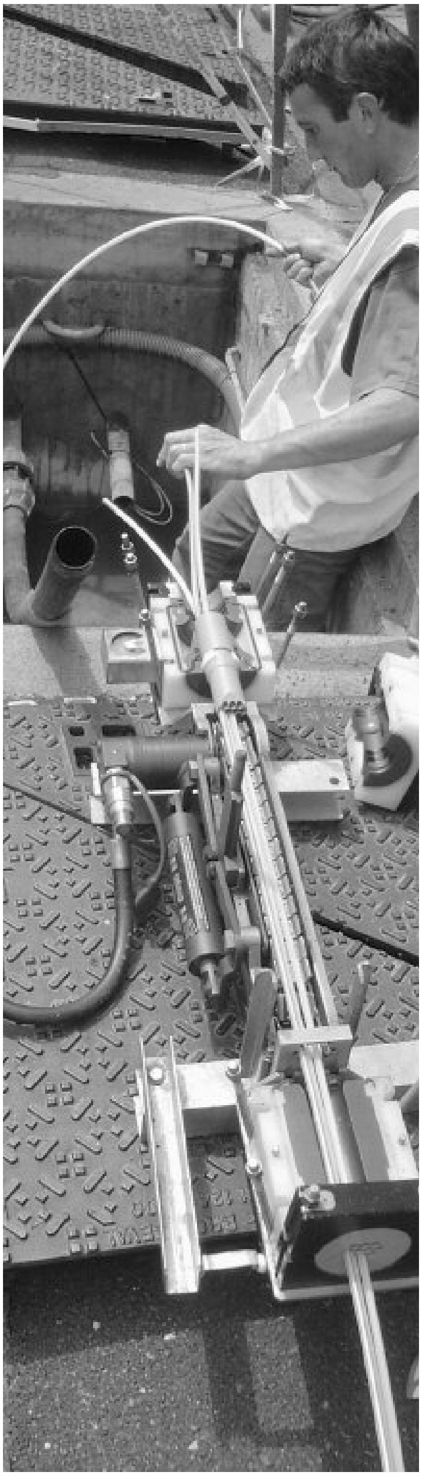
White Paper

FTTP Measurements

An in-depth review of Fiber-to-the-Premises technology and its associated optical testing



Introduction

Broadband, including high-speed internet, always-on video, always-on data, and voice connectivity, represents the next phase in the evolution of telecommunications requiring new network technologies. The most relevant example of new network technologies is Fiber-to-the-Premises (FTTP). In most cases, FTTP requires the implementation of Passive Optical Networks (PONs). By eliminating the need for regenerators and active equipment components of typical fiber networks, PONs significantly reduce the costs associated with both installation and deployment. Therefore, the deployment and usage of Passive Optical Networks (broadband) will significantly impact the global competitiveness of nations and businesses in the future.

With the enormous interest of consumer broadband technologies such as ADSL and cable modem, residential broadband deployment has grown steadily over the past few years. However, the most powerful physical media enabling unlimited bandwidth capacity is the singlemode fiber, making its use mandatory for broadband services. Therefore, Fiber- to-the-Premises (FTTP) technology has been developed and deployed in response to several residential access market drivers, including the following:

- The internet explosion.
- The increased competition in the market as well as the actions of federal and state regulators.
- The declining costs of optical equipment, making the cost of FTTP similar to alternative available options.
- The significant savings in maintenance costs associated with FTTP as compared to other technologies.
- A technology life cycle that dictates both a need to deploy the right technology at the right time and the need to future-proof existing networks. Fiber has a life expectancy of about 100 years compared to copper with a life expectancy of 20 to 30 years.

In order to make FTTP a viable solution, the cost of the optical network structure must be as low as possible. It must also make the use of active components such as regenerators unnecessary because they require power, adding to the complexity of the network and increasing maintenance issues. In most cases, a FTTP network is a Passive Optical Network (PON), consisting of only fiber and passive components such as splitters. Once splitters are installed, they do not require any further maintenance.

The purpose of this document is to describe FTTP technology as well as its requirements as far as physical layer testing is concerned.

Section 1: The Standards and Status of Passive Optical Networks

Although the concept of FTTP was invented by British Telecom in 1982, tremendous effort has been made in the past 10 years to standardize this technology. In the early 1990s, initial trials were conducted using FTTP, and JDSU actively collaborated with key providers including France Telecom, Deutche Telecom (OPAL system), and British Telecom (OTIAN system) to develop testing procedures for FTTP. At that time, though, the components required for the ONTs and OLTs were too expensive for a large scale deployment. Therefore, the project was halted even though it showed great promise.

In parallel, a group of seven telecom providers called Full Services Access Networks (FSAN) met in 1995 to develop common system specifications to accelerate the deployment of optical access systems. They were responsible for developing the specifications that are now known as the ITU-T G.983 recommendations.

While BellSouth (US) had an FTTP-like offering, NTT (Japan) was the first company, in 1999, to provide a full-scale FTTP deployment in Japan. Presently, Verizon and SBC (US) are heavily investing research and development dollars to provide FTTP to their customers as well. In Europe, providers, who currently provide point-to-point networks close to the customer premises, are still in the evaluation phase before embarking on a large-scale deployment using a point-to-multipoint network architecture.

There are several different types of Passive Optical Networks (PONs) including Broadband Passive Optical Network (B-PON) using mainly ATM, Gigabit Passive Optical Network (G-PON), and Ethernet Passive Optical Network (E-PON). While B-PON technology is the current offering, G-PON and E-PON are under investigation. The specifications and characteristics of each technology are listed in Table 1. The International Telecommunications Union (ITU) and the Institute of Electrical and Electronic Engineers (IEEE) are two organizations who are currently in the process of defining the standards for PONs.

	B-PON	G-PON	E-PON
Span	20 km	60 km max, 20 km differential	10 km today, 20 km planned
Maximum insertion loss		15/20/25 dB	15/20 dB
Maximum number of branches	32	64	16
Bit rate (Mbps)	Down: 155, 622, 1244 Up: 155, 622	Down: 1244, 2488 Up: 155, 622, 1244, 2488	Down: 1244 Up: 1244
Wavelengths	Down: 1480-1500 nm Video at 1550 nm Up: 1260-1360 nm	Down: 1480-1500 nm Video at 1550 nm Up: 1260-1360 nm	Down: 1490 nm Up: 1300 nm
Traffic mode	ATM	ATM, Ethernet, TDM	Ethernet
Architecture	Asymmetric or Symmetric	Asymmetric or Symmetric	Ethernet
Video overlay	Yes	Yes	No
Applicable standard/status	ITU-T G.983.x/complete	ITU-T G.984.x/will be completed in 2004	IEEE 802.11/will be completed in 2004
Chipset support	Available	First prototypes	First prototypes
Upstream burst time		Guard: 25.6 ns Preamble: 35.2 ns (typical) Delimiter: 16.9 ns	Laser turn on/off: 512 ns (max) AGC setting and CDR look: 400 ns

Table 1: The specifications and characteristics of B-PON, G-PON, and E-PON technologies

The major recommendations and standards for PON technology are listed in Table 2.

As PON technology is in its infancy, new standards will most likely be defined in the coming years. In addition, other technologies are being reconstructed using PON technology and architecture. They include:

– The use of Video over IP (IP Video) at the same wavelength for data and voice, making the requirement for video at 1550 nm no longer relevant.

– The use of WDM technology on a PON network. In the case of Wavelength Division Multiple Access (WDMA) technology, each customer will be accessed using their own wavelength. This requires the addition of a WDM element at the splitter location.

Standards	Description	Content
ITU-T G.982	Optical access networks must support services up to the ISDN primary rate or equivalent bit rate.	
ITU-T G.983.1	A broadband optical access system based on Passive Optical Networks (PONs).	Specifies an optical access system with symmetrical line rates of 155.520 and 622.080 Mbps and asymmetrical line rates of 155.520 Mbps upstream and 622.080 Mbps downstream (B-PON).
ITU-T G.983.2	An ONT management and control interface specification for ATM PON.	
ITU-T G.983.3	A broadband optical access system with increased service capability by wavelength allocation.	Adds an additional wavelength band to G.983.1 to enable the distribution of unidirectional or bidirectional video broadcast or data services.
ITU-T G.983.4	A broadband optical access system with increased service capability using dynamic bandwidth assignment.	Specifies enhancements to G.983.1 using dynamic bandwidth assignment.
ITU-T G.984.1 (in progress)	General characteristics of Gigabit-capable Passive Optical Networks (G-PON).	Specifies an optical access system with up to 2.488 Gbps symmetrical line rates.
IEEE 802.3ah (in progress)	Ethernet in the First Mile (EFM)	E-PON

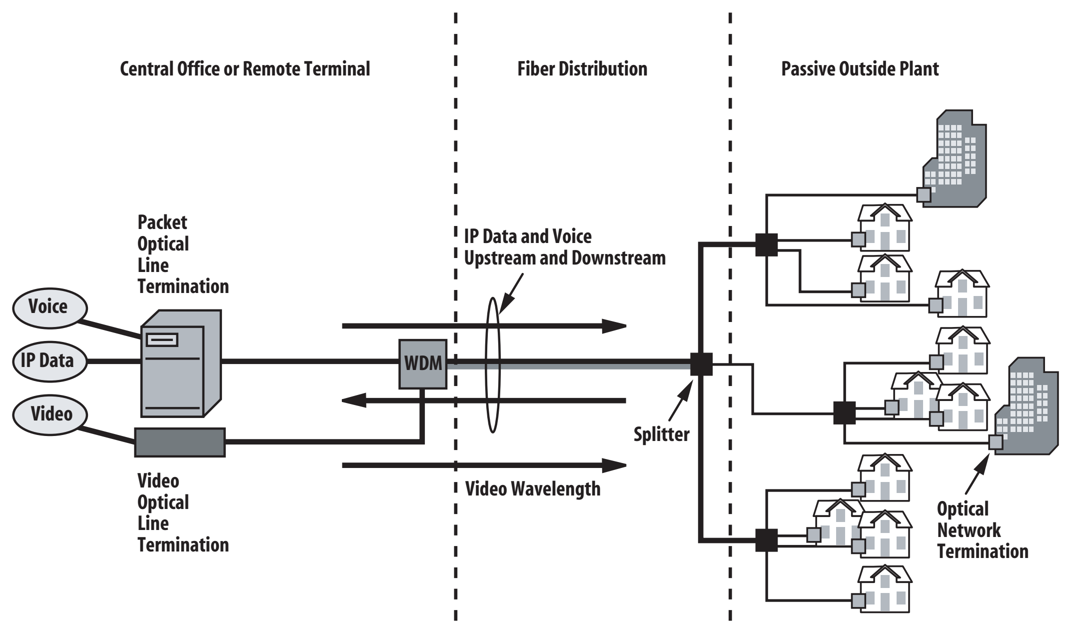
Table 2: Major recommendations and standards for PON technology

Section 2: FTTP Technology

PON Signals and Network Structure

The following section describes a typical passive optical network (PON). A PON can also be called an Optical Access Network (OAN).

In a standard FTTP system (Figure 1), as defined by ITU-T G.983.1, the Central Office (CO) is interfaced to the public switched telephone network (PSTN) using DS-X/OC-Y signals and is connected to ATM or Ethernet interfaces. Data and voice signals use the 1490 nm wavelength for downstream signals and the 1310 nm wavelength for upstream signals. Video services enter the system from a cable television headend or from a satellite feed. Video signals currently use the 1550 nm wavelength (downstream signals only).



- Passive outside plant – signal is passively split
- Coarse WDM supports three wavelengths – 1490/1310/1550 nm
- Two wavelengths for IP data and voice – separate 1490 nm downstream and 1310 nm upstream wavelengths
- Optional 1550 nm third wavelength – one way broadcast for analog and digital RF video

Figure 1: A standard FTTP system

In a typical FTTP network (Figure 2), the signals are combined into a single fiber using WDM techniques at the CO with an optical line terminal (OLT). At the CO, a fiber distribution frame (FDF) integrates a number of OLTs together with splicing trays and connectors, which, in turn, connect the OLTs to the fiber network. Because the CO may use old optical networks, the type of connectors at the OLTs is most often Ultra Polished Connectors (UPC).

Because customers may be located far apart along the feeder, there may be splice cases located in aerial or underground environments. In this case, one cable may be divided into a number of fibers going to different directions. A feeder distance is typically 30,000 ft (10 km).

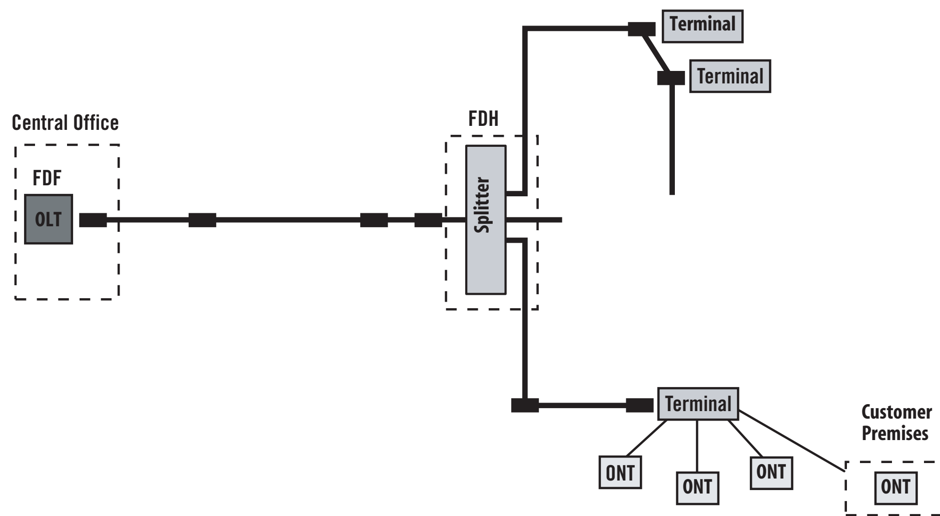


Figure 2: A typical FTTP network

The signals are then transmitted along the complete feeder to fiber distribution hubs (FDH), where the signal distribution occurs through the use of passive optical splitters. There is a maximum of 32 branches per splitter and usually a maximum of 10 splitters per FDH. Therefore, the FDH houses multiple splitters as well as splicing trays and connectors. No power is required at this location because all of the components are passive components. This hub is also called the Primary Flexibility Point (PFP) or the Fiber Cross Connect (FCC). If there are different splitters along the cable, then the other splitters are located at a Fiber Distribution Panel (FDP).

After the FDH in the network, there is a distribution cable. One fiber is dedicated to each customer. Once a customer has been designated, the splitter is connected to the fiber of this specific customer. Before a customer is designated, the fibers coming from the distribution cable and from the splitters are left open. They are positioned in a “parking lot” and are not connected together. Parking lot is an industry term used to define a staging or waiting area for connectors. In order to satisfy the constraints of the ORL, the type of connectors used here is Angled Polished Connectors (APC).

The cable is then distributed along to the customer locations. Access terminals close to the customer’s premises enable some fibers of the cable (usually 4 to 12) to branch out of the distribution cable and be terminated with the use of a splice tray. The type of connectors used here is APC. Most of the time, the other fibers go through the splice tray using slack loops. A distribution distance is typically of 20,000 ft (6 km).

From the access terminals, a drop cable of a maximum of a several hundred feet (10-300 m) spans to the customer premises where the Optical Network Terminal (ONT) is located. The type of connectors used here is APC.

At the ONT, the optical signal is converted into an electrical signal using an optical-electrical converter (OEC). This converter then splits the signal into the services required by the end user. The various interfaces include RJ-11 twisted pair jacks for Plain Old Telephone Service (POTS), Category 5/6 RJ-45 10/100/1000 Base-T Ethernet jacks for high-speed data (IP interface), and 75 ohm coaxial ports for CATV and Digital Broadcast Services (DBS). The 75 ohm coaxial port is connected to the set top box, which is connected to the TV monitor.

FTTP Optical Structure

While providing fiber directly to the home (FTTH) is a very attractive offering for customers, it is not always the most cost-effective solution for providers. Therefore, for cost-saving alternatives, providers will try to utilize their existing plants to deploy different types of fiber architectures. Fiber-to-the-Premises (FTTP) is a summary of several different offerings. The various types of FTTP fiber architecture are shown in Figure 3.

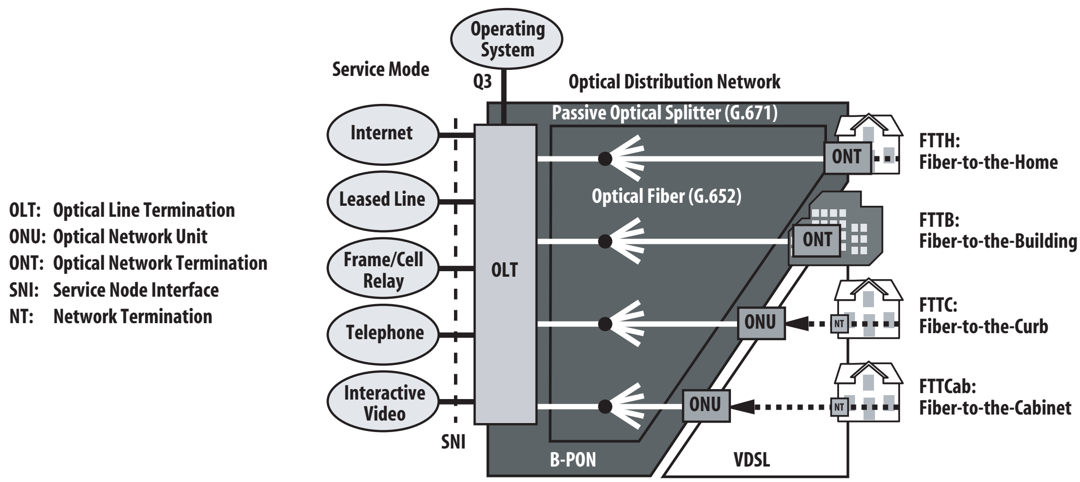


Figure 3: The various types of FTTP fiber architecture

For new homes and new residential areas where there is no network available yet, providers will provide complete Fiber-to-the- Home (FTTH) technology. These new areas are termed “greenfield” applications.

For “brownfield” or overlaid/overbuilt applications, many providers will end the fiber before the customer premises in order to continue their attempt to leverage their existing network infrastructure. Stopping just short of the customer premises allows providers to bypass the cost of pulling fiber under driveways. Therefore, the following technologies have been defined:

(1) Fiber-to-the-Cabinet (FTTCab) - The fiber goes to a street-side cabinet or digital loop carrier (DLC) and uses ADSL2 technology to access customers. Typical distance to the customer premises is up to 12,000 feet (4 km).

(2) Fiber-to-the-Node/Neighborhood (FTTN) - The fiber goes to a large street-side cabinet or optical network unit (ONU) and uses ADSL2 or ADSL2+ technology to access customers. FTTN typically serves about 200 residential or small business customers with a radius of 3,000 to 8,000 feet (1 to 2.5 km).

(3) Fiber-to-the-Curb (FTTC) - The fiber goes to an outdoor cabinet beside homes or office buildings approximately 1,000 to 2,000 feet (300 to 600 m) from the customer premises. FTTC may use VDSL technology to access customers.

(4) Fiber-to-the-Building/Basement/Business (FTTB) - The fiber goes to a building. FTTB is the same as FTTH except that it serves multiple customers. It can also serve multi-dwelling units as opposed to single-family units for FTTH.

Figure 4 shows the maximum downstream speed as a function of loop length for ADSL2, ADSL2+, and VDSL technologies.

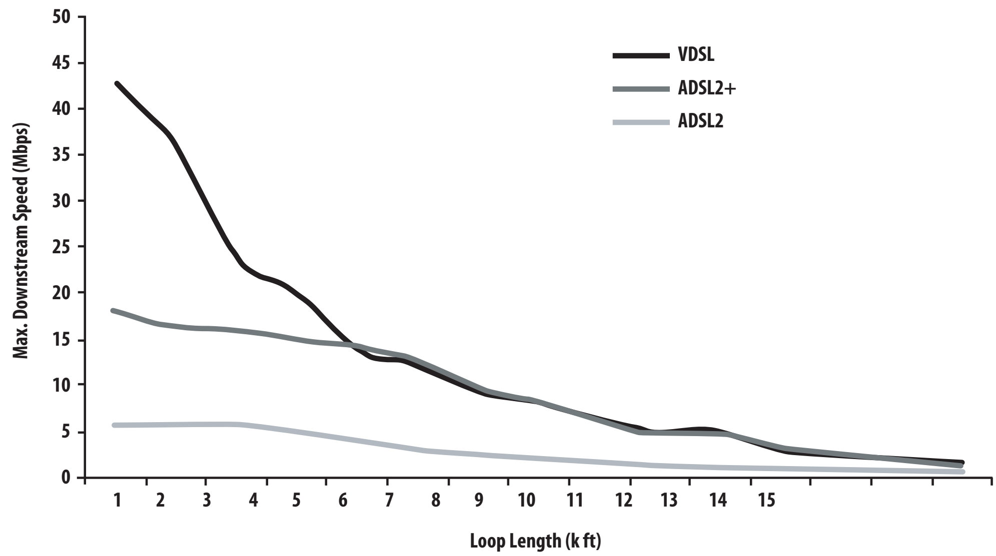


Figure 4: Maximum downstream speed as a function of loop length

For large residential areas, as is the case for the first installations of FTTP in the United States, the optical distribution network will use only 1:32 splitters. For smaller residential areas, the splitters can be spread out in order to be closer to other smaller areas using a single FTTP. There may be a 1:4 splitter at one FDH followed by four 1:8 splitters at other FDHs, or there may be a 1:8 splitter followed by eight 1:4 splitters.

An FTTP network can follow a star/tree (standard), ring, or bus topology, with the possible use of active components depending on the locations of the customers. However, an FTTP network can also be a simple point-to-point network (P2P). This is the case in Japan, for example, where there is a high-density population and where Ethernet switches or active components are used instead of splitters.

A Point-to-Multipoint Network

FTTP, as opposed to a standard P2P optical fiber network, is usually a point-to-multipoint network (P2MP). This means that although there is one fiber at the OLT, the other end of the distribution network can have up to 32 fibers under the same optical network. This is because FTTP uses a passive optical component called a splitter (Figure 5).

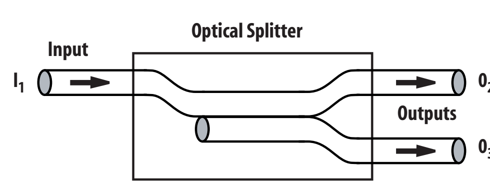


Figure 5: A schematic diagram of a splitter

The splitter allows for one port at one end and up to 32 ports at the other end. Therefore, a signal sent at one end can be possibly seen by 32 customers simultaneously. This application is ideal for video distribution. For data and voice, the use of Time Division Multiple Access (TDMA) enables customers to receive and send exactly what they want, without knowing what other customers are receiving and sending. In addition, other technologies are currently under investigation. The most attractive alternate technology is Wavelength Division Multiple Access (WDMA) in which a particular wavelength is dedicated to each customer.

The main benefit of a splitter is that it is a passive component, requiring no maintenance and no power activation. The main drawback of a splitter is its high rate of insertion loss. The insertion loss is defined as 10log(1/n), where n is the number of ports (2 to 32). Table 3 shows the expected insertion loss that corresponds to a specific number of ports.

Number of ports	Insertion loss
2	3 dB
4	6 dB
8	9 dB
16	12 dB
32	15 dB

Table 3: Expected insertion loss based on number of ports

This insertion loss factor has a high impact on the distances associated with FTTP, limiting them to a distance of approximately 20 km (30 dB maximum network insertion loss). This distance limit also takes into consideration that low-cost components are often used at the OLT and ONT.

Video Signal Evolution

Because the quality of a video image is key, video signals are very sensitive. Video signals are, therefore, amplified with the use of an optical amplifier. Power levels are in the range of +17 dBm to +23 dBm compared to +0 dBm to +5 dBm for data/voice signals. Analog signals are also very sensitive to reflections coming from the network, requiring the use of APC connectors with a low reflectance value of -60 dB.

Although the ITU-T G.983.1 standard defines the use of analog and digital video using the 1550 nm wavelength, one alternative solution is to offer Video over IP. This new technology is currently under evaluation and may simplify network topology. In this case, video signals will be integrated into the data structure transmitting at 1490 nm. This technology may be ready for large-scale deployment in 2005.

Section 3: Fiber Installation and Testing

Fiber installation and testing is usually performed by fiber construction crews.

Fiber Installation

For an FTTP application, the optical cable, containing the fibers, is laid using one of three methods.

(1) Direct burial installation - The optical cable is placed underground in direct contact with the earth and rocks that make up the surrounding soil. It is inserted into the ground by either creating a ditch or by simultaneously plowing a slot and inserting the cable. This is the most expensive method and is only used for high-density population areas.

(2) Duct installation - The optical cable is placed inside a pre-installed duct that runs between access points.

(3) Aerial installation - The optical cable is placed on poles or towers, allowing routing of the optical transmission path above ground. This method is usually used for network overlaid (brownfield) applications.

Once the cable is laid on the feeder, splices can be performed on the fiber, either to join two fibers or to divide one large cable into multiple smaller cables going to different locations. Splicing is performed on a splice enclosure that can be located either on an aerial vault or underground in a manhole. In order to test and qualify the splicing, an OTDR is used from the central office (Figure 6).

The cable, containing the fiber, is laid (aerial or underground). The fiber is spliced and tested with an OTDR. This procedure can be sub-contracted.

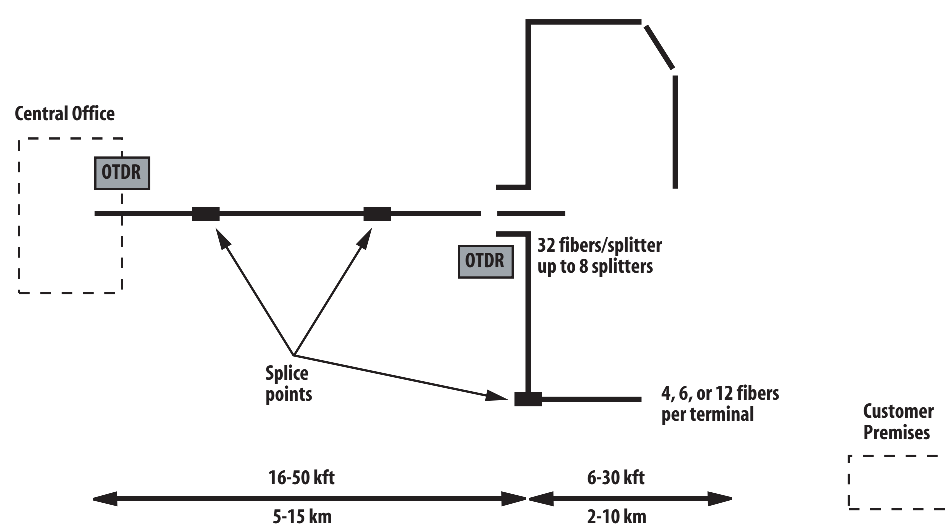


Figure 6: The fiber installation process

For a distribution network, splices are performed in the same way, and an OTDR is also used to qualify the splices.

Cables and fibers can be of any type, depending on the application and the density, including loose tube or ribbon fiber.

Fusion splicers have been specifically designed for FTTP applications. They are cost-effective instruments that are much lighter, battery-operated, accurate, and quite simple to use. However, fiber installation is still a complex and time-consuming process. It requires managing the fiber in the splice tray, cleaning and cleaving the fiber, splicing the fiber, and then closing the splice enclosure. Table 4 lists the tasks involved in fiber installation.

	Task	Objective	Test Tool(s)
1	Lay the cable, containing the fibers, for the feeder and distribution network.	Provide cable between the CO and the customers.	
2	Position splice enclosures and splice fibers for the feeder.	Perform continuity along the feeder.	Fusion splicer and an OTDR
3	Position splice enclosures and splice fibers for the distribution network, if necessary.	Perform continuity along the distribution network.	Fusion splicer and an OTDR

Table 4: Tasks involved in fiber installation

Frame Installation and Connection

The second step of the FTTP process is frame installation. There are several different types of frames installed along the FTTP network (Figure 7).

The first frame usually installed is the Fiber Distribution Hub (FDH). The FDH is where the splitters will be installed. This frame consists of an outside cabinet. At this location, all of the fibers coming from the CO are spliced to the input of the splitters. An OTDR measurement is then performed from the CO to verify the splice quality. All connectors coming from the output of the splitters are then put into the parking lot. Next, all of the fibers going to the distribution network are also spliced to a pigtail to be terminated. An OTDR measurement is then performed from the FDH to verify the splice quality. All of the distribution network connectors are also put into the parking lot.

The second frame usually installed is the terminal. The terminal is located close to the customer premises. This frame consists of a splice enclosure located either on an aerial vault or in a manhole. A set of fibers (usually 4, 6, 8, or 12) coming from the cable is extracted and spliced in order to be connected. An OTDR measurement is then performed from the FDH to verify the splice quality.

The Fiber Distribution Hub (FDH) is installed first. Then, the terminal and the Fiber Distribution Frames (FDFs) are installed. The splitter is spliced, and the CO and terminal are spliced and connected. Testing is performed with an OTDR during splicing. Connectors at the splitter location are left open.

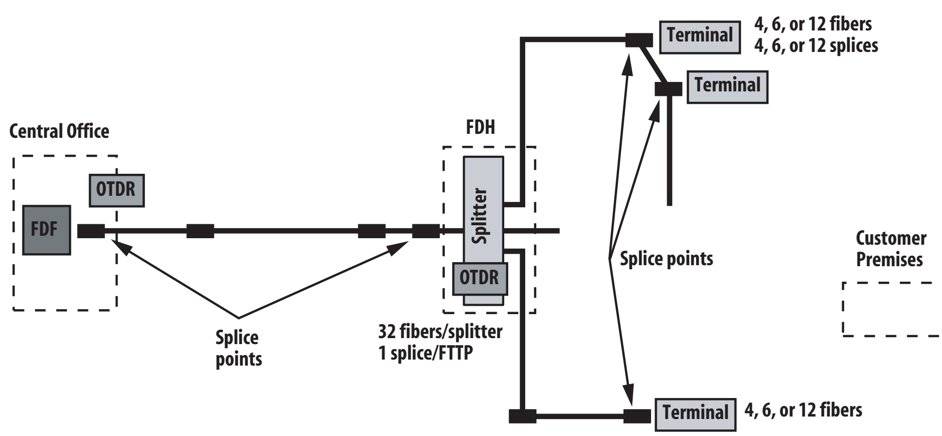


Figure 7: The frame installation and connection process

The third frame usually installed is the Fiber Distribution Frame (FDF). It is located at the CO. This frame consists of a cabinet. Like the other frames, the fiber is spliced to a pigtail in order to be connected to the patch panel. An OTDR measurement is then performed from the CO to verify the splice quality. For large networks, other FDFs may be located on the feeder in order to distribute the different cables. The same process applies to those frames.

At the end of the frame installation and connection process, the feeder and the distribution network are complete and are ready to provide the Optical Access Network (OAN). Table 5 lists the tasks involved in frame installation and connection.

	Task	Objective	Test Tool(s)
1	Install the FDH and the splitter at the hub. network.	To prepare for continuity between the feeder and the distribution	Fusion splicer and an OTDR
2	Install the terminals.	To prepare for continuity between the distribution network, the drop cable, and the ONT.	Fusion splicer and an OTDR
3	Install the FDF at the CO.	To prepare for continuity between the OLT and the feeder.	Fusion splicer and an OTDR

Table 5: Tasks involved in frame installation and connection

Acceptance Testing of the Optical Access Network

This process serves to perform an acceptance test of the complete OAN. Insertion loss and Optical Return Loss (ORL) measurements of the feeder and the distribution network are obtained. Most technicians use a bidirectional loss and ORL test set to perform this acceptance test. For simplification purposes, this test set is termed "tester" throughout the remainder of the document. Alternatively, an OTDR can also be used.

The technician can perform automatic insertion loss and ORL measurements with the tester. ORL testing is mandatory if analog video at 1550 nm is used due to the sensitivity of this technology to reflectance. In order to test the feeder, one tester is positioned at the CO location and is connected to the network by the technician. Then, the same technician leaves this tester connected and goes to the FDH. There, a second tester is connected to one connector of the splitter. An automatic measurement can then be obtained (Figure 8). The benefit of the tester is that it can both identify the fiber and also perform both bidirectional loss and ORL tests, increasing the accuracy of the measurements. Some technicians test all of the connectors going out of the splitter. Others only test a set of connectors (four, for example). Optionally, an OTDR may be used for testing at the CO as well as testing from the FDH.

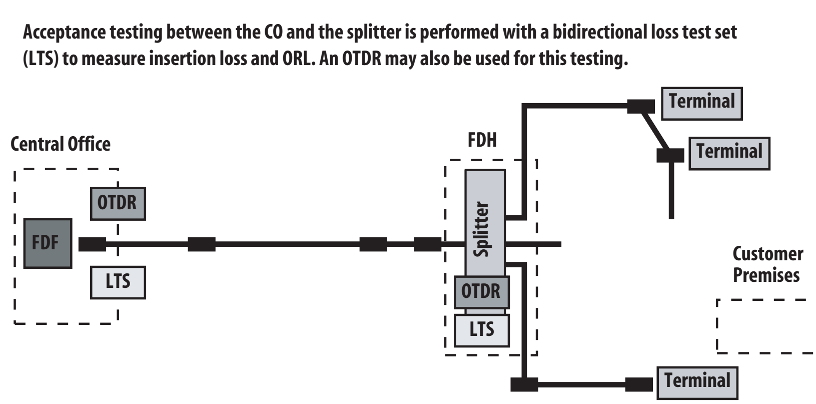


Figure 8: Acceptance testing between the CO and the splitter

The same tests are then performed for the distribution network. For this process, it is critical to accurately identify all of the fiber numbers because the terminal locations may be scattered. Typically, one technician stays at the FDH to connect one tester to one fiber while a second technician travels along to the terminals to connect the other tester to the other end of the fiber (Figure 9). A Visual Fault Locator (VFL), which can display a visible red light up to 15,000 ft, is used to easily identify the tested fiber at the other end. Once the two testers are connected, the required measurements can be obtained. This process is repeated for all the fibers on the network. Optionally, an OTDR may be used for testing the distribution network.

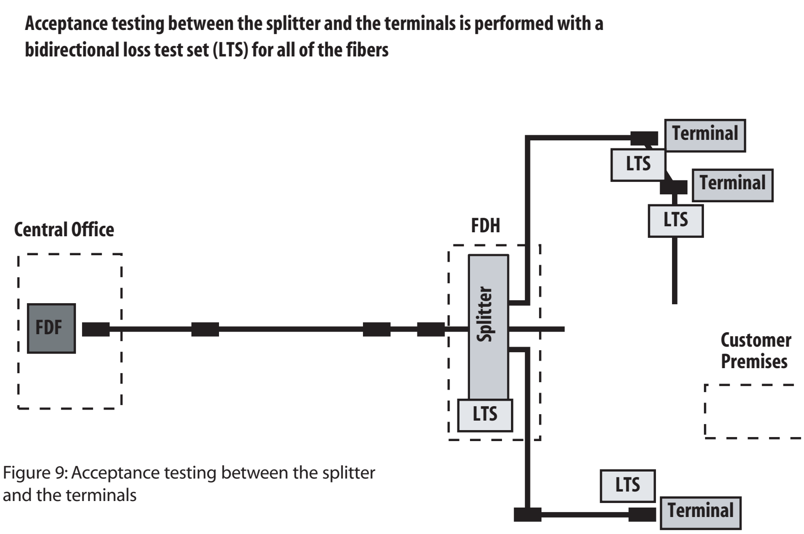


Figure 9: Acceptance testing between the splitter and the terminals

Table 6 lists the tasks involved in the acceptance testing of the OAN.

	Task	Objective	Test Tool(s)
1	Insertion loss/ORL testing of the feeder.	Acceptance testing of the feeder.	Two bidirectional loss and ORL test sets (or an OTDR)
2	Insertion loss testing of the distribution network.	Acceptance testing of the distribution network.	Two bidirectional loss and ORL test sets (or an OTDR)

Table 6 lists the tasks involved in the acceptance testing of the OAN.

Why Isn't Overall Acceptance Testing Performed?

For a traditional fiber network, an overall end-to-end acceptance test is always performed. This is not the case with FTTP because, until a customer has been established, the connectors at the splitter location are not connected. An overall end-to-end acceptance test would only be possible if all of the customers were connected at exactly the same time for a given FTTP network. But most of the time, only a selection of customers are activated initially, and others are added afterwards. This makes overall acceptance testing impossible because it would require disconnecting the OLT for the existing customers.

Section 4: FTTP Equipment Installation and Testing

FTTP equiment tests are usually performed by CO personnel for optical line terminals (OLTs) and by technicians in charge of the customer premises for optical network terminals (ONTs).

Once fiber construction is complete, all of the active equipment (OLTs and ONTs) can be installed. OLTs are installed at the CO, and ONTs are installed at the customer premises once customers have been established (Figure 10).

At the customer premises, the drop cable connecting the terminal and the ONT is also installed, using either aerial or underground technologies. The drop cable is usually a pre-defined connected cable that does not require further testing during its installation. Once the drop cable is installed, the technician goes to the terminal and connects the drop cable to the terminal. He then goes to the FDH to connect the fiber, which was previously stored in the parking lot, for this specific customer.

When this procedure has been completed, technicians perform bidirectional loss and ORL testing again by connecting one tester to the FDH and the other tester to the ONT location. Although more costly, an alternative solution is to use an OTDR from the ONT location. Table 7 lists the tasks involved in FTTP equipment testing.

Once customers have been established, ONTs and OLTs are installed. Next, the drop cable is installed. When the ONTs and OLTs are activated, testing with a selective power meter (PM) is performed at the ONT and OLT locations. At the OLT location, ORL testing may be performed.

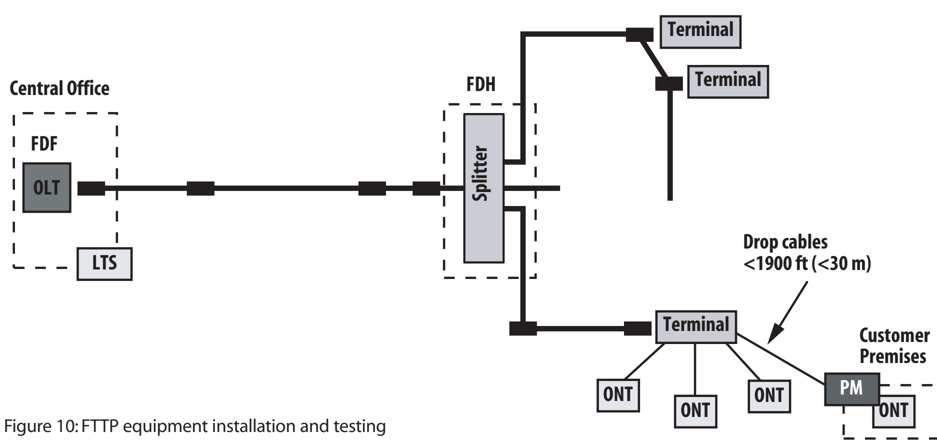


Figure 10: FTTP equipment installation and testing

Photonic Layer Testing of the OLT and ONT Signals

Once the OLT and ONT can be activated, basic photonic layer testing is performed. This testing is accomplished by first activating the 1490 and 1550 nm wavelengths of the OLT as well as the 1310 nm wavelength of the ONT and then by measuring the power level (usually at the ONT location). Both the 1490 and 1550 nm wavelengths can be easily activated by the OLT, making measurements at those wavelengths easy to obtain.

	Task	Objective	Test Tool(s)
1	Insertion loss testing of the distribution network with the drop cable.	Acceptance testing for the distribution network with drop cable.	Two bidirectional loss and ORL test sets (or an OTDR)

Table 7: Tasks involved in FTTP equipment testing

This is not the case for the 1310 nm wavelength, though, because most FTTP equipment providers do not allow the activation of the 1310 nm signal only. The 1310 nm wavelength, provided by the ONT, is effectively activated by the 1490 nm signal coming from the OLT. Therefore, a specific power meter, called a "through mode" power meter, is used (Figure 11). The through mode power meter is a two-connector power meter where the fiber coming from the OLT is connected to one port of the power meter and the fiber coming from the ONT is connected to the other port of the power meter. The through mode power meter connects the OLT to the ONT and, at the same time, performs measurements of all of the wavelengths. In addition, because 1310 nm signals are emitted in a burst mode most of the time, specific power measurements are performed. For example, burst measurement is performed as opposed to CW measurement, which is what a classical power meter measures.

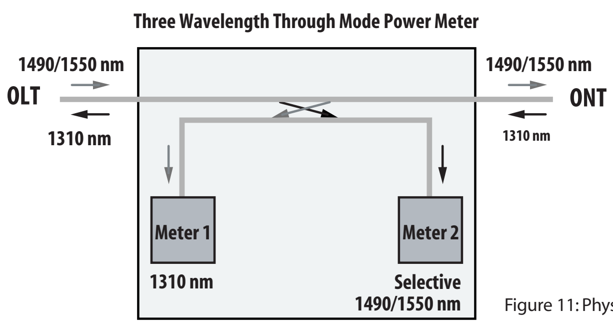


Figure 11: Physical layer testing using a through mode power meter

Some technicians only measure the 1490 and 1550 nm wavelengths, making the assumption that these measurements validate the fiber quality. If the 1310 nm wavelength is not transmitting to the CO, then the ONT is in failure and requires changing.

Additionally, if video is using the 1550 nm transmission with analog signals, then ORL measurements of the feeder are performed from the CO following the OLT connector.

Table 8 lists the tasks involved in physical layer testing of the OLT and ONT signals when 1550 nm video is used.

	Task	Objective	Test Tool(s)
1	Power level measurements at the OLT location.	Verify the levels at the ONT with pass/fail indication.	1.4/1.5 µm selective power meter
2	ORL measurements from the OLT.	Verify the ORL in the case of analog video transmission with pass/fail indication.	ORL meter
3	Power level measurements at the ONT location.	Verify the levels at the ONT with pass/fail indication.	1.3/1.4/1.5 µm power meter with through mode or 1.4/1.5 µm selective power meter

Table 8: Tasks involved in physical layer testing of the OLT and ONT signals with 1550 nm video

If IP Video technology is used exclusively, then 1550 nm testing becomes irrelevant. This simplifies the testing tools drastically, as a broadband power meter calibrated at 1490 nm would be the only meter required. Table 9 lists the tasks involved in physical layer testing of the OLT and ONT signals when IP Video is used.

	Task	Objective	Test Tool(s)
1	Power level measurements at the OLT location.	Verify the levels at the ONT with pass/fail indication.	1.49 mm power meter
2	Power level measurements at the ONT location.	Verify the levels at the ONT with pass/fail indication.	1.3/1.49 mm power meter with through mode or 1.49 mm power meter

Table 9: Tasks involved in physical layer testing of the OLT and ONT signals with IP Video

Section 5: FTTP Troubleshooting

Troubleshooting is usually performed by the technicians in charge of the customer premises. If there are any fiber network issues, then they are handled by the fiber construction crew (Figure 12).

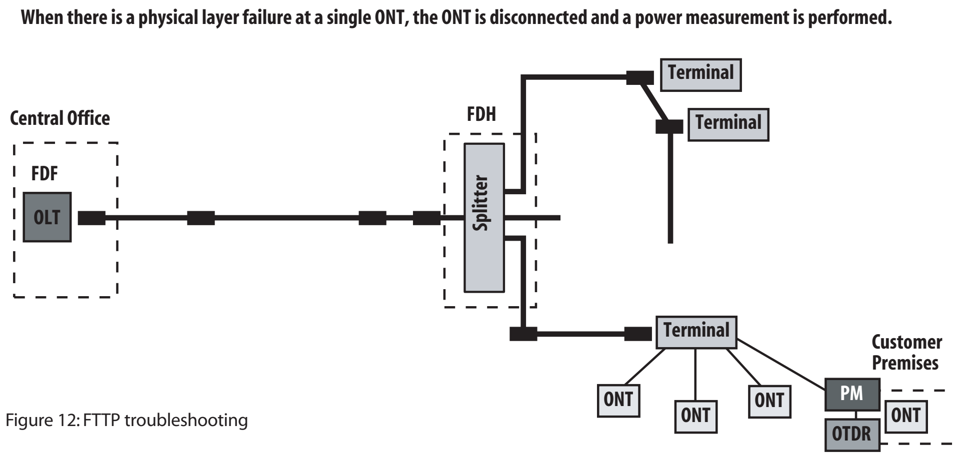


Figure 12: FTTP troubleshooting

Analyzing ONT Outage When Not All of the ONTs Are Out-of-Service

When few, but not all, of the ONTs are working, this indicates that the OLT and the feeder network are working properly. The problem, in this case, is probably either along the distribution network or at a specific ONT location. Therefore, the technician goes to the specific ONTs and tests the power levels at those locations. There are three possible scenarios:

(1) If the wavelength power levels are correct, then the distribution network is working properly. Therefore, the ONT is in failure and must be changed.

(2) If the wavelength power levels are incorrect (even after the connectors are cleaned), then the distribution network is in failure. In this scenario, wavelength power levels are then measured at the terminal. If the wavelength power levels are correct at the terminal, then the drop cable must be changed.

(3) Then, if the wavelength power levels are still not correct at the terminal (even after the connectors are cleaned), the connector at the FDH of this fiber link is disconnected and OTDR measurements are performed (either from the FDH or from the ONT location). These measurements will identify the location of the break/bend. Repairs may require the cooperation between the technicians and the fiber construction crew.

Table 10 lists the tasks involved in analyzing ONT outage when not all of the ONTs are out-of-service.

	Task	Action (Pass)	Action(Fail)
1	Measure power levels at the ONTs and verify connections.	Go to task 2.	The ONT is in failure. Change the ONT.
2	Measure power levels at the terminaland verify connections.	Change the drop cable.	Go to task 3.
3	Disconnect the connector on the FDH, perform OTDR measurements of the distribution network, and verify connections.	N.A.	Identify the break/bend and repair the fiber.

Table 10: Tasks involved in analyzing ONT outage when not all of the ONTs are out-of-service

Analyzing ONT Outage When All of the ONTs and the OLT Are Out-of-Service

When all of the ONTs and the OLT are out-of-service, the technician goes to the CO first to check that the OLT is transmitting with the correct wavelength power levels.

If the OLT is not transmitting the correct power levels (even after the connectors are cleaned), then the OLT is in failure and must be changed.

If the OLT is transmitting the correct power levels, then the fiber network is in failure. First, an OTDR measurement is performed from the OLT connection to identify the location of the break/bend at the feeder network. (Note: This is the portion of the OTDR trace just before the splitter trace drop.) Then, any necessary repairs are made.

If the feeder network measurements are correct, then the problem may be within the FDH. In this case, the technician goes to the FDH and verifies the connectors and splitters at this location. OTDR testing is performed to clearly identify the break/bend in the event that is not visible. Then, any necessary repairs are made.

Table 11 lists the tasks involved in analyzing ONT outage when all of the ONTs and the OLT are out-of-service.

	Task	Action (Pass)	Action(Fail)
1	Disconnect and measure power levels at the OLTs.	Go to task 2.	The OLT is in failure. Change the OLT.
2	Measure the feeder from the OLT location with an OTDR.	Go to task 3.	The feeder network is in failure. Repair the fiber.
3	Go to the FDH and verify the connections.	Go to task 4.	Modify the connections.
4	Test the distribution network with an OTDR.	N.A.	The distribution network is in failure. Repair the fiber.

Table 11: Tasks involved in analyzing ONT outage when all of the ONTs and the OLT are out-of-service

Section 6: P2MP Reflectometer Trace Analysis

Because OTDRs are the main tools used to troubleshoot a classical fiber link, one would think that an OTDR can also be used to test the complete FTTP optical network. Unfortunately, due to the use of point-to-multipoint (P2MP) networks, the resulted OTDR traces are much more difficult to interpret.

Traditional OTDR analysis uses both the Rayleigh backscatter effect and the Fresnel back reflection effect to characterize events and fiber ends. The OTDR then displays a trace that is the signature of the fiber link. The Rayleigh backscatter effect takes into consideration that part of the transmitted light is reflected back to the transmitter due to fiber impurities. The Fresnel back reflection effect relies on index discontinuities. It has the same effect as Rayleigh backscatter effect, but its effect is due to fiber-to-air connections.

These effects usually give an easy-to-understand signature of the link as long as there is only one branch along the link. Because a PON network provides multiple branches along the link, the P2MP OTDR signature becomes very complex to interpret. This is because the OTDR is not able to differentiate the reflected light coming from a default of one branch location to another branch location, since they are located at the same distance to the OTDR. The result is an aggregate trace that does not display the effect of each branch individually; instead, it displays the effect of all of the branches at the same time. P2MP Reflectometer Trace Analysis takes into consideration the backscatter response after the splitter that is used in P2MP networks. It allows for the identification of the optical branch, the localization of faults, and attenuation estimation.

Therefore, in order to analyze a P2MP network, a specific test procedure, described below, is required.

Typical Reflectometer Traces

This section compares two typical scenarios, a core network and a distribution network, to explain the importance of P2MP Reflectometer Trace Analysis.

For the core network, the OTDR trace shows the splices and connectors along the link. The analysis of this trace is simple, and it is done automatically by most of the OTDRs currently on the market. The OTDR provides a signature of the link and a table of events, which can be stored for maintenance purposes (Figure 13).

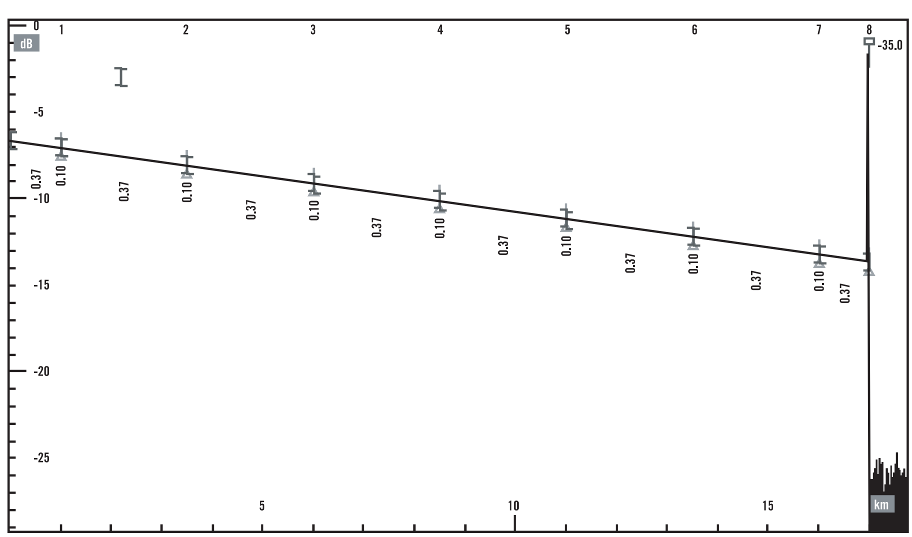


Figure 13: An OTDR trace of a core network

For the P2MP network, the OTDR trace shows the splitter, splices, and connectors along the link. Prior to the splitter, the analysis is simple and is similar to the analysis of the core network. But following the splitter, the analysis becomes more complex. With only the trace and the table of events given directly by the OTDR, it is impossible to locate and measure the different events of the different branches that are located after the splitter. The OTDR trace does not take into account the fact that there are different branches. It only analyzes the light that reflects from the entire network (Figure 14). All the information is available on the trace itself, though. It is just necessary to decode the information coming from the OTDR. Further software analysis is required for this decoding procedure.

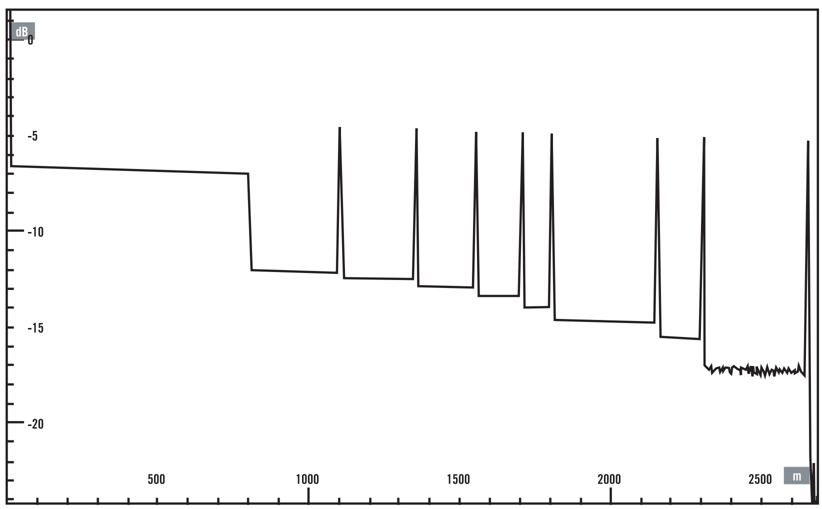


Figure 14: An OTDR trace of a P2MP network

Theoretical Method of P2MP Reflectometer Trace Analysis

The difficulty in analyzing a P2MP network is directly linked to the use of the splitter. When a splitter is used, analysis of the backscatter response after the splitter is necessary. Figure 15 shows a P2MP reflectometer trace analysis of a simulated network with one splitter. The splitter can have any number of branches with fiber of different lengths.

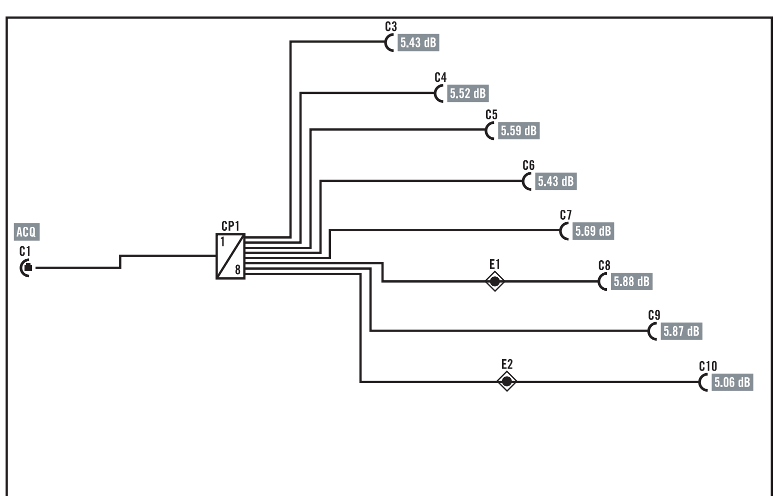


Figure 15: A simulated P2MP network with one splitter

Figure 16 shows the P2MP reflectometer trace given by the OTDR of a simulated network with one splitter.

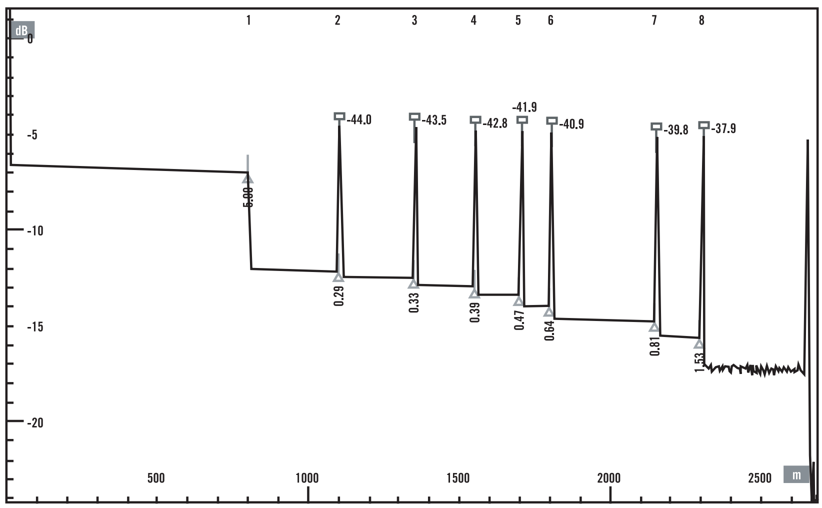


Figure 16: An OTDR trace of a simulated P2MP network with one splitter

Displayed Attenuations on a P2MP Reflectometer Trace

There are two types of attenuation on a multi-branch backscattered signal. The first type, Ac, is located at the splitter. The second type, AFEi, is located where fiber branch 'i' ends, corresponding to a fiber end. These attenuations are closely dependent on the adjacent fiber parameters (backscatter coefficients) as well as the splitter parameters (forward and reverse insertion losses).

In order to more fully understand the analysis, a simplified version of the theoretical formula is defined. It requires the following assumptions:

(1) The different fibers connected to the splitter have very similar characteristics, including bidirectional symmetry behaviors, backscatter coefficients, and attenuation.

(2) The splitter has the same characteristics for both directions.

Taking into account these assumptions, the different types of attenuation are calculated by the following formulas:

$A_C = 5x\log(m) + E.L.$

$A_{FE}i = 5x\log[(m-i+1)/(m-i)]$

where E.L. is the excess loss of the splitter, m is the number of outputs, and i is the analyzed branch.

Analysis Method of P2MP Reflectomer Trace Analysis

This example uses a 1:8 splitter with the same assumptions as in the theoretical method. A standard OTDR is used to obtain the signature of the link. The analysis method requires a learning acquisition phase. This phase uses an optical network OTDR measurement simulator. This innovative simulator, developed by JDSU's Optical Transport Division, can be used with both point-to-point and point-to-multipoint networks. In addition to classical fiber, connector, splice, and attenuator simulation, the software algorithms integrate n to m splitter synthesis based on an attenuation behavior formula similar to the calculations of A_C and $A_{FE}i$.

Learning Acquisition Phase

The learning acquisition phase can be divided into three main steps:

(1) OTDR acquisition simulation with construction data (Figure 17).

(2) OTDR acquisition in the field under real conditions (Figure 18).

(3) Comparison between the two acquisitions, including distance tuning and locking.

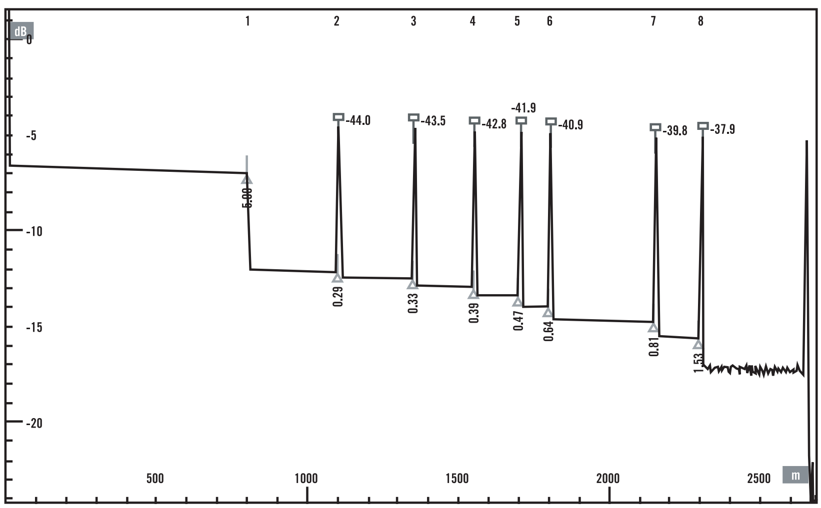


Figure 17: OTDR acquisition simulation with construction data

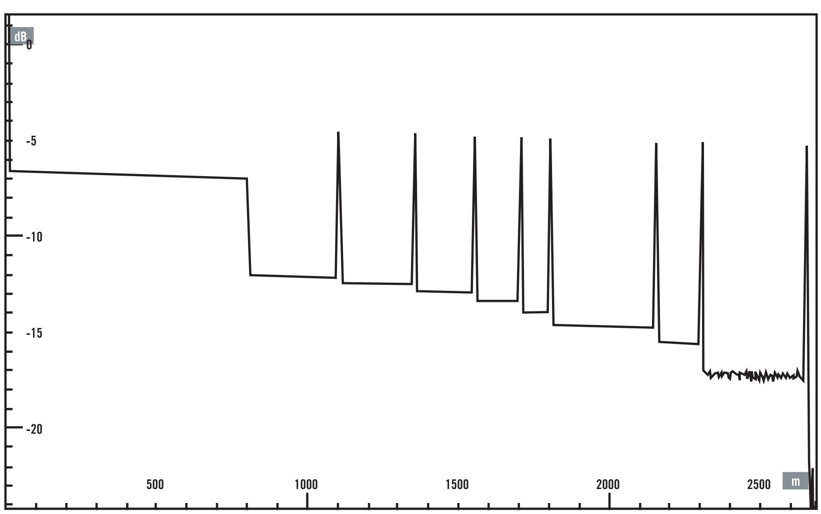


Figure 18: OTDR acquisition in the field under real conditions

This learning acquisition phase allows for the generation of a Reference Pattern (RP) and an Event Reference Table (ERT). The RP corresponds to the trace, and the ERT includes the reflective and non-reflective events list. The analysis does not require all of the non-reflective events in order to run. After this phase, the analysis can be performed using real conditions in the field.

Analysis Phase

Analysis can be performed during installation, monitoring, or maintenance applications. During in-service monitoring, if the system detects an OTDR signature deviation, then analysis can be performed. During maintenance, if a failure occurs during traffic, then the fault location can be determined. In addition, the failure level is established, if possible. In both cases, the analysis method consists of a comparison between the current pattern (CP) and the reference pattern (RP).

The following sections discuss the different events that can occur during analysis.

(a.) Optical Branch Identification

During optical branch identification, two different possibilities can appear:

1. Fresnel reflection extinction or attenuation

   When analyzing the pattern comparison, if a fiber end reflective event deviation is detected, then the affected optical branch can be directly identified (Figure 19).

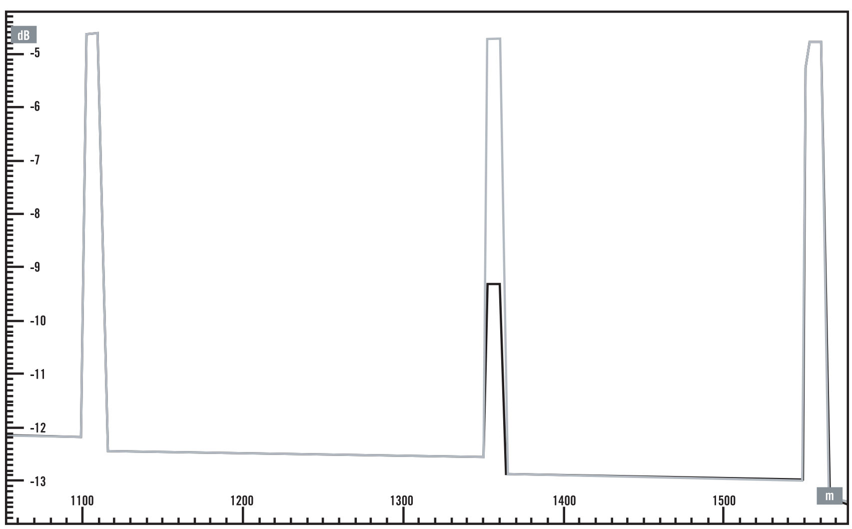


Figure 19: Reflective event deviation

2. Attenuation deviation

   When analyzing the pattern comparison, if an attenuation deviation along a fiber section is detected, then the affected fiber is the one that ends at the same distance that the deviation stops appearing (Figure 20). In this example, branch number six is affected.

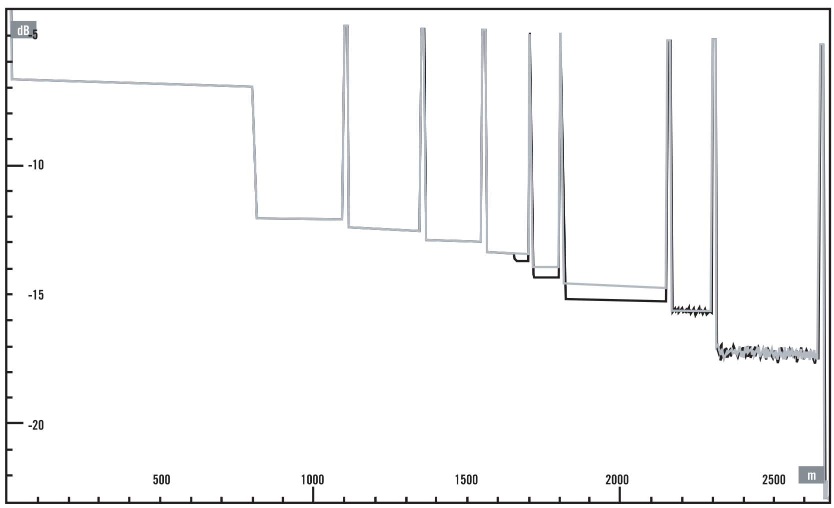


Figure 20: An attenuation deviation

(b.) Fault localization and attenuation estimation

After locating the distance where the deviation begins to appear, the location of the fault can be identified. Eventually the fault can be associated with an event recorded in the reference table.

Due to the mixing of multiple branches, fault attenuation cannot be directly calculated from the attenuation deviation between the two curves (Figure 21).

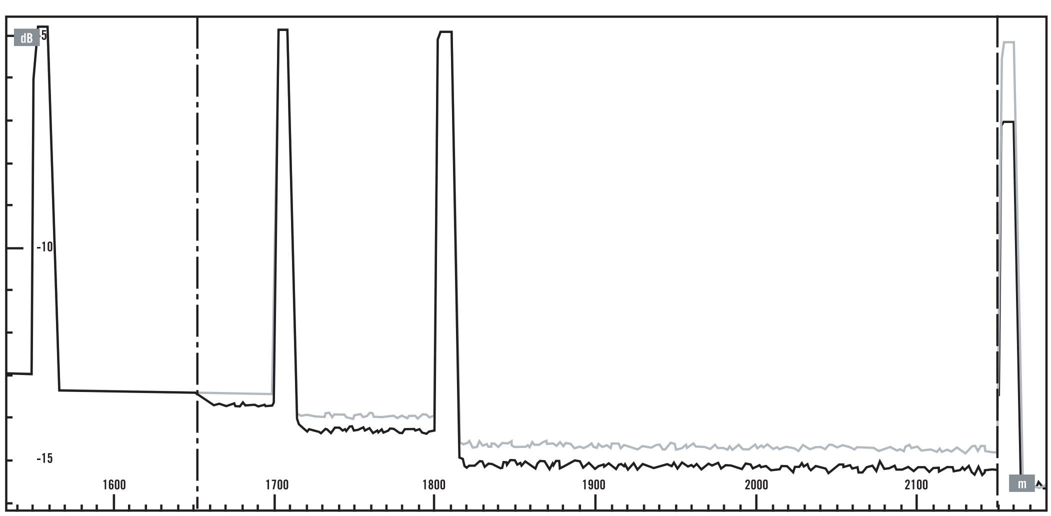


Figure 21: Identifying the location and attenuation of a fault

Using a pattern simulator, though, a virtual attenuator can be inserted into the affected branch and the attenuation can be increased until the same deviation from the reference pattern is achieved. This technique allows for an approximation of the attenuation level of the fault.

Accuracy and Limitations of the Method

Because this type of analysis involves measurements, it is necessary to point out its accuracy and limitations. As far as accuracy is concerned, the main source of error lies in the reality of the simulator models and data entry uncertainties. For example, optical splitters reverse and forward parameters may need to be entered. The fiber backscatter coefficient deviations add some uncertainty on the attenuation estimation and could be integrated into the theoretical formula.

Moreover, when P2MP networks are measured with a high level of splitting, the sensitivity depends on the amount of backscatter contribution that is lost. Therefore, sensitivity depends on the location of the fault compared to the fiber ends.

As in other OTDR measurements, the signal-to-noise ratio (the dynamic range, for example) can disturb the acquisition. If the network has a large total loss, then the dynamic range of the OTDR may not be enough to provide a backscatter trace along the entire link. Therefore, it is important to have enough dynamic range to go through a splitter with the OTDR.

If the network has branches of similar distances, then the OTDR may not differentiate the different events and branches. For this reason, new OTDRs are being developed, providing event spatial resolutions of 1 m or better.

In any case, if the concept of resolution is taken into consideration during the construction of a network to avoid reflection coincidence, then the maintenance of the network will be easier to perform.

Test & Measurement Regional Sales

NORTH AMERICA	LATIN AMERICA	ASIA PACIFIC	EMEA	WEBSITE: www.jdsu.com
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