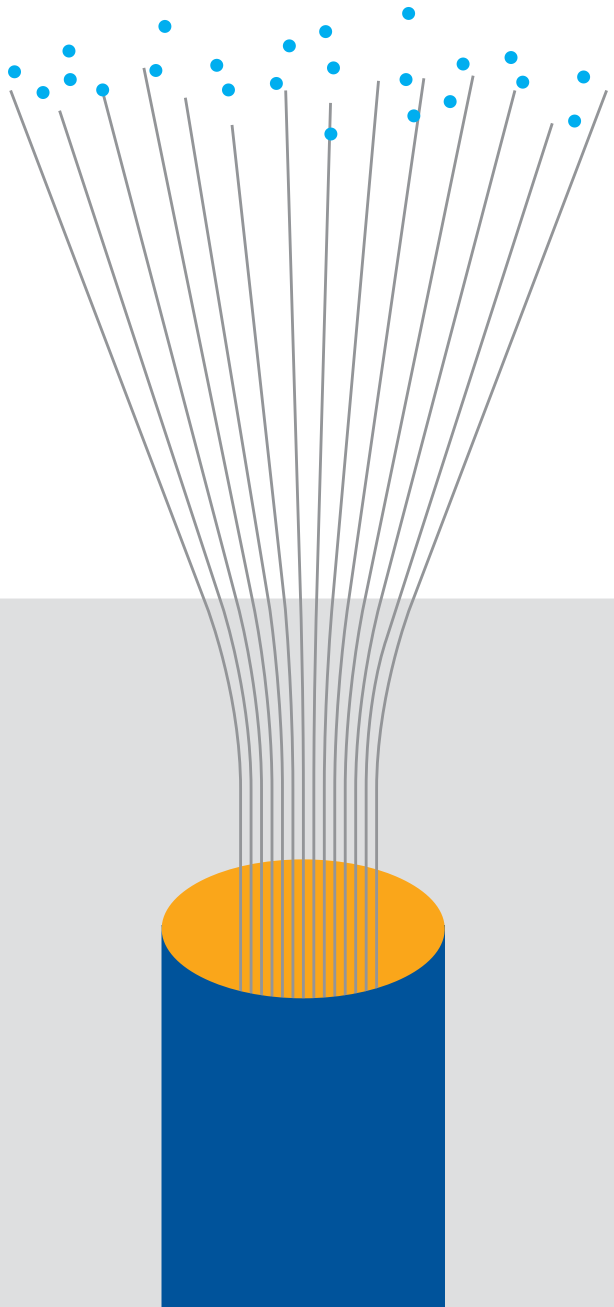
SENKO®
Advanced Components

White Paper | MAY 2015

PASSIVE OPTICAL SPLITTER

Benchmarking the Performance of Next Generation High Speed Access Networks

Bernard Lee



SENKO ADVANCED COMPONENTS, INC.

America
USA EAST 1-888-32-SENKO
USA WEST 1-858-623-3300
TEXAS 1-972-661-9080
Sales-Americas@senko.com

South America
BRAZIL +55-21-3736-7065
Sales-Brazil@senko.com

Asia
HONG KONG +852-2121-0516
SHANGHAI +86-21-5830-4513
SHENZHEN +86-755-2533-4893
Sales-Asia@senko.com

Europe
FRANCE +44 7939364565
Salesfrance@senko.com
GERMANY +49(0)15117683072
Sales-Germany@senko.com
ITALY +39 338 8919089
Sales-Italy@senko.com
POLAND +44 (0) 7796444488
Sales-Europe@senko.com
SPAIN & PORTUGAL +34 678042829
Sales-Iberia@senko.com
UK +44 (0) 1256 700880
Sales-UK@senko.com
OTHER +44(0) 1256 700880
Sales-Europe@senko.com

Asia Pacific
AUSTRALIA +61 (0) 3 9755-7922
Sales-Asia-Pacific@senko.com

Middle East North Africa
DUBAI +971 4 8865160
Sales-MENA@senko.com

Japan
TOKYO +81 (0) 3 5825-0911
Sales-Japan@senko.com

GR-1209 & GR-1221: BENCHMARKING THE PERFORMANCE OF NEXT GENERATION HIGH SPEED ACCESS NETWORKS

Contents

Executive Summary

In 2012, a leading market and technology analysts announced the Asia Pacific region (APAC) region leads in the consumption of Planar Lightwave Circuit (PLC) splitter compact devices with 68% of the worldwide value, followed by the American region and finally the EMEA region. The increase of mass FTTx PON network deployment dominates the worldwide PLC splitter compact device consumption value in 2012 with 77% in relative market share; followed by the cable TV segment, the PLC splitters used in Test and Measurement.

According to market analysis by ElectroniCast Consultants, the sales of PLC splitters reached $259.6m in 2013. PON based FTTH network deployment is dominating the worldwide PLC splitter consumption value in 2014. While the Americas region is forecasted for a flat annual growth of about 1% over the 2013-2018 period, the EMEA is set for a 7% growth per year; and Asia Pacific should increase at 15% per year, for component level PLC splitters. (http://optics.org/news/5/2/32)

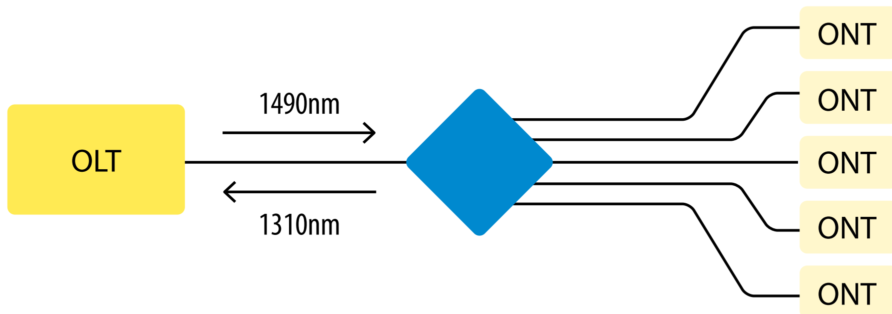
In Passive Optical Network (PON), optical splitters play an important role in Fiber to the Home (FTTH) networks by allowing a single PON interface to be shared among many subscribers. Splitters contain no active electronics and does not require any power to operate. Optical Splitters are installed in each optical network between the PON Optical Line Terminal (OLT) and the Optical Network Terminals (ONTs) that the OLT serves. Networks implementing BPON, GPON, EPON, 10G EPON, and 10G GPON technologies all uses these simple optical splitters. Nevertheless, for the experimental WDM-PON, in place of an optical splitter, an Arrayed WaveGuide (AWG) is being used.

Before large-scale deployment of FTTx, most splitter modules and other passive optical components were installed in central offices where it is in a stable temperature controlled environment. When the number of FTTH deployments increased, the deployment of optical splitters in the OSP network became a more cost effective solution. The common locations for optical splitters to be deployed in the OSP are in cabinets, in aerial or underground closures and also in wall-mounted enclosures in a building basement such as a Multi Dwelling Unit (MDU). Hence these splitters need to deliver both optical and mechanical performance when installed in any of these conditions.

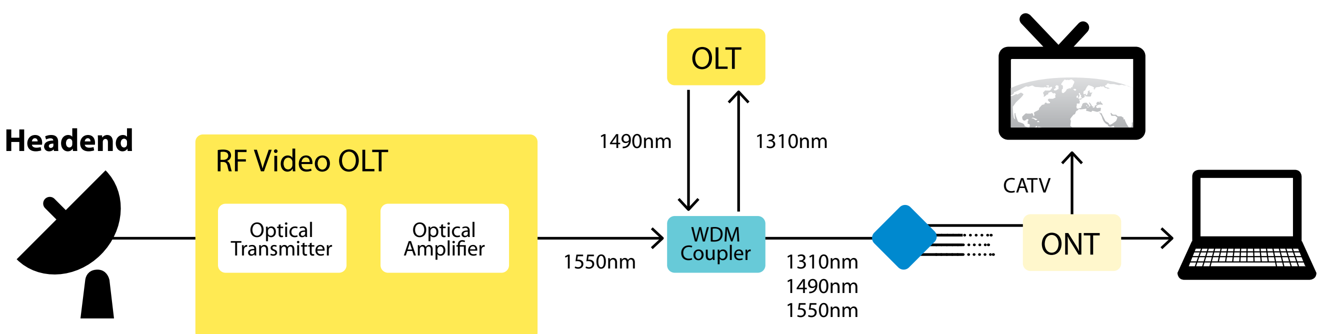
This paper describes the relevance of the criteria in the applicable industry specifications, as well as the importance of the physical parameters and how they relate to the performance of the optical splitters. This paper discusses the importance of quality, reliability, and performance as they relate to industry standards and manufacturing practices covered by the Telcordia GR-1209 requirements and GR-1221 testing procedures pertaining to one of the most important component in the Next Generation Access Networks – the Passive Optical Splitter.

Introduction to the functionality of an Optical Splitter

An optical splitter is an essential component used in an FTTH PON where a single optical input is split into multiple output. This enables the deployment a Point to Multi Point (P2MP) physical fiber network with a single OLT port serving multiple ONTs. The most common split ratios are 1:2, 1:4, 1:8, 1:16 and 1:32. Although other split ratios are available, they are usually custom made and commands a premium.



Optical fiber systems have also begun to replace coax networks which were used to transmit CATV analogue RF signals. Wavelength Division Multiplexer Couplers are used to overlay the 1550nm analogue signal from the CATV digital transmitter at the headend to the 1310nm and 1490nm signal from the PON equipment.



The most common splitters deployed in a PON system is a uniform power splitter with a 1:N or 2:N splitting ratio, where N is the number of output ports. The optical input power is distributed uniformly across all output ports. Splitters with non-uniform power distribution is also available but such splitters are usually custom made and command a premium.

The optical splitter in a PON system functions to share the cost and bandwidth of the OLT among multiple ONTs as well as reduce the fiber lines required in the OSP. Splitters can be deployed in a centralized splitting configuration or a cascaded splitting configuration depending on the customer distribution. The 1:N splitters are usually deployed in networks with a star configuration while 2:N splitters are usually deployed in networks with a ring configuration to provide physical network redundancy.

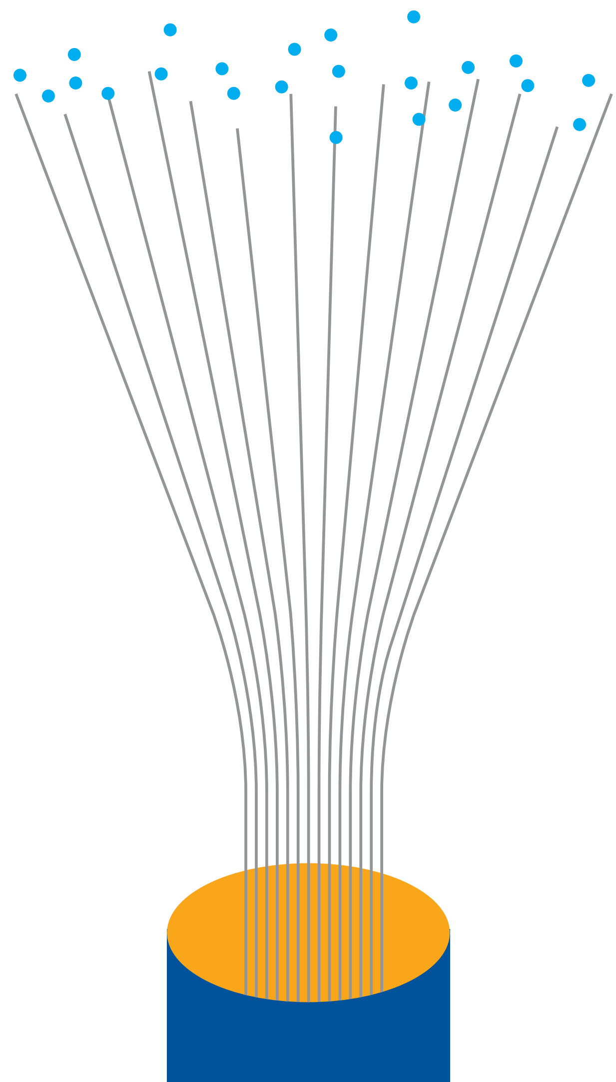
Introduction to GR-1209 & GR-1221

An introduction to GR's history and objective of implementation of the standard. Also touch on evolution of the standards (recently added requirements for anti-fungus)

Telcordia GR1209 & GR-1221 standards outline the generic criteria for passive optical components to ensure continuous operation of the components over its lifetime. The standards specify performance tests to reflect a composite picture of various conditions. These compliance tests cover three main features of an optical splitter which are the general requirements for an outside plant component, the functional design criteria and its performance criteria.

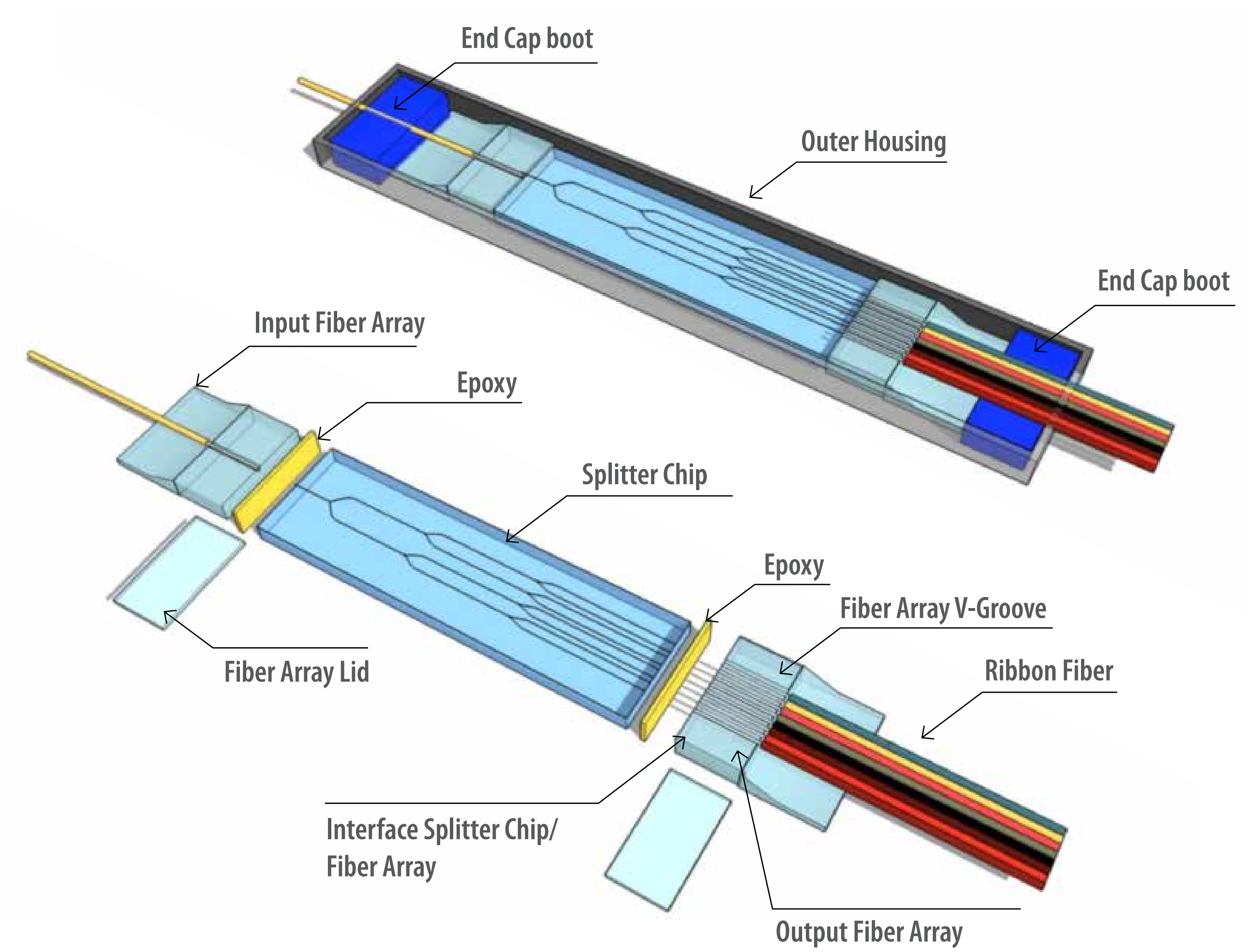
The environmental and mechanical tests outlined in the GR-1209 standard is designed to demonstrate the short term operational performance of a passive optical component. The normal lifespan of an FTTH network is at least 25 years, thus it is recommended for the environmental and mechanical test criteria to be based on the GR-1221 standard.

The performance tests are intended to reflect a composite picture of various conditions. The generic criteria, desired features and test methods may be subject to change. Such changes or addition is done to enhance the reliability criteria of the passive component under test. An example of such an update is the inclusion of an anti-fungus test in the GR-1209 test standard.



Basics of PLC Splitter Manufacturing Procedure

Among the many miniature parts which makes up a passive optical PLC splitter, there are three main components which are the fiber array for the input and output, and the chip. The design and assembly of these three component is the key to produce a high quality PLC splitter.



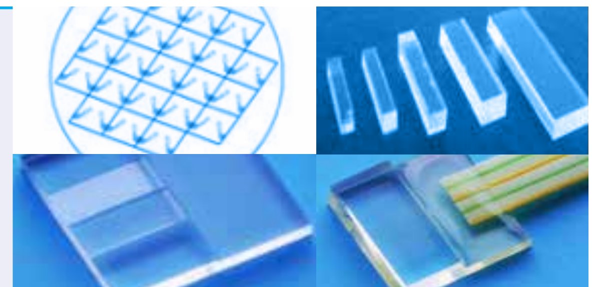
Key steps of manufacturing an optical splitter

The following section outlines the key steps of manufacturing an optical splitter where each step requires strict Quality Control on the environment, equipment used and also detailed precision in alignment and assembly.

Step 1

Components Preparation

The PLC circuit chip is designed and embedded on a piece of glass wafer. Each end of the glass wafer is polished to ensure high precision flat surface and high purity.
The v-grooves are then grinded onto a glass substrate. A single fiber or multiple ribbon fiber is assembled onto the glass substrate. This assembly is then polished.



Step 2

Alignment

After the preparation of the three components, they are set onto an aligner stage. The input and output fiber array is set on a goniometer stage to align with the PLC chip.
Physical alignment between the fiber arrays and the chip is monitored through a continuous power level output from the fiber array. Epoxy is then applied to the fiber array and the chip to affix their positions.

Step 3

Cure

The assembly is then placed in a UV chamber where it will be fully cured at a controlled temperature.

Step 4

Packaging

The bare splitter is aligned and assembled into a metal housing where fiber boots are set on both ends of the assembly. A temperature cycling test is done for a final screening to ensure the final product condition.

Step 5

Optical Testing

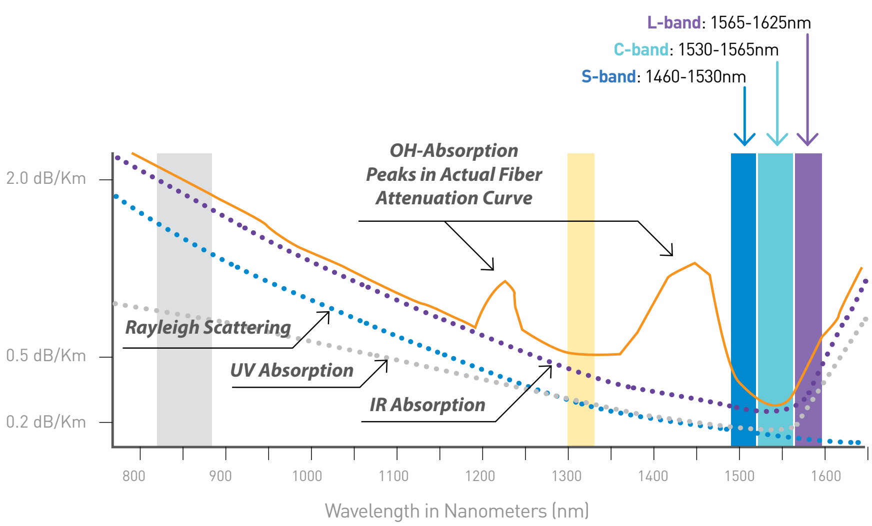
Optical testing such as Insertion Loss, Uniformity and Polarization Dependent Loss (PDL) is performed on the splitter to ensure compliance to the optical parameters of the manufactured splitter in accordance to the GR-1209 CORE specification.

How do You Determine the Quality of a PLC Splitter

The GR-1209 standard provides comprehensive optical performance criteria for a passive optical splitter. There are **six main specification** that is outlined in this standard. The following section outlines each of the specification and their importance for a fully functional optical splitter.

1 Optical Bandpass

For a fiber optic network, there are six nominal optical bandpass ranges which are outlined in the diagram below:



A PON system has a downstream transmission using the 1490nm wavelength while the upstream transmission is a 1310nm wavelength. In addition, there needs to be consideration for any requirement for RF video overlay and network testing/maintenance. RF video overlay is usually transmitted through the 1550nm wavelength. According to the ITU L.41 recommendation, the 1550nm or 1625nm wavelength is used for network for testing and surveillance. With these considerations, the required optical band needs to be determined. The standard operating wavelength for a PON splitter is the 1260-1650nm which covers most of the optical bands.

2 Optical Insertion Loss

The optical splitter is the component with the largest attenuation in a PON system. The insertion loss is the fraction of power transferred from the input port to the output port. In order to conserve the power budget of a PON system, the insertion loss from the splitter needs to be minimized. Based on the GR-1209 standard, the maximum allowable insertion loss for an optical splitter used in a PON system can be determined by using the calculations outlined in Table 2. This loss calculation does not include the loss from connectors.

Table 2

1xN Optical Splitter	**0.8 + 3.4 log2N**
2xN Optical Splitter	**1.0 + 3.4 log2N**

Note: N denotes the number of output ports

3 Optical Return Loss

Optical Return Loss is the fraction of power transferred from one input port back to the same input port or from an output port back to the same output port. A high return loss reduces the power reflected back to the transmitting port thus minimizing noise which may result in a system power penalty.

4 Uniformity

Uniformity is the maximum insertion loss value between one input port and any two output ports or between two input ports and one output port. This requirement ensures that for a PON system, the transmission power at each splitter output port is the same, thus simplifying the network design. Custom optical splitters with non-uniform coupling ratio can be manufactured for specific network deployment. In such a situation, this criteria is not applicable. The usage of a non-uniform splitter in a PON system increases the complexity in testing, design and maintenance while reducing the network flexibility.

5 Directivity

Directivity is the fraction of power transferred from one input port to another input port or from an output port to another output port. For a 2xN optical splitter, when light is injected into one of the input ports, light does not only propagate out of the output ports. Some of the light propagates back through the second input port. Vice versa, when light is injected into one of the output ports, light propagates back through the other output ports.

In a bidirectional transmission system such as a PON, directivity is important to reduce the power back to the transmitting port to reduce signal crosstalk. In addition, a high directivity value will also incur a higher insertion loss due to the loss in optical power..

6 Testing Method

The details of the optical performance criteria critical to a PON system is outlined in Table 1.

Optical Bandpass	*The optical bandpass can be tested by connecting the optical splitter to an optical spectrum analyzer with a high-powered light source having a central wavelength of the required bandpass. The attenuation across the required bandpass shall meet the splitter requirements.*
Insertion Loss	*The insertion loss is tested by using a light source and power meter. The reference power level is obtained and each of the output port of the optical splitter is measured.*
Return Loss	*The return loss is tested by using a return loss meter. The input port of the splitter is connected to the return loss meter and all the output ports are connected to a non-reflective index matching gel.*
Uniformity	*The uniformity of the optical splitter can be determined by referring to the results from the insertion loss test to ensure that the difference between the highest loss and the lowest loss is within the acceptable uniformity value.*
Directivity	*Directivity can be measured in a manner similar to the insertion loss test. However, the light source and power meter are connected to each of the input ports of to two output ports.*

Optical splitters deployed for a WDM PON system have additional performance criteria such as Polarization Dependent Wavelength (PDW) and Temperature Effects on DWDM, but these will not be covered in this paper.

Outline of GR-1221 Test Standards

The GR-1221 standard outlines the environmental and mechanical tests to ensure long term operational performance. The following section provides an overview of each of the test requirements and the importance for compliance.

Mechanical Integrity

The Mechanical Integrity category consists of three main components which are the **Mechanical Shock, Vibration** and **Thermal Shock**. These tests are designed to ensure the optical splitter performance when subjected to normal conditions during storage, transportation and installation.

Endurance

The Endurance category consists of five main components which are the **High Temperature Storage (Dry), High Temperature Storage (Damp), Low Temperature Storage, Temperature Cycling and Cyclic Moisture Resistance.** These tests are designed to simulate an accelerated aging effect to test the estimated lifetime of the optical splitter. The effects of moisture coupled with varying temperature levels have a degradation effect on the components within the optical splitter, especially the epoxy which provides a certain level of structural integrity to the PLC, optical fiber and the splitter housing.

Testing Method

The details of the optical performance criteria critical to a PON system is outlined in the Table below:

Mechanical Shock	*Mechanical Shock testing is performed to verify that the optical splitters are not damaged when they are dropped or knocked. The splitter is mounted rigidly on a fixture at 1.8m height and dropped 8 times at each of its three perpendicular axes. This test cycle is repeated 5 times.*
Vibration	*In a vibration test, the products being tested are mounted to a "shaker." By stressing the optical splitter, the test will reveal whether high frequencies of vibration induce performance change. The splitter is held on the shaker set with a sinusoidal vibration at a frequency of 10 to 2,000Hz with 1.52mm amplitude for 12 cycles where each cycle is a change from 10Hz to 2,000Hz and back in 20 minutes. This test is done for each of 3 mutually perpendicular axes.*
Thermal Shock	*The Thermal Shock Test is performed in a temperature chamber to verify that the optical splitters are not structurally compromised when transported from a one temperature extreme to another. The temperature chamber is heated to 100°C and the splitter is placed within the chamber. It is left to dwell at 100°C for 30 minutes, the temperature dropped to 0°C*

High Temperature Storage (Dry)

The splitter is stored within a temperature chamber heated to 85°C with <40%RH for 2,000 hours for qualification and to 5,000 hours for information on the performance of the splitter. Interval testing of the optical splitter is performed at 168, 500, 1000, 2000 and 5000 hour intervals.
Insertion loss is monitored for all ports

High Temperature Storage (Damp)

The splitter is stored within a temperature chamber heated to 75°C with <90%RH for 2,000 hours for qualification and to 5,000 hours for information on the performance of the splitter. nterval testing of the optical splitter is performed at 100, 168, 500, 1000, 2000 and 5000 hour intervals.
Insertion loss is monitored for all ports.

Low Temperature Storage

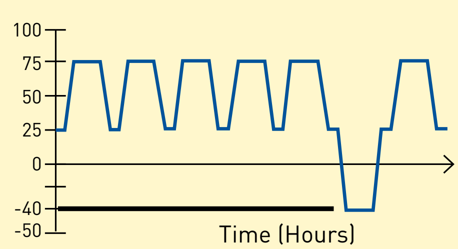
The splitter is stored within a temperature chamber cooled to -40°C for 2,000 hours for qualification and more than 5,000 hours for information on the performance of the splitter. Interval testing of the optical splitter is performed at 100, 168, 500, 1000, 2000 and 5000 hour intervals.
The strength of the epoxy joints are tested after 2000 and 5000 hours

Temperature Cycling

The splitter is stored within a temperature chamber.
For CO based splitters, the temperature range is -40°C to 70°C
For Uncontrolled environments, the temperature range is 40°C to 85°C
Temperature is cycled from the extremes with a dwell time of at least 15 minutes at each of the extremes. The number of temperature cycles required is:
For CO based splitters, 100 cycles for qualification, 500 for information.
For Uncontrolled environments, 500 cycles for qualification, 1000 for information.

Cyclic Moisture Resistance

The splitter is stored within a temperature chamber. The temperature cycle profile is as below 85-95%RH at 75°C, RH uncontrolled at 25°C and -40°C. Dwell time at extremes is 3-16 hours. 5 cycles in total.



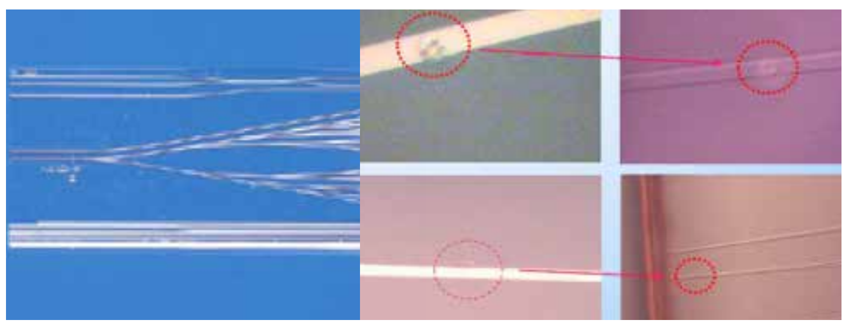
Non GR-1209 & GR-1221 Certified PLC Splitters

The adoption of the GR-1209 and GR-1221 standard provides an assurance to the performance and long term reliability of the product. However, there are many PLC splitter manufacturers who do not practice the level of quality control throughout the manufacturing process and thus unable to produce a compliant product. These manufacturers may be selling the products in the market claiming similar a similar level of quality as those who have taken the effort and due diligence to comply with the stringent standards.

The failure of an optical splitter is critical to a PON system because multiple customer connections may be affected. In addition, the restoration requires the re-splicing or re-termination of multiple fiber especially for a high split ratio splitter. This increases the cost and time to restore. This section provides information on some case studies where non-compliant products have failed and affected service providers' network.

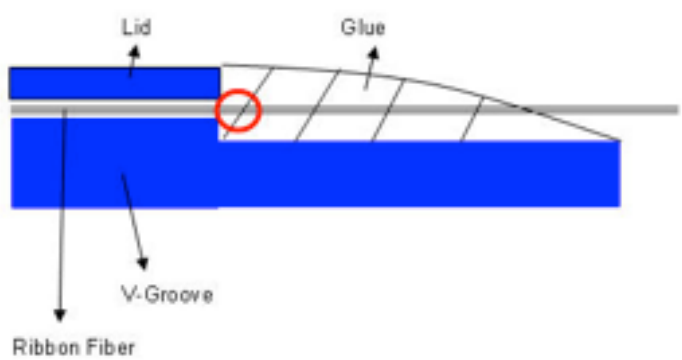
Damaged Waveguide

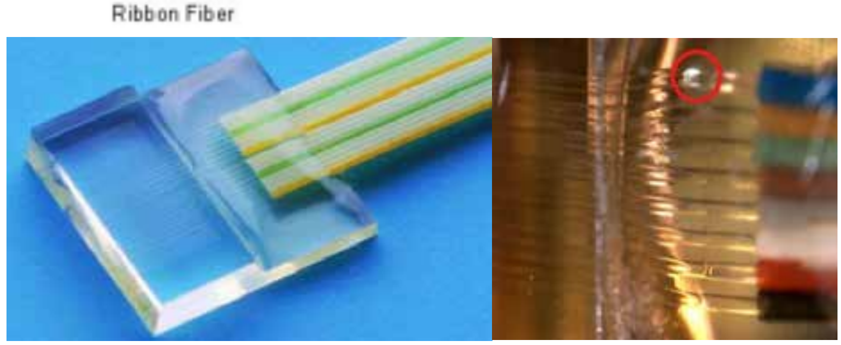
The damaged part of the waveguide is usually caused by the use of a waveguide mask with imperfections. This point on the waveguide increases the light scattering effect thus increasing the return loss and increases the attenuation.



Broken Fiber in Array

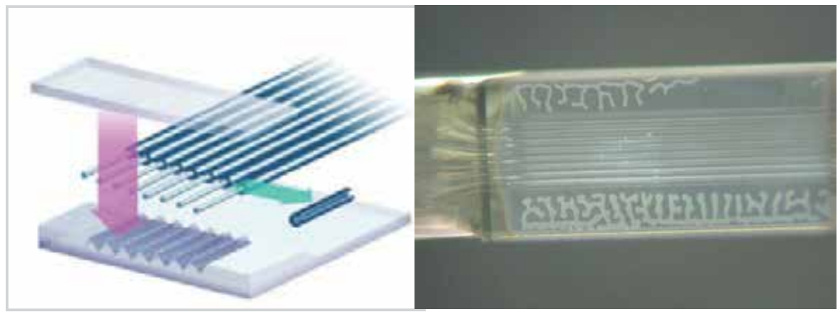
The fiber within the fiber array v-groove is observed to be broken. This is usually caused by imperfect fiber stripping, cleaning and cleaving of the ribbon fiber during the manufacturing process. A small scratch or crack on the optical fiber can become a stress point during the resin curing process or from prolong usage where it may be subjected to temperature fluctuations or vibrations.





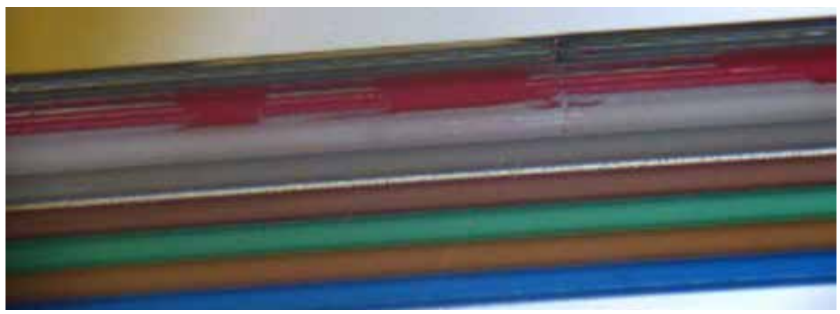
Delamination

A lid is held to the fiber array v-groove by an adhesive to hold the fibers in place. Delamination of these two parts may occur due to the quality of the adhesive or due to the mismatch in the glass array material with the adhesive used. Delamination will increase over time and cause the fibers to move out of the v-groove array. This may cause the fibers to be pinched and increase the insertion loss.



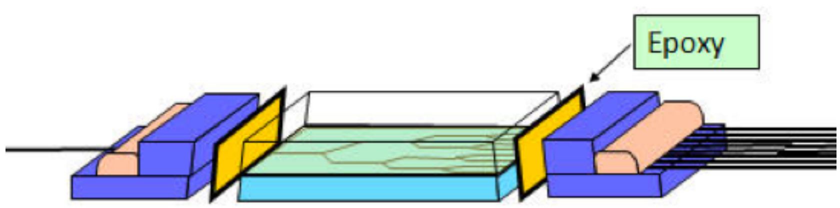
Ribbon Fiber Coating

The optical fiber used in the manufacturing of the splitter is also very crucial to producing a high quality product. In this example, a low quality ribbon fiber with a low quality and non-uniform outer coating matrix is used. It was found that the coating matrix has peeled off, thus exposing the 250um fiber. This will pose a risk for fiber breakage when the ribbon is bent in that location where the exposed fiber may be subjected to a higher stresses.



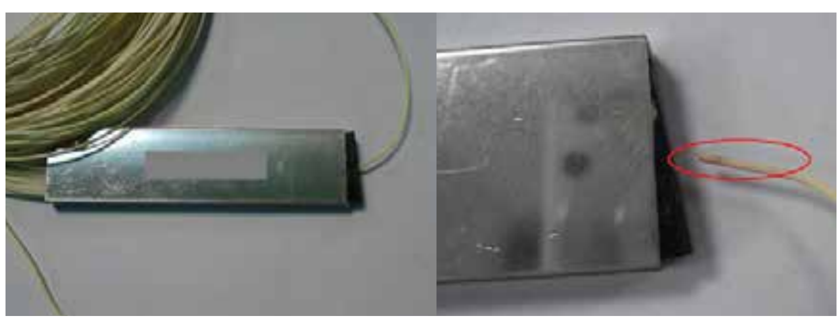
Chip and Fiber Array Alignment

Some of the possible reasons for the PLC splitter chip and the fiber array to become misaligned may be due to the lack of manufacturing precision, the usage of a low quality epoxy or a non-optimal curing process. The splitter appearance does not change but the aligned position drifts and may cause a change in the optical parameters such as increased attenuation and more susceptible to failure due to mechanical and environmental stresses.



Unsecured Fiber Boot

This example shows the 900um fiber and tubing became detached from the splitter housing. This is caused by multiple failures from the fiber end boot, fiber array lid, epoxy quality and curing process. This increases the risk of fiber breakage where the 250um fiber is exposed.



Summary

Optical splitter quality and performance is not only guaranteed by using high quality components and stringent manufacturing processes and equipment, but also by adherence to a successful Quality Assurance program. There are many factors which needs to be considered other than the insertion loss and return loss performance. The selection of the materials need to be complimentary to each other to ensure proper cohesion when assembled and cured in the optimal condition. One of the most important factors is the epoxy which binds the fiber to the three main components of the splitter which ensure the adhesion of every component. The epoxy needs to be injected without introducing inconsistency or having trapped air bubbles and it needs to be cured at the right temperature at the right duration.

In conclusion, the integrity, performance and long term reliability of the optical splitter is paramount throughout the lifetime of a PON system. The adherence to the GR-1209 CORE and GR-1221 CORE test standards provides such an assurance.

References

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

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

Biography

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.

www.senko.com