Technical Note of Fiber Bragg Grating embedded Fiber Optic Reflector

White Paper

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Introduction

This paper is intended for readers to have some basic knowledge of Optical Networks and Optical Time-Domain Reflectometer (OTDR) backscatter traces within Passive Optical Networks (PON).

This paper explains the fundamentals of an optical filter or sometimes called a reflector, which is interchangeable. The basic techniques involved in manufacturing the two technologies i.e. Fiber Bragg grating and Thin Film Filter. The understanding of reflectors used in PON for remote fiber testing and monitoring (RFTS). The Reflectors are an important part of an RFTS to fault find in real time and therefore reduce-down time. An OTDR is used in combination to display the reflectance from the filter. A PON can be automatically monitored in service if one of the leg branches are reflective. The level of the peak that the reflective termination generates is checked at each point. The peak disappears if the fiber is cut or its reflective termination level decreases because of fiber attenuation. This system enables checking fiber continuity from the Central Office (CO) to the customer or Optical Network Unit (ONU). When it detects a fiber cut it (a peak is missing), it can accurately locate it using the OTDR. The paper also explains the different types of filters including, Plug, In-Line, Pigtail and Field Installable.

History of OTDR Testing with Reflective Termination Filters

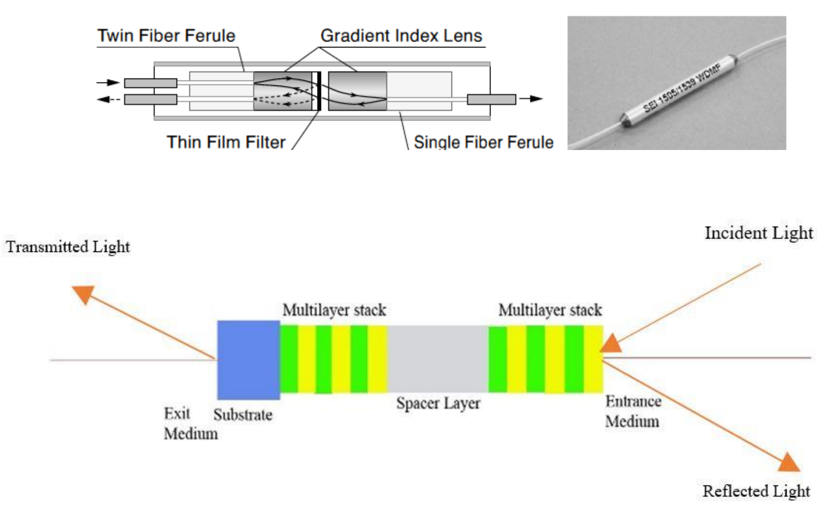
In the mid-2000s Nippon Telegraph and Telephone (NTT) in Japan developed and deployed a test method that allowed them to verify link integrity from the central office to the subscriber end. The measurement is obtained through an in-service Passive Optical Network (PON) using a standard 1650nm Optical Time-Domain Reflectometer (OTDR) at the node. In the early days of FTTH the Optical Network Unit (ONU) was placed outside the house and therefore more readily accessible. Today, most service providers opt for equipment inside the home, placing 1650nm highly reflective filter in the termination box inside the ONU where a jumper connects to the unit transceiver optical port. The filter is used to remotely verify that an Optical Network Terminal (ONT) is connected to the network as well as isolate the transceiver unit from the OTDR test signal. The termination filters provide a distance-based discrimination of each PON branch when tested from the Central Office (CO). This gave NTT added value, allowing a link-down situation to be analysed and diagnosed with an OTDR test, when the problem was distribution-fiber or equipment related. This allowed them to dispatch the appropriate team with proper instructions and tools to quickly fix the problem. These filters typically add 1dB loss to the line budget. The network design must therefore consider this additional loss if the filter is permanently affixed to the line.

Filter Technology

Thin Film Filter (TFF)

TFF was adopted very early on and has been widely deployed since because it can be applied into smaller packages. Optical TFF typically consists of multiple alternating layers of high and low refractive index material deposited on a glass or polymer substrate. This substrate is made to let only specific wavelengths pass through, while all others are reflected. They are mainly used in CWDM applications due to the compact size.

Within a typical structure of an optical filter, a thin film filter is inserted in the collimated optics by gradient index lenses at the end faces of a twin fiber ferule and single fiber ferrule.

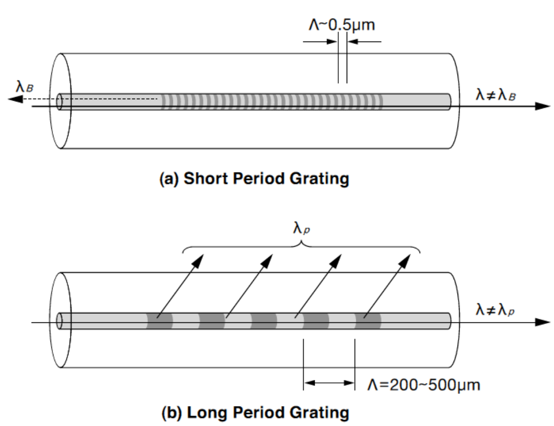


Typical TFF construction

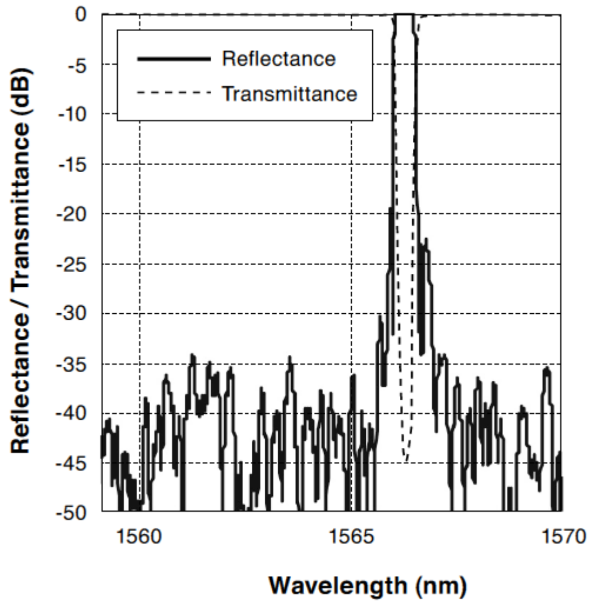
As light travels through the optical filter, its course adjusts as it passes through each layer, which leads to internal interference. This is because of the contrast between the refractive indices of the materials found in the dielectric thin-film coating.
An optical filter which influences different wavelengths of light in different ways is created due to the way the layers are configured. Light can be transmitted through the filter, reflected off it, or absorbed by it depending on the type and wavelength of the optical filter.

Fiber Bragg Grating (FBG)

A Bragg grating is made of small section of fiber that has been modified by exposure to ultraviolet radiation to create periodic variations in refractive index of the fiber. This will generate wavelength specific dielectric mirrors, so to reflect certain wavelengths of light and transmit all others. FBG are used in many applications such as stress, strain and temperature measurements, as well as remote testing.
An FBG is a reflective device composed of an optical fiber that contains a modulation of its core refractive index over a certain length. The grating reflects light propagating through the fiber when its wavelength corresponds to the modulation period.
In FBG plug type reflectors, photosensitivity is put onto the fiber Bragg grating in the core of the fiber. The fiber is inserted through ceramic ferrule, and the grating area is completely encapsulated in the ceramic ferrule core. During the process of reflector insertion and removal, the fiber Bragg grating will not be affected by dirt, it is very stable to use.
Fiber gratings are periodic changes of refractive index of optical fibers manufactured of silica glass to UV radiation. Depending on the period grating (short or long) provides a refractive index in the order of the wavelength.



In the case of a typical short period grating for 1550nm, ^ is around 0.5um, the total number of refractive index layers therefore becomes as large as twenty thousand for a grating with length of 10mm.

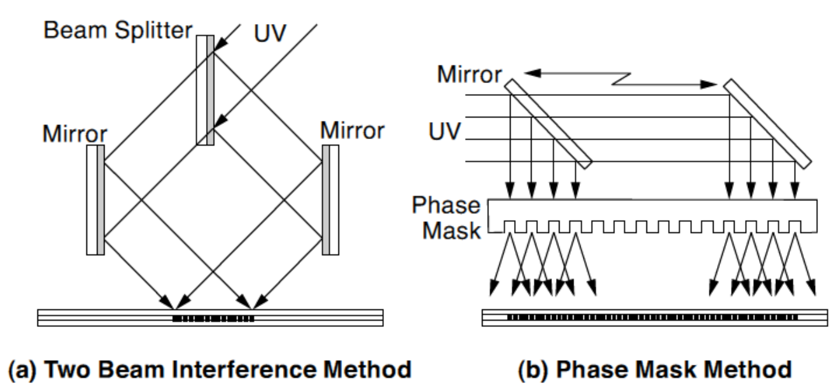


Example of a short period grating of transmission and reflection spectrum

FBG Manufacturing Methods

Two Beam Interference method is manufactured by illuminating the interference pattern of UV light from the lateral side of the optical fiber.

In the phase mask method, the pattern between diffracted beams are manufactured from a phase mask.

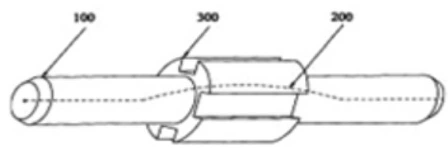


FBG vs TFF

In many ways they are complementary. Index difference for FBG is much less than TFF (10^{-4} vs 0.5). FBG are good for very deep and narrow filter, while TFF are good for broad not so deep filters.

The reflect band of TFF type Reflector is wider. Valuable service band of 1600-1625nm might not be usable. Considering NG-PON2 in the network in the future, the FBG type reflector is suitable. FBG type reflector is simple structure and SEI's reflector is specially designed to test the PON network.

FBG Reflector

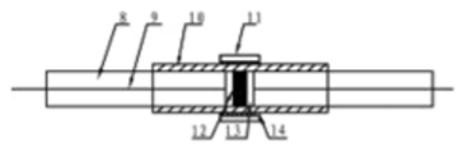


FBG has one continuous embedded fibre and therefore there are only two optical interfaces.

Better than 35dB in the pass band is attainable.

FBG has almost no influence on the pass band, so the attenuation of the reflect could be ≤1 dB

TFF Reflector



Because of the thin film embedded in the reflector, there are four additional optical interfaces coupled by the air gap which will seriously influence the reflectance during the propagation. A typical reflectance of 17dB is achievable.

IL between passband is ≤1.2dB

Fiber Bragg Grating Advantages

High, uniform filter reflectance ensures the reliable and repeatable measurement of end to end attenuation at 1650nm. This measurement can be traced to a standard reference. The high reflectance (-0.5 dB at 1650nm) means that end to end attenuation of the OTDR can be measured in excess of 30dB, with spatial resolution under 50cm, in relatively short period of time.

The spectral selectivity of FBG filters produces strong reflection at 1650nm, but at 1625nm, it is nearly identical to the reflection produced by a mated UPC connection. The detection or activation of a filter on the line can be reliably achieved by looking at the differential reflectance response of every interface at both 1625nm and 1650nm.

Although initially designed for troubleshooting and monitoring applications, this process allows operators to certify the work done by contractors, audit their work or ensure a more stringent and rigorous quality control over newly installed home passes.

- **Centralized**
  From the CO side, a single test instrument that can be shared by a group of technicians or contractors. Results are immediately available online, making process automation possible and easier to implement.

- **Automated**
  When operated with an optical switch unit, it can automatically test hundreds of fibers.

- **Time-Saving**
  It can help validate that the connectivity from CO to endpoint is proper and well documented.

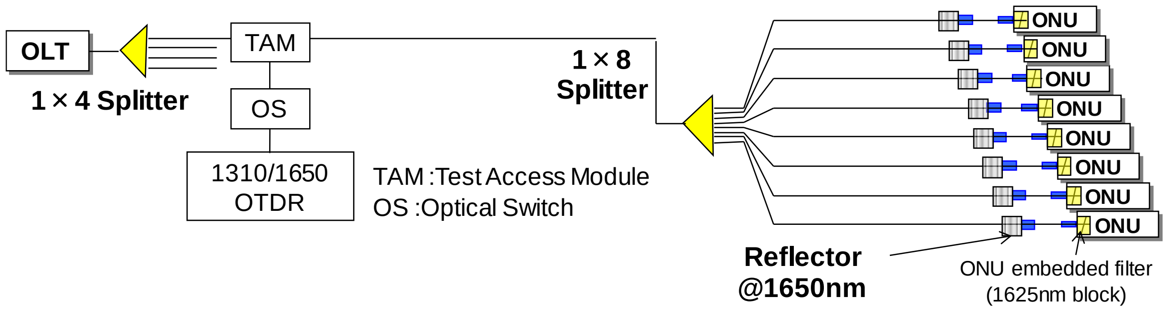
- **Efficient**
  It can test a PON, end to end, in just a few minutes requiring very little experience and manipulation.

- **Valuable**
  It can provide length information on each test point in order to audit the amount of cable installed. Since it tests at 1650nm it can provide a go/no go result because it will typically show higher loss when excessive bending is present, but roughly the same loss at 1550nm when fibers are properly aligned.

Fiber Reflector in PON

Fiber reflector, also known as Fiber Bragg Grating (FBG) filter, which reflects wavelengths of light (such as 1650nm +/- 5nm or 1625nm +/- 5nm) and transmits all others that are not within the specific reflection wavelength range, it is usually installed in the front end of Optical Network Unit (ONU) of optical networks. When an OTDR detects the presence of the reflected detection signal, it indicates that the optical connection from the central office to the user terminal is normal. Otherwise, the value of the reflected signal is too low or there is no reflection, it indicates that the fiber is damaged or broken. It provides a high reflectance for the monitoring signal at the termination of a PON.
Due to the low insertion loss in the transmission wavelength range and high reflectivity in the reflection wavelength range they are ideal for FTTx monitoring combined with OTDR equipment, they are suitable for point-to-point (PTP) or point-to-multipoint (PTMP) network monitoring of optical link, which can reflect faults quickly and accurately without disrupting the flow. Reflectors are best if they have low insertion loss, high reflectivity, convenient installation, etc., and is an ideal optical device for remote fiber testing monitoring in Passive Optical Networks (PON). As an example, at 1650nm the reflector will reflect other specific wavelengths

In PON testing, Test Access Module (TAM) is used in combination with an Optical Switch (OS) and OTDR. The TAM is basically the coupling element, which is used in remote testing and monitoring applications. The OS is used to switch the distribution nodes and manage the polarity.



A standard SC plug type (FBG) reflector adopts a male to female structure for convenient and fast connection. With an in-line type reflector the FBG is encased in a tube and can be spliced at both ends to be incorporated in a splice cassette enclosure.

The reflector can be conveniently placed in series at customer end of the network. As long as the optical measurement system is connected to the front end of the splitter, when the centre wavelength is detected, the optical connection of the customer end is normal. If the central wavelength does not exist or has decreased in the reflection value, this will indicate that the link at the customer end is damaged or broken and requires maintenance.

With increase in FTTH projects, deployments of passive optical networks are increasing. Detecting an optical fault quickly and accurately is particularly important for the maintenance of the network. The reflector is an ideal choice for line monitoring.

Feature of PON Monitoring RFTS

- Monitoring the whole optic lines of PON, from CO to far end fiber line subscriber's site.
- Checking the time-dependent variation of the whole lines by comparing the current trace and the original trace, raising an alarm when any abnormality happens.
- Distinguish each branch fiber line or subscriber by using the high-reflection termination filter installed before the ONU.
- The termination filter has a good performance of high reflection for testing optical signals and low loss for communication signals.

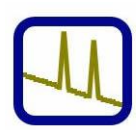
Main functions of PON monitoring RFTS

Function	Description
From the ONU	• Detecting the fault e.g. fiber broken or an increase in loss therefore raising the alarm • Locating the fault • Analysing the OTDR trace and making judgement
From Central Office	• Detecting the failed branch • Distinguish passive or the active equipment • Estimating the loss of the whole fiber line by checking the variation of the high reflection peaks
Dark Fiber testing	• Monitoring before subscriber goes live • Completion acceptance from CO • No on site fiber line checking • Batch testing of lines
Active Fiber testing	• Monitoring while subscriber is active • Quickly detecting an abnormal event by periodic or continuous test • Testing the fibre line on demand from CO when a claim arises • Confirming the restoration

The Advantages of using a Reflector within an RFTS in PON

One time install by 24/365 central monitoring

Hassle free maintenance by 24/365 central monitoring



Easy to detect failure from the remote office

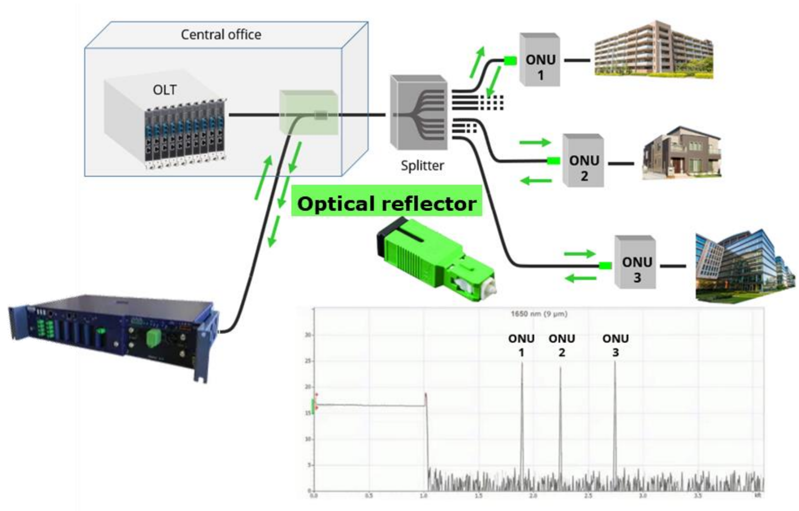
Instant launch of service by quick installation

24/365 line assurance without additional expense

Quick recovery from failure by quick identification the causes

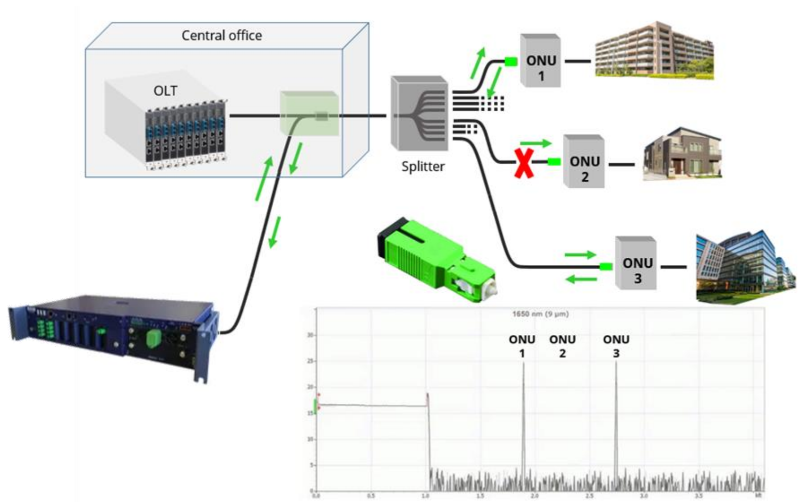
How the RFTS works (OTDR Traces)

At normal operation high reflections can be seen on an OTDR trace from the reflectors at the ONUs.



When there is a break in the line the OTDR trace shows the elimination of the reflection. The break can be seen instantaneously, and field engineers sent to the damaged fiber, ensuring downtime is limited.

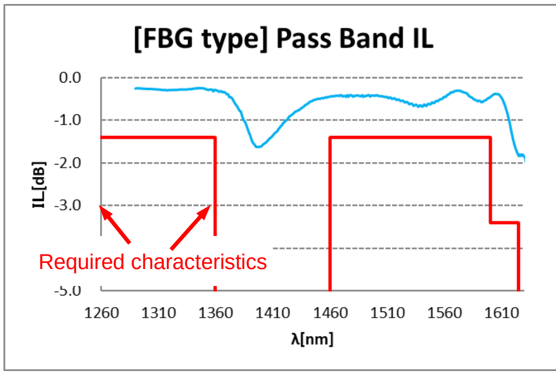
When there is a disappearance of one of the reflections from the OTDR trace the link has broken and can be flagged up for inspection or repair in real time reducing the downtime for the customer.

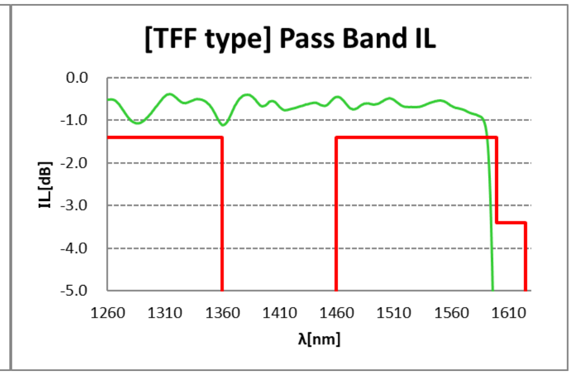


Characteristics of Reflector

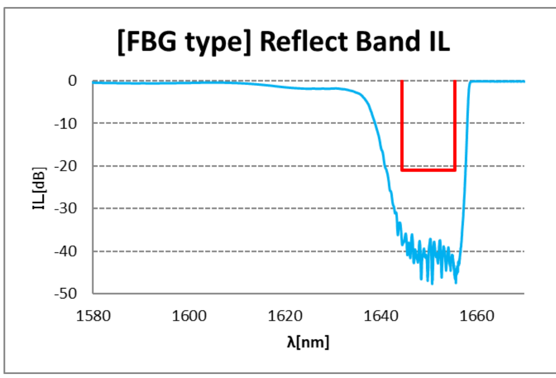
High reflection, small deviation of the reflectivity of each reflector and narrow reflection bandwidth at the monitoring wavelength are necessary for the reflector using active fiber monitoring system. Low insertion loss at signal and monitoring wavelengths are also needed. Generally, two types of reflectors are used in the system, FBG type and Thin film filter (TFF) type.

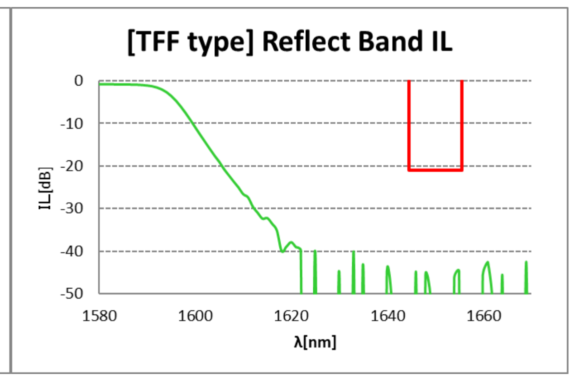
Required characteristics and the typical characteristics of FBG vs TFF reflectors



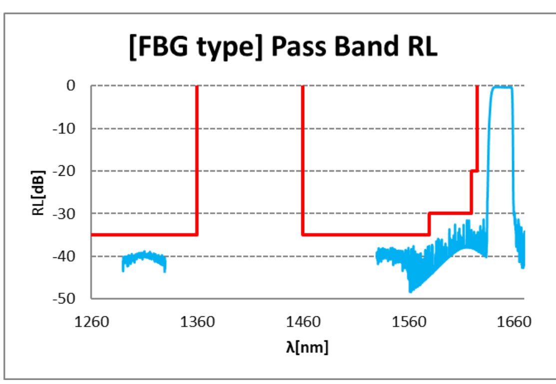


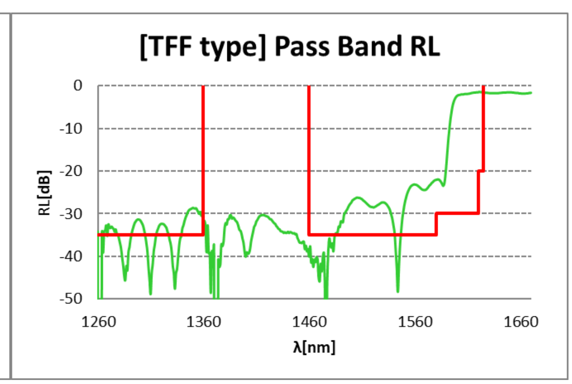
At the passband wavelengths 1260 - 1370nm (used for XGS-PON, XGS-PON and GPON) the Insertion Loss (IL) for FBG has a maximum of 1dB. The IL for TFF has maximum of 1.2dB. At the passband wavelengths 1460 – 1600nm (used for GPON, NG-PON2, Video overlay, XGS-PON and XG-PON1) the IL for FBG has a maximum of 1dB. The passband wavelength for TFF fall off at 1581nm. The IL from 1460-1581nm has a maximum of 1.2dB. This shows that the FBG has a wider bandwidth and lower IL.



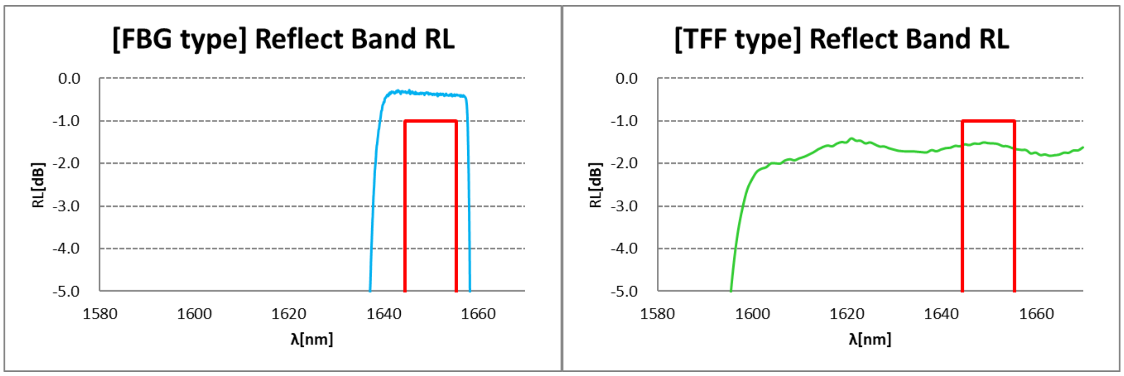


The IL of the Reflect Band of FBG versus TFF at 1645-1655nm shows that the FBG is lower with a wider bandwidth. OTDR's require a narrow bandwidth and low IL for testing.





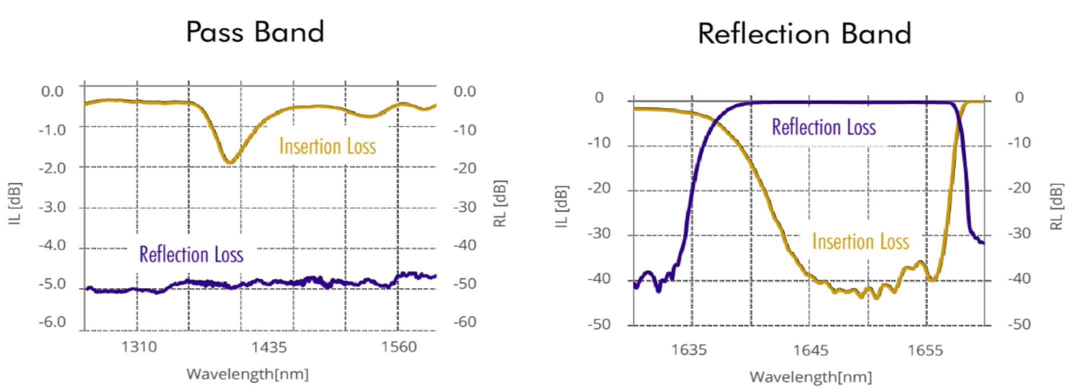
The FBG Pass Band wavelength 1260 - 1370nm has a minimum Return Loss (RL) of 39dB. At this wavelength the TFF has minimum RL of 29dB.
The FBG Pass Band wavelength 1460 - 1600nm has a minimum RL of 30dB. TFF wavelength 1460 - 1581nm the RL minimum is 2dB. The TFF falls of at 1581nm.
The FBG Passband wavelength 1600 - 1625nm has a minimum RL of 20dB.
This shows that the Return Loss in the three operating wavelengths for the FBG is better especially for OTDR testing.



The FBG Reflect Band wavelength 1645 - 1655nm has a maximum RL of 0.3dB. At the same wavelength the TFF has a maximum 1.5dB. The TFF has a much wider bandwidth compared to the FBG and therefore is not suitable or the OTDR testing.

Pass and Reflect Bands

The main function of the reflector is to have a low reflection at Pass Band and high reflection at Reflected Band while keeping the Insertion loss low as possible.



In general, the Pass Band of 1260nm – 1630nm the insertion loss is typically below 2dB and the Return Loss greater than 35dB. In the Reflect Band 1645-1655nm the Insertion Loss is typically below 2dB and the Return Loss less than 1dB.

Types of Filters

Plug Jack

Pigtail

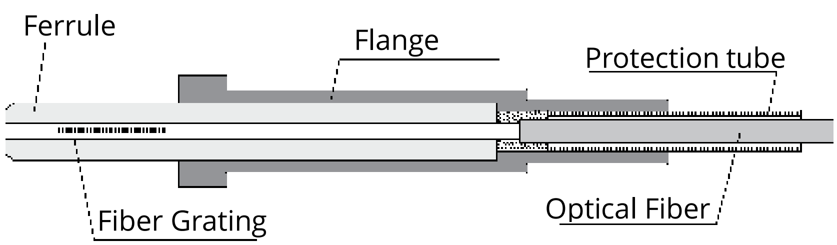
Inline

Field Installable (mechanical splice)

Field Installable (fusion splice)

Embedded Adaptor Filter Plug Jack type

In an embedded adaptor filter the fiber grating is inscribed in the fiber inside the ferrule of the connector and fixed with adhesive. It is easy to obtain reflectivity higher than 90%, and advantageous from the viewpoints of productivity and cost. Field installable connectors embedded with a fiber grating are a popular technology for termination filters.

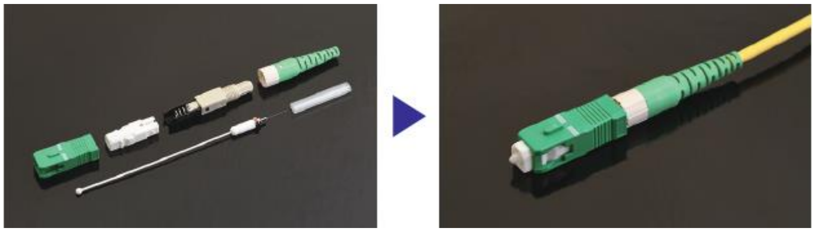


Bi-directional filters

Plug type filters are typically mono directional but can also be Bi-directional so that they can pass and reflect in both directions e.g. A to B (Backward), B to A (Forward)

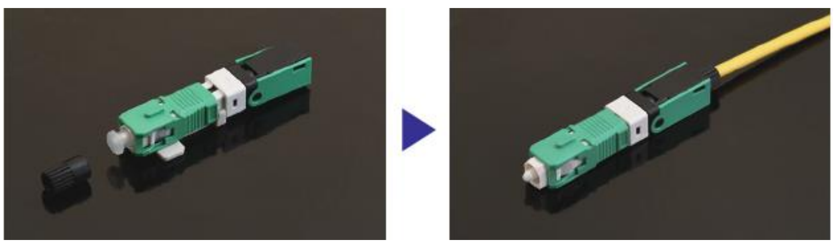
Splice-On – Field Installable

The Splice-On field installable reflector is based on the SC/APC connector. A fusion splicer is required to splice the connector to the fiber. The reflector cased within the connector and therefore can be plugged straight in the ONU.



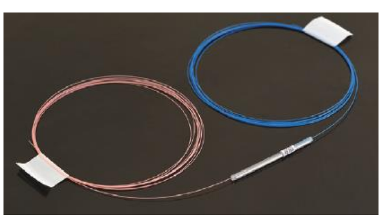
Mechanical – Field Installable

The mechanical field installable reflector is based on the SC/APC connector. No special tools are required to splice the fiber to the connector. The performance of the Splice-on type will be more superior, but the mechanical requires less processes to complete. This can also be plugged straight into he ONU.



In Line

The In-Line type is cased in a steel tube that can be spliced at both ends and installed in splice cassette.



Pigtail

The pigtail type is factory manufactured with the fiber or chord at applicable lengths. This can be spliced to connectorized off or on-site.

Conclusion

Active fiber monitoring (testing) is necessary to improve the solidity of the PON network. Reflectors, such as FBG type Reflectors are suitable for PON network monitoring applications in order to avoid bad surprises and expensive troubleshooting.

Reference information

Remote monitoring website:

https://sumitomoelectric.com/Remote_Monitoring_FTTx

LinkedIn Showcase:

https://www.linkedin.com/showcase/sumitomo-electric-passive-components/

Message or inquiries:

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