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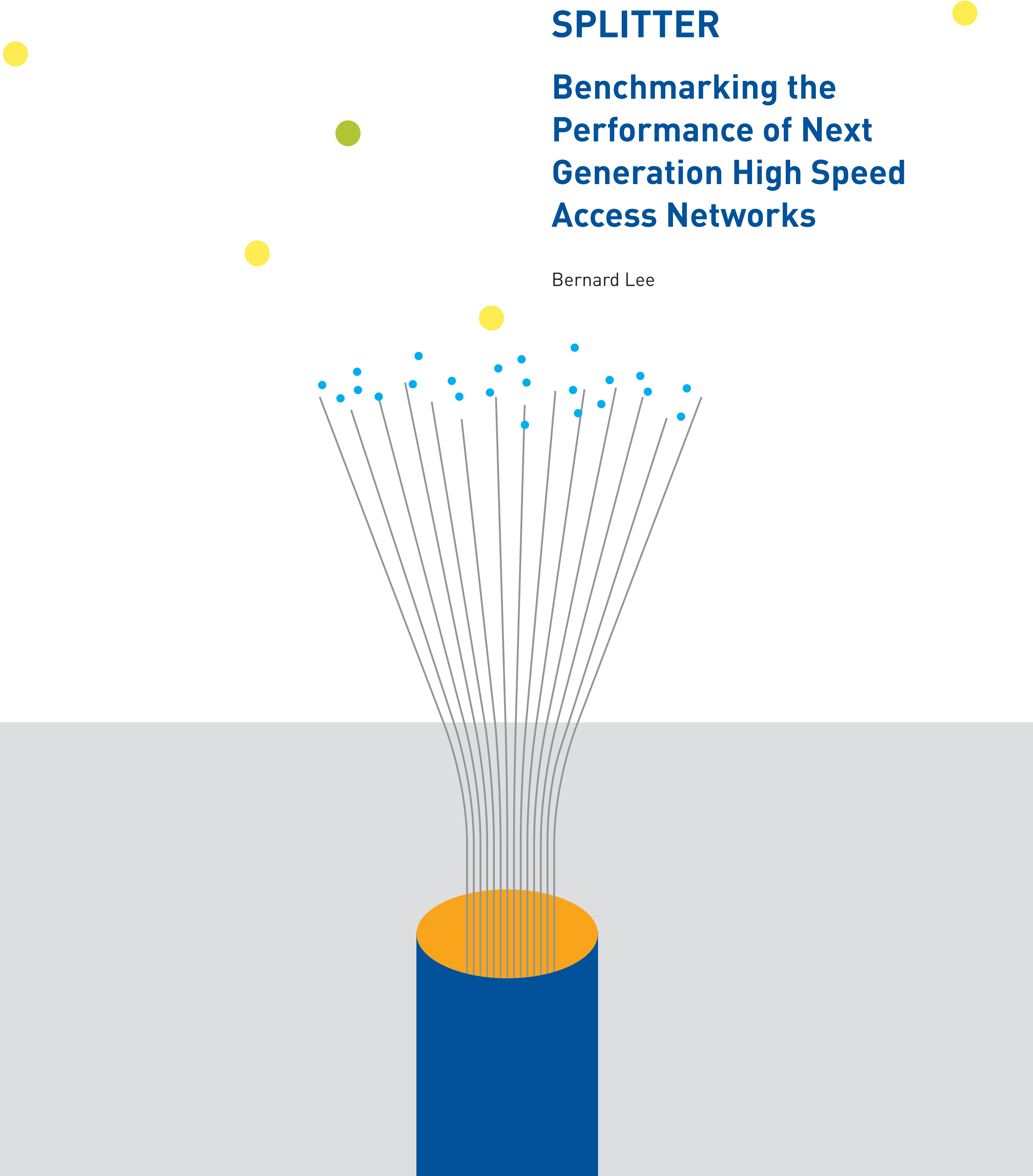
PASSIVE OPTICAL SPLITTER

Benchmarking the Performance of Next Generation High Speed Access Networks

Bernard Lee



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

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Executive Summary

The Asia Pacific region (APAC) leads worldwide consumption of Planar Lightwave Circuit (PLC) splitter compact devices with a 68% share, followed by the Americas and the EMEA (Europe, Middle East, and Africa) region. The global PLC Fiber Optic Splitter market was valued at $4.47 Billion USD in 2020 and is expected to grow at an average rate of 5.28% from 2020 to 2027, according to market analysis by MarketResearch.biz.

A Passive Optical Network (PON) is a fiber optic technology utilizing point-to-multipoint topology and optical splitters to deliver data from a single transmission point to multiple user endpoints. Passive refers to the unpowered condition of the fiber and splitting/combining components. Both fiber and splitter require no electricity to run between the endpoints.

G.984, a commonly known GPON (Gigabit-capable Passive Optical Network), is a standard PON published by the ITU Telecommunication Standardization Sector (ITU-T). It is commonly implemented within the last mile of Fiber to the Premises (FTTP) services. GPONs are the main variation of PONs that allow for higher speeds of transmission and data reception through a single fiber. With a point-to-multipoint architecture, it enables optical fiber to the home/business with access to Video, Voice, and Data and was designed to enhance existing copper networks.

Optical splitters play an important role in Fiber to the Home (FTTH) networks by allowing a single GPON interface to be shared among many subscribers. Splitters do not contain any active electronics and do not require any power to operate. Optical Splitters are installed at each optical network between the Optical Line Terminal (OLT) and the Optical Network Terminals (ONTs) that the OLT serves. GPON variation networks, such as BPON, EPON, 10G EPON, and 10G GPON technologies, all employ simple optical splitters. However, the experimental WDM-GPON uses an Arrayed Wave Guide (AWG) in lieu of an optical splitter.

Optical splitters take a single fiber and refract and duplicate it multiple times to outbound fibers. GPON deployment uses a splitting ratio of 1:32 or 1:64. Current GPON standards specify up to 128 splits on a single GPON port. These same standards set the distance between active devices at up to 20 kilometers.

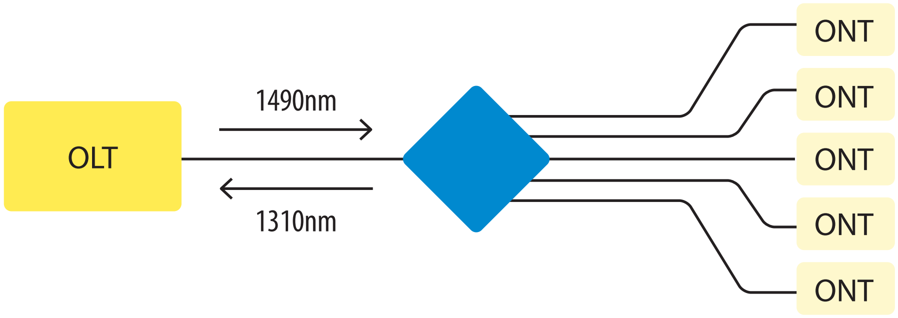
Before large-scale deployments of FTTx, most splitter modules and other passive optical components were installed in central offices within a stable, temperature-controlled environment. When the number of FTTH sites increased, the deployment of optical splitters in the Open Settlement Protocol (OSP) network became a more cost-effective solution. In the OSP, optical splitters are commonly deployed in cabinets, in aerial or underground closures, and in wall-mounted enclosures in the basement of a building, such as a Multi Dwelling Unit (MDU). Therefore, the splitters need to be able to perform both optically and mechanically under a variety of conditions.

GPON growth is fueled by an increase in worldwide internet traffic, where 80% is expected to be allocated for video consumption. Company investments in the latest variation of GPONs, called XGS-PON, are increasing rapidly with spending up at over 500% year to year according to Optical Connection Magazine (summer 2021). XGS-PON is estimated to grow from USD 6.3 billion in 2020 to USD 8.3 billion by 2025, at a Compound Annual Growth Rate (CAGR) of 5.8%, according to global forecasts by MarketsandMarkets™ Inc. Major factors fueling GPON market growth include a high demand for triple and quad-play services, an increasing demand for high-speed broadband services, advancements in GPON technology, and 5G network deployment. GPONs have always been feasible for LTE macrocells, but never provided a clear advantage. Trials today demonstrate that GPONs are extremely well-suited for addressing small cell challenges and facilitating 5G deployment.

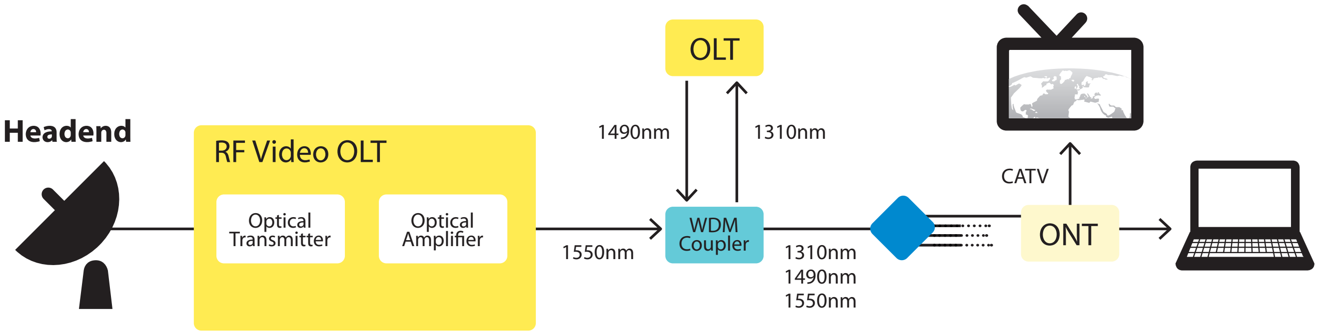
As stated, PONs use multiple passive components that are required to work reliably within a network. This paper describes the relevance of applicable industry specifications and physical parameters, and how they relate to the performance of passive components, such as optical splitters, WDMs, AWGs, etc. Also discussed are the importance of quality, reliability, and performance in relation 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 components of Next Generation Access Networks.

Introduction to the Functionality of an Optical Splitter

An optical splitter is an essential component used in an FTTH GPON where a single optical input is split into multiple outputs. This enables the deployment of 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, 1:32, and 1:64. Other split ratios are available, but they are usually custom made and command a premium.

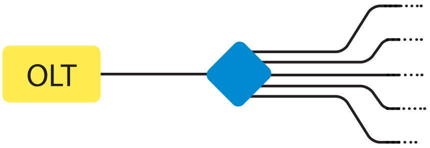


Optical fiber systems are replacing coax networks, which were used to transmit CATV analogue RF signals. Wavelength Division Multiplexer (WDM) Couplers are used to overlay the 1550 nm analog signal from the CATV digital transmitter at the headend to the 1310 nm and 1490 nm signal from the PON equipment.

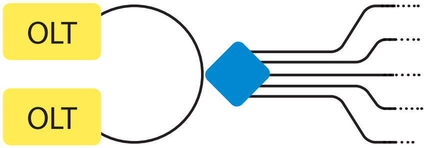


The most common splitters deployed in a GPON system are uniform power splitters with a 1xN or 2xN splitting ratio, where N is the number of output ports. The optical input power is distributed uniformly across all output ports. Splitters with non-uniform power distribution are also available, but these are usually custom made to user specifications.

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



Star Configuration



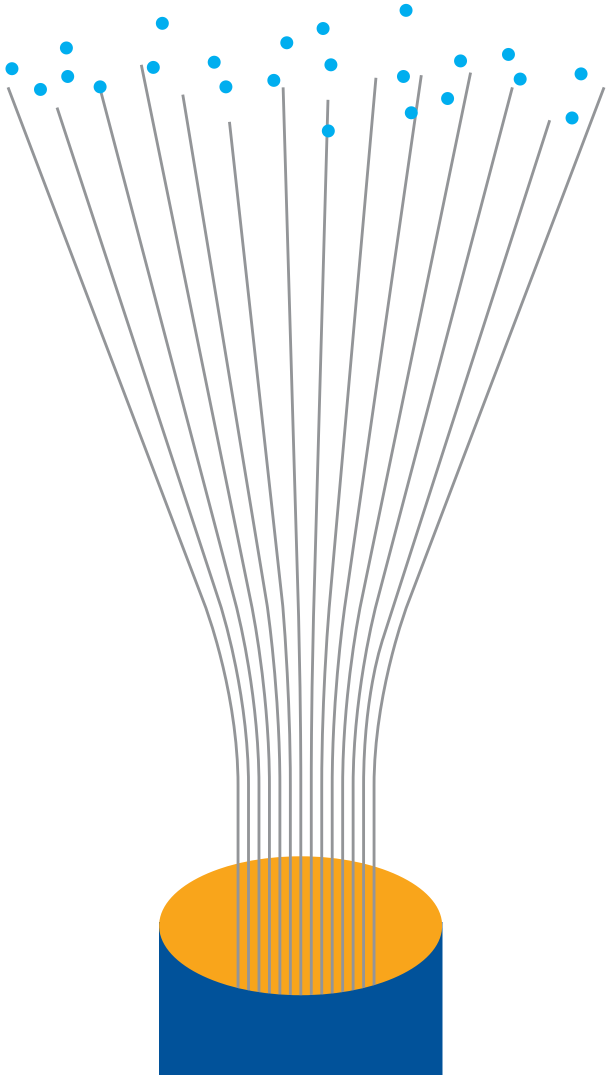
Ring Configuration

Introduction to GR-1209 & GR-1221

Telcordia GR1209 & GR-1221 standards outline the generic criteria for ensuring the continuous lifetime operation of passive optical components. These standards specify performance tests that simulate real-life conditions. These compliance tests address three main features of an optical splitter, which are functional design criteria, performance criteria, and general requirements for an external plant component.

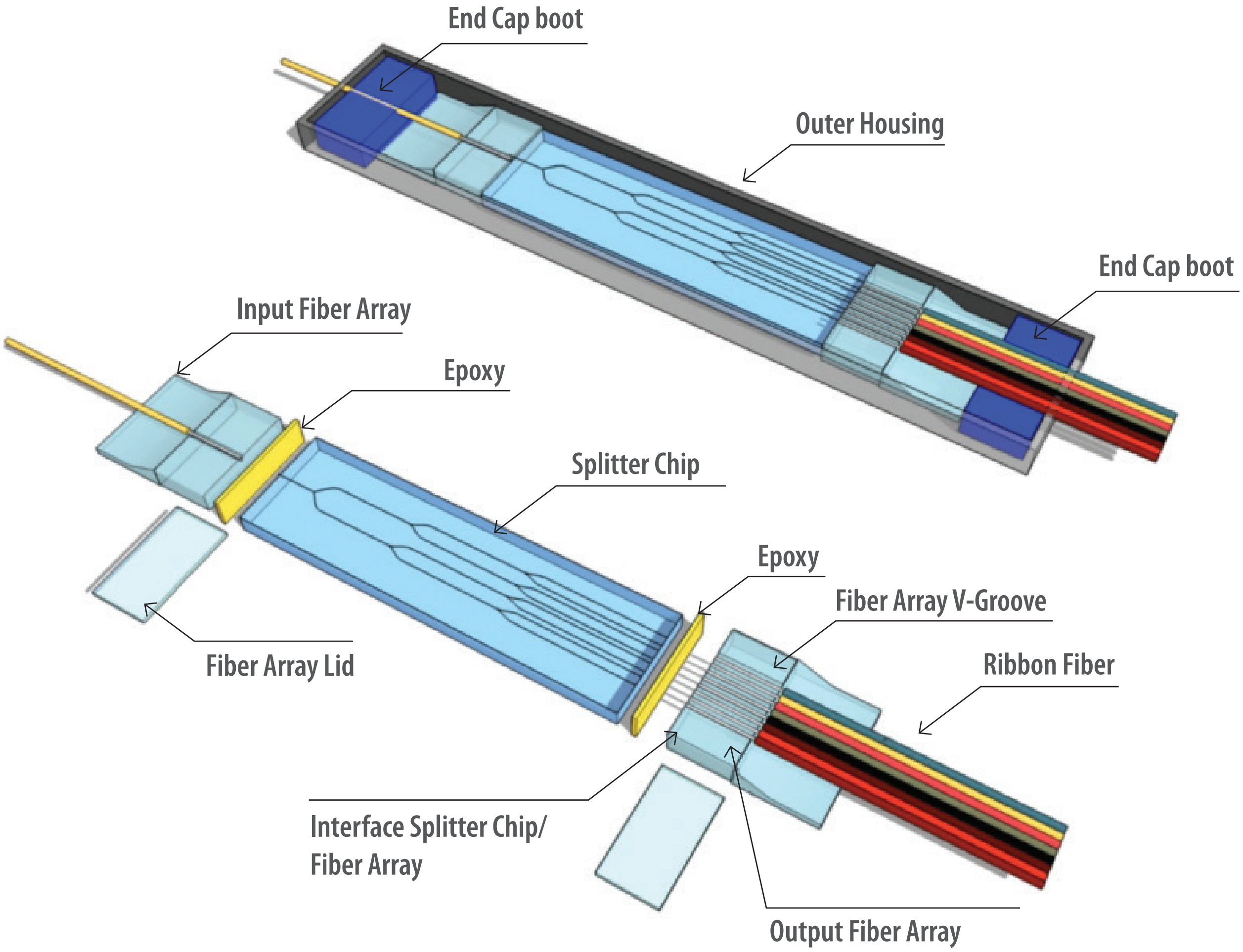
The environmental and mechanical tests, outlined in the GR-1209 standard, are designed to demonstrate the short-term operational performance of a passive optical component. The typical lifespan of an FTTH network is at least 25 years, therefore it is recommended to base the environmental and mechanical test criteria on the "long-term" GR-1221 standard.

The performance tests generate a composite picture of component functionality under various simulated conditions. The generic criteria, desired features, and test methods may be subject to change. Updates are released to enhance the reliability criteria of the passive component under test. An example is the inclusion of a fungal resistance test in the GR-1209 standard.



Basics of the PLC Splitter Manufacturing Procedure

Among the many miniature parts that make up a passive optical PLC splitter, there are three main components: the input and output fiber arrays, and the chip. The design and assembly of these three components is the key to producing a high-quality PLC splitter.



Key Steps to Manufacturing an Optical Splitter

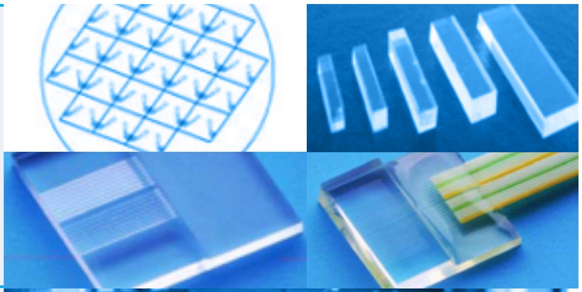
The following section outlines the key steps to manufacturing an optical splitter, where each step requires strict Quality Control of the environment and the equipment used, and detailed precision during alignment and assembly.

Step 1

Component 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 a 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. The assembly is then polished.



Step 2

Alignment

After preparation, the three components are set onto an aligner stage. The input and output fiber arrays are set onto a goniometer stage for alignment with the PLC chip. Physical alignment between the fiber array and the chip is performed by live monitoring the output power through the fiber array. Epoxy is then applied to affix the fiber arrays and the chip into their final positions.

Step 3

Cure

The assembly is placed into a UV chamber where it is fully cured at a controlled temperature.

Step 4

Packaging

The bare splitter is aligned and assembled into a metal housing by setting fiber boots on both ends of the assembly. A temperature cycling test is performed to evaluate the final product condition.

Step 5

Optical Testing

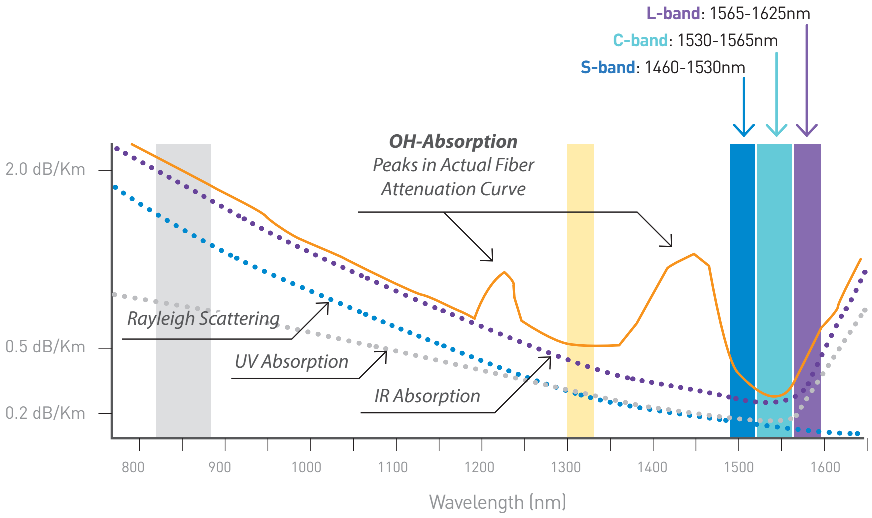
Optical testing such as Insertion Loss, Uniformity, and Polarization Dependent Loss (PDL) is performed on the splitter to ensure compliance with the manufacturer's optical parameters in accordance with the GR-1209 CORE specification.

How do You Determine the Quality of a PLC Splitter

The GR-1209 standard details comprehensive optical performance criteria for a passive optical splitter. There are **six main specifications** that are outlined in the standard. The following section outlines each of the specifications and their importance towards achieving 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 transmits downstream at 1490 nm and transmits upstream at 1310 nm. In addition, consideration must be made for any RF video overlay and network testing/maintenance requirements. RF video overlay is usually transmitted at 1550 nm. According to the ITU L.41 recommendation, either the 1550 nm or 1625 nm wavelength is to be used for network testing and surveillance. With these considerations, the required optical band needs to be determined. The standard operating wavelength for a PON splitter is in the 1260 - 1650 nm range, 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 power, 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 using the calculations outlined below. These calculations do not include loss from connectors.

Table 2

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

N = number of output ports

3 Optical Return Loss

Optical Return Loss is the fraction of power transferred from one input or output port back to itself. **A high return loss** reduces the power reflected back to the transmitting port, thus minimizing the noise that 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 simplifies PON design by ensuring equivalent transmission power at each splitter output port. However, custom optical splitters with non-uniform coupling ratios can be manufactured for specific network deployment, where the uniformity criterion is not applicable. The usage of a non-uniform splitter in a PON increases the complexity of testing, design, and maintenance, while reducing network flexibility.

5 Directivity

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 simplifies PON design by ensuring equivalent transmission power at each splitter output port. However, custom optical splitters with non-uniform coupling ratios can be manufactured for specific network deployment, where the uniformity criterion is not applicable. The usage of a non-uniform splitter in a PON increases the complexity of testing, design, and maintenance, while reducing network flexibility.

6 Testing Method

The details of the optical performance criteria critical to a PON system are outlined below.

Optical Bandpass	*Optical bandpass can be tested by connecting the optical splitter to an optical spectrum analyzer equipped with a high-powered light source with a central wavelength at the required bandpass. The attenuation across the required bandpass must meet the splitter requirements. A wideband component test system that uses a tunable laser, high-dynamic range detectors, and intelligent software can also accomplish this testing with high speed and accuracy.*
Insertion Loss	*Insertion loss is tested by using a stable light source and power meter. The reference power level is obtained for each of the output ports of the optical splitter are measured. If using a wideband component test system the IL can be measured during the equipment sweeping.*
Return Loss	*Return loss is tested by using a return loss meter. Depending on the type of equipment used, the process can be different. If using Optical Continuous Wavelength Reflectometry Technology, index matching gel is typically used on the far end to isolate the splitter. With the emergence of technology, some Optical Time Domain Reflectometry equipment can select the area of interest to extract the RL at the splitter.*
Uniformity	*Uniformity of the optical splitter is 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 is measured in a similar manner to the insertion loss test. However, the light source is connected to the input port and the power meter is also connected to another input port. It can be considered to be the light returning into another input port other than where the source is connected.*

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 are not be covered in this paper.

Outline of GR-1221 Test Standards

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

Mechanical Integrity

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

Endurance

The Endurance category consists of five main components which are: **High Temperature Storage (Dry), High Temperature Storage (Damp), Low Temperature Storage, Temperature Cycling and Cyclic Moisture Resistance.** These tests are designed to simulate the accelerated aging of the optical splitter to predict its estimated lifetime. Moisture, coupled with varying temperature levels, has a degradative effect on the components within the optical splitter; especially the epoxy, which provides 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 are outlined 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 to a fixture 1.8 m high and dropped 8 times. This test cycle is repeated 5 times.*
Vibration	*Vibration testing is performed by mounting the product to a "shaker." The test reveals whether high frequencies of vibration (i.e. vibrational stress) induce performance changes in the optical splitter. The "shaker" runs with a sinusoidal vibration at frequencies of 10 to 2000 Hz, with a 1.52 mm amplitude, for 12 cycles, where each cycle ranges from 10 to 2000 Hz and back in 20 minutes. This test is performed on each of three perpendicular axes.*
Thermal Shock	*Thermal Shock testing is performed in a temperature chamber to verify that the optical splitters are not structurally compromised when transported from one temperature extreme to another. The splitter is exposed to a temperature of 100°C for 30 minutes, at which point the temperature is dropped to 0°C.*

High Temperature Storage (Dry)

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

High Temperature Storage (Damp)

The splitter is stored within a temperature chamber heated to 75°C with < 90% RH for 2000 hours for qualification purposes and up to 5000 hours for an additional performance interval. Interval testing of the optical splitter is performed at 100, 168, 500, 1000, 2000, and 5000 hour intervals. Insertion loss is monitored at all ports.

Low Temperature Storage

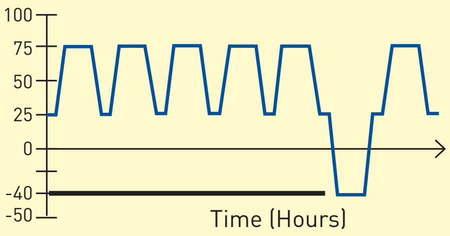
The splitter is stored within a temperature chamber cooled to -40°C for 2000 hours for qualification purposes and up to 5000 hours for an additional performance interval. Interval testing of the optical splitter is performed at 100, 168, 500, 1000, 2000, and 5000 hour intervals. The strength of the epoxy joints is tested at 2000 and 5000 hours.

Temperature Cycling

The splitter is stored within a temperature chamber where the temperature is cycled between the extremes, with a dwell time of at least 15 minutes at each of the extremes. The temperature ranges are:
CO-based splitters: -40°C to 70°C. Uncontrolled environments: 40°C to 85°C.
The number of temperature cycles required are:
CO-based splitters: 100 cycles for qualification, 500 for performance evaluation.
Uncontrolled environments: 500 cycles for qualification, 1000 for performance evaluation.

Cyclic Moisture Resistance

The splitter is stored within a temperature chamber with the following cycle profile: 85 - 95% RH at 75°C, RH uncontrolled at 25°C and -40°C. 5 complete cycles are completed (each complete cycle has 5 sub-cycles).



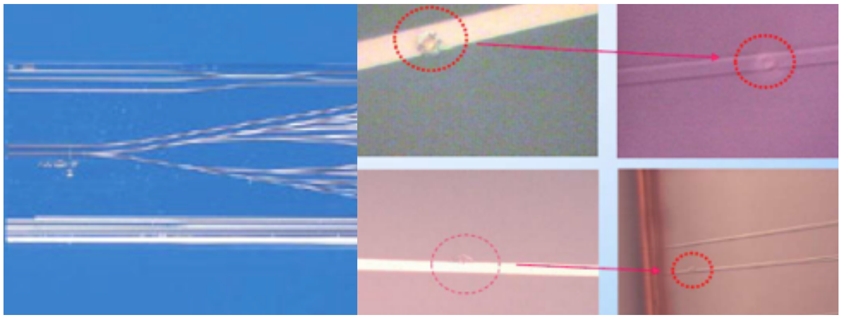
Non GR-1209 & GR-1221 Certified PLC Splitters

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

The failure of an optical splitter is catastrophic to a PON system because multiple customer connections may be affected. Restoration requires re-splicing and/or re-termination of multiple fibers, especially when dealing with high split ratio splitters. This increases the cost and time to restore. This section provides examples of how non-compliant products have failed and affected network service.

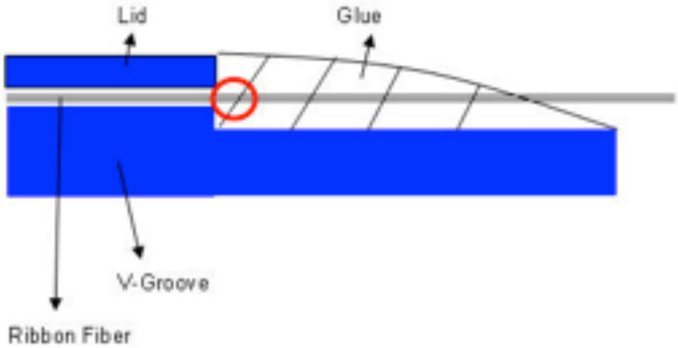
Damaged Waveguide

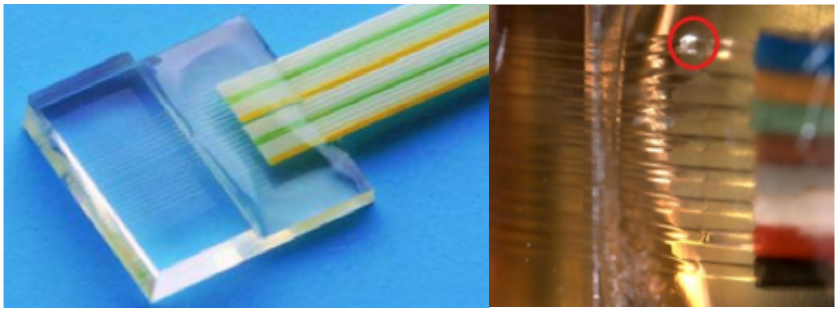
Damage to the waveguide is usually caused by using a waveguide mask with imperfections. This area on the waveguide increases the light scattering effect, thus increasing the return loss and attenuation.



Broken Fiber in Array

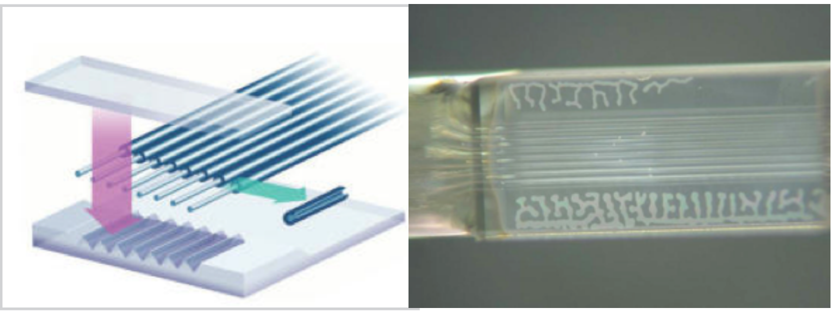
A broken fiber within the fiber array V-groove is usually caused by imperfect fiber stripping, cleaning, and cleaving of the ribbon fiber during the manufacturing process. A small scratch or crack on the optical fiber can become a stress point during the resin curing process or during prolonged usage in conditions with temperature fluctuations and/or vibrations.





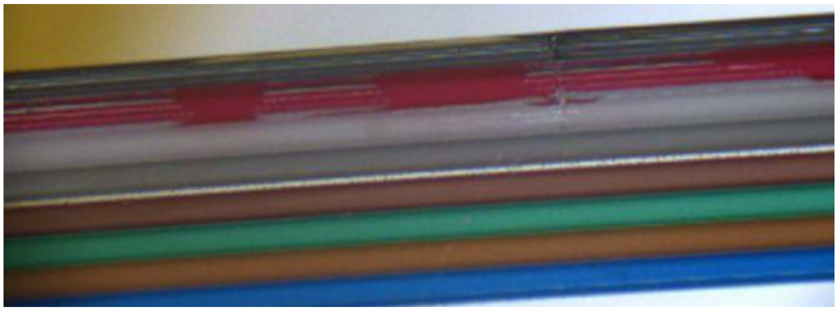
Delamination

A lid is fastened to the fiber array V-groove by an adhesive that holds the fibers in place. Delamination may occur when the quality of the adhesive is poor or when a mismatch occurs between the glass array material and the adhesive used. Delamination will increase over time and cause the fibers to move out of the V-groove array. This may pinch the fibers and increase insertion loss.



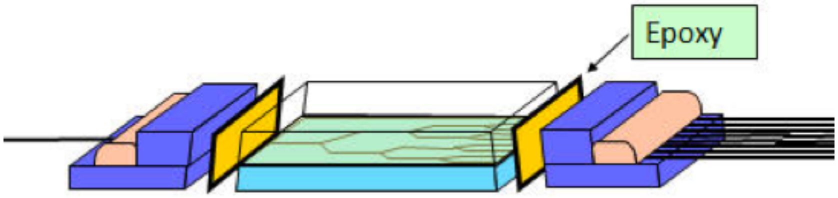
Ribbon Fiber Coating

The ribbon fiber used in manufacturing optical splitters is crucial towards producing a high-quality product. In this example, a low-quality ribbon fiber, with a low quality and non-uniform outer coating matrix, was used. As a result, the coating matrix has peeled off and exposed the 250 μm fiber beneath. The risk of breakage is increased with exposed fibers.



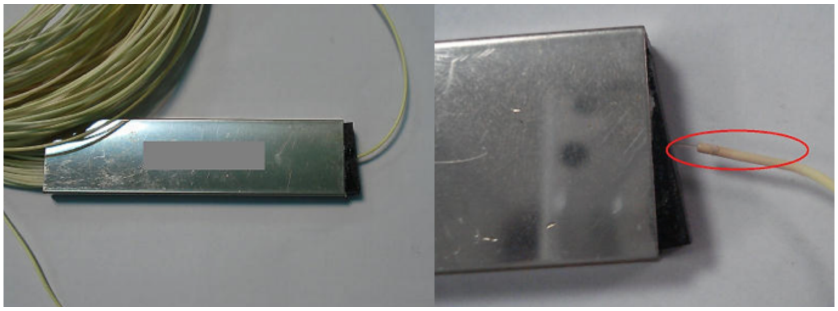
Chip and Fiber Array Alignment

Misalignment of the PLC splitter chip and the fiber array may occur due to poor manufacturing precision, the use of low-quality epoxy, and/or a suboptimal curing process. Although not visibly evident, minute changes in the positional alignment may affect optical parameters, resulting in increased attenuation and susceptibility to failure from mechanical and environmental stressors.



Unsecured Fiber Boot

In this example, the 900 μm fiber and tubing have become detached from the splitter housing. This can result from failures associated with the fiber end boot, fiber array lid, epoxy quality, and curing process. The now exposed 250 μm fiber is at an increased risk of breakage.



Summary

As internet traffic grows the expectations and the busines plans for every deployment becoming highly custom and unique. Knowing the advantages and disadvantages of each architecture helps in the deployment selection process. There are many technologies where fiber optic splitters are utilized. Passive optical splitters became an integral part of PON. GPON provide a solution that minimizes the physical footprint, increases distances and bandwidth, reduces latency and improves network security. The splitters decrease physical fiber usage making the network deployment and maintenance cost effective. A single fiber in today's GPON can feed up to 128 ports that equates to 128 users reducing the strains on the fiber back bone. Choosing the right fiber optic splitters help increase the efficiency of the optical infrastructure. Making an educated decision regarding initial product selection is the key to developing a network architecture that will last well into future bandwidth demands.

Optical splitter quality and performance is guaranteed not only by using high quality components and stringent manufacturing processes and equipment, but also by adhering to a successful Quality Assurance program. Many factors need to be considered beyond insertion loss and return loss performance. The materials selected need to be complementary with one another to ensure proper cohesion during assembly and curing. The epoxy, which binds the fiber to the three main components of the splitter to ensure proper adhesion of every component, is one of the most important elements. The epoxy must be injected without introducing any inconsistencies or trapped air bubbles and needs to be cured at the proper temperature for the proper duration of time.

In conclusion, with PON system architecture growing in popularity it is important to maintain the integrity, performance, and reliability deployed optical components. Adherence to the GR-1209 CORE and GR-1221 CORE test standards provides assurances to Internet Service Providers that their deployed networks will withstand the test of time.

References

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2. Telcordia GR-1221-CORE, "Generic Reliability Assurance Requirements for Passive Optical Components", Issue 3, Telcordia Technologies, September 20100
3. Optical Connection Magazine, Summer Issue 2021

Biography

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).

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 an LTE RAN launch project team. Andrei holds several 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.

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