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Workforce Shortage? Technology to the Rescue:

Built-in Intelligence and Thoughtful UI Design Simplify Fiber Test, Avoid Errors and Reduce Test Time

A Technical Paper prepared for SCTE by

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1. Introduction

Fiber deployment is booming driven by a perfect storm of fiber-to-the-home (FTTH) broadband access, 5G transport, hyperscale datacenters, and edge computing. At the same time, the "Great Resignation" exacerbates the growing demand for experienced fiber installers, creating a crippling shortage in the fiber installation workforce.

Expanding the skilled workforce cannot happen overnight. However, cable, component, and equipment manufacturers are introducing products and providing training to simplify fiber splicing and termination. They are doing this by further automating single- and multi-fiber connector inspection as well as by integrating intelligence into installation test and diagnostic equipment so less skilled users can install, verify, troubleshoot, and repair optical networks more efficiently.

This article summarizes recent improvements in cabling, components, and fiber installation, verification and troubleshooting equipment, and then identifying how service providers and contract installers may utilize those improvements to successfully complete more work with less skilled workers.

2. Why a Critical Shortage of Skilled Fiber Installers?

Telecommunications industry news is replete with articles regarding the critical shortage of skilled workers to deploy and maintain rapidly expanding fiber optic networks [1, 2]. The causes for both the surge in demand and the shortage of skilled workers are commonly understood:

Table 1 - Surging demand is only one cause of skilled worker shortage.

Surge in Demand	Shortage of Workers
• Telco deployment of FTTH is booming…	• Demand for workers is growing...
• Applying pressure to cable operators to increase subscriber bandwidth including more upstream bandwidth…	• Even while the most experienced workers are aging out of workforce…
• Causing operators to split nodes and accelerate deployment of fiber deep into the network …	• Or simply not returning from COVID shutdowns or vaccine mandates…
• Compounded by 5G rollouts requiring fiber backhaul for more closely spaced macro-cells, micro-cells and DAA.	• As newer, less skilled workers begin to fill the gap, coax technicians must be retrained to install and maintain fiber.

In response, vendors, government, and industry trade associations -- including the Society of Cable Telecommunications Engineers (SCTE), the Fiber Broadband Association (FBA), and the Fiber Optic Association (FOA) – have been expanding their fiber optic skills training programs [3, 4, 5].

Even as training expands the pool of semi-skilled workers, what else can be done to simplify and accelerate fiber optic network installation, verification, and maintenance to enable a still limited supply of workers to accomplish more in less time? Here's where technology can come to the rescue.

3. Technology Can Help Overcome Skilled Installer Shortage

Installing, verifying, and maintaining fiber networks requires a fair amount of sophisticated equipment including fusion splicers, fiber termination (aka connectorization) equipment, laser sources and power meters, connector end-face inspection and cleaning products, non-intrusive optical fiber identifiers, optical time domain reflectometers (OTDRs), and live passive optical network (PON) troubleshooters.

Coincident with the broadband-fueled surge in fiber deployment which began several years ago, equipment manufacturers began integrating increased intelligence into fiber installation, verification, and maintenance equipment. At the same time, technology advancements enabled equipment users to reduce the time required to:

- Splice fibers;
- Inspect and clean connectors;
- Verify network insertion and return loss; and
- Characterize the location, loss and reflectance of installed components including connectors, splices, and PON splitters or taps.

Technology advancements associated with personal computers, tablets and phones have also enabled equipment vendors to incorporate larger, high visibility, higher-resolution displays, gesture-recognition touchscreen controls, and powerful processing and communications capabilities into smaller, lighter, more rugged, battery-operated packages.

Let us review how technology improvements simplify and reduce the time required to join, terminate, verify, and maintain optical networks.

3.1. Fiber Splicing

Due to the length of outside plant networks, obstacles encountered during installation, and the need to branch networks at various locations, fiber cables must be installed in sections, joined, or terminated in splice closures or cabinets, and verified post installation.

Fibers can be joined in two ways: by thermally fusing glass fibers together or by mating cleaned and cleaved fibers in a mechanical splice. Fusion splicing always reduces optical power loss and reflectance, and with an installed splice protector forms a more robust joint. However, fusion splicing traditionally required expensive and possibly delicate splicing equipment, a skilled operator to strip, clean, cleave, splice, and then install a heat-shrink protector one fiber at a time. With today's cables carrying hundreds or thousands of fibers, fusion splicing one cable to another could take days. Mechanical splicing was not any faster; you still had to strip, clean, cleave, and splice one fiber at a time. While it does not require a fusion splicer, the material cost per splice is higher and splice performance is reduced.

With technology advances, multiple cameras integrated into the fusion splicer, and processor-controlled motor driven chucks that optimally align fiber cores, today's single fiber fusion splicers provide higher quality splices in less time. Ribbon fiber splicers are also available to align and simultaneously splice twelve fibers in flat or rollable ribbon cable, dramatically reducing splice time and the staff required to splice multi-fiber cables.

Bad splices are typically the result of poor fiber preparation, inadequate cleaning, or poor mechanical cleaves. Splicer-integrated cameras evaluate splice quality and alert installers of poor splices, usually requiring the technician to re-splice and increasing the time to complete an installation. Once again, technology provides solutions. Cleavers that track the number of cleaves since the last blade rotation, communicate with the fusion splicer via Bluetooth and provide motorized blade rotation to prevent dull edges from producing poor cleaves. Real-time arc control in the fusion splicer improves splicing performance when fibers are cleaved with less than ideal cleave angles. This results in fewer bad splices and shorter time to job completion.

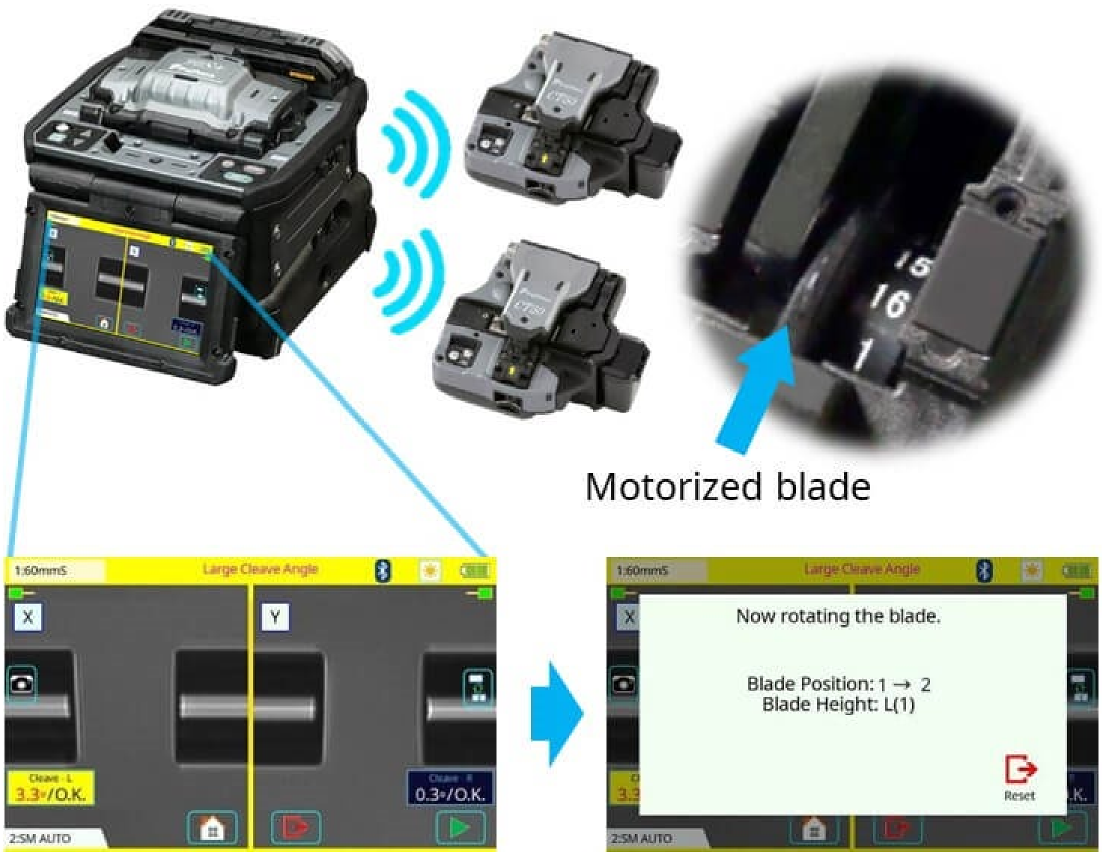


Figure 1- Automated fiber alignment, Bluetooth communications and real-time arc control reduce the skill and time required to produce high quality splices.

3.2. Fiber Termination

Terminating fiber requires installing a fiber connector. Terminations allow networks to be reconfigured without having to break and resplice the fiber. Single, duplex, and multi-fiber connectors are all commercially available. Field termination previously required the installer to strip, clean and cleave the fiber, epoxy it into the ceramic ferrule, then polish the connector end to remove any excess epoxy, producing a smooth, convex-polished end, without over-polishing which would create an air gap at a mated connection. Air gaps are a source of unacceptable insertion loss and/or reflection.

Once again, technology has provided a solution which simplifies connector installation, reduces the skill required to terminate, reduces termination time, and provides consistent, high-quality connections. The solution? Splice-on or mechanically spliced connectors containing a pre-polished fiber stub. Available in both fuse-on and mechanically spliced form factors, installation utilizes the familiar strip, clean, and cleave process followed by either fusion splicing or mechanical alignment. When fully assembled, the connector body combined with strain relief protect the fusion or mechanical splice inside the connector body.

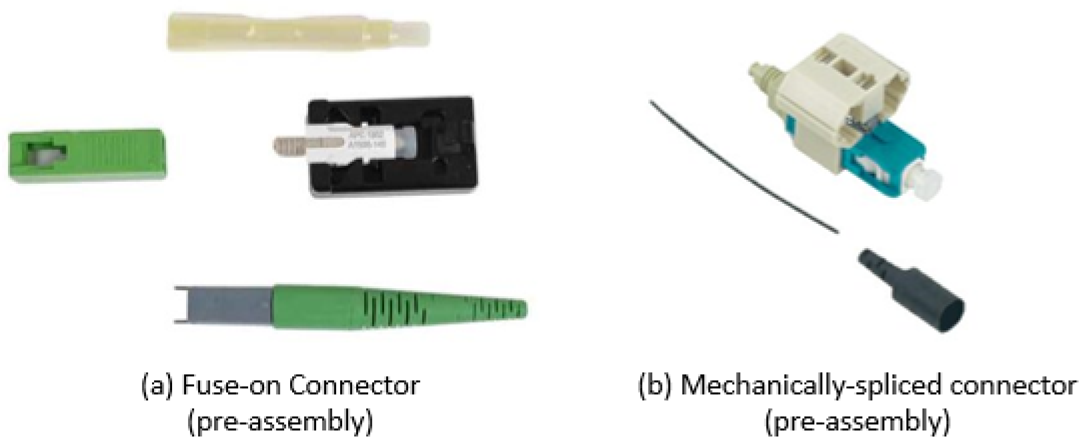


Figure 2 - Pre-terminated fuse-on or mechanical splice connectors simplify connector termination.

3.3. Connector End-Face Inspection and Cleaning

A survey of fiber installers by NTT [6] identified dirty and damaged connectors as the single most frequent cause of fiber network problems. Dirty connector end-faces reduce or prevent light transmission through a mated connection. Damaged connectors can create an air gap at a mated connection resulting in excess loss and reflection at the connection, and increased error rate on optical signals transmitted through the connection. Mating a dirty connector to a clean connector may damage both connectors as spring force in the mated connection grinds dirt into both end-faces.

Service providers all preach cleaning to their technicians. Unfortunately, the more inconvenient cleaning is, the less likely technicians are to follow good cleaning practices. Technology's solution: make cleaning as simple and fast as possible. Today's "one-click" cleaners can rapidly clean the end-faces of exposed ferrules on patchcords as well as ferrules mounted behind bulkhead adapters in patch panels. While some one-click cleaners require the user to install or remove a ferrule alignment cap when switching between cleaning patch cord and bulkhead-mounted connectors, the newest one-click cleaner for common SC connectors and field-hardened optical connectors cleans both connector types without cap swapping (see Figure 3). While this may seem a simple improvement, if it means the difference between an installer cleaning or not, it also can help prevent a poor connection or having to replace one or both connectors, often at a later time after the error has been identified.

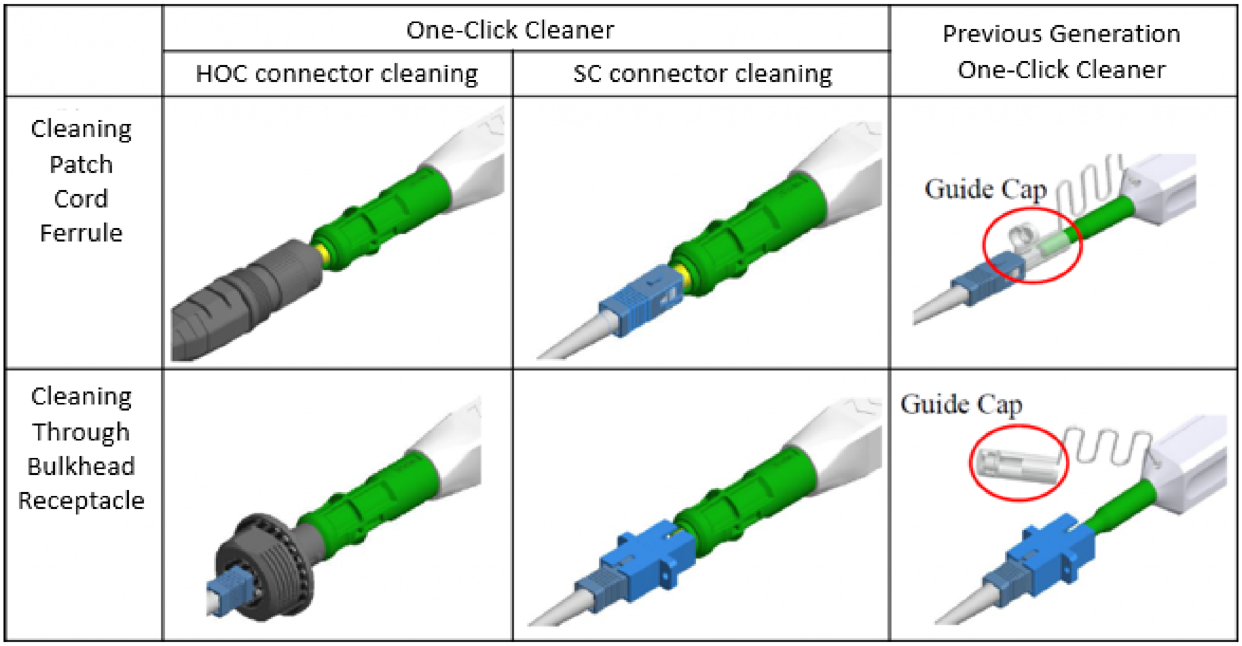
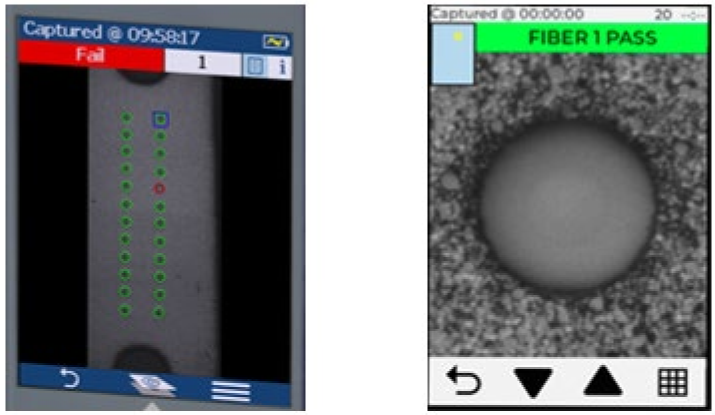


Figure 3 - Latest generation one-click cleaners clean both SC and HOC connectors without swapping cap to test patch cords or through bulkhead adapters.

The small diameter of optical fibers (smaller than a human hair) requires a microscope to examine the connector end-face for contamination or damage. Today's preferred solution is a video microscope capable of at least 400x magnification. To objectively evaluate the presence or absence of scratches, contamination or defects, IEC developed a standard [7] to establish the size and number of permissible scratches or defects in the core, cladding, and physical contact region of a connector end-face. Pass/fail limits are a function of fiber type (single-mode or multimode) and core diameter (8-9 um for single-mode, 50-62.5 um for multimode).

Technology incorporated into today's connector inspection probes simplifies and reduces test time by implementing auto-focus, auto-center, capture, analyze and display at the press of a button. Displayed connector end-face and pass/fail results may be automatically saved and/or sent via Bluetooth to a mobile device for remote archiving and/or reporting.

The latest generation of MPO multi-fiber connector inspection probes can auto-focus, capture and analyze the end-faces of all fibers in a single- or multi-row MPO connector at once, further reducing test time for MPO-terminated cables (see Figure 4).



(a) MPO-24 Full End-face (b) Individual Fiber End-face

Figure 4 - MPO inspection probes image entire end-face of a multi-row connector (a), while providing sufficient resolution to evaluate pass/fail for each fiber end-face (b).

3.4. Post-Installation Network Verification

Once optical network cables are installed, spliced, and terminated, the installed optical plant must be verified. At a minimum, network length, insertion loss and optical return loss (ORL) must be tested against expected length, maximum allowed loss, and minimum acceptable return loss limits. More typically, service providers also require verification of each splice and connection against maximum allowed loss and reflectance limits.

While an optical loss test set (OLTS) can verify length, loss and possibly ORL, it cannot locate and evaluate connectors and splices within the network. An OTDR is capable of also measuring length, loss and ORL, while additionally locating, identifying, and measuring the loss and reflectance of connectors, splices, splitters (in FTTH PONs), and defects such as breaks or macro-bends.

Operating like a radar, OTDRs transmit narrow pulses of light down the fiber measuring the time and amplitude of light backscattered or reflected from anomalies back to the OTDR. OTDRs can present a trace of returned backscatter and reflections vs. distance. A skilled operator can interpret this graph to identify splices, connectors, and the fiber end, measure the distance to each, and measure the loss or reflectance at each location. Manual settings allow the user to configure test range, select the pulse width, select test wavelengths, and adjust the averaging time, all of which affect the quality of the obtained trace. Wider pulse widths improve signal to noise ratio (SNR), but closely-spaced events may overlap and be interpreted as a single event. Longer averaging time also reduces noise in the traces, but at the expense of longer test times.

Intelligence integrated into today’s OTDRs has significantly reduced the skill required to configure an OTDR and interpret results. Auto-ranging selects optimal test range. Multi-pulse acquisition allows the OTDR to automatically test the network using multiple pulse widths, selecting the best traces to evaluate for each event. Most importantly, signal processing software interprets the trace, locating, identifying, and measuring length, loss, ORL, and the location, event type, loss, and reflectance of each event.

A ”LinkMap” view depicts detected events as a linear sequence of easily understood, color-coded icons, where each icon indicates the type of event and its pass/fail status (see Figure 5). Touchscreen navigation allows the user to pan along the LinkMap, viewing each event and its associated measurement results. Displayed results may be saved internally and uploaded via Bluetooth or Wi-Fi for often mandatory archiving and reporting. Some OTDR models even include integrated print to PDF capabilities for built-in report generation.

Often overlooked in OTDR model design are uncomplicated features which reduce required operator skill. These include auto-saving results, restoring last result and last-used setup on power-up, and auto-off and display auto-dimming to prevent draining the battery when it is left unattended.

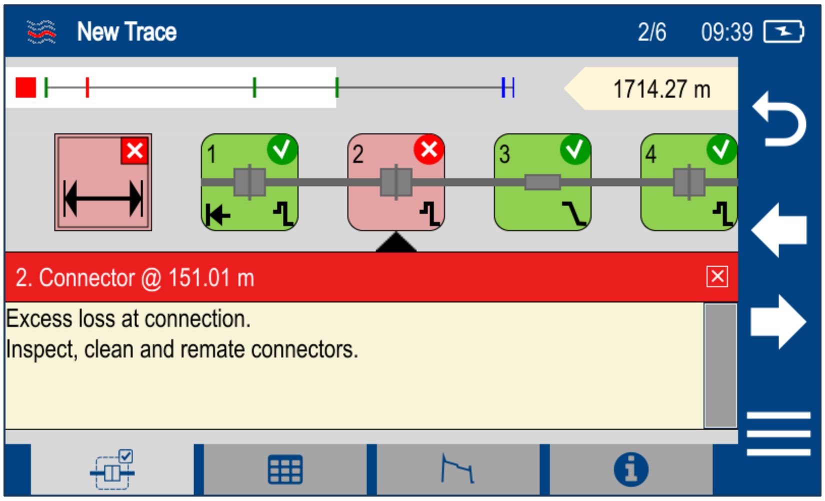


Figure 5 - Color-coded LinkMap icons identify detected events and pass/fail status.

3.5. Live PON Troubleshooting

Unlike point-to-point (P2P) transport networks, FTTH passive optical networks (PONs) utilize a point-to-multi-point architecture (PMP). In this architecture, a single feeder fiber carries both upstream and downstream traffic to/from the headend from/to an optical splitter (typically 1:32 or 1:64 split ratio) located close to subscribers' homes or apartments. Individual distribution and drop fibers can then connect splitter outputs to up to 32 or 64 subscribers.

In this architecture, one or more subscribers may lose service while others remain in service. When this occurs, a maintenance technician will likely need to troubleshoot the network from the subscriber's premise or an access point near the premise. A typical test procedure involves checking to see if the downstream signal from the headend is present at the access point or subscriber's terminal. If the downstream power level is absent or too low, but other customers remain in service, there is likely a fault in the distribution or drop fiber for that subscriber. If downstream power level is present and within expected min/max limits, the problem is likely the connection from the test point to the customer's optical network terminal (ONT), the ONT itself, or in-home connections.

Because PONs are a PMP system and all ONTs transmit upstream using the same wavelength and spectrum, they are allowed to transmit only in timeslots assigned to them by the optical line terminal

(OLT) in the headend. A consequence of this is measurement of an ONT's output power level cannot occur unless an OLT is simultaneously connected.

A through mode PON power meter (TPPM) can monitor the downstream and upstream signals as they pass through the test set. With a TPPM, a user can verify the presence and power level of both the upstream and downstream signals simultaneously. Once again, software intelligence can automatically apply pass/fail limits based on the test location and PON protocol, providing clear pass/fail indications to the user rather than requiring them to interpret power levels.

As PONs migrate from today's widely deployed GPON and EPON technology to 10Gb/s XG/XGS/10GE PON technology, additional downstream and upstream wavelengths using wavelength division multiplexing (WDM) will be utilized. This is intentional as it allows previously deployed GPON/EPON to coexist with emerging XG/XGS/10GE PON. A TPPM which identifies which wavelengths are present, measures each independently, and evaluates them against appropriate pass/fail levels reduces the skill level required to identify if PON signals are present and within acceptable power limits.

Figure 6 - PON power meter evaluates pass/fail of detected PON power levels.

Just as an OLTS cannot identify the location and cause of excess loss or reflection in a P2P network, a PON power meter cannot identify the root cause of absent or low PON power levels in an FTTH PON. An OTDR is well-suited for that task, but a traditional OTDR faces several challenges unique to PONs:

- If the PON is live and multiple customers remain in-service while one or a few are out of service, disconnecting the fiber at the headend or the input to the splitter will disrupt service to all subscribers.
- Additionally, when testing downstream through the splitter, backscatter and reflections from all 32 or 64 fibers connected to the splitter will be combined and overlap in the OTDR's trace. It is not possible to determine the backscatter or reflections contributed from each subscriber's distribution and drop cable, so results beyond the splitter are not useful.

- However, when testing in the upstream direction from the subscriber's premise, the OTDR pulses traverse only a single distribution and drop fiber before reaching the splitter, then continue through the single feeder fiber.
- The PON's PMP architecture means there may be live downstream signals present. These would normally interfere with an OTDR test in the upstream direction. To overcome this, live PON OTDRs (or troubleshooters) integrate a filter to block PON wavelengths and test using an out-of-band wavelength (typically 1625 or 1650 nm).

The newest generation of live PON troubleshooters combine both a downstream PON power meter supporting GPON/EPON, video and XG/XGS/10GE PON wavelengths, along with a live PON OTDR or troubleshooter capable of testing upstream to detect, locate and measure the loss and reflection of splices, connections, splitters, and faults. Once again, to reduce the skill level required of technicians activating and maintaining subscriber connections in a PON, built-in software intelligence compares downstream power levels, event loss and reflectance to pass/fail limits and provides clear pass/fail indications. A live PON troubleshooter may even recommend corrective action when poor splices or connections are detected.

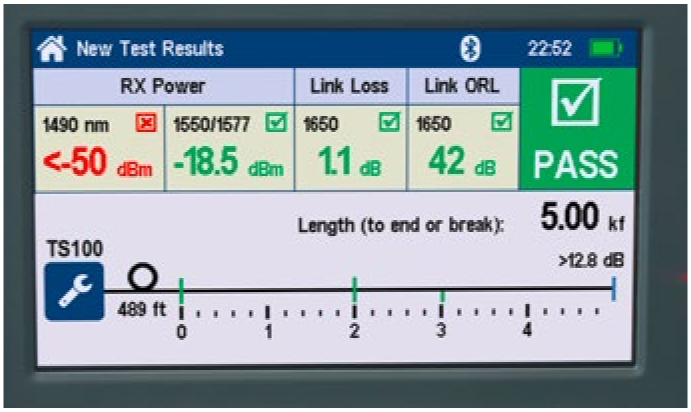


Figure 7 - Live PON troubleshooters provide clear pass/fail indications based on detected PON power levels, link loss, ORL and detected events.

4. Conclusions

The shortage of skilled fiber installation and maintenance technicians is well documented. Causes of the shortage and the service providers' need to meet bandwidth demand for residential, business and mobile backhaul services are also well understood. Numerous training programs have been created to grow the pool of skilled workers. Not as well documented are the technology-based improvements equipment manufacturers have been developing to reduce the skill and the time required to install and maintain fiber networks. Technicians and managers have a growing array of technology-based features to consider when selecting splicing, termination, inspection, cleaning, network verification and troubleshooting equipment for their growing, but less-skilled workforce. Easy-to-use products with built-in intelligence enable novice workers to deliver expert results.

5. Abbreviations and Definitions

5.1. Abbreviations

DAA	distributed antenna array
EPON	ethernet PON
FBA	Fiber Broadband Association
FOA	The Fiber Optic Association
FTTH	fiber to the home
GPON	gigabit PON
MSO	multiple system operator
OLT	optical line terminal
OLTS	optical loss test set
ONT	optical network terminal
ORL	optical return loss
OTDR	optical time domain reflectometer
PMP	point-to-multi-point
PON	passive optical network
P2P	point-to-point
SCTE	Society of Cable Telecommunications Engineers
TPPM	through-mode PON power meter
XG-PON	10Gb/s asymmetric PON
XGS-PON	10Gb/s symmetric PON
5G	fifth generation mobile network
10GEPON	10Gb/s ethernet PON

5.2. Definitions

Downstream	Information flowing from the headend to the user
Upstream	Information flowing from the user to the headend
Headend	Cable operator facility from which voice, data, video services originate
Node	Point at which coax or fiber splitter branches services to multiple subscribers
Patchcord	Fiber jumper used to interconnect equipment
Patch Panel	Connector panel enabling optical signals to be rerouted by reconnecting patchcords

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