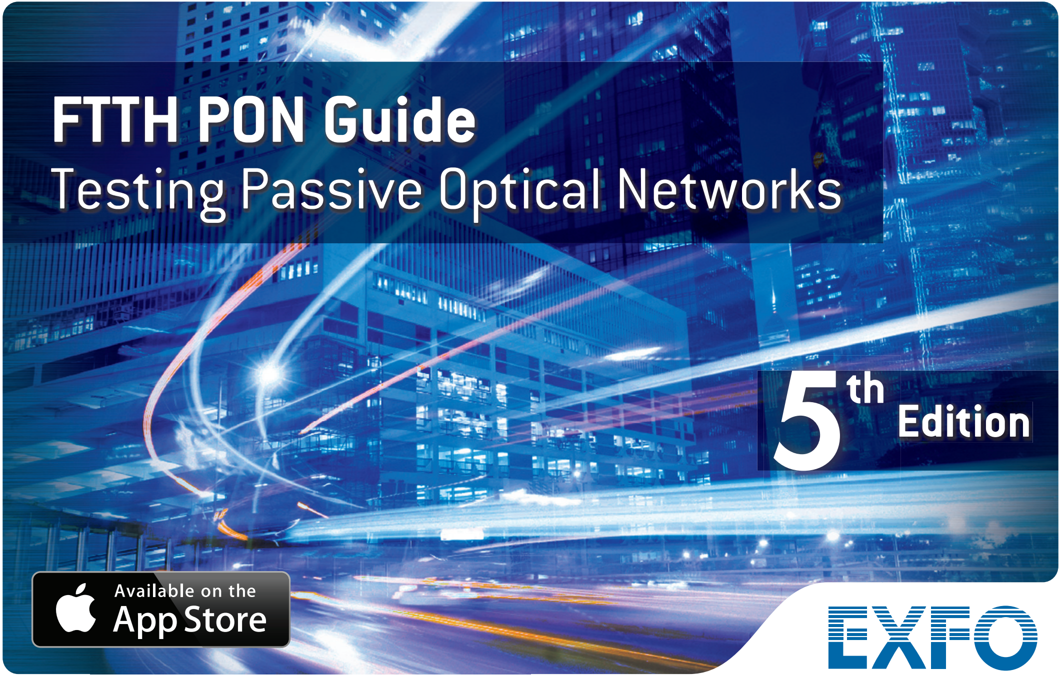
FTTH PON Guide

Testing Passive Optical Networks

5th Edition



EXFO

This pocket guide provides an introduction to FTTH technology and testing during installation, activation and troubleshooting of passive optical networks (PONs).

From POTS to PONs

The invention of the telephone in 1876 and the founding of the Bell Telephone Company in 1878 set the stage for the widespread development of what is now known as the plain old telephone system (POTS). Two years later, a photophone, as it was called, allowed for the transmission of sound over a beam of light.

Over the years, various pioneers have made a long series of fascinating discoveries and technological breakthroughs, including the laser and the singlemode optical fiber, that make it possible to transmit massive amounts of information over long distances using light. Today, more than 90% of US long-distance traffic is carried over optical fibers. However, twisted pairs of copper wire are still widely used for the short-distance connections between the central office (CO) and subscribers.

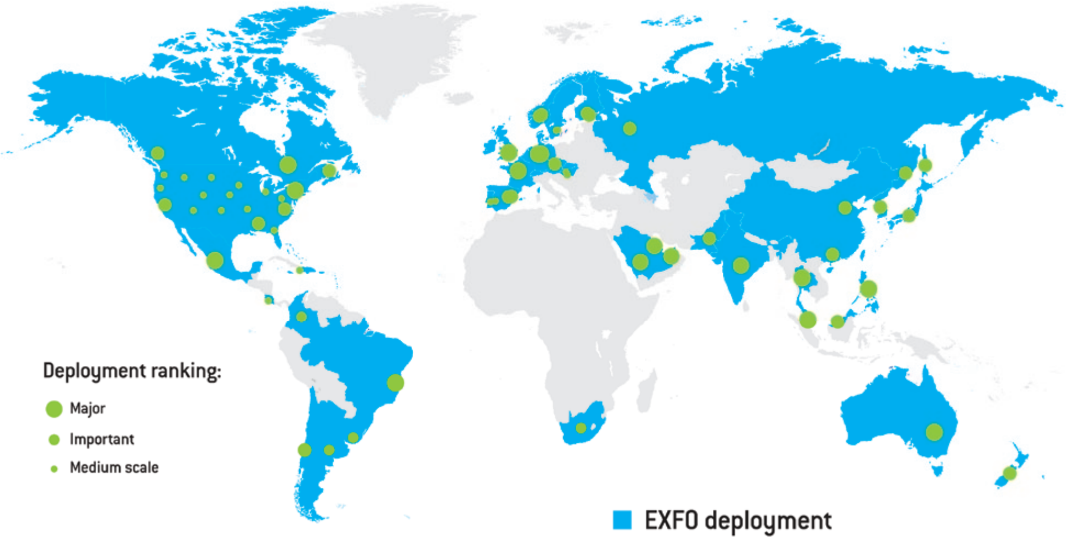
Fiber-to-the-home (FTTH) technology represents an attractive solution for providing high bandwidth from the CO to residences and to small- and medium-sized businesses. FTTH is cost-effective because it uses a passive optical network (PON). What makes FTTH even more interesting is the increased network reliability and ease of network testing, measuring and monitoring. These systems follow the same basic principles as standard fiber networks, enabling the use of much of the same gear for installation and maintenance.

Faster, more reliable FTTH deployments? Easy with EXFO solutions.

When FTTH was first deployed, EXFO was there to test it—namely by pioneering the simultaneous upstream/downstream measurement technique (via a pass-through connection). Since then, we have continued to focus on providing innovative FTTH test solutions that will help you meet the needs created by your network—every step of the way. FTTH is growing, and so is our FTTH technology leadership and expertise.

EXFO provides network operators with expert testing knowledge, tools and environments to bridge the OPEX gap created by the increased bandwidth demand. With field-proven methods and procedures, smart and integrated test solutions and cloud-based data management, FTTH networks can now be deployed reliably and cost-effectively.

Participating in FTTH deployments worldwide



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1 Introduction to FTTx

1. Introduction to FTTx

Singlemode optical fiber, with its almost unlimited bandwidth, is now the transport medium of choice in long-haul and metropolitan networks. The use of fiber-optic cable—rather than copper cable—significantly reduces equipment and maintenance costs, while dramatically increasing quality of service (QoS); and, now more than ever, many corporate customers have access to point-to-point (P2P) fiber-optic services.

Fiber-optic cables are now deployed in the last mile—the segment of the network that extends from the central office (CO) to the subscriber. Since, until recently, this segment has typically been copper-based, the high-speed services available to residential customers and small businesses have been limited to generic digital subscriber lines (xDSL) and hybrid fiber-coaxial (HFC) transmissions. The main alternative—wireless transmission with direct broadcast service (DBS)—requires an antenna and a transceiver. Therefore, in today's context, with its explosive demand for bandwidth and higher-speed services over longer reaches, copper- and wireless-based transport presents the following shortcomings:

› Limited bandwidth

› Different media and equipment requiring extensive maintenance

Although fiber-optic cables overcome all of these limitations, one of the obstacles to providing fiber-optic services directly to residences and small businesses has been the high cost of connecting each subscriber to the CO. To overcome the cost issues, key industry players created the Full-Service Access Network (FSAN) standards organization, which was founded to facilitate the development of suitable access-network-equipment system specifications. The International Telecommunications Union (ITU-T) turned FSAN specifications into recommendations. The FSAN specification for ATM-based passive optical networks (PONs) became an international standard in 1998 and was adopted by the ITU as recommendation G.983.1.

Technologies Used in FTTx

New standards, such as those established by the ITU-T, the IEC and the Institute of Electronic and Electrical Engineers (IEEE), have greatly increased the design commonality, survivability and security of PONs.

Table 1. Currently Deployed PON Technologies

<table>
<tr><th colspan="2" rowspan="2">Type</th><th colspan="4" rowspan="2">Broadband PON (BPON)</th><th colspan="4">GPON (Gigabit-Capable PON)</th><th colspan="2" rowspan="2">EPON (Ethernet PON)</th></tr>
<tr><th colspan="2">GPON</th><th colspan="2">GPON-ERG</th></tr>
<tr><td>Standard</td><td>km</td><td colspan="4">ITU-T G.983 series</td><td colspan="2">G.984 series</td><td colspan="2">G.984.6</td><td colspan="2">IEEE 802.3ah</td></tr>
<tr><td>Protocol</td><td></td><td colspan="4">ATM</td><td colspan="4">Ethernet, TDM, TDMA</td><td colspan="2">Ethernet</td></tr>
<tr><td>Services</td><td></td><td colspan="4">Voice, data, video</td><td colspan="4">- Voice, data
- Triple-play
- File exchange, remote learning, tele-medecine, IPTV, video-on-demand</td><td colspan="2">Triple-play</td></tr>
<tr><td>Maximum physical distance (OLT to ONT)</td><td>km</td><td colspan="4">20</td><td colspan="2">20</td><td colspan="2">Up to 60 (ODN distance)</td><td colspan="2">1000BASE-PX10: 10
1000BASE-PX20: 20</td></tr>
<tr><td>Split ratio</td><td></td><td colspan="4">up to 32</td><td colspan="2">up to 64</td><td colspan="2">16, 32 or 64
(restricted by path loss)</td><td colspan="2">1x16
1x32 (with FEC or DFB / APD)</td></tr>
<tr><td></td><td></td><td colspan="2">Downstream OLT Tx</td><td colspan="2">Upstream ONU Tx</td><td>Downstream</td><td>Upstream</td><td>Downstream</td><td>Upstream</td><td>Downstream</td><td>Upstream</td></tr>
<tr><td>Nominal bit rate</td><td>Mbit/s</td><td>155.52
622.08</td><td>1244.16</td><td>155.52</td><td>622.08</td><td>1244.16 / 2488.32</td><td>155.52/ 622.08/
1244.16</td><td>2488.32</td><td>1244.16</td><td>1000</td><td>1000</td></tr>
<tr><td>Operating wavelength band</td><td>nm</td><td>1480-
1580</td><td>1480-
1500</td><td>1260-
1360</td><td>1260-1360 (MLM1, SLM)
1280-1350 (MLM2)
1288-1338 (MLM3)</td><td>-1480-1500
-1550-1560
(Enhancement band for video)</td><td>1260-1360
Possibility of using shorter C-band wavelengths downstream and 1550 nm upstream</td><td>1480-1500
(Basic band)
1550-1560
Enhancement band- for video distribution</td><td>OEO (ONU EXT):
1260-1360
OEO (OLT EXT):
1290-1330
OA:
1300-1320
(OBF)</td><td colspan="2">100BASE-PX10:
Downstream:
1490 nm + PIN Rx
Upstream: 1300 nm
(low-cost FP optics + PIN Rx)
100BASE-PX20:
Downstream: 1490 nm + APD Rx
Upstream:1300nm
(DFB optics + PIN Rx)</td></tr>
<tr><td>ORL_{MAX}</td><td>dB</td><td colspan="4">>32</td><td colspan="4">>32</td><td colspan="2">15</td></tr>
</table>

This brings about the opportunity for economies of scale and lower costs that previously were not conceivable. Tables 1 and 2 describe the main parameters defining those standards.

Table 2. Next-Generation PON Technologies

Type		Gigabit-Capable PON (GPON) 10G-PON		Ethernet PON (EPON) 10G-EPON		WDM PON	
Standard	**Units**	G.987		802.3av™		None at the moment	
Protocol		Ethernet, TDM, TDMA		Ethernet		TBC	
Services		- Voice, data - Triple-play - File exchange, distance learning, tele-medecine, IPTV, video-on-demand		- Voice, data - Triple-play - File exchange, distance learning, tele-medecine, IPTV, video-on-demand		- Voice, data - Triple-play - File exchange, distance learning, tele-medecine, IPTV, video-on-demand	
Maximum physical distance (OLT to ONT)	**km**	20		PRX10-PR10: 10 PRX20-PR20-PRX30-PR30: 20		TBC	
Split ratio		up to 1x64		up to 1x32		TBC up to 1x32	
Nominal bit rate		Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
Asymmetric	**Gbit/s**	10	2,5	10	1,25	Virtually no limits e.g., 1 Gbit/s per user	Virtually no limits e.g., 1 Gbit/s per user
Symmetric	**Gbit/s**	10	10	10	10		
Operating wavelength band	**nm**	1577 -2, +3	1270 ±10	1577 -2, +3	1270 ±10	TBC e.g., DWDM in C Band	
ORL_{MAX}	**dB**	>32		>20		TBC	

1.1 FTTH Architectures

Figure 1-1 illustrates the general architecture of a typical FTTH network. At the CO (also referred to as the headend), the public-switched telephone network (PSTN) and Internet services are interfaced with the optical distribution network (ODN) via the optical line terminal (OLT). The downstream 1490 nm and upstream 1310 nm wavelengths are used to transmit data and voice. Analog RF video services are converted to optical format at the 1550 nm wavelength by the optical video transmitter. The 1550 nm and 1490 nm wavelengths are combined by the WDM coupler and transmitted downstream together. IPTV is now transmitted over 1490 nm.

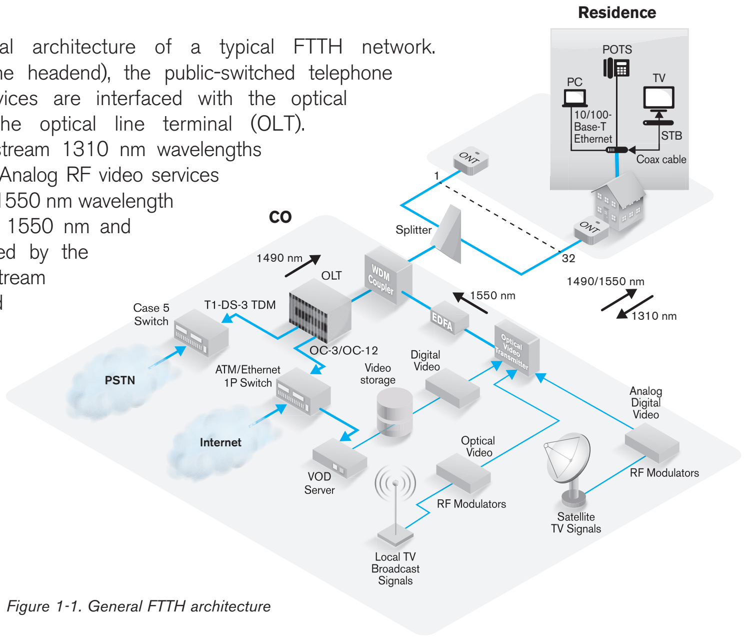


Figure 1-1. General FTTH architecture

In summary, the three wavelengths (1310, 1490 and 1550 nm) simultaneously carry different information and in various directions over the same fiber. The F1 feeder cable carries the optical signals between the CO and the splitter, which enables a number of ONTs to be connected to the same feeder fiber. An ONT is required for each subscriber and provides connections for the different services (voice, data and video). Since one OLT provides service to up to 32 subscribers (more than 64 with GPON), many OLTs originating from the same CO are usually required in order to serve a community. There are different architectures for connecting subscribers to the PON. The simplest uses a single splitter (see Figure 1-2), but multiple splitters can also be used (see Figure 1-3).

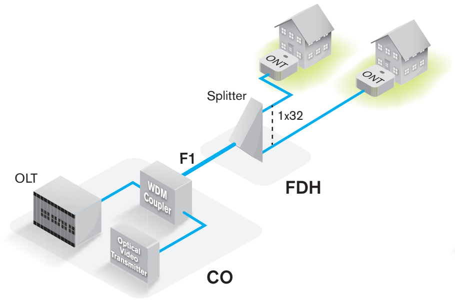


Figure 1-2. Single-stage architecture

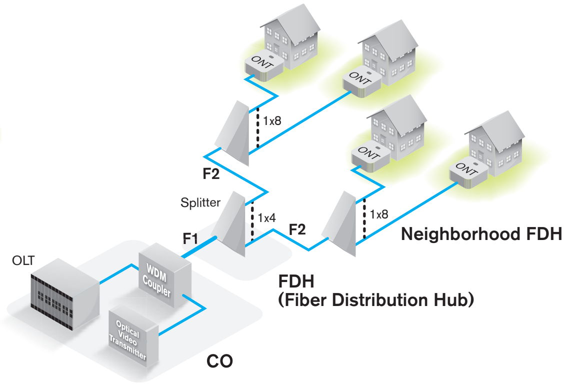


Figure 1-3. Two-stage architecture

1.2 Passive Optical Distribution Network Equipment

Passive optical distribution network (ODN) equipment consists of gear and components located between the OLT (active) and the customer premises (the ONT; active); this includes both optical and non-optical components of the network. The optical components make up the optical distribution network (ODN) and include splices (fusion and mechanical), connectors, splitters, WDM couplers, fiber-optic cables, patchcords and possibly drop terminals with drop cables. The non-optical components include pedestals, cabinets, patch panels, splice enclosures and miscellaneous hardware (see Figure 1-4).

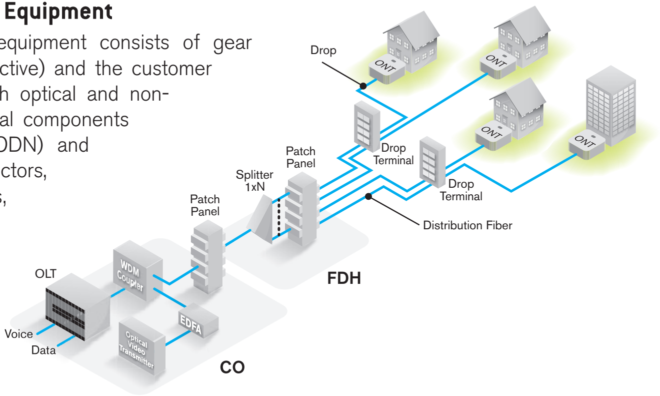


Figure 1-4. Passive ODN equipment

Fibers

Fiber-optic cable installation is one of the most costly elements in PON deployment, and how to proceed depends on various factors, including cost, rights-of-way, local codes, aesthetics, etc., and on whether the fiber will be installed in a new premises (Greenfield installation) or in an existing development over active routes (overlay/overbuild). There are three basic cable-installation methods being used:

- Direct burial—With this method, the cable is placed underground, in direct contact with the soil; this is done by trenching, plowing or boring.
- Duct installation—In this case, the optical cable is placed inside an underground duct network. Although the initial duct installation is more expensive than a direct-burial installation, the use of ducts makes it much easier to add or remove cables.
- Aerial installation—With this approach, the cable is typically installed on poles or towers, above the ground. This type of installation, commonly used for overbuilding, is usually more affordable than underground installation and does not require heavy machinery. The optical cable can be secured to a supporting messenger cable or self-supporting optical cables can be used.

For densely populated areas with particular right-of-way challenges, several alternative methods are also available. For example, cable can be installed in grooves that have been cut into the pavement or inside drainpipes, sewer pipes and natural gas pipelines.

Splitters

The bidirectional optical branching device used in point-to-multipoint (P2MP) PONs is called an *optical splitter* or simply a *splitter*, which has one input from the F1 port and multiple output ports. Splitters are considered passive because they require no external energy source other than the incident light beam. They are broadband and only add loss, mostly due to the fact that they divide the input (downstream) power. This loss, known as *splitter loss* or *splitting ratio*, is usually expressed in dB and depends mainly on its number of output ports, as shown in Table 3. The input (downstream) optical signal is divided equally into a cascade or branches; for instance, a 1x2 splitter only has two branches or one split that bears a 3 dB loss (50% light in each path). In a 1x4 splitter, another two branches are added to each path of the original 1x2 split, adding another 3 dB, for a total loss of 6 dB. In a 1x8 splitter, two more branches or 1x2 split are added to each path of the original 1x4 split, again adding another loss of 3 dB for a total loss of 9 dB. A 1x16 splitter will then bear a loss of 12 dB, and a 1x32 splitter will have a minimum loss of 15 dB, not counting any additional loss due to connections and imperfections (typically, 1 dB is added to the original splitting loss); therefore, a 1x32 splitter will usually have a loss of 16 dB.

PONs use an equal part of the output ports to F2, allowing multiple users to share a single optical fiber and, consequently, a shared bandwidth. In the upstream direction, optical signals are combined from a number of ONTs into a single fiber (F1).

It should be noted that, contrary to what one might expect, the splitter adds approximately the same amount of loss—even for light traveling in the upstream direction.

Table 3. Splitter Loss

Number of Ports	Splitter Loss (dB) (excluding connections and excess splitter loss)
2	3
4	6
8	9
16	12
32	15
64	18

In an FTTx network, there can be one splitter or several cascaded splitters, depending on the topology. ITU-T Recommendation G.984 currently enables split ratios up to 32, while Recommendation G.984.6 extends the ratio up to 64. Regardless of the topology, the splitter must accommodate the allowed optical-loss budget.

Splitters can be packaged in different shapes and sizes, depending on the basic technology used. The most common types are the planar waveguide (typically for high-split ratios) and the fused-biconic taper (FBT) fiber (typically for low counts). Both types are manufactured for mounting in enclosure-tray assemblies. Figures 1-5 and 1-6 illustrate the two technologies.

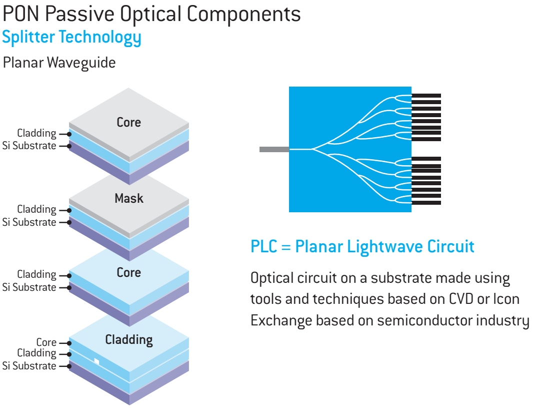


Figure 1-5. Planar waveguide splitter

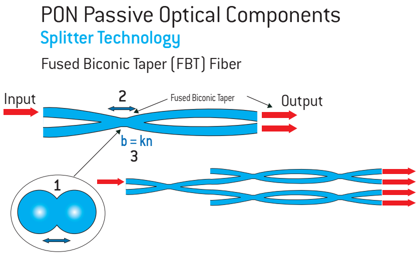


Figure 1-6. FBT splitter

Connectors

There are three distinct categories of connectors:

1. Simplex–connector with one terminated fiber
2. Duplex–connector with two terminated fibers
3. Multifiber–connector with more than two fibers (up to 72)

Simplex connectors are currently the most popular for FTTH deployments. Figure 1-7 shows the most common types of simplex connectors:

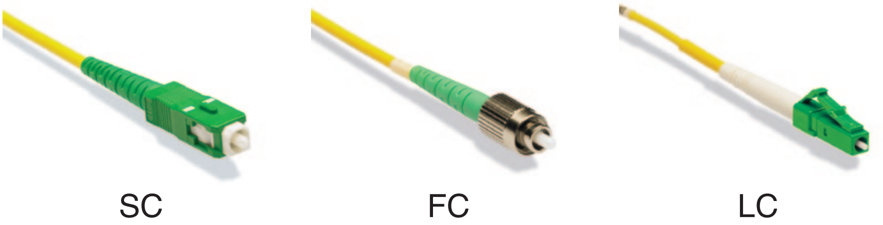


Figure 1-7. Simplex connector types

Another category of connector that is gaining popularity is the multifiber connector (or MT). A single MT connector can hold from 4 to 72 fibers. The most commonly used type of multifiber connector in PONs is the MTP type. This connector is often repackaged and used to build more rugged cable, specially designed for the harsh environments of typical FTTH deployments.

It should be noted, however, that the most common connector type used in FTTH deployments at the moment is the angle-polished connector (APC), mainly because the 8° slope on the ferrule reduces reflections by more than 60 dB (typical loss is ≤0.5 dB). APC connectors can easily be identified by their green color (Figure 1-7).

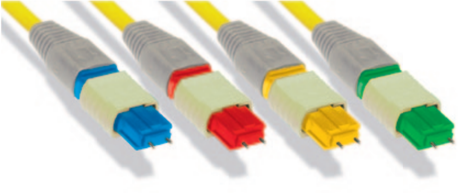


Figure 1-8. MTP connector (source US Conec)

Splices

Splices can be mechanical or fused, and they are protected from the environment by splice enclosures. Mechanical splices are the least expensive but have higher insertion loss and backreflections than fused splices, which have very low loss (0.02 dB) and almost no backreflection. However, fused splices typically require expensive and extensive fusion-splicing equipment and a well-trained technician. The number of splices on a link depends on the length of the cable sections used (typical section lengths are ≤2 km, 4 km and 6 km). The shorter the length, the easier the maintenance, but the whole cable assembly requires more splices, more time and more money. In contrast, using longer-length cable sections is less costly to deploy, but the subsequent maintenance is more difficult and expensive.

When splicing different types of fiber and testing with a reflectometry-based method (OTDR or iOLM), a significant loss or gain could appear due to the difference in the fibers' mode-field diameters. A good example of this would be splicing G652D fiber with G657 fiber.

Indoor Multidwelling Unit Equipment

Depending on the type of multidwelling (MDU) architecture to be deployed (see Figure 1-9 and 1-10), the equipment used can be similar to that used in OSP deployments or specially designed for indoor use (see Figure 1-9). Indoor equipment is less subject to harsh environmental conditions and therefore does not require the same ruggedness as the outside plant (OSP) equipment. The following items will generally be found in indoor deployments:

Fiber-optic cables:

› The feeder cables form the segment between the CO and the fiber distribution hub (FDH) and are generally located in the basement of the building.

› The riser cables form the segment between the FDH and the fiber distribution terminal (FDT) and are located on each floor or at the fiber collector (FC). Riser cables can be composed of a single fiber per splitter port or MTP cables.

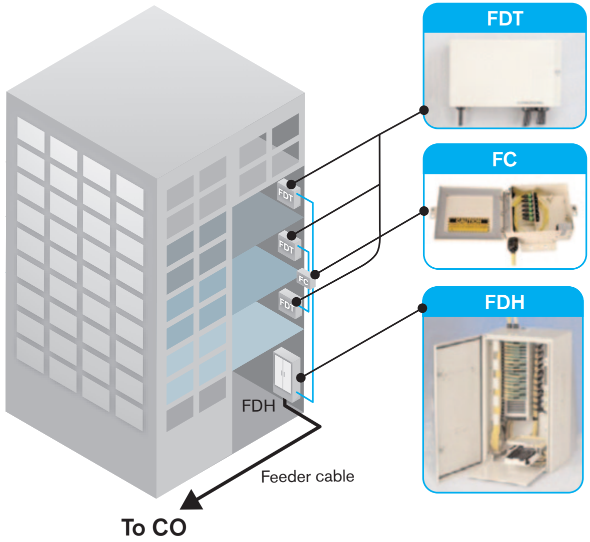


Figure 1-9. High-/medium-rise MDU equipment

› The drop cables form the segment between the FDT and the ONT and are located at the apartment. It is generally made of fiber that is insensitive to micro/macrobends.

Fiber distribution hubs (FDHs) include:

› Cabinets, splice enclosures

› Splitter(s)

› Patch panel(s)

› Fiber-management elements

Fiber distribution terminal (FDT):

› The FDT—located on each floor—serves as the junction between the FDH and the drop cable; it can be connectorized or spliced.

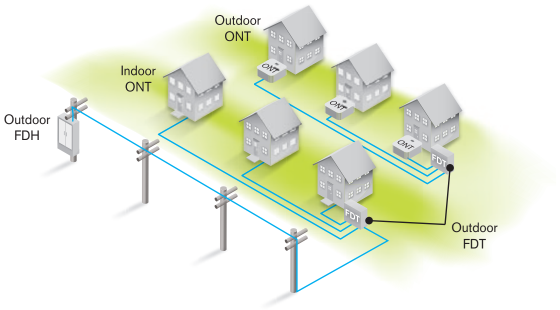


Figure 1-10. Horizontal/garden-style MDU

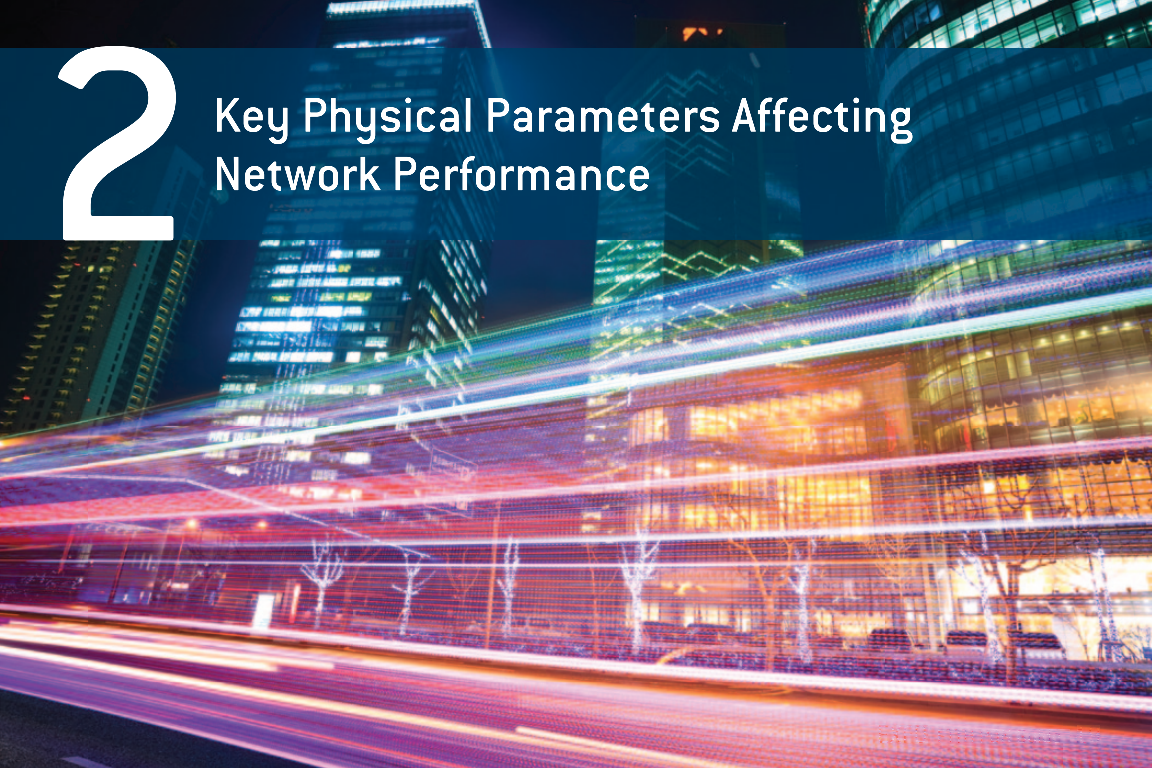
Fiber collector (FC):

› The FC serves as a junction point between the FDH and a few FDTs (see Figure 1-9).

Table 4. MDU Riser Cable Deployment Approaches (Highlights)

Traditional Fusion-Splice Terminations	Spooled Pre-Terminated Components
Positive Factors	**Positive Factors**
› Once the splices are properly done, the network design is very stable	› More attractive for brownfield situations
› Less connectors in the design, especially at intermediate points between the FDH patch panel and the ONT connector; therefore less chance of contamination or dirt accumulation—especially before construction has been completed	› Attractive proposition for situations where splicing crew is more expensive or hard to get › Increase the speed deployment of the project (less splicing time)
› Lower cost of components	› Decrease the cost of the labor in the project (less splicing fees) › Allow additional test connection points between the FDH patch panel and the connector at the ONT
Negative Factors	**Negative Factors**
› If splicing fees are expensive or splicing labor is hard to get for a particular project, this approach may be an issue	› Many connectors in the design, in addition to at the FDH patch panel location, can create dirt accumulation—especially before construction has been completed
› Does not provide intermediate test access point between the FDH patch panel and the ONT connector	› Increase in the cost of components
General Appreciation	**General Appreciation**
› De-facto approach: contractors are used to splices and the presence of connectors in non-hardened cabinet, especially when construction is not finished, can create a situation where the connector becomes contaminated and major cleaning or re-connectorization is required at some places	› This approach is obligated to provide evidence for its position. This is what the vendors are working on now and customers are listening. Interviewees have been open-minded and some have said that this approach must generate savings >20-30% to justify the use of this type of component

2 Key Physical Parameters Affecting Network Performance



2. Key Physical Parameters Affecting Network Performance

The purpose of any fiber-optic network is to perform high-speed, error-free data transmission. Adequate testing during each phase of the network deployment guarantees that products meet specifications, plus it minimizes costly and time-consuming troubleshooting efforts by locating dirty/damaged connectors, questionable splices and other faulty components before they disrupt service.

One of the most important factors in ensuring proper transmission is controlling the power losses in the network against the link's loss-budget specifications from the ITU-T recommendation and standard, which is done by establishing a total end-to-end loss budget with enough of a buffer, while reducing backreflections to a minimum. This is particularly true for high-power analog RF video signals (normally at 1550 nm) from extremely narrowband lasers, since strong backreflections degrade the quality of the video transmission. This section discusses the main parameters that can greatly affect the performance of the network.

2.1 The Loss Budget

One of the first tasks to perform when designing fiber-optic networks is to evaluate the acceptable loss budget in order to create a product that will meet application requirements. To adequately characterize the loss budget, the following key parameters are generally considered:

› Transmitter: launch power, temperature and aging

› Fiber connections: splitter, connectors and splices

› Cable: fiber loss and temperature effects

› Receiver: detector sensitivity

› Others: safety margin and repairs

When one of the above-listed variables fails to meet specifications, the performance of the network can be greatly affected, or worse, the degradation can lead to network failure.

Depending on the type of PON being deployed, the loss budget will vary. For example, in the case of a class B GPON system, as shown in Table 5, the maximum loss budget for the upstream path at 1.25 Gbit/s can be 32 dB (delta between minimal sensitivity and maximum launch power). Note that the launch power of the transmitter can vary, and if we consider the same system but with a launch power of –2 dBm, the loss budget will then become 26 dB (delta between minimal sensitivity and minimal launch power).

Table 5. BPON/GPON ODN Class Loss Budgets

Type		BPON								GPON									
Standard		ITU-T G.983 series								ITU-T G.984.1									
Optical distribution network class (ODN)		B	A	B	A	B	B	A	B	A	B	A	B	A	B	A	B	A	B
		Downstream					Upstream			Downstream				Upstream					
Nominal bit rate		156	622,08		1244,16		156	622,08		1244,16		2488,32		155,52		622,08		1244,16	
<P_{launch}>Min	dBm	– 4	– 7	– 2	– 4	+ 1	– 4	– 6	– 1	– 4	+1	0	+ 5	– 6	– 4	– 6	– 1	– 3	– 2
<P_{launch}>Max	dBm	+ 2	– 1	+ 4	+ 1	+ 6	+ 2	– 1	+ 4	+ 1	+ 6	+ 4	+ 9	0	+ 2	– 1	+ 4	+ 2	+ 3
Sensitivity Min	dBm	– 30	– 28	– 28	– 25	– 25	– 30	– 27	– 27	– 25	– 25	– 21	– 21	– 27	– 30	– 27	– 27	– 24	– 28

An example of the typical total loss budget calculation can be illustrated as follows:

- Splitter loss (1x4, 1x8, 1x16, 1x32) usually accounts for the majority of the loss in the system: approximately 16 dB for 1x32 splitters.
- Insertion loss is typically around 0.7 to 1.0 dB per WDM coupler, generally used to combine the video signal (1550 nm) with data and voice signals (1310/1490 nm).
- Connector and splice losses are typically around 2.0 to 3.0 dB for the complete link, from the OLT to ONT.
- Fiber loss equals attenuation multiplied by distance. The maximum distance being limited by the loss budget at worst-case attenuation wavelength (1310 nm with around 0.33 dB/km attenuation). The maximum length typically ranges from 4 to 20 km.

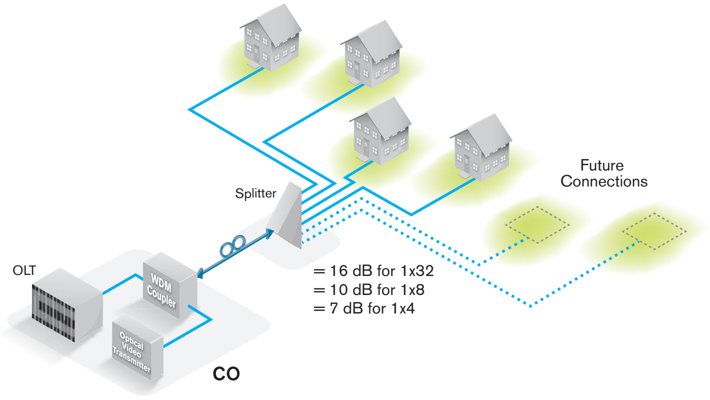


Figure 2-1. Total loss budget calculation

The loss budget calculation should be one of the first things verified prior to any deployment, and it should be mandatory to ensure that the class of the system selected is compatible with the topology that will be deployed. If, for example, a system is designed with the elements listed in Table 6 and if the launch power of the transmitter at 1310 nm is −4 dBm with a detector sensitivity of −28 dBm, the allowed loss budget of 24 dB will compromise the system's performance at 1310 nm (upstream).

Table 6. Example of Budget Loss Calculation

	Typical Loss (dB)	Number/Length	Total Loss (dB)
Splitter (1x32)	≈ 16 - 17	1	17
WDM coupler (1x2)	≈ 0.7 - 1.0	1	1
Splice (fused)	≈ 0.02 - 0.05	4	0.2
Connector (APC)	≈ 0.2	2	0.4
Fiber G.652C			
1310 nm 1490 nm 1550 nm	≈ 0.35/km ≈ 0.27/km ≈ 0.20/km	18.2 km	6.4 4.9 3.6
Total Loss Budget			
1310 nm 1490 nm 1550 nm			25.0 23.5 22.2

Therefore, the total loss measured during network deployment should not exceed the total loss budget allowed by the system design, and it should have enough of a buffer to allow for any loss fluctuation that could occur during the lifecycle of the system.

2.2 What Can Affect the Loss Budget?

As seen in the previous section, the ODN consists of several elements that will respectively contribute to the overall loss of a system. In theory, considering the insertion loss (e.g., fiber attenuation) of each element should be sufficient to make sure the budget loss will be respected once deployed. Unfortunately, in practice, this is not always the case. The following sections highlight phenomena that could eventually affect the insertion loss or optical return loss of these elements when they are deployed in the field.

Insertion loss (IL) is the increase in attenuation caused by inserting a connector pair (or passive component) into a fiber-optic link. A certain amount of signals will be lost at each point.

Optical return loss (ORL) is the ratio of the forward optical power to the reflected optical power. When light is injected into a fiber-optic component, such as a connector, a multiplexer or the fiber itself, some of the energy is transmitted, some is absorbed and some is reflected. The total light that comes back (i.e., reflected) is what we call *ORL*.

ORL is caused by two fundamental effects. The first is the Rayleigh scattering effect; specifically, the part that goes back to the source point, known as *backscattering*. The second effect consists of Fresnel reflections, which are small portions of light that are reflected back when light travels through materials of differing indexes of reflection.

Rayleigh backscattering consists of reflections that result from light-scattering due to impurities in the fiber and is intrinsic to the fiber itself; the light interacts with the density fluctuations of the fiber. The phenomenon can be caused by a variation in the material density and composition, which give rise to variations in the fiber's refractive index. This causes part of the wave to escape from the waveguide. When the size of the defect is less than one-tenth of the wavelength's incident light, it is referred to as *scattering*, while *backscattering* refers to the part that is captured in the fiber and that propagates in the backward direction.

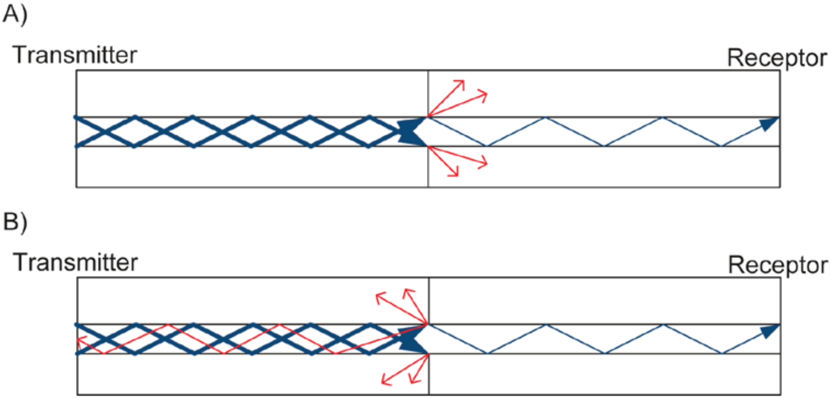


Figure 2-2. A) insertion loss B) optical return loss

Bad Connections

In order for the system to work properly, network elements must be interconnected. Currently, there are two main ways being used to connect two optical elements:

› Connectors

› Splices

Dirty or Damaged Connectors

Connectors are key components that interconnect all network elements, which is why it is essential to maintain them in good working condition; doing so ensures that all the equipment operates at maximum performance and avoids catastrophic network failure.

The singlemode fibers used in most connectors have very small cores, typically 9 to 10 μm in diameter, so a single particle of dust or smoke may block a substantial transmission area and significantly increase the loss.

Damaged or dirty connectors can lead to the following:

› Erroneous test results

› Poor transmission (high IL or ORL)

› Permanent damage to the link during high-power transmissions

Connectors can get damaged in various ways:

› Soil contamination on a connector's endface (dust, isopropyl alcohol, oil from hands, mineral oils, index matching gel, epoxy resin, oil-based black ink and gypsum).

› Angled-polished connectors (APC) connected to ultra-polished connectors (UPC).

› Physical damage to the connector's endface.

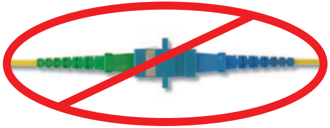


Figure 2-3. UPC connector connected with APC connector

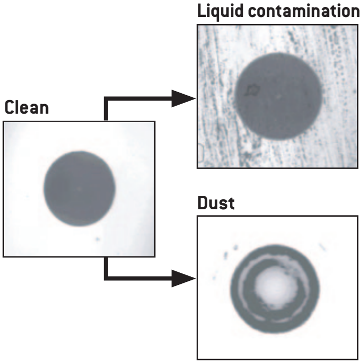


Figure 2-4. Example of soiled connector endfaces

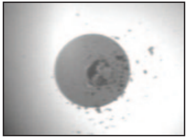


Figure 2-5. Chipped connector

Incorrect Splicing

Poor fiber-core alignments are the main causes of coupling loss when two fibers are connected using a splice. Another major source of coupling loss is the difference in optical properties. If the spliced fibers have different core or cladding diameters, then coupling losses may increase; this is referred to as *core mismatch*.

- Core misalignment–Exaggerated loss
- Core mismatch–Gainer

For more details on splice characterization, please refer to the OTDR and iOLM sections.

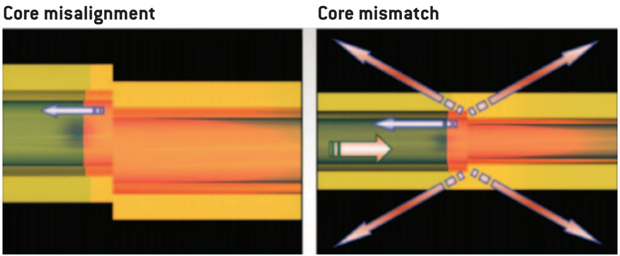


Figure 2-6. Possible issues of spliced fibers

Effects

A bad connection will generally increase the insertion loss of a device/element (e.g., splitter) in the ODN, which will contribute to the overall loss budget. If there are too many bad connections in the ODN, or if there is one with exaggerated loss, the overall loss budget may not be respected, potentially resulting in a non-functional network that does not deliver the services it should.

Another effect that can result from a bad connection (e.g., UPC connector connected to an APC connector) is the increase in the overall ORL. This parameter was not taken into consideration for testing in the past. Now, with the analog-video-over-PON networks, ORL measurement from the CO to the ONT is strongly recommended in order to obtain ghost-free transmissions when analog video is present. In general, high ORL may have the following effects on the network:

- Strong fluctuations in laser output power
- Potential permanent damage to the OLT
- Higher bit-per-error rate (BER) in digital systems
- Distortions in analog video signals

Macrobends

As the word suggests, a macrobend consists of a curvature in an optical fiber; the curvature's radius is a few centimeters. Macrobends locally decrease mode confinement, causing radiation loss. In addition, it is widely recognized that the induced attenuation increases with wavelength, due to a wider modal distribution and more power in the cladding.

Figure 2-7. Macrobend detected with VFL

Most of the time, macrobends are found in fiber organizers and at (or near) patch panels and are the result of cable mishandling or mechanical stresses due to the environment. In many optical-fiber communication systems, macrobends will occasionally boost link loss to a point that it exceeds the system's loss budget. Since the wholesale replacement of transmitters and receivers is not cost-effective, it becomes the responsibility of local maintenance crews to locate and repair these macrobends.

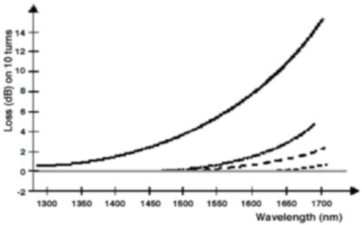


Figure 2-8. Ten wraps on a mandrel produce this type of curve for several types of optical fiber

3 Testing Procedures—Construction Phase

3. Testing Procedures—Construction Phase

Once the design of the network has been completed, the lifecycle of a network generally consists of three main phases: construction, activation and maintenance.

The following sections will highlight some of the key testing elements that should be considered during the lifecycle of a PON for an FTTH application.

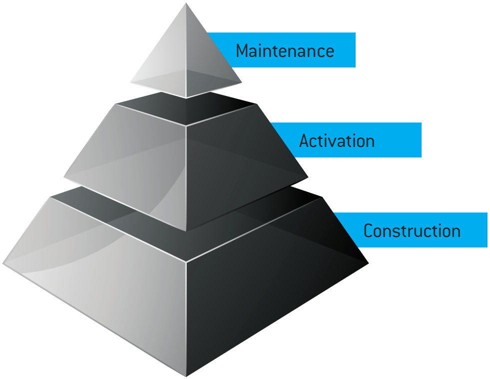


Figure 3-1. FTTH testing pyramid

The bottom of the pyramid (Figure 3-1) indicates the most extensive phase of FTTH deployment; i.e., construction. It is during this phase that most of the work required to prepare the dwelling gets done; namely, the fiber connections, which usually reach the fiber distribution panel. In some cases, a fiber installation contractor will be responsible for installing and, subsequently, maintaining the fiber within this demarcation (i.e., FDH).

Proper FTTH installation is the most important step towards an easy-to-maintain broadband network and a high return on investment. Appropriate testing during the construction/installation phase will minimize costly and time-consuming troubleshooting efforts after the fact, as it helps locate problematic splices, dirty or damaged connectors and other faulty components ahead of time, before service disruption occurs. Some of the main reasons to conduct testing during the construction phase include:

- Qualifying the outside plant section of the network (or ODN) and documenting it for future reference
- Making sure the network meets transmission-system requirements (standards)
- Avoiding delays and costly repairs upon system turn-up

Table 7. Summary Table for FTTH Testing–Construction Phase

	Test Type	Why Test?	Test Parameters	Test Gear	Testing Considerations
Construction	Out-of-service tests	› To qualify the outside plant of the network, including each element › To make sure the installation meets transmission-system requirements › To avoid delays and costly repairs upon system turn-up › To future-proof the network with emerging standards	› Fiber › Connector and ferrule cleanliness › Optical loss or insertion loss (IL) of each element › Total end-to-end loss compared to optical loss budget › Fiber mapping (documentation) › Optical return loss (ORL) measurement, especially for RF/analog video	› OLTS › OTDR or iOLM › Video inspection probe › Cleaning kit	› OLTS testing at different wavelengths (1310, 1490, 1550 nm) for bidirectional IL and ORL › Automation for P2MP testing › OTDR trace documentation from ONT to OLT using 1310/1550 and 1625 nm (reporting) › Data storage › Testing total link or segments › Experience of labor involved

As shown in Table 7, proper connector care and fiber handling are an important piece of the puzzle to make a network less problem-prone. Another critical aspect is end-to-end fiber mapping/documentation, as this ensures that once the network is up and running, any service interruptions due to network-related issues are resolved in the shortest possible time.

3.1 Maintaining Connectors

As discussed above, connectors are key elements that interconnect the different components of a network; failing to inspect them and clean them as needed can lead to network failure. Knowing where, when and how these tasks should be performed can save you valuable time and money in the long run.

Where to inspect/clean

The following items should always be on your inspection/cleaning list:

› Patch panel (e.g., splitter cabinet)

› Test jumper

› Cable connectors

Figure 3-2. Patch panel inspection

When to clean

The very first step to fiber testing is connector inspection, and this applies to all testing phases–construction, activation and maintenance. ***Connectors should be cleaned only if they are proven dirty after completing the inspection.***

What to look for

When inspecting a connector ferrule, two types of problems can be encountered: a damaged endface or a dirty endface.

Physical damage to the connector endface is usually permanent and will, in most cases, require a connector replacement—unless the damage is not detrimental to the endface. In order to determine whether the damage is detrimental or not, a good rule of thumb is to discard or replace any connector that has scratches near or across the fiber core (see Figure 3-3a), since these scratches can generate high loss and affect connector performance. For physical damage, including chipped cladding (see Figure 3-3b), worn connectors and/or excessive epoxy residue on the cladding, the connector must be replaced.

In an ideal world, free of contaminants, connector endfaces would always be clean and would not require in-depth maintenance; however, this is not the case, and many fiber-optic connector contaminants exist.

For example, a 1 µm dust particle on a singlemode core can block up to 1% (0.05 dB loss) of the light—imagine what a 9 µm dust particle can do. Another important reason for keeping endfaces free of contaminants is the effect of high-power components on the connector endface—some of today's telecommunication components can produce signals with a power level up to +30 dBm (1 W), which can have catastrophic results when used with a dirty or damaged connector endface (e.g., fiber fuse).

A) B)

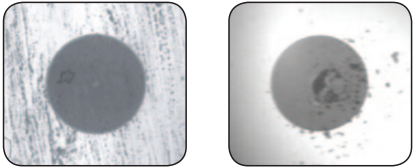


Figure 3-3. a) Scratch in the core region
b) Chipping on the cladding

Dust, isopropyl alcohol, oil from hands, mineral oils, index matching gel, epoxy resin, oil-based black ink and gypsum are among the contaminants that can affect a connector endface. Some of these contaminants are single soil or they may come in complex soil combinations. Note that each contaminant looks different, but regardless of appearance, the most critical areas to inspect are the core and cladding regions, as contamination in these regions can greatly affect the quality of the signal. Figure 3-4 illustrates the endfaces of different connectors that have been inspected with a video inspection probe.

Good practice for avoiding connector endface damage or contamination is to always keep a protective cap on the unused connector—thereby stressing the importance of storing unused protective caps in a sealed container to prevent contamination. When inserting the protective cap on a ferrule, do not insert it all the way, since small dirt particles can accumulate at the bottom of the cap, and if the bottom of a contaminated cap comes into contact with the connector endface, the cap can contaminate it. Note that outgassing from the manufacturing process of the dust cap can leave a residue from the mold release agent or materials in the cap. Therefore, the presence of a dust cap does not guarantee cleanliness; it is a protective device to prevent damage. Another interesting fact about brand-new test jumpers and connectors is that they are not always cleaned before the bag is sealed, so they could be dirty. Fortunately, using the proper cleaning tools and cleaning procedures can effectively clean a soiled connector.

NOTE: New factory-delivered jumpers and cables should also be inspected to ensure cleanliness.

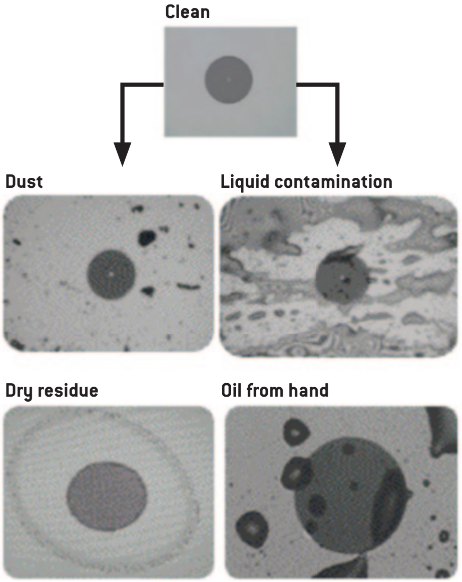


Figure 3-4. Clean connector endface vs. different contaminant types

How to inspect connectors?

The core and cladding are the two main sections of the fiber; it is critical that they be maintained in good condition to minimize the loss that occurs when two connector ferrules are mated. In order to properly carry out connector maintenance, the connector endface must first be visually inspected. The core diameter of a singlemode fiber is less than 10 microns, which means that without the proper inspection tool, it is impossible to tell if the ferrule is clean, making it essential to have the right tools.

To properly inspect the connector endface, the use of a microscope that is specially designed for fiber-optic connector endfaces is recommended. There are many types of inspection tools on the market, but they all fall into two main categories: fiber inspection probes (also called video fiberscopes) and optical microscopes. For security purposes, the tool recommended in this document is the fiber inspection probe. The table below lists the main characteristics of this tool.

Table 8. Fiber Inspection Probes—Main Characteristics

Inspection Tool	Main Characteristics
Video fiber inspection probes	› Image display on an external video screen, PC or a test instrument › Eye protection from direct contact with a live signal › Image-capture capability for report documentation › Ease of use in crowded patch panels › Ideal to inspect patchcord, patch panel, multifiber connector (e.g., MTP) › Different degrees of magnification available (100x/200x/400x) › Adapter tips for all connector types available › Automated analysis capabilities

To remove subjectivity and ensure a common level of acceptance between suppliers and installers using a high-magnification fiber inspection probe such as EXFO's FIP-400 and automated analysis software such as ConnectorMax is highly recommended.

FTTH networks typically use SC/UPC or SC/APC connectors, so when using automated analysis software, the proper standard must be selected as follows:

Table 9. Connector Types and Associated Standards

Connector Type	Analysis Standard
SC/UPC male or female 	IEC-61300-3-35 singlemode single-fiber UPC connector with ORL ≥45 dB
SC/APC male or female 	IEC-61300-3-35 singlemode single-fiber APC connector

Step-by-Step Inspection Instructions

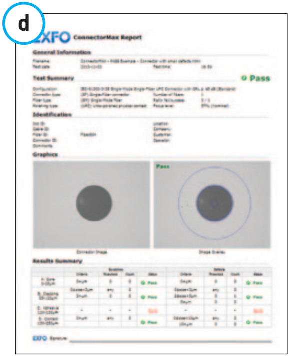
To properly inspect connectors, follow these steps:

a. Connect the probe to the connector that will be inspected, and select the corresponding IEC standard (see Table 9 on page 39).

b. Adjust magnification to 400x.

c. Start the analysis using the Capture button.

d. The results appear.



e. Clean or replace the connector depending on the analysis result.

f. Save the analysis report.

If the user does not have access to an automated analysis software such as ConnectorMax, a manual/visual inspection, using a probe (FIP-400) and standard display (e.g., FIP-400-D display), can be performed to determine whether the connector is good or not. When using this method, however, the technician must refer to strict analysis criteria and cannot tolerate defects in the core or cladding area to ensure proper network operation. Of course, being that stringent can also lead to unnecessary connector rejection. And according to standard recommendations, at least one cleaning attempt should be made before rejecting any connector.

Below is a flow chart demonstrating the inspection procedure recommended by the IEC-61300-3-35 standard:

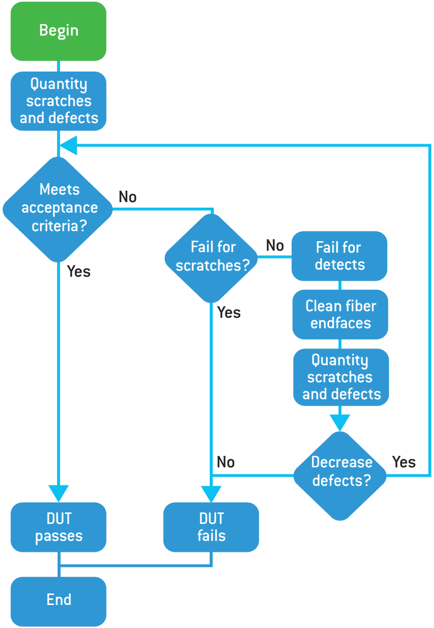
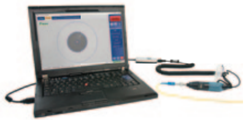


Figure 3-5. Inspection procedure flowchart

Good Practices for Connector Maintenance

- When testing in a patch panel, only the port corresponding to the fiber under test should be uncapped—protective caps should be replaced immediately after testing.
- Unused caps should be kept in a small plastic bag.
- The life expectancy of a connector is typically rated at 500 matings.
- The test jumpers used in conjunction with the test instruments should be replaced after a maximum of 500 matings (refer to EIA-455-21A).
- If a launch cord is used for OTDR testing, do not use a test jumper between the OTDR and launch cord or between the launch cord and the patch panel. Launch cords should be replaced or sent back to manufacturers for repolishing after 500 matings.
- Unmated connectors should never be allowed to touch any surface, and a connector ferrule should never be touched for any reason other than cleaning.
- Each connector should be cleaned and inspected using a videoscope after cleaning or prior to mating in PON applications.
- Test equipment connectors should also be inspected and cleaned (when required) every time the instrument is used.

Table 10. Fiber Inspection Probes—Configurations

Image	Description	Part Number	Recommended Cleaning Method
	FIP-400 handheld stand-alone kit. This basic solution supports manual inspection only. No analysis or data storage capability.	FIP-400-SINGLE-D or FIP-400-DUAL-D	Dry
	FIP-400 Fiber Inspection Probe used on EXFO's FOT-930 OLTS or AXS-110 OTDR. This basic solution supports manual inspection only. No analysis or data storage capability.	FP4S or FP4D option	Dry
	FIP-400 Fiber Inspection Probe used on EXFO's portable platforms such as the FTB-1 or FTB-200. Provides automated analysis, data storage and report generation in the field on the same unit as the OTDR.	FP4S or FP4D option and FPSA ConnectorMax	Wet
	FIP-400 Fiber Inspection Probe used on a PC or laptop. Provides automated analysis, data storage and report generation.	IFIP-400-USB2-SINGLE or FIP-400-USB2-DUAL and FPSA-PC ConnectorMax	Dry

Fiber inspection probes come with different tips to match the different connector types found in PON deployments: angle-polished connectors (APC) and flat-polished connectors (PC or UPC).

Table 11. Common FTTH Inspection Tips

Image	Description
	SC/UPC female inspection tip (for patch panels)
	SC/APC female inspection tip (for patch panels)
	SC/UPC male inspection tip (for test jumpers/2.5 mm ferrule)
	SC/APC male inspection tip (for test jumpers/2.5 mm APC ferrule)

Image	Description
	OptiTap™ bulkhead adapter
	MT/APC type OptiTip™ multifiber
	Male adapter tube for FIPT-400-OTIP-MT-APC tip

For more connector inspection tips, please refer to EXFO's Connector Inspection Guide www.EXFO.com/Connector-Inspection-Guide

Connector Cleaning Accessories

Connectors that fail endface inspection must be thoroughly cleaned using appropriate tools and cleaning methods in order to avoid connector damage and network failures.

The main steps to perform adequate cleaning are as follows:

Dry Cleaning

Dry cleaning using a mechanical cleaner is recommended as the first step. Mechanical cleaners can be used for connectors with a 2.5 mm ferrule; they are also appropriate for cleaning both male (jumpers) and female (patch panel) ends.

If, after two dry cleaning attempts, soil is still present on the connector, proceed to a combination cleaning.

Figure 3-6. Mechanical cleaner

Combination Cleaning

Combination cleaning is a mix of the wet and dry cleaning methods and involves using solvent. The first step in hybrid cleaning is to clean the connector endface with a solvent and then dry any remaining residue with either a wipe or a swab.

If, after using the combination cleaning method, the connector still fails to meet the acceptance criteria, you may then consider replacing the connector.

Figure 3-7. QbE Dry Fiber-Optic Wipes

Cleaning and Inspection Kits

Recommended all-in-one inspection and cleaning kits come fully equipped. Below are a few examples of what such kits include:

1. Fiber Inspection Probe
2. Handheld display with 3.5-inch TFT screen
3. Inspection tips for bulkheads and jumpers
4. Electro-Wash® MX cleaning pen
5. QbE™ Dry Fiber-Optic Wipes
6. Mechanical cleaner for 1.25 mm connectors
7. Mechanical cleaner for 2.5 mm connectors
8. CLETOP® Ferrule Cleaning Cassette, Blue Tape Reel (Type B), Green
9. Watertight transit protector case

Figure 3-8. EXFO's cleaning kit deluxe single or dual models

Advanced Inspection/Certification Kits

Basic kit:

1. FTB-1 Intelligent Fiber Inspection and Certification Test Set
2. Video Inspection Probe
3. Inspection tips for bulkheads and jumpers
4. Electro-Wash® MX Cleaning Pen
5. QbE™ Dry Fiber-Optic Wipes
6. 1.25 mm and 2.5 mm cleaning swabs
7. FTB-1 Utility Glove
8. ConnectorMax (Optional)
9. Power meter (Optional)

Deluxe kit:

1. FTB-1 Intelligent Fiber Inspection and Certification Test Set
2. Video Inspection Probe
3. Inspection tips for bulkheads and jumpers
4. Electro-Wash® MX Cleaning Pen
5. QbE™ Dry Fiber Optic Wipes
6. Mechanical cleaner for 2.5 mm connectors
7. Mechanical cleaner for 1.25 mm connectors
8. FTB-1 Utility Glove
9. ConnectorMax (Optional)
10. Power meter (Optional)

Figure 3-9. Advanced fiber inspection test kits (TK-1-FIP-400)

Table 12. Summary of Recommendations—Test Gear for Successful Connector Maintenance

Product Name and Complementary Products			Use for	Main Characteristics	Compare to	Advantages	Disadvantages
Solution no.	**Main Production Solution**	**Complementary products**					
1	**FIP-400-D-SINGLE or FIP-400-D-DUAL**	**None**	Connector inspection	› Basic solution allowing manual inspection › Includes a video inspection probe and a handheld field display	2	› Easy to carry in the field › Inspection solution at an affordable entry-level price	› No automated analysis › No data storage capability › Requires technician with a good understanding of connector maintenance
2	**FIP-400-USB2-DUAL-FPSA or FIP-400-USB2-SINGLE-FPSA**	**Require extra PC**	Connector inpsection with automated analysis	› Complete solution allowing inspection with automated diagnostics (ConnectorMax software)	1	› Eliminates guesswork › Ensures consistent acceptance criteria (based on IEC/IPC) throughout the company › Help eliminate unnecessary truck rolls › Allows for work documentation (data saving)	› Requires an extra PC (or laptop for field application) › Can be hard to operate in some field applications
3	**FP4S-FPSA or FP4D-FPSA**	**Portable Platform: FTB-1 or FTB-200 or FTB-500**	Connector inspection with automated analysis	› Complete solution allowing inspection with automated diagnostics (ConnectorMax software), in a field-adapted platform	1	› Eliminates guesswork › Ensures consistent acceptance criteria (based on IEC/IPC) throughout the company › Help eliminate unnecessary truck rolls › Allows for work documentation (data saving) › Can be combined with other testing needs (e.g., OTDR) for an all-in-one solution	
					2	› Platforms are easier to carry in the field compared to ordinary laptops. › Can be combined with other testing needs (e.g., OTDR) for an all-in-one solution	

3.2 Characterizing Insertion Loss and Optical Return Loss

In this step, both loss and fiber attenuation of the ODN elements must be measured to ensure that they meet supplier specifications (as well as the loss budget; see section 2.1 for details). As a first step, it is recommended to test/characterize each fiber that connects the OLT (central office) to the splitter (before splicing or connection). This portion of the ODN is often called F1. Each fiber from the splitter to the ONT should also be tested (again, before splicing or connection). This portion of the ODN is often called F2.

There are several ways of characterizing the ODN during construction and various testing methods can be used to measure key parameters such as IL and ORL. For example, spliced networks provide limited access points to perform testing compared to a connectorized ODN.

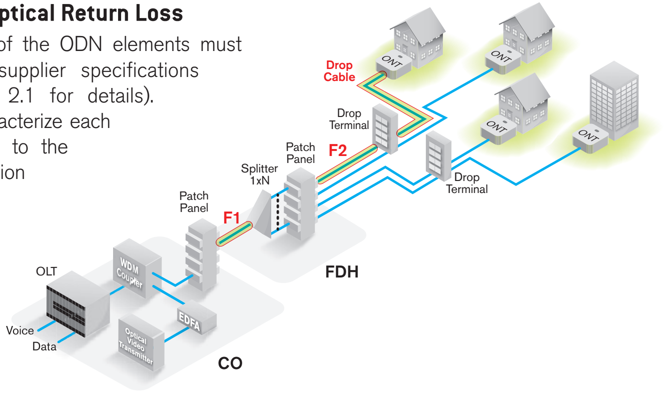


Figure 3-10. Fiber sections in an FTTH ODN

Figure 3-11 below shows different spliced ODN configurations. In scenario A, fiber could be deployed all the way to the premises, and characterization could be performed once all the elements are spliced together, whereas in other situations, a different methodology would be more appropriate.

The next section explains how characterization is performed during the construction phase, using the following measurement tools:

› Optical loss test set (OLTS)

› Reflectometry-based solutions:

  › Traditional optical time-domain reflectometer (OTDR)

  › Intelligent Optical Link Mapper (iOLM)

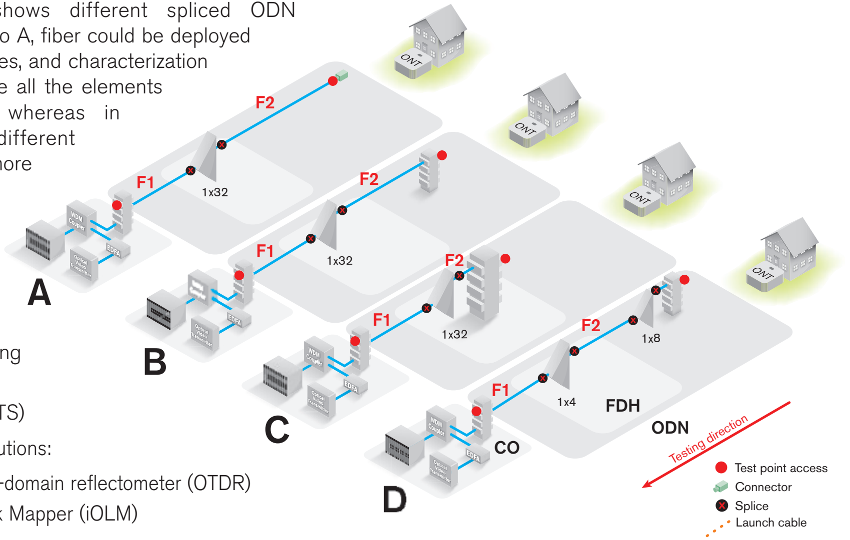


Figure 3-11. Examples of spliced ODNs

3.3 The Tools and Approaches

An **automated OLTS** determines the total amount of loss or attenuation in a fiber span under test. At one end of the fiber, a stable light source emits a signal that consists of a continuous wave at a specific wavelength. At the other end, an optical power meter detects and measures the power level of that signal. To obtain accurate results, the power meter must be calibrated for the same wavelength as the incoming signal. In very general terms, the difference in power level of the signal measured at the transmitting and receiving ends corresponds to the loss of the fiber under test. Compared to a standard OTLS, the automated version has an integrated source and power meter in each unit (both in a single port) and has ORL measurement capabilities.

In addition to measuring total IL and ORL, an **OTDR** identifies and specifically locates individual events in a fiber-optic span, which typically consists of sections of fiber joined by connectors and splices. The reflectometry test is single-ended and is performed by one technician. The unit transmits pulsed light signals along a fiber span in which light-scattering occurs due to discontinuities such as connectors, splices, bends and faults. The OTDR then detects and analyzes the parts of the signals that are returned by Fresnel reflections and Rayleigh backscattering. The OTDR method is extremely accurate, yet can be complex and time-consuming.

The most recent test tool for this application is the intelligent optical link mapper (**iOLM**). This tool uses the same method as the OTDR, but performs the test procedure automatically. It does this by using different pulse widths to fully characterize the various sections of an FTTH network—each section being characterized with the optimal pulse. Then, the iOLM consolidates all this information into a single comprehensive Link View; the operator does not have to manually compare results at different pulses like a traditional OTDR. The iOLM provides the link's loss and ORL, in addition to identifying all network elements such as splices, splitters and connectors. It also provides the loss and reflectance values of the identified elements. And when a specific element or the link itself gets a "fail" verdict, it offers a diagnosis to help the operator solve the problem. The whole routine takes 30 to 60 seconds, depending on network complexity.

A reflectometry-based measurement technique is the only way to fully characterize splice loss. In order to determine the real loss of a splice, a bidirectional analysis is a must, as one-directional measurements can be contradictory; i.e., one direction could show an exaggerated loss, while the other direction could show a gain.

This happens when two fibers with different field diameters are spliced; e.g., G.652 fiber spliced with G.657 fiber. Based on the analysis of field trials, it seems to be increasingly common for operators to test bidirectionally when the absolute value of the splice in one direction exceeds a specific value. Oftentimes, testing techniques will be dictated by the way the ODN elements are connected, i.e., spliced or connectorized. Networks that use splices will not have access to the same test points as networks that use connectors.

The following pages will show the different testing methods that can be used to characterize the IL/ORL on spliced and connectorized network.

3.4 OTDR-Based Techniques

Testing methods and tools based on reflectometry, such as OTDRs and iOLMs provide the IL/ORL characterization during the construction phase, but it will also detect and locate the following issues, if present on the link:

› Fiber-connector misalignment

› Fiber mismatch

› Splice loss

› High-loss or reflective connectors

› High-loss splitter branches

› Fiber breaks

› Fiber section attenuation (dB/km)

› Macrobends

The two scenarios described below will highlight the main difference between a traditional OTDR and advanced technologies such as the intelligent Optical Link Mapper (iOLM)—a revolutionary OTDR-based application.

Traditional OTDR

Figure 3-12, shows the possible test points where the OTDR can be connected in order to conduct the characterization of a spliced ODN.

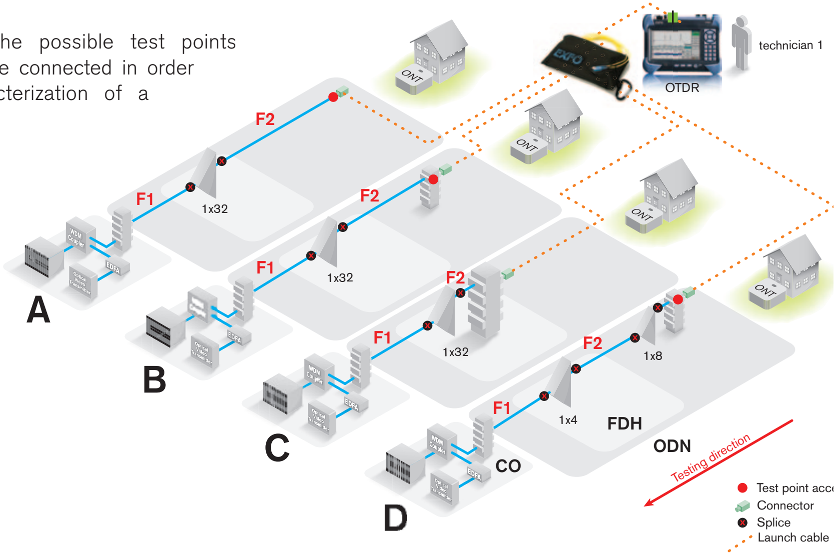
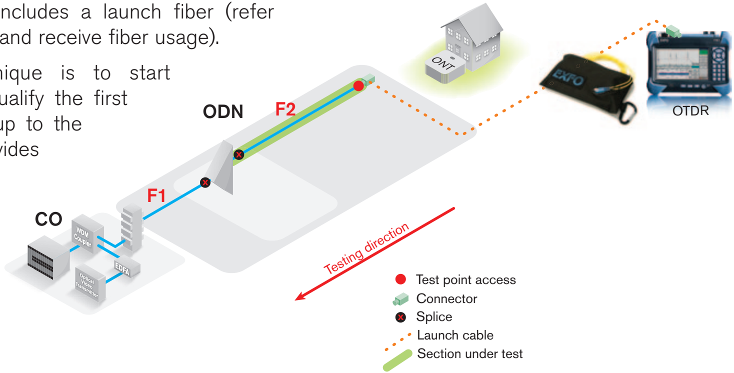


Figure 3-12. Spliced ODN characterization using an OTDR

Note that the following example includes a launch fiber (refer to Appendix A for details on launch and receive fiber usage).

The recommended OTDR technique is to start by using a short pulse width to qualify the first part of the link (the drop cable), up to the splitter. A short pulse width provides high resolution to make sure that the front-end connector, the drop point connector/splice or any other closely spaced events along the drop fibers meet predefined specifications and that all splices are within acceptable limits.



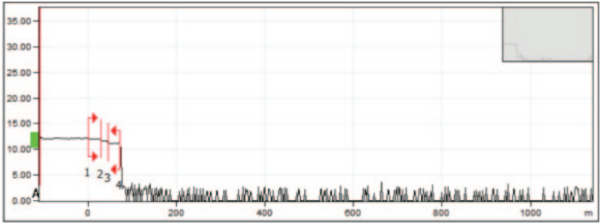
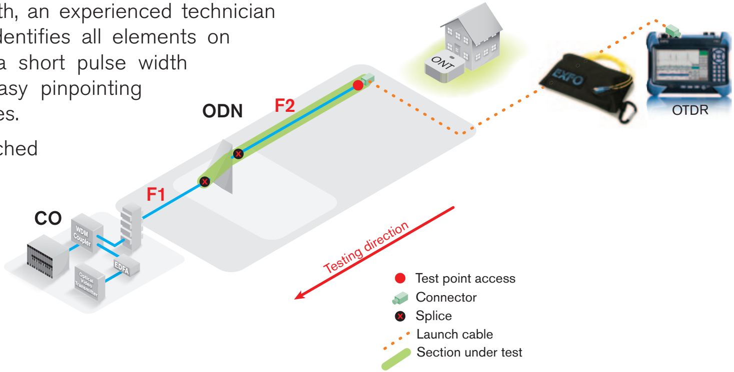


Figure 3-13. OTDR trace using a short pulse width

Using a 5 ns to 10 ns pulse width, an experienced technician verifies the first connector and identifies all elements on a link, up to the splitter; using a short pulse width provides better resolution and easy pinpointing of problematic connectors or splices.



Then, a second acquisition is launched using a medium pulse width; this provides a better dynamic range while maintaining good resolution. The technician measures loss at the splitter to verify if it is within acceptable limits.

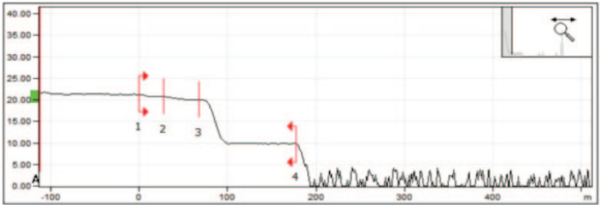
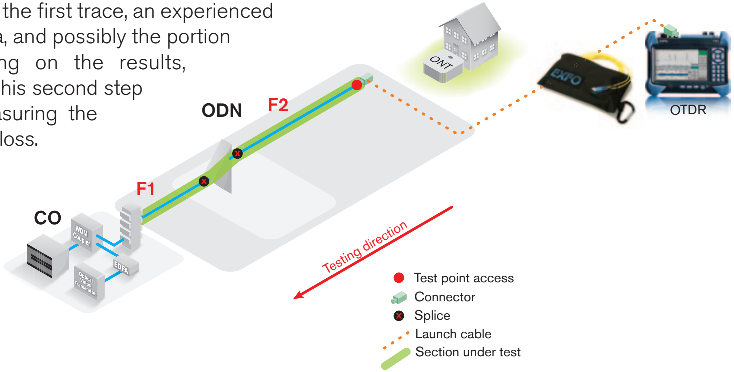


Figure 3-14. An OTDR trace using a medium pulse width

Using a longer pulse width than for the first trace, an experienced technician qualifies the splitter area, and possibly the portion between two splitters. Depending on the results, the technician may need to repeat this second step to find the optimal pulse for measuring the splitter loss and/or the end-to-end loss.

Finally, the technician completes the test with a pulse width that has enough dynamic range to allow end-to-end loss qualification. A long pulse width provides the required dynamic range, but offers lower resolution; this can also be related to a longer dead zone, which will not identify closely spaced events located at the front and possibly the first stage of the splitter.



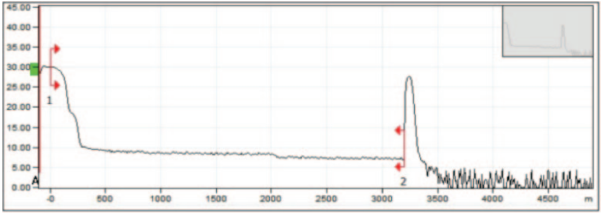


Figure 3-15. OTDR trace using a long pulse width

This process results in three or four OTDR traces that will need to be consolidated. Good OTDR skills are required to set the proper pulse widths to test the link as well as to analyze the OTDR results. A fair amount of time will be spent comparing results at the different pulse widths to determine which one provides the best measurement for each section and event. Plus, if a single report must be provided at the end, extra time will also be required to extract information from the different traces and input the data into a custom report template. Overall, the entire process could take between 5 to 10 minutes, depending on the complexity of the network and the technician's skills.

To detect macrobends, this sequence must be performed a second time at a second wavelength (e.g., 1310 nm and 1550 nm) to compare the loss of each event between both wavelengths. To fully characterize an FTTH network, one must therefore analyze information gathered from many traces.

Figure 3-16 summarizes each step that is required to perform a full ODN characterization. It should be noted that to generate a single report containing all the tests (three OTDR acquisitions and connector information), post-processing will be required.

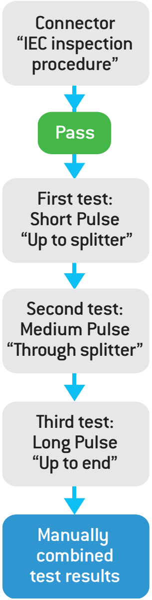


Figure 3-16. OTDR characterization process

iOLM Tool

Figure 3-17 shows the possible test points where the iOLM can be connected in order to conduct the characterization.

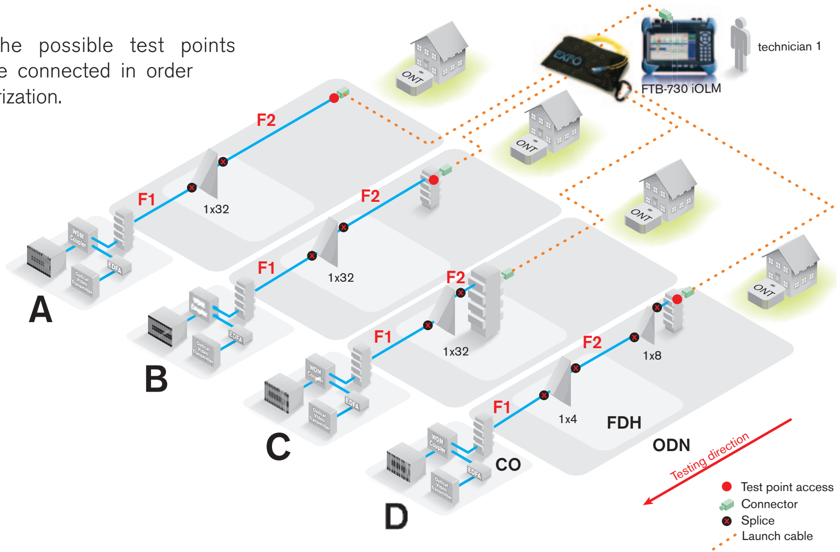


Figure 3-17. Spliced ODN characterization using an iOLM

Once the user has selected the proper test configuration according to the fiber being tested, he can simply start the test. Note that the entire link will be characterized with a single acquisition.

Once the test is complete, the iOLM will show the link view results; in this representation, each element is identified by a distinct pictogram, helping the technician to immediately see all the elements in the link. Viewing and correcting a problem becomes very easy, as even an entry-level technician with minimal experience in optics will be able to perform tests just like any other experienced technician, and will do so in less time. The iOLM can also save all results in a comprehensive report that can easily be transferred to a database.

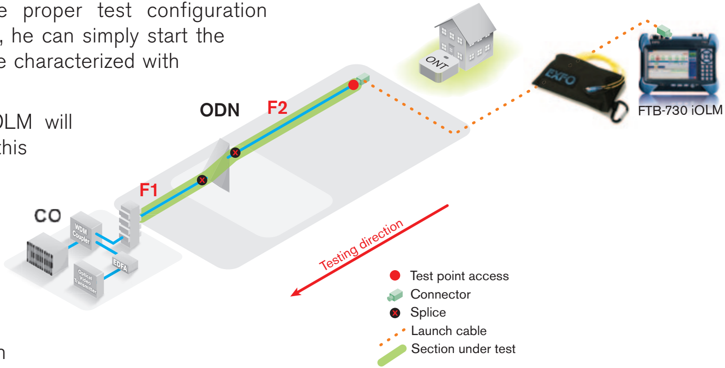


Figure 3-18. iOLM testing

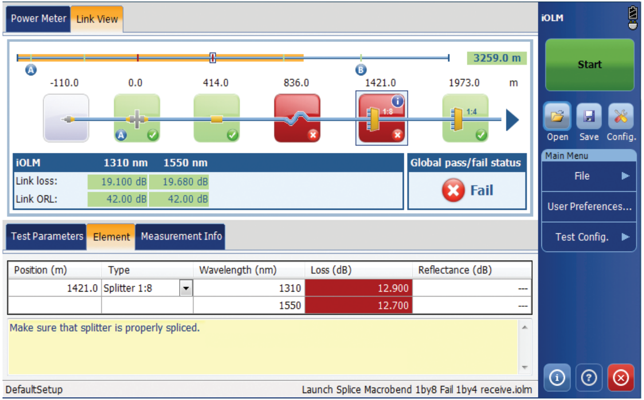


Figure 3-19. EXFO's iOLM Link View

Among the key information iOLM provides is diagnostics, which are used to provide additional data on detected problems or ambiguous measurement situations, such as the identification of possible causes for a fail status of a link element.

As shown in Figure 3-20, the iOLM can detect bad splices and ask the user to consider resplicing to fix the problem.

Such diagnostics help troubleshoot faulty connectors, understand why link elements are tagged as fail, indicate unexpected instrument or test conditions and so forth.

Link elements with an associated diagnostic are marked with an icon in the link view.

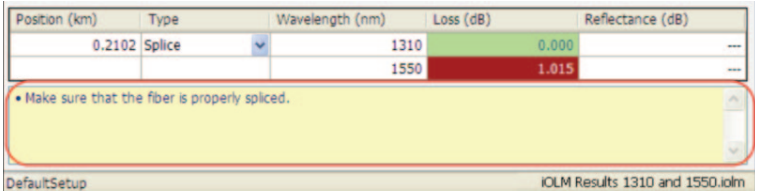


Figure 3-20. Example of EXFO's iOLM diagnostics

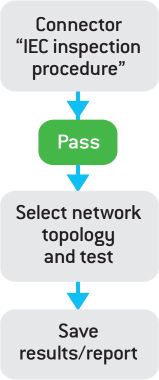


Figure 3-21. iOLM characterization process

Figure 3-21 summarizes the steps required to fully characterize an ODN using an iOLM. It should be noted that iOLM reports include information on each element of the link on a single test report.

As demonstrated in the previous pages, with the iOLM, less experienced technicians are able to test as if they were experts and experienced technicians are able to test faster.

Table 13. Main Differences between Traditional OTDR and iOLM

Characteristics	OTDR	iOLM
Number of technicians required	1	1
Technical expertise needed to perform test	Medium to high	Low
Number of acquisitions required to characterize a PON network	An average of three depending on link complexity; each acquisition estimated at an average of 45 s/wavelength	1 (average of 45 seconds; multiple acquisition are done automatically by the iOLM)
Average test time per fiber	Typically 6-15 minutes depending on link complexity and technician's skills	≈ 45 seconds to 1 minute
Physical mapping of the link	Yes	Yes
Graphical representation of the link	Traditionnaly graphical representation	Link view with icons
Provides insertion loss	Yes	Yes
Provides optical return loss	Yes	Yes
Provides length of the fiber	Yes	Yes
Live-fiber testing port	Yes	Yes
In-line power meter	Yes	Yes
Automatic diagnostics	Macrobend detection and pass/fail status	Yes, global and individual pass/fail status plus diagnosis information for each failure
Test from premises (ONT) to CO (OLT)	Yes	Yes
Test from CO (OLT) to premises (ONT)	No	No
Troubleshooting	Yes	Yes
Live testing	Yes	Yes
Offers easy transpose fiber detection	No	No

3.5 OLTS-Based Techniques

Figure 3-22, shows the possible test points where the two automated OLTS units can be connected in order to conduct the characterization.

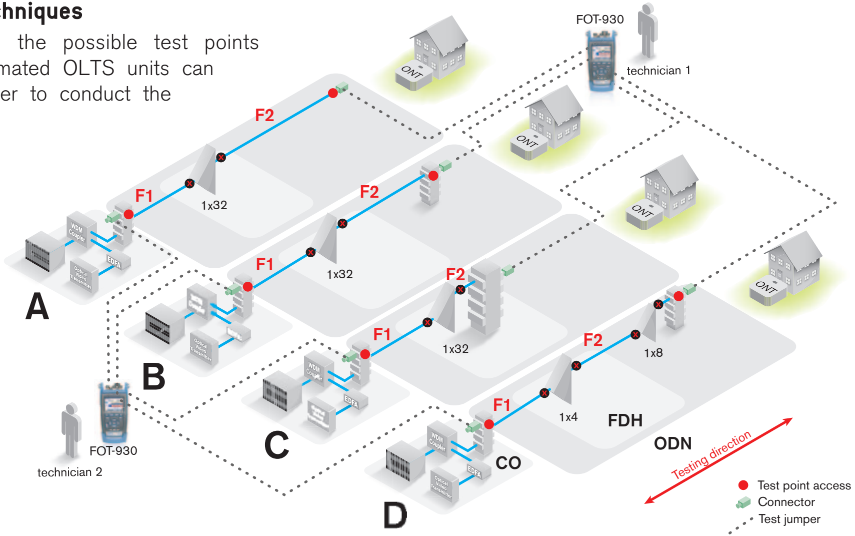
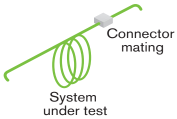
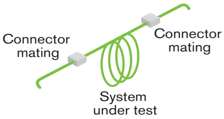


Figure 3-22. Standard test configuration using an automated OLTS

This testing technique consists of using one unit at the CO and a remote unit at the access test points available in the ODN.

Prior to performing the test, the two units must be referenced. Referencing consists of subtracting the loss caused by the test setup components (test jumpers) from the overall loss measured during the test. The final result will then represent the loss inserted by the system under test alone. With an automated OLTS, two referencing methods are available. Table 14 shows the main characteristics of each method.

Table 14. FOT-930 Referencing Methods

	Side-by-Side Method (Best)	Loopback Method
Description	Reference taken with both units together using their Fastest ports. Slightly more accurate value than loopback method.	Reference taken separately on each unit (Fastest port connected to power meter port).
Location of units	Must be at same location.	Can be at different locations.
Loss included in Fastest result	Loss due to system under test and one connector mating. 	Loss due to system under test and the two connector matings. 
Elements to consider	Includes neither an ORL reference nor an ORL zero measurement. To obtain them, use the ORL Meter pane With multiple referencing, you may coordinate an FTB-3930 with up to 10 FOT-930 units.	When measuring ORL (Fastest or ORL meter), accounts for connector loss and adjusts ORL calibration accordingly. Not recommended for short links.

Usually, the unit in the CO (connected to the F1) doesn't require any assistance once the referencing is performed and the instrument is connected on the feeder fiber (in this case F1) of the PON under test. The technician at the ODN goes to different drop locations, performing automated tests; the unit at the CO will simply respond to a call for testing from the remote unit and initiate IL and ORL automated testing.

Advanced automated OLTS solutions, such as EXFO's FTB-3930 coupled with the FOT-930, can allow multiple technicians to access the same unit. As the FTB-3930 can manage up to 10 references, it can be placed in the CO, connected to the link under test. The technicians in the field, equipped with FOT-930s can use the unit at the CO to perform the test. Note that once the referencing is performed, no technician is required to operate the FTB-3930, and all the test results can automatically be saved in this main unit at the CO.

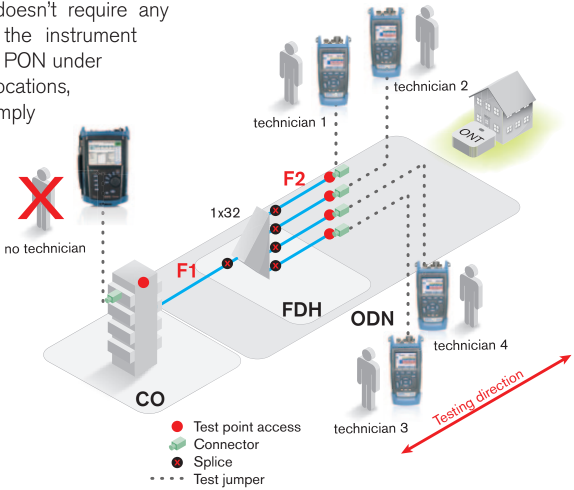


Figure 3-23. Optimized characterization using the FTB-3930 with FOT-930

Table 15 briefly highlights the main differences between an automated OLTS and OTDR or iOLM:

Table 15. Automated OLTS–Technological Comparison Table

Characteristics	OLTS	OTDR	iOLM
Number of technicians required	1	1	1
Technical expertise needed to perform test	Low	Medium to high	Low
Number of acquisitions /tests per fiber	1	An average of three to fully characterize all elements. Each acquisition estimated at an average of 45 s/wavelength	Average of 45 seconds, includes all wavelengths
Average test time per fiber*	10 to 15 seconds	2.5 minutes	45 seconds
Physical mapping of the link	No	Yes	Yes
Graphical representation of the link	No	Traditional graphical representation	Link view
Provides insertion Loss	Yes	Yes	Yes
Provides optical return Loss	Yes	Yes	Yes
Provides length of the fiber	Yes	Yes	Yes
Automatic diagnostics	No	Yes, but limited (macrobend detection)	Yes
Test from premises (ONT) to CO (OLT)	Ye	Yes	Yes
Test from CO (OLT) to premises (ONT)	Yes	No	No
Troubleshooting	No	Yes	Yes
Live testing	No	Yes	Yes
Offers easy transpose fiber detection	Yes	No	No

In contrast to spliced ODNs, connectorized ODNs provide more test access points. Figure 3-24 illustrates four typical connectorized ODN configurations. In Scenario B, fiber could be deployed all the way to a distribution terminal, and characterization could be performed from this location. Connectorization of remaining fiber could take place once the customer decides to subscribe to the service. Although these differences do exist, test techniques for connectorized ODNs are basically the same as for all-spliced ODNs. The only major difference as far as testing is concerned is that connectorized ODNs provide multiple access points, which is a clear advantage, when troubleshooting.

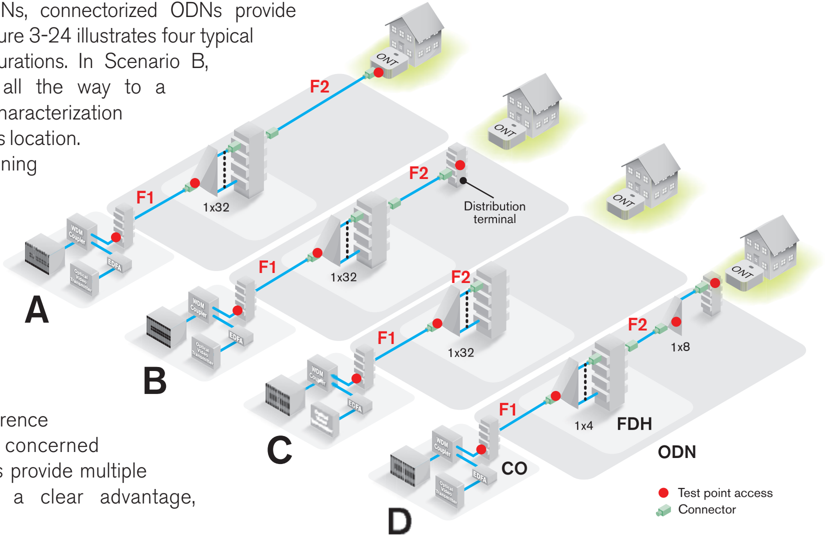


Figure 3-24. Examples of connectorized ODNs

4 Testing Procedures—Activation Phase

4. Testing Procedures—Activation Phase

Service activation is associated with what is known as “home-connect” service turn-up. This process includes the connection between the fiber drop point (FDP) and the optical network terminal (ONT) at the customer’s premises.

To validate the integrity of the last mile, the same IL and ORL tests conducted during the construction phase can be repeated on the drop cable prior to installing the ONT.

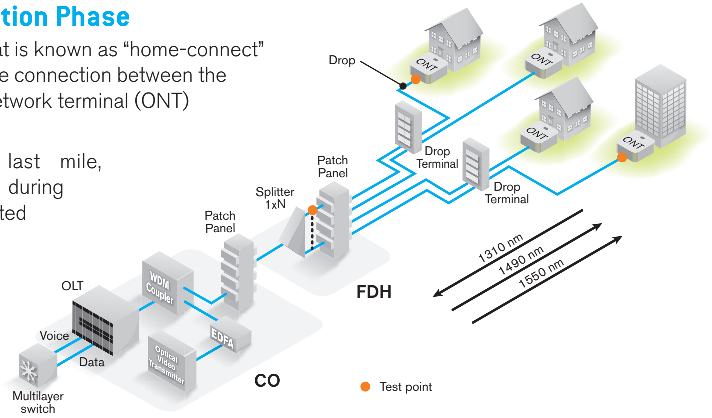


Figure 4-1. Test points during activation

As FTTH networks link one location to multiple locations (i.e., they are P2MP networks), each drop fiber corresponds to a specific customer or ONT. It is mandatory to measure all passive optical signals (downstream: 1550/1490 nm, and upstream: 1310 nm) for every customer to eliminate power budget issues during service turn-up. It is of utmost importance to implement proper fiber management in order to reduce problems related to splice loss, connectors, macrobends and human error.

4.1 Testing Power in Passive Optical Networks

False power readings often lead to discrepancies between values measured and manufacturer specifications; this is particularly true for PON applications. It is therefore critical that accurate, PON-specific power meters with good track records are used for measurement and documentation purposes.

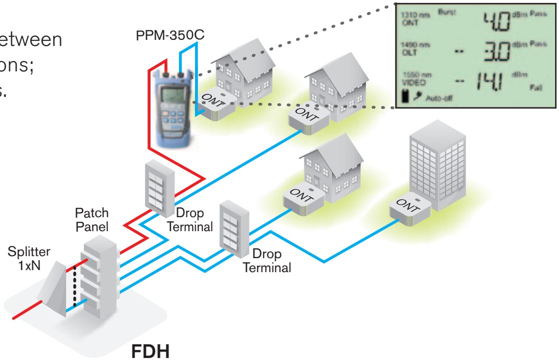


Figure 4-2. PON power reading

The minimum requirements for PON power meters are as follows:

› Ability to measure both upstream (at 1310 nm) and downstream (at 1490 nm and 1550 nm) transmissions

› Ability to measure true upstream burst signals (at 1310 nm; see Figure 4-3)

› Ability to save results and generate coherent reporting for integration with ODN results database (OLTS and OTDR)

Verifying optical levels at various locations along the same fiber path helps pinpoint problems and/or defective components before activating a customer's service. Since FTTH network problems are often caused by dirty or damaged connectors, component inspection greatly reduces troubleshooting, as power levels are verified for each network section. It is also highly recommended to inspect each connection point using a fiber inspection probe (such as EXFO's FIP-400), before each power measurement.

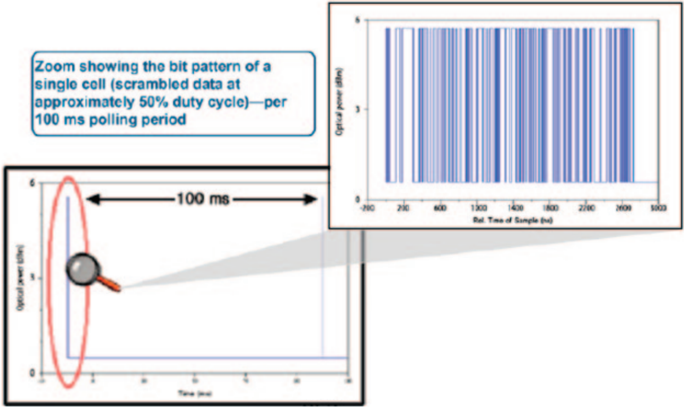


Figure 4-3. Upstream burst signal transmitted by the ONT

Testing at the FDP (Point 2)

Power-level verification at the drop terminal (F2) characterizes the distribution fiber and the drop terminal ports. Usually, a splice tray is included within the drop terminal, which can cause macrobend-related issues. To proceed with measurement, a dual-port PON power meter is connected (via pass-through mode) to Location 2 and both results are saved within the PON power meter (with location ID of the FDP).

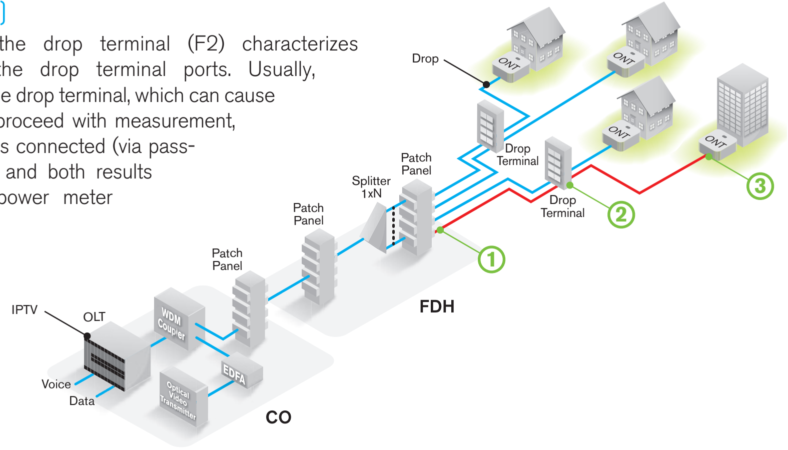


Figure 4-4. Activation testing using a PON power meter

Testing at the ONT (Point 3)

The fiber connecting the drop terminal to the customer premises, also called the *last mile or drop cable*, is generally installed during service activation. The process covers fiber management, splicing, civil works, completion of the last-mile installation and, finally, testing and verifications. To ensure reliable services, the network and the customer ONT must meet specifications. In order to guarantee service turn-up, a pass-through connection test is required to fully characterize all operating wavelengths (upstream and downstream) in the PON. A dual-port PON power meter is connected via a pass-through to Location 3 and both results are saved within the PON power meter (with location ID of the FDP) Note that if pass-through mode is not used, only downstream signals from the CO will be certified, missing important upstream burst signal.

Testing at the FDH Splitter (Point 1)

If the above testing scenarios at Points 2 and 3 fail, the splitter branch will need to be verified to ensure it is working properly. This simple assessment allows users to confirm that all network components from the CO (including the feeder fiber, or F1) to the splitter output are in good condition. A repeat PON power measurement at Point 1 is required to see if the splitter output is in good condition.

4.2 Working with a PON-Optimized Power Meter

Since the service-activation phase is often performed by subcontractors, reporting and data-authenticity protection have become major factors in PON deployments, where hundreds of results may be generated for a single PON activation. So, following the right steps in day-to-day activations ensures a smooth workflow and high productivity.

PON power meters with an onboard workflow management system (such as EXFO's PPM-350C) include a Job Editor mode, as well as post-processing and reporting tools.

With Job Editor Mode, managers and technicians alike can preconfigure upcoming jobs by entering information about specific customers. As shown in the Figure 4-5, simple job IDs (e.g., JOB ID 3) can be defined; they can correspond to a specific work order, with additional details in the OSS or GIS. Once these jobs are created using a straightforward PC software application, they can be loaded onto the unit through a USB connection.

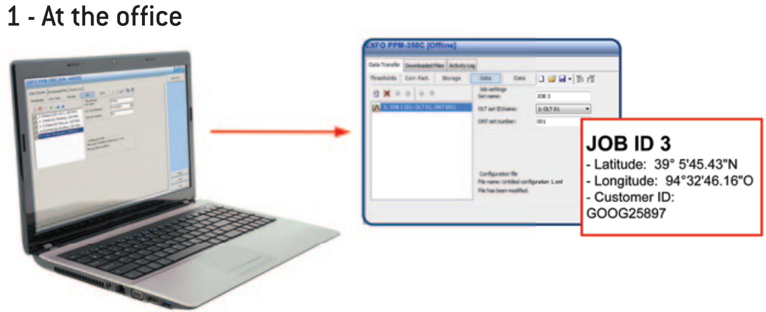


Figure 4-5. PPM-350C data-naming in the office

In the field, the technicians simply select the proper JOB ID, perform testing and save the results corresponding to this job. Back at the office, test results can be uploaded on a PC, and optimized activation reports can be easily generated.

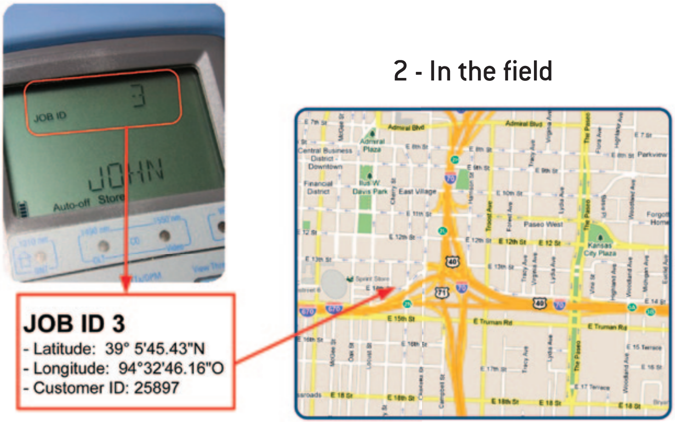


Figure 4-6. PPM-350C data-naming in the field

5 Testing Procedures—Maintenance Phase

5. Testing Procedures—Maintenance Phase

When service is activated on a passive optical network (PON), telephony, high-speed Internet and video signals are sent from the optical line terminal (OLT) at the central office (CO) to various optical network terminals (ONTs) at different residential customer locations. In this situation, if one of the ONTs goes down and cannot restart its synchronization with the OLT, this branch of the PON becomes inactive and the customers associated with this branch lose service. The result is that a technician is called in to troubleshoot and restart the service.

5.1 Troubleshooting Live Systems

The technician's first step when troubleshooting a live system is to locate and identify the source of the optical problem in what may be a complex optical network topology that includes several splitters, fibers and ONTs. Figure 5-1, on the following page, shows a multisplitter network topology. The numbers indicate the different zones where a problem may be located. If a break occurs in the cable between the OLT and a downstream splitter, all ONTs downstream from that splitter on, will be affected; however, if a problem like macrobends or dirty connectors causes optical power to be lost somewhere in the network, only a number of downstream ONTs may be affected. Since the attenuation in fiber-optic cables is proportional to length, distant ONTs receive a weaker downstream optical signal than closer ones. The upstream optical signals received at the CO from the more distant ONTs are also weaker and the OLT will detect such a decrease in performance.

Problems that may occur in an FTTH network include:

› Optical power level at one or more ONTs does not meet the specified minimum power level

› Loss of signal (no power)

› Increased BER or degraded signal (may be caused by insufficient power)

› Hardware problem with an active component (at ONT or CO)

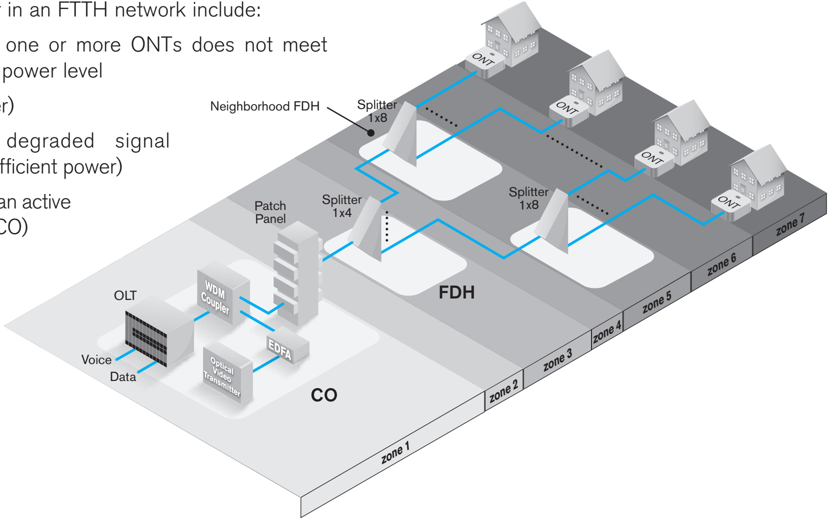


Figure 5-1. Troubleshooting zones in a typical FTTH network

Since most of the components in the network are passive, problems are often due to dirty/damaged/misaligned connectors or breaks/macrobends in the fiber-optic cable. These will affect one, some, or all subscribers on the network, depending on the location of the problem.

The faulty zone can be isolated using the following equipment:

› **PON power meter**:
This instrument is connected as a pass-through device, allowing both downstream and upstream traffic to travel unimpeded. It measures the power at each wavelength simultaneously. It also detects the burst power of the ATM traffic. This meter can be used for troubleshooting at any point in the network (see Figure 5-2).

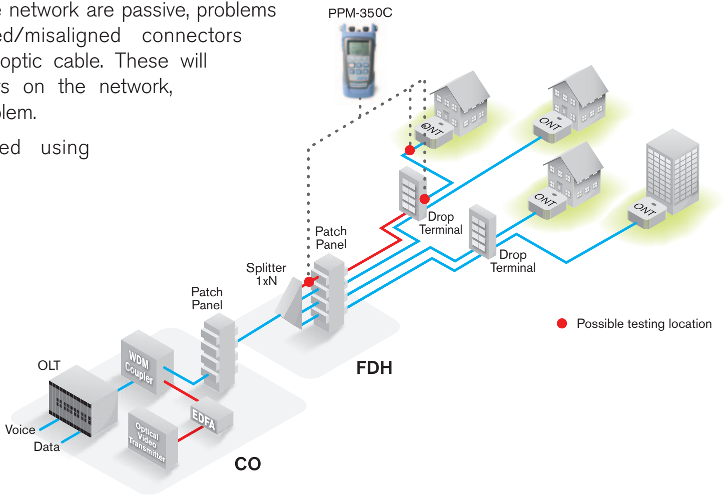


Figure 5-2. Using a PON power meter for troubleshooting various points in an FTTH network

Even though a PON power meter can help isolate the affected zone, it cannot provide the exact location of the fault. In order to physically pinpoint the location of a fault, the technician must use what we refer to as a PON-optimized OTDR or iOLM with a dedicated port for testing at 1625 or 1650 nm and incorporate a filter that rejects all unwanted signals (1310, 1490 and 1550 nm) that could contaminate the OTDR-iOLM measurement.

Only the OTDR or iOLM signal at 1625 or 1650 nm is allowed to pass through the filter, generating a precise OTDR or iOLM measurement. In-service OTDR or iOLM troubleshooting of optical fiber should be done in a way that does not interfere with normal operation and expected performance of the information channels. Testing at 1625 or 1650 nm does just that.

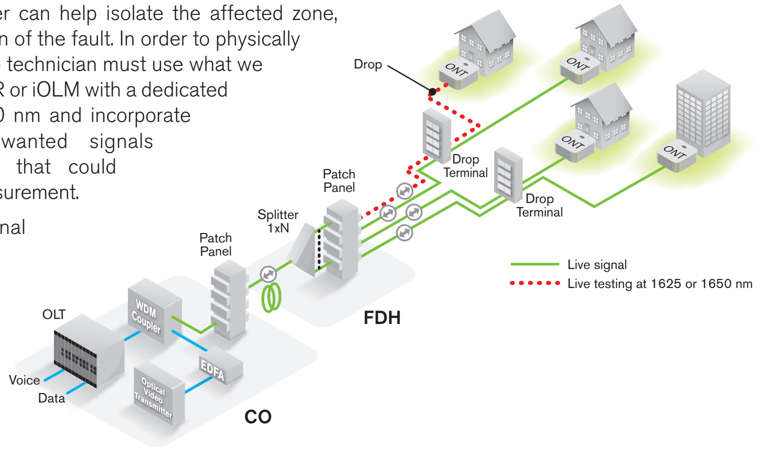


Figure 5-3. Live testing with OTDR or iOLM

A PON-optimized OTDR or iOLM does not interfere with the CO's transmitter lasers because the 1650 nm wavelength complies with ITU-T L.41 Recommendation: *Maintenance wavelength on fibers carrying signals*. This ITU-T recommendation suggests a 100 nm difference between the OTDR or iOLM wavelength used for in-service maintenance and the closest transmission wavelength, in this case, 1550 nm. The addition of a broadband filter, acting as a 1625 or 1650 nm testing port at the CO's WDM coupler, may also be beneficial. As a result, the quality of service provided to other subscribers serviced by the same 1xN splitter is not affected. Armed with this technology, the technician can connect the OTDR or iOLM's 1625 or 1650 nm port to the ONT and send the signal toward the CO (Figure 5-3). If a 1625 or 1650 nm testing port is added to the CO, it is also possible to perform tests on F1 section from the CO down to the ONT, but a 1625 or 1650 nm filter may be needed at each ONT.

Another test scenario that can be considered is the use of an inline power meter added to a PON-optimized OTDR or iOLM. This type of power meter uses the same optical path (see Figure 5-4) as the OTDR or iOLM. The advantage of such a power meter is that the test port does not have to be disconnected or switched to perform a power measurement or an OTDR or iOLM test. Another particularity of this type of power meter is that two signals/wavelengths that are travelling along the same fiber can be distinguished. This is really useful in FTTH applications, as there are often two downstream wavelengths (1490 and 1550 nm) travelling toward the ONT (premises). Just like a PON power meter, using this power meter, the user will be able to isolate each signal and measure their respective power levels.

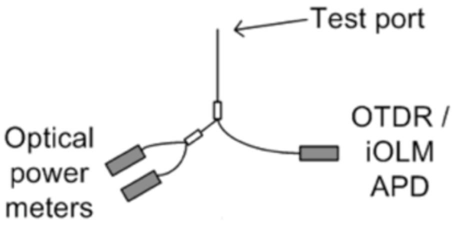


Figure 5-4. Inline power meter

Such capabilities in the same port as the OTDR or iOLM filtered port provide a powerful troubleshooting advantage in that they help to quickly locate a fault and fix the issue. All the technician has to do is to connect the fiber to be tested to the port with the inline power meter and check the power level of the signals.

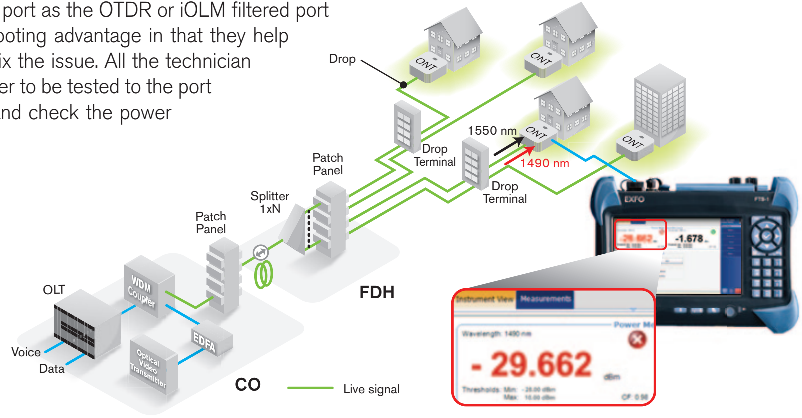


Figure 5-5. Testing with an inline power meter

If there is a problem with one of the signals (as shown in Figure 5-5), the technician can simply launch the OTDR or iOLM application, select the live testing mode and locate the issue (Figure 5-6).

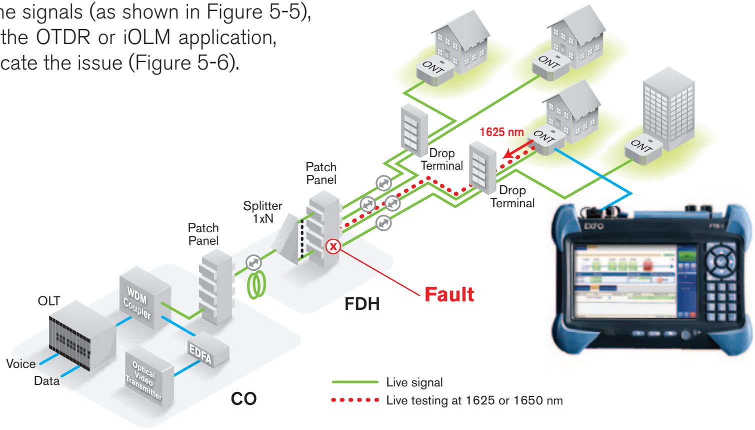


Figure 5-6. Live testing with an iOLM

6 Test Documentation

6. Test Documentation

Although network test documentation is clearly helpful when planning and expanding network capacity (bandwidth, routing), most people think about the need for documentation when a problem occurs. When the network is down, productivity is normally lost and customers may not be supported, which could lead to high revenue loss. If network documentation is available, when there is a problem that needs to be resolved, the team in charge of resolving the issue can quickly obtain an understanding of the network and minimize the mean-time-to-repair, resulting in lower costs. Proper documentation not only helps when a problem occurs, but it also assists in internal and external transfer of knowledge.

Another aspect to consider is that many networks are built by contractors or subcontractors, who usually have to provide test reports in order to get paid. It therefore becomes mandatory for them to save the test results of the work performed in the field.

Sometimes, measurements gathered in the field will not require extra post-processing but, in most cases, extra processing will be needed to perform proper analysis, establish accurate diagnoses and ultimately document (test report or birth certificate) the network appropriately, as per customer requirements or as per the network owner's standard.

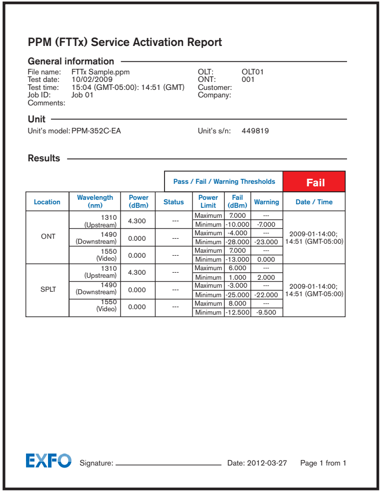
The three logical steps (Table 16) in data post-processing generally consist of editing, analyzing and documenting the test results.

Table 16. Data Post-Processing Actions

<table>
<tr><th>1- Edit</th><th>2- Analyze</th><th>3- Document</th></tr>
<tr><td>Adjust cable and fiber parameters
(ex: Job Information)</td><td>Perform OTDR bidirectional batch analysis</td><td>Report customization</td></tr>
<tr><td>Add/remove OTDR-iOLM events</td><td>Detect duplicated measurements</td><td>Various report types</td></tr>
<tr><td>Adjust detection thresholds</td><td rowspan="3">Easily identify the results failing network requirements</td><td rowspan="3">Combined reports such as:
> Fiber characterization
> iOLM with connector inspection results
> OTDR with connector inspection results</td></tr>
<tr><td>Perform manual measurements on OTDR files</td></tr>
<tr><td>Set pass/fail thresholds</td></tr>
</table>

Performing these three steps on hundreds of measurements can be a real challenge if your tools are not integrated (different software for different measurement types), with no batch-processing capabilities.

To help decrease the time spent on data processing, EXFO has developed FastReporter 2. By supporting various measurement types, batch capabilities and specialized reporting (see Figure 6-1 and 6-2), FastReporter 2 can cut processing time in half, compared to the time required when using other reporting tools.



PPM (FTTx) Service Activation Report

General information

File name: FTTx Sample.ppm
Test date: 10/02/2009
Test time: 15:04 (GMT-05:00): 14:51 (GMT)
Job ID: Job 01
Comments:

OLT: OLT01
ONT: 001
Customer:
Company:

Unit

Unit's model: PPM-352C-EA
Unit's s/n: 449819

Results

Pass / Fail / Warning Thresholds — **Fail**

Location	Wavelength (nm)	Power (dBm)	Status	Power Limit	Fail (dBm)	Warning	Date / Time
ONT	1310 (Upstream)	4.300	---	Maximum	7.000	---	2009-01-14:00; 14:51 (GMT-05:00)
				Minimum	-10.000	-7.000	
	1490 (Downstream)	0.000	---	Maximum	-4.000	---	
				Minimum	-28.000	-23.000	
	1550 (Video)	0.000	---	Maximum	7.000	---	
				Minimum	-13.000	0.000	
SPLT	1310 (Upstream)	4.300	---	Maximum	6.000	---	2009-01-14:00; 14:51 (GMT-05:00)
				Minimum	1.000	2.000	
	1490 (Downstream)	0.000	---	Maximum	-3.000	---	
				Minimum	-25.000	-22.000	
	1550 (Video)	0.000	---	Maximum	8.000	---	
				Minimum	-12.500	-9.500	

EXFO Signature: ______________ Date: 2012-03-27 Page 1 from 1

Figure 6-1. PPM FTTH activation report

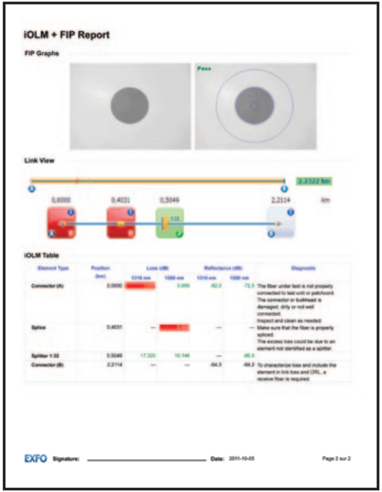


Figure 6-2. iOLM and FIP report

7 Abbreviations and Acronyms

7. Abbreviations and Acronyms

ADS	Additional digital service
ADSL	Asymmetric digital subscriber line (copper based)
APC	Angled physical contact/angled polished connector
APD	Avalanche photo diode (detector)
ATM	Asynchronous transfer mode protocol
BER	Bit error rate (ITU-T uses bit error ratio)
BLEC	Building local exchange carrier
BPON	Broadband passive optical network
CD	Chromatic dispersion
CDMA	Collision detected multiple access
CLEC	Competitive local exchange carrier
CO	Central office
CVD	Chemical vapor deposition
CWDM	Coarse wavelength-division multiplexing
DBS	Direct broadcast service
DFB	Distributed-feedback (laser)
DSL	Digital subscriber line (copper based)
DSLAM	Digital subscriber line access multiplexer
DUT	Device under test
DWDM	Dense wavelength-division multiplexing
EDFA	Erbium-doped fiber amplifier
EFM	Ethernet in the first mile
EFMA	Ethernet-in-the-first-mile alliance
EPON	Ethernet-ready passive optical network
FBT	Fused biconic taper (fiber coupler/splitter)
FCC	Federal communications commission (US)
FDH	Fiber Distribution Hub
FDT	Fiber Distribution Terminal
FEC	Forward Error Correction
FC	Fiber Collector
FO	Fiber-optic
FP	Fabry-Perot (laser)
FSAN	Full-service access network
FTTB	Fiber-to-the-building
FTTC	Fiber-to-the-curb
FTTCab	Fiber-to-the-cabinet
FTTH	Fiber-to-the-home
FTTN	Fiber-to-the-node
FTTP	Fiber-to-the-premises
FTTx	Fiber-to-the-x, where x = (H)ome, (C)urb, (B)uilding, (N)ode, (P)remises, etc.
FUT	Fiber under test

GEM	GPON encapsulation mode
GPON	Gigabit-capable passive optical network
HDD	Horizontal direct drilling
HDSL	High-bit-rate digital subscriber line (copper based)
HDTV	High-definition television
HFC	Hybrid fiber coaxial transmissions
IEC	International electrotechnical commission
IEEE	Institute of electrical and electronic engineers
ILEC	Incumbent local exchange carrier
IP	Internet protocol
IPTV	Internet protocol television
ITU	International telecommunication union
ITU-T	International telecommunication union—telecommunications standardization sector wavelength
LFD	Live fiber detector
MAN	Metropolitan area network
MDU	Multidwelling Unit
MFD	Mode-field diameter
MLM	Multilongitudinal mode (Laser)
MM	Multimode
MMF	Multimode fiber
MWM	Multiwavelength meter
NF	Noise figure (noise from an optical amplifier in dB)
OC	Optical carrier (transport rate)
ODN	Optical distribution network
ODU	Optical distribution unit
OLT	Optical line terminal/termination
OLTS	Optical loss test set
ONT	Optical network terminal/termination
ONU	Optical network unit (non-transmitting ONT)
OPM	Optical power meter
ORL	Optical return loss
OSA	Optical spectrum analyzer
OSC	Optical service channel
OSNR	Optical signal-to-noise ratio
OSP	Outside plant
OTDR	Optical time-domain reflectometer
P2MP	Point-to-multipoint
P2P	Point-to-point
PBX	Private branch exchange
PC	Polished connector
PIN	Positive-insulator-negative (detector)

PLC	Planar lightwave (or lightguide) circuit
PMD	Polarization mode dispersion or physical medium dependent
PON	Passive optical network
POTS	Plain old telephone service
PSB	Pulse suppressor box
PSTN	Public switched telephone network
QoS	Quality of service
RBOC	Regional Bell operating company
Rec	ITU-T Recommendation
RLEC	Rural local exchange carrier
RT	Remote terminal
Rx	Receiver
SC	Supervisory channel or service channel
SDH	Synchronous digital hierarchy
SM	Singlemode
SMF	Singlemode fiber
SNR	Signal-to-noise ratio
SONET	Synchronous optical network
STM	Synchronous transfer mode (SDH transfer rate)
TDM	Time-division multiplexing
TDMA	Time-division multiple access
TIA	Telecommunications Industry Association
Tx	Transmitter
UPC	Ultra-polished connector
VDSL	Very-high-speed digital subscriber line (copper based)
VFL	Visual fault locator
VOD	Video-on-demand
VoIP	Voice over Internet protocol
WDM	Wavelength-division multiplexing
xDSL	Generic digital subscriber line (copper based)

8 Appendixes

APPENDIX A: Launch and Receive Fiber

Unlike a traditional OTDR, the iOLM requires only a short launch fiber (>50 m) to benefit from all the advantages of this referencing method, regardless of the link length and loss. A launch fiber longer than 200 m is not recommended when testing PON links. Because the output port of an OTDR may degrade its loss and ORL performances after multiple connections, the use of a launch cable is always recommended.

The first element of the tested link is tagged with the letter A in the link view. A launch cable allows you to properly characterize the first connector of the fiber link under test (A) and exclude the OTDR connector's wear from the link evaluation. A reasonable amount of degradation of the OTDR connector is acceptable when using an APC interface; the ORL remains low due to the angle polish, preventing poor near-end resolution. By using a launch fiber, the OTDR connector loss is excluded from the measurement. The iOLM evaluates the OTDR connector loss each time a measurement is performed to inform you about the condition of the connector. It is important to understand that excessive loss at this connector will eventually degrade the measurement capabilities of the instrument. In addition, using a launch cable will help protect your OTDR connector by limiting the number of connections performed directly on that connector. It is easier to repair or replace a launch cable than to replace the OTDR connector.

The last element of the tested link is tagged with the letter B in the link view. A receive fiber cable can be used at the end of the link opposite the test module in order to characterize the last connector of the link (B) and increase the precision of the total insertion loss result by comparing the differential level of two known fibers (to avoid errors due to different backscatter coefficients of the fiber used in the link). If no receive cable is used, the iOLM application will be able to measure the position and ORL of this connector in unmatched condition, but not its loss. No pass/fail status will be displayed for that connector. The required length of the receive fiber will depend on the loss of the link under test. A higher loss requires a longer pulse to reach the receive fiber level. Unlike the launch fiber, the receive fiber has the same limitations than that of a traditional OTDR. Test of a 1 km fiber span with less than 2 dB of loss will require only 100 m of receive fiber. Testing of a 23 dB PON link will require a receive fiber of 500 m to 2 km, depending on the fiber length after each splitter.

iOLM Tool

Figure 8-1 shows the possible test points where the iOLM can be connected in order to conduct the characterization.

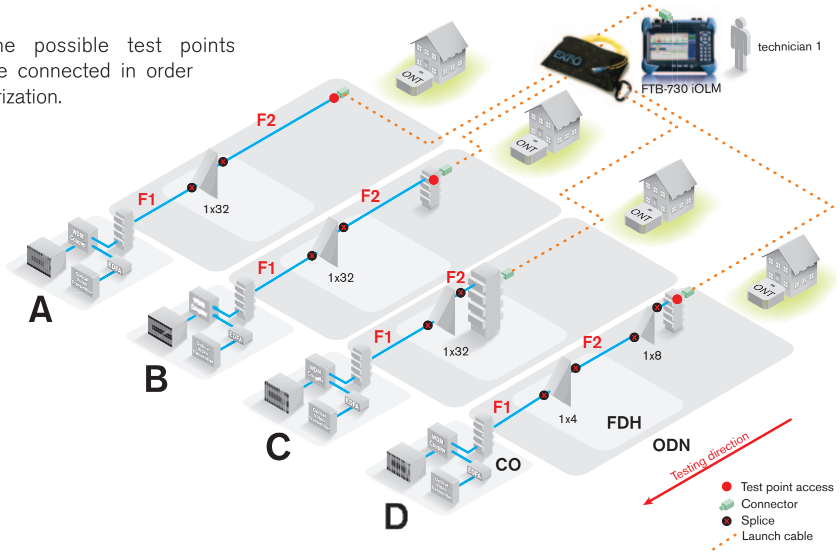


Figure 8-1. Spliced ODN characterization using an iOLM

The iOLM application allows you to manually set the lengths of both your launch and receive cables. In addition, it is possible to automatically measure the launch or receive cables. When carrying out the calibration, the application will perform a fast measurement and evaluate the length of the fiber. For this reason, only the cable under test must be connected to the module when performing a calibration.

If the link elements are found on the fiber under calibration or if the OTDR connector is defective, the calibration will fail and a warning is displayed to explain the reason for the failure. A short patchcord (<5 m) is accepted between the instrument and the fiber under calibration and will be included in the calibrated length. If the calibration is successful, the launch or receive fiber length will be updated in the Test Parameters tab.

When performing a measurement, the iOLM will try to match the defined launch and receive fibers with elements found on the link to set the A and B connector positions. If no events are found at specified distances because of a “perfect” connection between the link and the launch or receive cable, the iOLM will insert an element at a specified position (with zero loss and ORL).

APPENDIX B: Next-Generation Optical Access Networks (OAN)

Bandwidth demand continues to increase at an astonishing pace as consumers are constantly adopting new applications and services. To accommodate the ongoing surge in traffic, service providers are looking into ways to make their network faster—be it long-haul, metro, 40 Gbit/s or access.

One of the key solutions that the telecommunications industry adopted to meet rising bandwidth demand was to bring the fiber as close as possible to the end users. Standardization bodies, such as the International Telecommunication Union (ITU) and the Institiute of Electrical and Electronic Engineers (IEEE), defined standards to normalize the deployment of these technologies we now know as FTTx (or fiber-to-the-x; where x can refer to home, curb, cabinet, node, etc.). Currently, FTTx technologies can deliver up to 100 Mbit/s to the end user, but will this be sufficient for tomorrow's applications? In order to stay ahead of market demands for high bandwidth, service providers are now actively looking into next-generation access technologies.

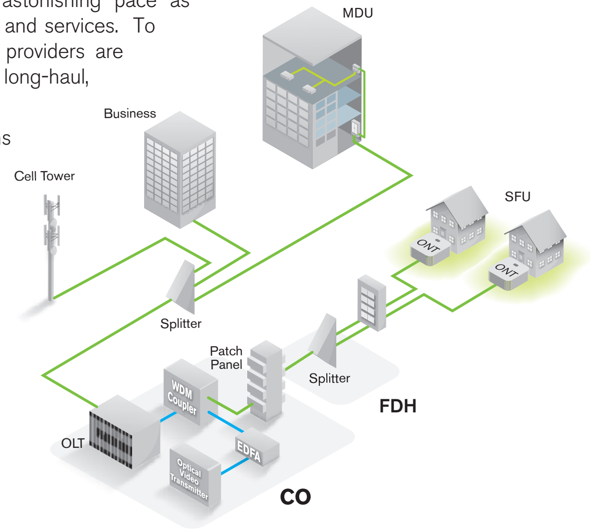


Figure 8-2. Potential customers for next-generation OANs

Key drivers and applications for deploying next-generation optical access networks (OANs) can be easily found anywhere in today's society. The table below lists a few examples in both the business and residential markets.

Table 17. Applications Driving the Deployment of Next-Generation OANs

Segment	Applications/Drivers
Mobile backhaul/remote access network (RAN)	Mobile Internet users (smartphones, tablets)
Business	Cloud computing, video-conferencing
Multidwelling units	High concentration of users in a single location; i.e., increased subscriber split per PON
Single-family units	VoIP, VoD, HDTV, 3DTV, online gaming, P2P, file transfers

Promising Technologies

Among all the technologies that could possibly allow service providers to increase the bandwidth per user, two currently stand out to become the technology of choice for next-generation OANs: NG-PON1 and NG-PON2.

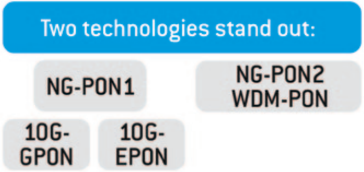


Figure 8-3. Next-generation OAN technologies

Besides the fact that these technologies can offer higher bandwidth per user, one of the main reasons that these options are ahead of the others is that they are based on passive optical networks (PONs), so service providers who have already deployed FTTx will be able to re-use the same optical distribution network (ODN) and therefore protect their current investment.

The table below describes a few of the main characteristics defining each technology and Figure 3 shows an example of a NG-PON1 overlay within an existing PON.

Table 18. Technical Description and Requirements for NG-PON1 and NG-PON2

Type		10G-GPON		10G-EPON		WDM-PON	
Standard	Units	G.987		802.3av™		None at the moment	
Protocol		Ethernet, TDM, TDMA		Ethernet		TBC	
Services		- Voice/data - Triple-play - File exchange/remote learning/IPTV/ VOD		- Voice/data - Triple-play - File exchange/remote learning/IPTV/ VOD		- Voice/data - Triple-play - File exchange/remote learning/IPTV/ VOD	
Maximum physical distance (OLT to ONT)	km	Up to 20		Up to 20		TBC	
Split ratio		up to 1x64		up to 1x32		TBC	
Nominal bit rate *		Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
Asymmetric	Gbit/s	10	2,5	10	1,25	Virtually no limits E.g., 1 Gbit/s per user	Virtually no limits E.g., 1 Gbit/s per user
Symmetric	Gbit/s	10	10	10	10		
Operating wavelength band	nm	1577 –2, +3	1270 ± 10	1577 –2, +3	1270 ± 10	TBC E.g., DWDM in C-band	
ORL_{MAX}	dB	≥32		≥20		TBC	

One interesting characteristic of 10G-GPON and 10G-EPON is that the ITU and IEEE committees have defined them within a “coexistence mindset”, allowing for concurrent operation with current PON technology.

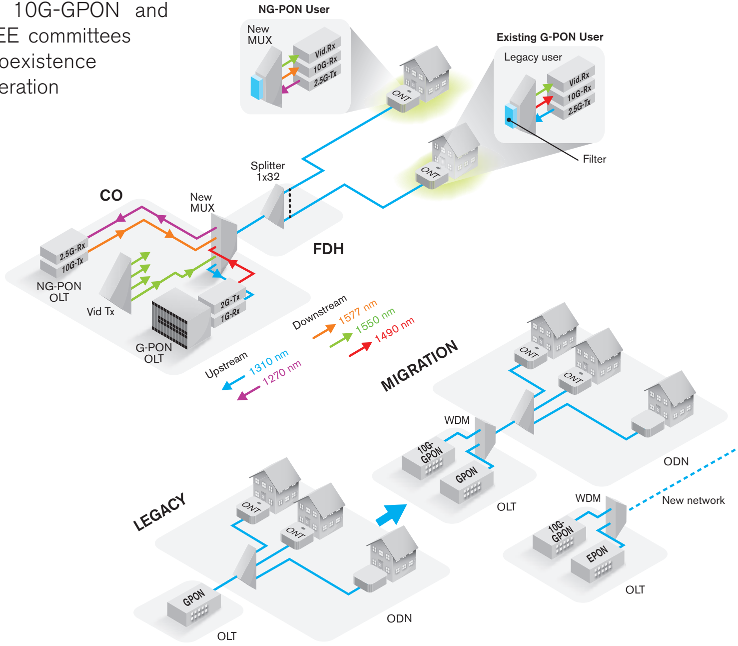


Figure 8-4. Technology coexistence

New Testing Challenges

As discussed in Chapter 3, FTTx deployment can generally be divided into three main phases: construction, activation and maintenance. Each of these phases present key testing challenges and there are currently ways to overcome today's issues. With the advent of next-generation OANs, new testing concerns will arise and will therefore have to be considered at each deployment stage.

Just like today's deployments, the challenges will be different depending on whether the new technology is deployed on an existing ODN (brownfield) or new ODN (greenfield).

In brownfield deployments where next-generation PON technology will coexist with current technology, customer will already be connected to the network, so special care will have to be taken to minimize the effects on subscriber services. As shown in Figure 3a, this type of deployment (brownfield) will require the installation of new optical components (such as WDM filters) to combine the two technologies, and adding these components could temporarily interrupt all services. Furthermore, adding new optical devices in the ODN will add extra loss to the overall loss budget, which could affect existing customers if the previous budget was not sufficient enough to compensate for extra loss in the network. In addition to the filters, next-generation ONTs will also have to be deployed, and power measurements should be taken to ensure that each of these ONTs will receive enough power to respect the requirements set by the different standards (see table above).

For new deployments (greenfield), the impact on existing customers will not be an issue and testing the ODN infrastructure during the construction stage will be very similar to what is being done for current PON networks. However, in order to conduct proper testing during the activation and maintenance phases, new test instruments will be required, as current tools must be adapted to new requirements. For example, in order to measure the new upstream signals at 1270 nm ± 10, the PON power meter will have to be able to:

- Detect faster burst signals – In next-generation PON systems, the burst duration will be shorter in order to support the upstream bit rate of 2.5 Gbit/s (asymmetric) or 10 Gbit/s (symmetric).
- Detect and differentiate signals – For example, the 1490 nm signal from both legacy and next-generation systems will need to be detected. As mentioned earlier, in some deployments, both PON generations could coexist, which means that at the premises, both 1490 nm and 1577 nm signals could be present. Therefore, the PON power meter will have to filter out each wavelength in order to measure their respective power.

As you can see, in some cases, next-generation PON networks will bring new testing challenges that will have to be considered. Table 3 below summarizes the particularities that each deployment type will bring.

Table 19. Testing Challenges—Next Generation PON ODN

		Testing Characteristics	
Deployment Phases	**ODN**	**10G-GPON/10G-EPON**	**Tools**
Construction	Greenfield (xG-PON only)	> Similar fiber characterization as for standard GPON	> OTDR - iOLM - OLTS - FIP - OPM -OLS
	Overlay (live)	> In-service fiber characterization techniques	> OTDR - iOLM with filtered port - current PPM
Activation	Greenfield (xG-PON only)	> New upstream and downstream wavelengths > Increased burst period	> 10G adapted PPM - Filtered OTDR or iOLM - FIP
	Overlay (live)	> New upstream and downstream wavelengths > Shorter burst period > Solution adapted for legacy and NG-PON	> 10G adapted PPM - current PPM - Filtered OTDR or iOLM - FIP
Troubleshooting	Greenfield (xG-PON only)	> New upstream and downstream wavelengths > Shorter burst period > Live signal	> 10G adapted PPM - Filtered OTDR or iOLM - FIP
	Overlay (live)	> New upstream and downstream wavelengths > Shorter burst period > Live signal > Coexistence	> 10G adapted PPM - current PPM - Filtered OTDR or iOLM - FIP

APPENDIX C: EXFO Connect

EXFO Connect is a comprehensive cloud-based managed service that is specially designed to tackle the major operational components essential to managing network testing. The software services delivered by EXFO Connect include a powerful reporting engine, 24/7 global access through a web-based interface, secure communication links, as well as a fully managed infrastructure for security and backups.

Figure 8-5. EXFO Connect–Keeping Your Test Fleet Connected

A cornerstone of EXFO Connect is the Test Data Manager (TDM) application. This application centralizes the test results generated on EXFO test instruments, thereby functioning as a repository for all test results, and provides access to view any test result as well as create custom reports based on the stored test data.

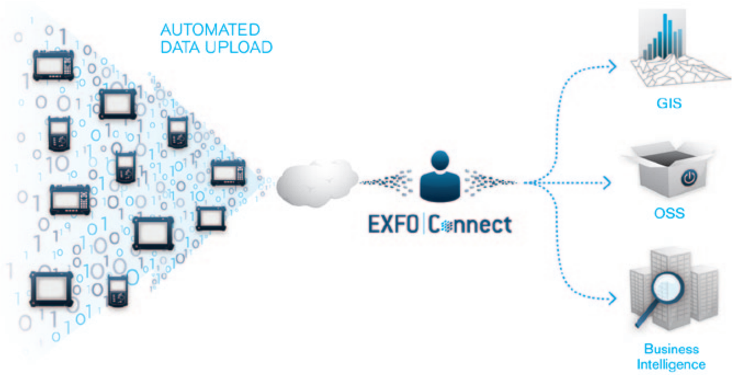


Figure 8-6. EXFO Connect–Test Data Manager Application

Another core application of EXFO Connect is the Test Equipment Manager (TEM). This application centralizes the management of all EXFO test instruments; it functions as a repository for software loads, licenses and platform profiles to ensure that configurations are up-to-date and consistent throughout the entire equipment pool. With a periodic connection to the EXFO Connect hosted server, a fully automated process updates all the relevant platform inventory information, downloads new software, options or test module configurations—without requiring any technician input. Simply put, from a technician's perspective, it's just plug-and-go in one simple action: connect your platform to the cloud and let EXFO Connect take over. With EXFO Connect, control is now centralized in the hands of test managers. Using a concept called platform profiles, they can create customized configurations that will enable them to standardize their teams' instruments, ensuring that all EXFO test equipment is up-to-date according to their specifications. Additionally, EXFO Connect provides managers with a global view of their entire test fleet, giving them the detailed status of their gear.

Figure 8-7. EXFO Connect–Test Equipment Manager Application

Reporting is what makes all the collected data usable in the real world; by correlating the data from the field into a single source of information. EXFO Connect enables the tailoring of this data to the different members of the organization. Having all this data available at your fingertips allows for better decision-making.

Figure 8-8. EXFO Connect–Reporting Application

APPENDIX D: Related Links

FTB-730-iOLM Intelligent Optical Link Mapper Video
www.EXFO.com/OTDR-vs-iOLM

iOLM Intelligent Optical Link Mapper Spec Sheet
www.EXFO.com/iOLM-spec-sheet

FOT-930 MaxTester Multifunction Loss Tester Spec Sheet
www.EXFO.com/FOT-930-spec-sheet

ConnectorMax Video
www.EXFO.com/ConnectorMax-video

Connector Inspection Guide
www.EXFO.com/Connector-Inspection-Guide

FTTH Solution Page
www.EXFO.com/FTTx

Notes

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