Meeting the Unique Test Challenges of FTTx Deployment

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Introduction

Rapid growth of fiber optic networks has resulted in an explosion of improved services to residential consumers. As of 2020, fiber-to-the-home (FTTH or FTTx) reaches more than 400 million subscribers in China[1], 172 million homes in Europe[2], plus 40 million in the United States[3]. As telecommunications companies replace aging copper networks with fiber, they can deliver more bandwidth, reliability, flexibility and security to end-users.

FTTH passive optical networks (PONs) are increasingly being deployed to provide optical fiber's bandwidth advantages at a lower cost than point-to-point architecture affords. However, PONs present unique test challenges when installing and maintaining an FTTH network. This article provides an overview of FTTx PON architectures, identifies test challenges unique to FTTx PONs, and describes optical tests recommended to verify or troubleshoot FTTx PONs, including in-service (live) PONs.

FTTH Network Architectures

FTTH networks may be deployed using either point-to-point or point-to-multipoint network architecture.

Point-to-point architecture provides a dedicated fiber connection from a service provider's central office (CO) to each subscriber's premise. A point-to-point architecture also requires dedicated electro-optics for each subscriber at both CO and the customer premise.

Switched Ethernet architecture may be used to aggregate traffic from multiple subscribers before backhauling it to the CO over a single fiber. However, this requires electrical power at the Ethernet switch, and still requires dedicated optics at both the switch and customer premise for each subscriber.

One of two PON technologies are widely deployed in point-to-multipoint networks: ITU-T defined Gigabit-capable passive optical network (GPON) or IEEE-specified Ethernet passive optical network (EPON). Increasingly, 10 Gb/s PONs based on ITU XG/XGS-PON or IEEE 10GEPON are being deployed instead of, or in addition to GPON/EPON. Both GPON/EPON and XG/XGS/10GEPON may coexist on the same physical PON fiber, further complicating testing.

Active electronics are located only at the end-points of the PON, reducing network cost and increasing network reliability. An optical line terminal (OLT) residing in the telco service provider's CO (or in the MSO provider's headend) communicates across the passive optical distribution network (ODN) to optical network terminals (ONTs) located at subscribers' premises (**Figure 1**).

In the ODN, a single feeder fiber connects the CO to a pedestal- or pole-mounted fiber distribution hub (FDH). The FDH may be located in a neighborhood or the entry level of a multi-dwelling unit (MDU).

In single splitter PON architectures, a single 1x32 or 1x64 splitter is installed at the FDH. A feeder fiber connects the central office to the splitter at the FDH. This passive splitter separates the downstream signal into 32 or 64 copies. Each of the many splitter ports are connected through distribution fibers to pedestal- or pole-mounted Access Point (AP) terminals. A drop fiber connects each AP terminal to an ONT installed at each premise.

A PON's trunk-and-branch architecture reduces the amount of fiber required. Additionally, the downstream signal is broadcast to all attached subscribers, so a single downstream transmitter serves multiple customers. In the upstream direction, subscribers are assigned unique time slots in which to transmit, with the signals from the subscribers combined at the passive splitter and sent to the CO over the single feeder fiber. Consequently, a single CO receiver also serves multiple customers.

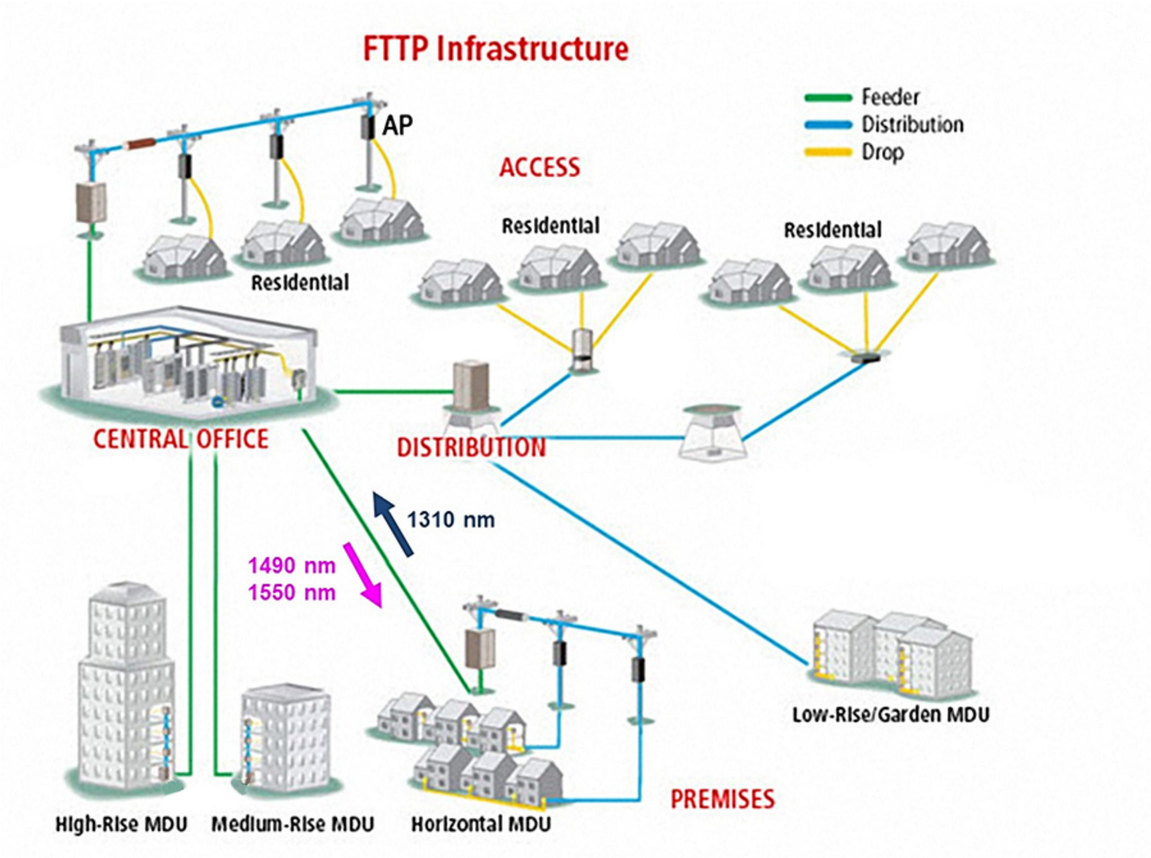

Figure 1 – FTTH PON Architecture using GPON or EPON

Traffic on the Network

Both GPON and EPON deliver voice, data, and IP video signals downstream using 1490 nm wavelength. An optional video overlay may be transmitted downstream at 1550 nm. Voice and data is communicated upstream from the ONT on the same fiber using 1310 nm wavelength.

XG/XGS/10GEPON deliver voice, data and IP video signals downstream using 1577 nm wavelength. Voice and data is transmitted upstream from the ONT on the same fiber using 1270 nm wavelength.

Downstream signals are optically divided at the splitter into multiple identical signals. The optical power of each signal is reduced by the split ratio plus some excess insertion loss. For example, the optical power level through a 1x32 splitter is reduced by approximately 16 dB – slightly more than 10 x log(32).

Multiple subscribers may simultaneously wish to send data upstream to the CO. Since all GPON/EPON ONTs use the same 1310 nm upstream wavelength (and all 10G PON use the same 1270 nm upstream wavelength), time division multiple access (TDMA) is utilized to prevent multiple ONTs from sending signals at the same time. With TDMA, the OLT assigns each ONT unique timeslots during which it can send a burst of data in the upstream direction, preventing multiple ONTs from transmitting simultaneously.

FTTH PON Testing Overview (installation, activation and maintenance)

Proper testing is a critical part of installing, activating and maintaining a PON. While most components are tested during the manufacturing process, they are tested again after splicing and installation of splitters and access terminals. Field testing is required to ensure no excess loss or reflectance has been introduced due to micro-bends in installed fiber, poor splices, macro-bends in splice closures or access terminals, or dirty, damaged, or improperly seated connectors. If not detected and corrected, excess loss or reflectance often results in poor network performance. Performance may initially seem acceptable, but over time, transmission errors may begin to increase long before the need for any maintenance activity would normally be expected.

Tests commonly used to verify optical links include the following:

- Connector end-face inspection and cleaning
- Insertion loss test
- Optical return loss test
- Optical time domain reflectometry (OTDR)

Connector contamination and damage are the most common causes of poor optical network performance.

Connector inspection and cleaning during installation and maintenance are among the most effective methods for ensuring an optical network will deliver expected performance. Connector inspection is typically performed using an optical microscope. To prevent accidental eye damage when inspecting fibers potentially carrying live traffic, a video microscope images the connector end-face and displays the magnified image on a handheld display. Dirt, debris, or damage are easily detected. Images may be captured before and after cleaning, then compared for any variation. Captured images may be analyzed for pass/fail by applying criteria specified in IEC 61300-3-35[5].

An **insertion loss test** measures the end-to-end loss of the installed link by injecting light with a known power level and wavelength at one end, measuring the received power level output from the other end. The measured difference between the transmitted and received power levels indicates the optical loss through the network. Insertion loss is considered acceptable when the measured loss level is lower than the budgeted loss level.

An **optical return loss test** injects light with known wavelength and power level into one end and measures the power level returned to that same end. The difference between the injected power level and the measured return level is the return loss. Return loss is considered acceptable when it is higher than the minimum allowed return loss. A low return loss value (below 35 dB) is often an indication of one or more sources of excess reflection in the network under test, typically due to dirty or damaged connectors, a fiber break, or an air gap at poorly mated connectors.

Since optical network loss is wavelength-dependent, insertion and return loss testing is typically performed using wavelengths at or near those which will be used during network operation. In the case of FTTx PONs, insertion and return loss testing at 1310 nm, 1490 nm, and 1550 nm may be required. In practice, testing is often performed only at 1310 nm and 1550 nm, reasonably expecting loss and return loss at 1490 nm to be between the levels measured at 1310 nm and 1550 nm.

As 1270 is close to 1310 nm, and 1577 is close to 1550 nm, one can expect that 1310/1500 test results can also be used to qualify PONs for XG/XGS/10GEPON operation.

If the loss and return loss measured at each wavelength are within the levels budgeted for the link, the optical network may be considered ready for activation. However, in many cases, the network operator requires the network to be more fully documented using an optical time domain reflectometer (OTDR).

An **OTDR** scans a fiber from one end to measure the length, loss and optical return loss of an optical network. It also locates and measures reflective and non-reflective events in the network due to connectors, splices, micro- or macro-bends, splitters or faults.

Operating like a radar, an OTDR injects narrow pulses of light into the fiber-under-test. As each pulse travels down the fiber, imperfections in the fiber scatter some of the light, with some of this Rayleigh-scattered light being guided back up the fiber.

Optical pulses and backscatter experience some loss as they traverse a mated connector pair, mostly due to imperfect alignment between the two connectors. By measuring the difference between backscatter levels before and after the connection, the OTDR is able to measure the loss across each connection.

A Fresnel reflection is generated whenever the pulse encounters a mismatch in the index-of-refraction, usually at a mated connector. An air gap at a poorly mated connector or an open connector end will generate a strong reflection. This reflected energy is also guided back up the fiber. (Note: The ends of APC connectors are angled to ensure that light is reflected off the end-face at such an angle that it is not captured and guided back up the fiber.)

The OTDR measures the level of returned backscatter and reflections vs. time, converts time-of-flight into distance, and creates a trace which plots changes in backscattered and reflected light levels vs. fiber length. Losses due to connectors or macro-bends appear as abrupt changes in the backscatter signal level. Reflections due to connectors, air gaps and open ends appear as spikes in the OTDR trace.

To simplify results interpretation, newer OTDRs analyze the trace to automatically detect, measure and identify network events creating a link map displaying each of the detected events using an icon to indicate event type and pass/fail status, along with the location, loss and reflectance of each event.

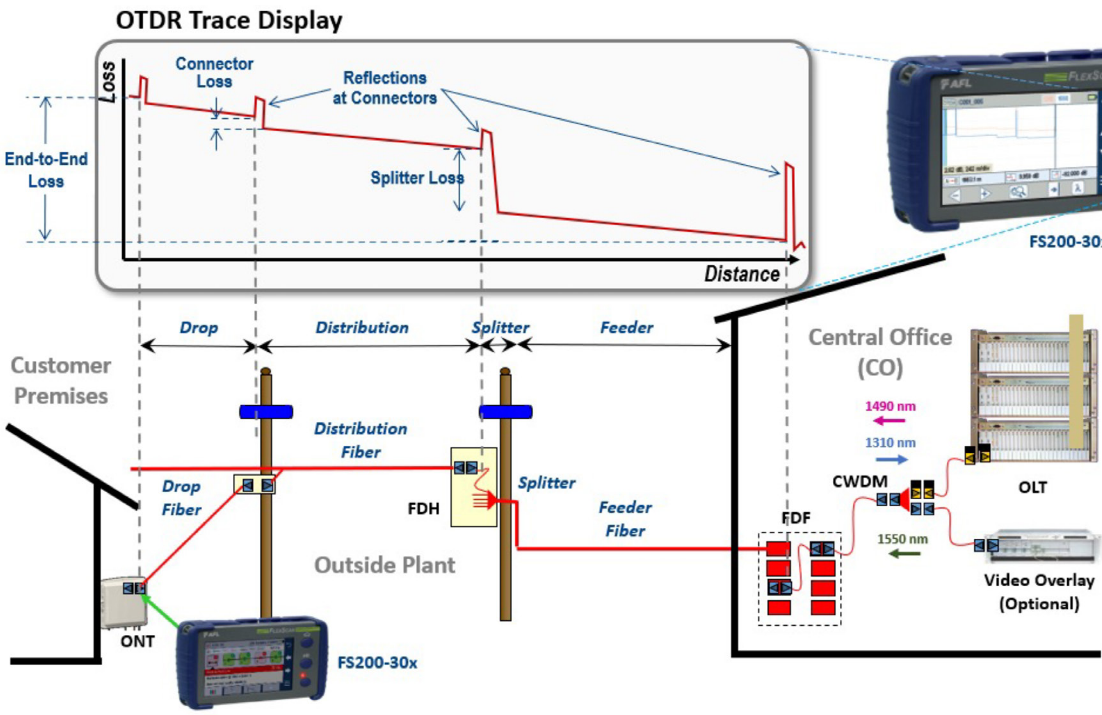

Figure 2 – Example OTDR trace showing backscatter, reflections and loss events

By analyzing the captured trace, the OTDR can also measure end-to-end link length, insertion loss, and ORL.

Insertion loss and ORL testing each provide individual numeric values which can be compared to network-specific limits to determine if the optical plant is within acceptable performance limits. When unacceptable or marginal values are found, insertion or return loss tests using source and power meter cannot locate the source of the problem. While an OTDR also measures link loss and ORL, an OTDR can additionally locate the sources of excess loss and reflections, reporting the distance to each high loss or high reflectance event.

Which Tests Should Be Performed, When and Where?

Optical testing is typically performed at various points in a network's lifetime:

Installation verification testing: Occurs as the network is being constructed or after network installation is complete, but before the network is activated. This is usually when the most complete testing is performed and may include insertion and return loss testing as well as OTDR testing. Pass/fail criteria may be applied to end-to-end length, loss and ORL results, as well as to individual event loss and reflectance measurements for splices, connectors, and splitters. Formal reports may be generated, including measured values, OTDR traces, pass/fail criteria and pass/fail results.

Maintenance troubleshooting: Performed as needed when service outages occur, and typically requires rapid response to restore service as quickly as possible. Troubleshooting may also require non-disruptive fiber identification to ensure in-service fibers are not disconnected. Additionally, maintenance personnel might require a visual fault locator (VFL) to precisely pinpoint the location of breaks or macro-bends in splice or access enclosures.

FTTx PON Insertion Loss Tests

Insertion loss testing may be performed on individual fiber segments as they're installed (e.g. test feeder fiber from CO to FDH, test distribution fiber from FDH to AP, or test drop fiber from AP to subscriber's premise). An end-to-end insertion loss test may also be performed on the FTTx PON after it is partially or fully installed.

A stable optical light source and an optical power meter are required to measure insertion loss. Access to both ends of the fiber-under-test is required. Consequently, this is typically an out-of-service test.

To measure loss, received power at one end of the fiber-under-test must be compared to transmit power injected into the fiber at the other end of the fiber-under-test. To simplify loss measurements, the power meter is initially connected to the source with a short jumper cable and the source power level is measured and stored as the 0 dB reference level for that wavelength. Since the source's output power levels and the power meter's detector response are different at each wavelength, the power meter must be referenced to the source at each test wavelength.

Once the source and power meter have been referenced at each of the test wavelengths, the source – with the reference jumper still attached – is connected to one end of the fiber under test. The power meter is connected to the other end of the fiber-under-test. The received power level can be measured and displayed. More conveniently, the power meter can compare the received power level to the stored reference, and directly display the insertion loss in dB.

Simple power meters measure power at only one wavelength at a time. To make loss measurements at multiple wavelengths, the source must be configured for each test wavelength in turn. At the same time, the power meter user must select the appropriate wavelength at the power meter so the correct detector calibration factor and reference level are applied. This is both time-consuming and error prone, as it requires coordination between the source operator on one end and the power meter user at the other end of the fiber-under-test.

To reduce test time and eliminate this potential for errors, AFL's FlexScan® family includes Wave ID. A Wave ID source alternately transmits light at each wavelength. A Wave ID power meter automatically synchronizes to the received wavelengths, eliminating the need for optical light source (OLS) and optical power meter (OPM) users to manually switch between wavelengths.

Test Steps Without Wave ID	Test Steps With Wave ID
Store references: 1. Connect OLS to OPM at one location. 2. Set OLS to 1310 nm. 3. Set OPM to 1310 nm. 4. Store reference. 5. Set OLS to 1550 nm. 6. Set OPM to 1550 nm. 7. Store reference.	Store references: 1. Connect OLS to OPM at one location. 2. Set OLS to Wave ID, 1310 / 1550 nm. 3. OPM detects Wave ID (< 2 secs) 4. Store reference (stores refs at both λ).
Measure network loss: 1. Connect OLS & OPM to network ends. 2. Set OLS to 1310 nm. 3. Tell OPM user to set OPM to 1310. 4. Wait for OPM user to meas loss @ 1310. 5. OPM user sets OPM to 1550 nm. 6. Tell OLS user to set OLS to 1550 nm. 7. Wait for OLS user to switch to 1550 nm. 8. Measure loss @ 1550 nm.	Measure network loss: 1. Connect OLS & OPM to network ends. 2. Set OLS to Wave ID, 1310 / 1550 nm. 3. OPM detects Wave ID, simultaneously measures loss at both 1310 & 1550 nm.

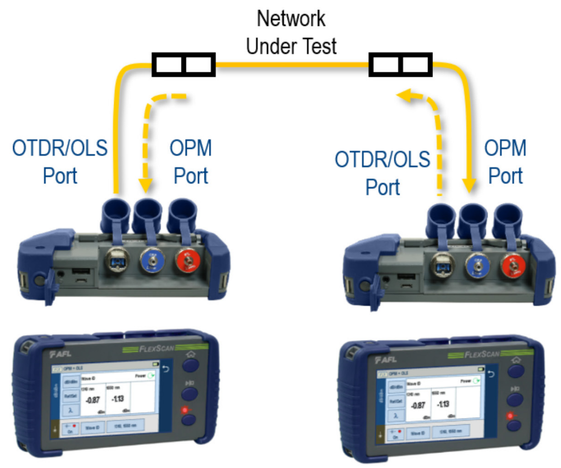

Figure 3 – Store reference and measure loss using Source and Power Meter with Wave ID

FTTx PON Out-of-Service OTDR Tests

OTDR testing is typically completed as the FTTx PON is being deployed. These may be tested as point-to-point links before the splitter is installed at the FDH.

If a splitter is spliced to the feeder fiber before testing, the loss through each of the splitter legs may be verified. However, this requires testing from each of the multiple splitter outputs and requires a launch fiber (500-1000 m recommended) to allow the splitter loss to be clearly seen and measured. Splitter losses through each of the legs cannot be easily verified by testing from the CO end of the feeder fiber.

Using an OTDR, distribution fibers may be tested from the FDH before they are connected to the splitter. Once attached to the splitter, these fibers may only be tested from a downstream access point or subscriber premise (if the drop fiber is also installed and connected). High-resolution of the distribution and drop fibers may be obtained using narrow pulses, but the OTDR may not be able to measure the splitter loss using narrow pulses. Wider pulses improve the OTDR's dynamic range, enabling it to more accurately measure the loss through the attached splitter. AFL's FlexScan family of OTDRs includes SmartAuto which automatically tests the network using narrow, moderate and wide pulse widths to best characterize the network both before and after the high loss of the splitter.

OTDR testing during FTTx PON installation testing is usually performed only at 1310 and 1550 nm. Fiber loss is highest at 1310 nm and lowest at 1550 nm, while bend-induced loss is highest at 1550 nm. If end-to-end loss is within acceptable limits at both 1310 and 1550 nm, it is nearly certain to be acceptable at 1490 nm. If no excess losses or reflections are found at 1310 or 1550, none are likely to be found at 1490 nm. Even if the PON will initially be operated using only 1490 and 1310, testing at 1310 and 1550 nm can detect any micro- or macro-bends, and ensures the FTTx PON is capable of adding 1550 nm video or 1270 and 1577 nm 10G PON wavelengths in the future.

Troubleshooting an In-Service FTTx PON

Because of its point-to-multi-point architecture, it is possible for one or only a few subscribers to lose service while other subscribers on the same PON continue to receive service. There are several possible causes:

- Equipment or connection problem inside the customer's premise
- Failed ONT at the customer's premise
- Fault in the distribution or drop fiber from the splitter to the subscriber
- Fault introduced at the splitter connection to the subscriber's distribution or drop fiber (e.g. macro-bend introduced while adding another subscriber, or inadvertently disconnecting the distribution or drop fiber to an active subscriber).

If some, but not all subscribers are affected and the FTTx PON is built using a distributed splitter architecture, it is possible that all of the affected customers are served from a single secondary splitter. In this case, likely causes include:

- Fault in the distribution fiber serving the secondary splitter
- Fault in the secondary splitter itself.

In either case, a fault in the feeder fiber or a failure within the OLT is not likely, since the feeder fiber and OLT are also shared by subscribers who are still receiving service.

Troubleshooting normally requires a visit to the subscriber's premise. A recommended process for troubleshooting a live PON is illustrated in Figure 4 on the following page and described below in greater detail.

Process Steps – Troubleshooting an In-service (Live) PON

1) If FTTH service is lost, disconnect drop fiber from ONT, inspect, clean and reinspect connectors.

2) Check the downstream power level at the ONT using a PON Power Meter. Some OTDRs include a PON Power Meter integrated into their OTDR port, enabling immediate detection and measurement of downstream power levels at both 1490 and 1550 nm..

3) If the measured downstream power level(s) are not acceptable, the problem is likely a fault in the distribution or drop fiber, or a fault introduced at the splitter in the FDH. In this case, connect a live PON OTDR to the drop fiber and initiate an upstream OTDR test using the out-of-band 1625 nm wavelength. To prevent disrupting service on the live PON, select an OTDR which prevents the user from initiating 1310, 1490, or 1550 nm OTDR tests when live traffic is present.

Some OTDRs also allow the operator to test only the customer fiber (distribution and drop), or to test through the splitter. Unless multiple customers are affected, the problem is most likely in the distribution and drop fiber, so testing only the distribution and drop fiber is a good bet.

4) Review the 1625 nm trace and event table to determine if there is a break or any excess losses or reflections in the distribution and drop fibers. If so, locate the problem location, repair the fault, then verify the fix by rescanning the fiber using the same 1625 nm test. To precisely pinpoint macrobends or breaks within a splice enclosure or access point, disconnect the OTDR and connect a Visual Fault Locator (VFL, a visible red laser). Enable the VFL and look for the point where the fault causes red light to escape from the fiber.

5) If no excess losses or reflections were identified in the OTDR trace, rescan the FTTx PON from the same location at 1625 nm using the "Test through Splitter" setup. This will provide a trace of the distribution and drop fibers with sufficient dynamic range to see through the splitter and measure the splitter loss. Since other probable causes have been eliminated, likely problems are a break or macrobend at the splitter, or the splitter has been disconnected from the distribution fiber. These will manifest themselves either as excess loss at the splitter, or as the fiber end being detected at the splitter. Repair the fault, then verify the fix by rescanning the fiber using the same setup.

6) Once fiber restoration is complete, verify the proper downstream power levels are available at the end of the drop fiber, clean and reconnect the drop fiber to the ONT, and verify the ONT synchronizes to the upstream OLT.

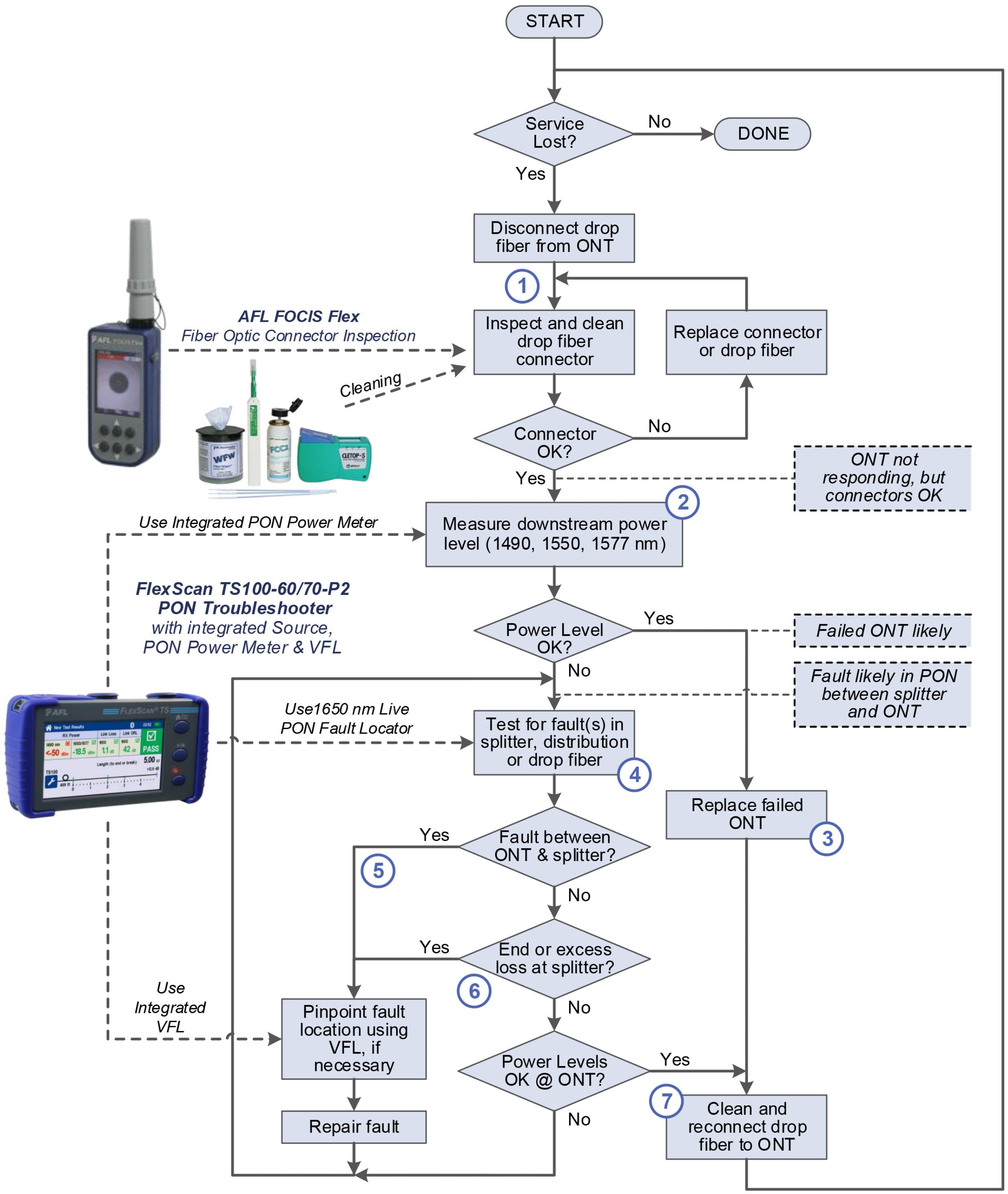

Figure 4 – Troubleshooting a Live PON

Summary

Passive optical networks are being deployed worldwide to more cost-effectively deliver higher bandwidth broadband services to subscribers. FTTx PONs present technicians with unique installation verification and maintenance troubleshooting challenges. These challenges are effectively overcome when technicians understand FTTx PON architecture and are equipped with test tools designed to address the unique test requirements of FTTx PONs

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About the Author

Michael Scholten is a Sr. Product Marketing Manager at AFL, one of the world's leading fiber optic manufacturers. The company's diverse product portfolio includes fibre optic cable, transmission and substation accessories, outside plant equipment, connectors, fusion splicers, test equipment and training. AFL's service portfolio includes market-leading positions with the foremost communications companies supporting inside plant central office, EF&I, outside plant, enterprise and wireless areas.

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