EPON Architecture and Testing

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SUMMARY:

- Increase knowledge and skill set around FTTH / PON technologies and test procedures

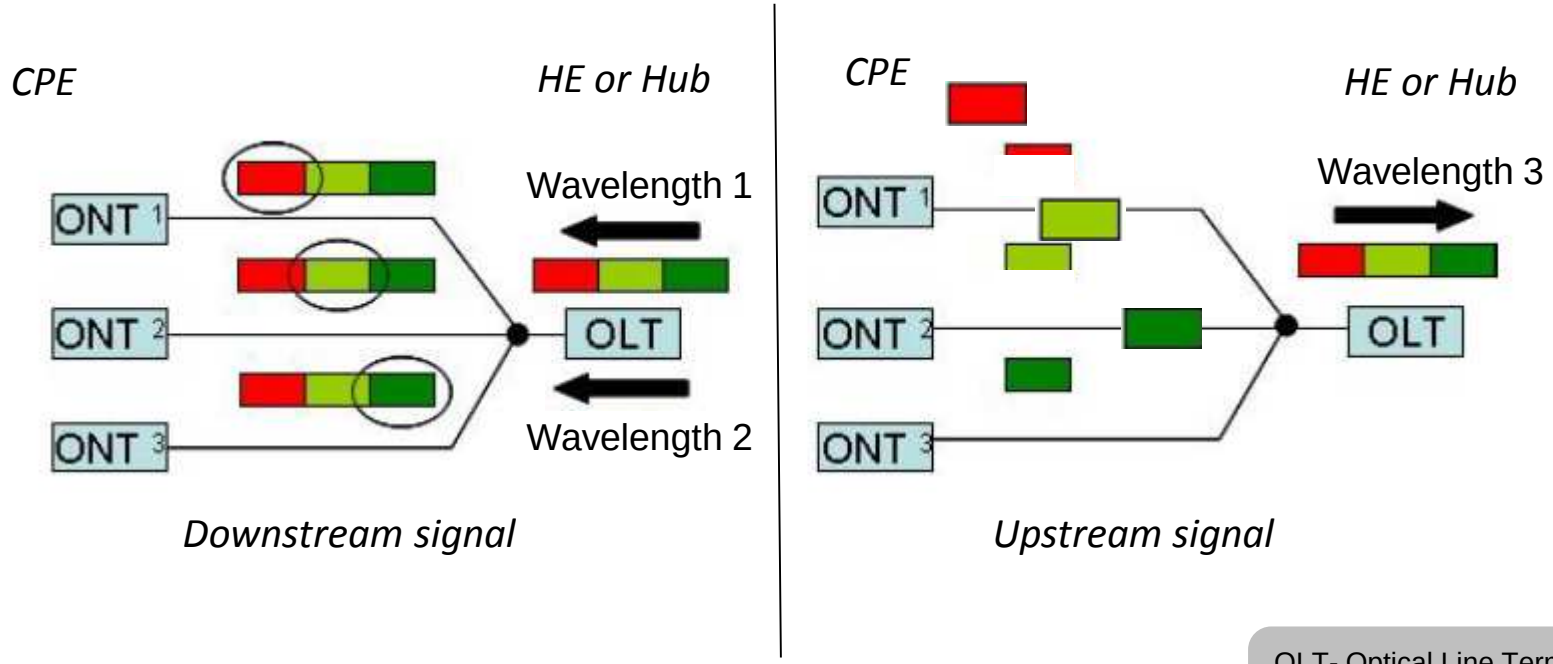
OUTLINE:

- FTTH/PON Introduction
  - Background
  - Architectures
  - Components
- FTTH Deployment and Maintenance Phases:
  - Construction
  - Service Activation
  - Maintenance
  - Service Performance
- FTTH Testing Tools
- Summary
- Q & A

FTTH / PON Introduction:

- Background
- Architectures
- Components

Why is the Passive Optical Network (PON) so Different?

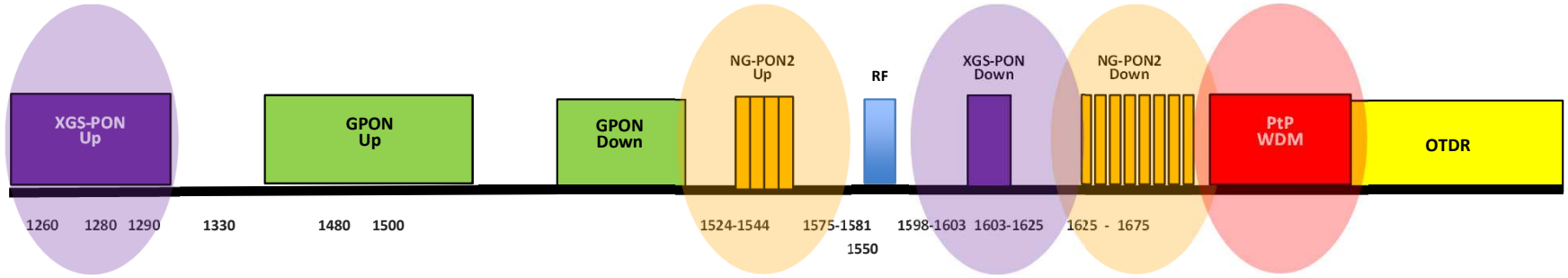


OLT- Optical Line Termination
ONU- Optical Network Unit
ONT- Optical Network Terminal

- Purely passive network
- Point to multi-point architecture
- Downstream data transmitted to all ONTs and filtered based on port ID
- Upstream uses Time Division Multiple Access (TDMA)
  - Each ONT gets a different time slot

PON Wavelength Allocation

- Today's **EPON & GPON** systems utilize 2 wavelengths for communication
  - Downstream 2.5 Gbps at 1490 nm
  - Upstream 1.2 Gbps at 1310 nm
- **RF overlay** at 1550 nm
- Overlay of 2 new λ for 10 Gbps services of **XGS-PON or 10G-EPON**
  - Downstream 10 Gbps at 1577 nm
  - Upstream 10 Gbps at 1270 nm
- **NG-PON2** supports multiple 10Gbps wavelengths
  - Downstream 4/8 x 10 Gbps at 4/8 TWDM wavelengths between 1598 – 1603 nm
  - Upstream 4/8 x 10 Gbps at 4/8 TWDM wavelengths between 1524 – 1544 nm
- Additional window for high speed **PtP WDM** channels: 1603 – 1625 nm
- Wavelength window for **in-service testing (OTDR):** 1625 nm – 1675 nm

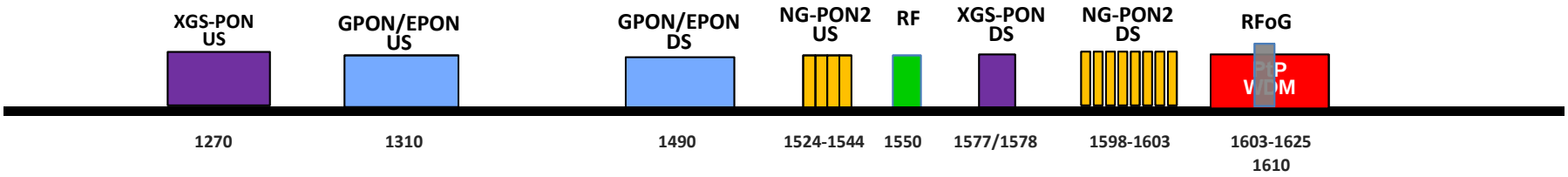


Source: FTTH EMEA D&O Committee FTTH Poland 2015

Current & Next Generation PON Standards

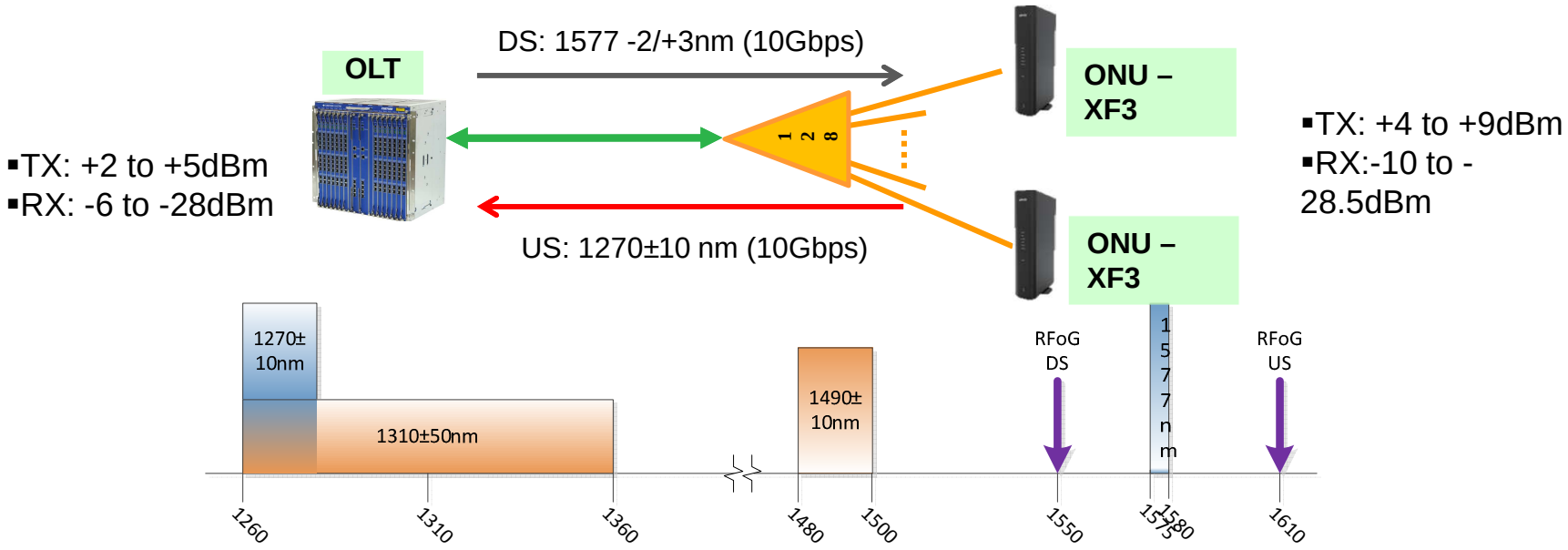
- Standards have been defined by ITU & IEEE:

	G-PON	XGS-PON *(sym)*	NG-PON2	GE-PON	10G-EPON	100G-EPON
Standards	ITU-T G.984 (2003)	ITU-T G.987.1 (2016)	ITU-T G.989 (2015)	IEEE 802.3ah (2004)	IEEE 802.3av (2009)	IEEE 802.3ca (2019 TBD)
DS / US Data Rates	2.5 / 1.25 GBps	10 / 10 GBps	40 / 10 GBps	1.25/1.25 GBps	10 / 10 GBps	Up to 100 /100
Wavelengths	1490 DS 1310 US	1578 DS 1270 US	1598-1603 DS 1524-1544 US	1490 DS 1310 US	1577 DS 1270 US	TBD
Split Ratio	up to 1:64	up to 1:128 (256)		up to 1:64	up to 1:128	TBD
Fiber Type	G.652	G.652 / G.657 (for new builds)		G.652	G.652 / G.657 (for new builds)	
Max Loss	**28 or 32dB**	**35 dB**	**35 dB**	**29 dB**	**29 dB**	**TBD**
Co-existence	N/A	YES with G-PON		N/A	Yes with GE-PON	

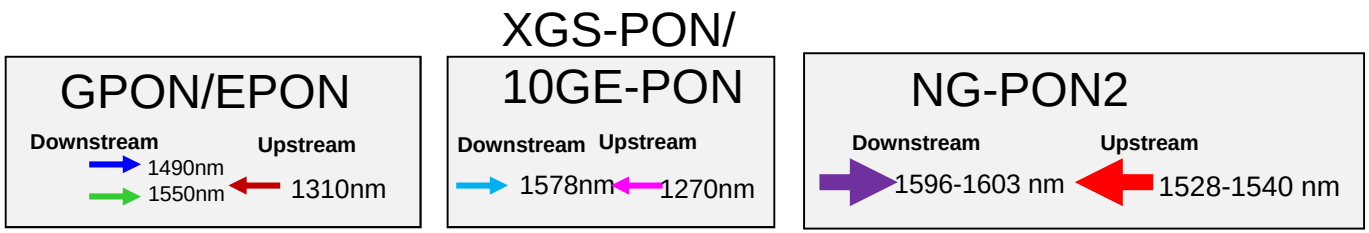


EPON US/DS Wavelengths

- An EPON system uses Wavelength Division Multiplexing (WDM) in order to achieve two way communication on a single fiber.
- Two multiplexing technologies are used:
  - Broadcast on the downstream flows (TDM)
  - TDMA on upstream flows



PON Coexistence Architecture




Mobile Backhaul


Data Center

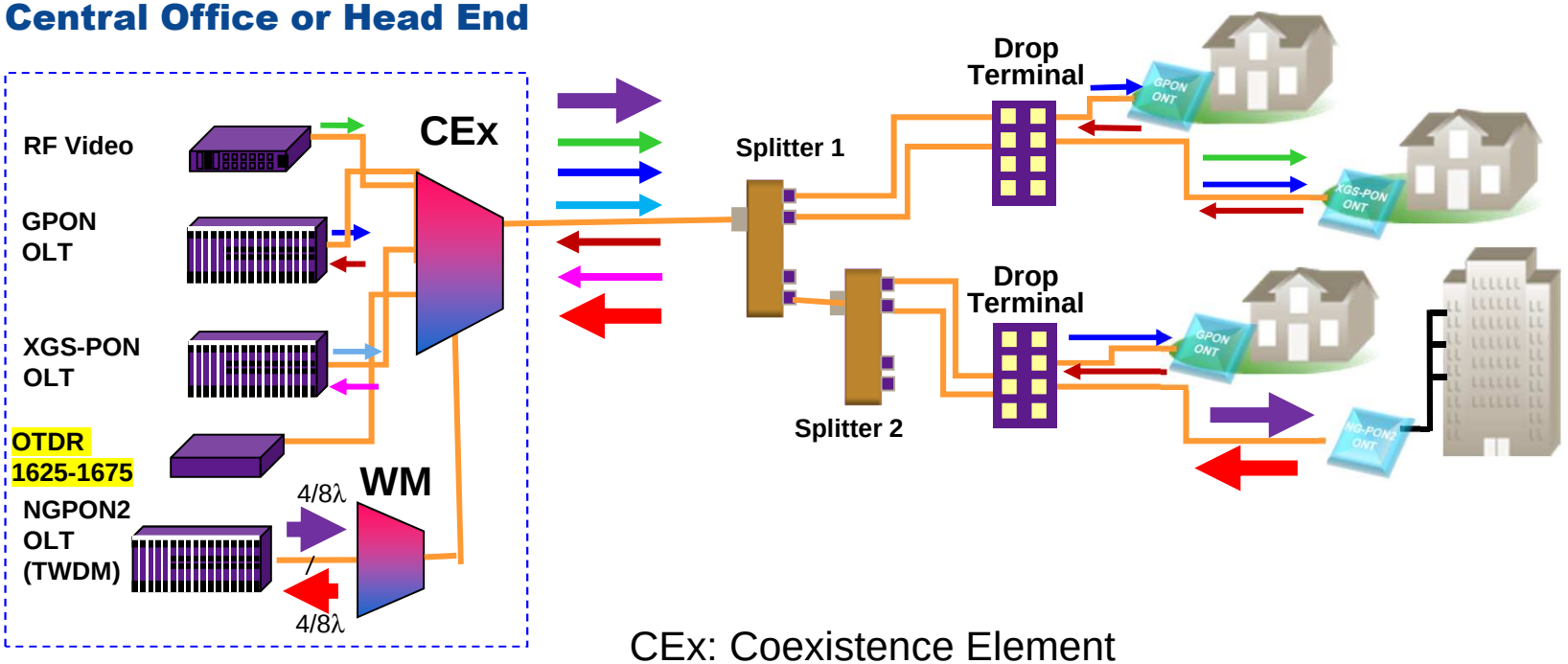

Office Park


Local Community


Cell Tower


Residential

Central Office or Head End

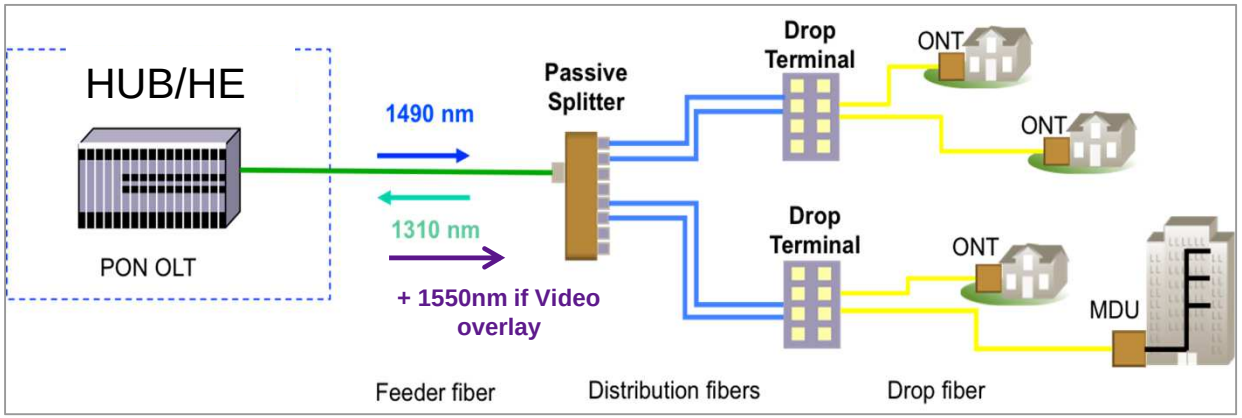


CEx: Coexistence Element
WM: Wavelength Multiplexer
OLT-Optical Line Terminal
ONU/ONT-Optical Network Unit/Terminal

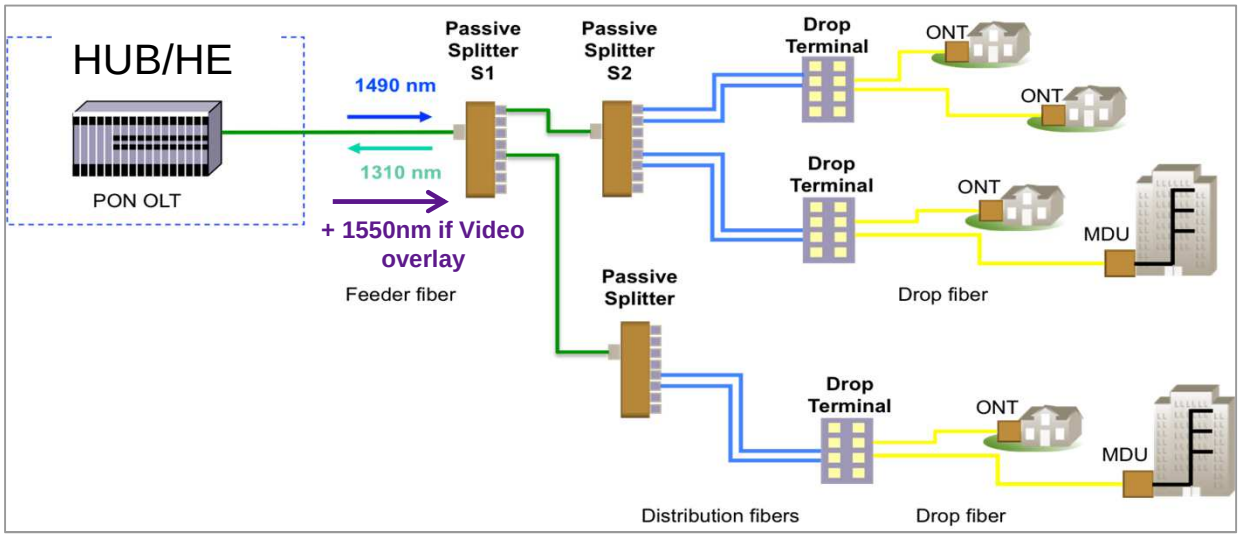
PON Architecture Splitters

- The larger the split ratio, the more attractive for the service provider
- Split ratios of up to 1x64 is common in today's deployments

Single Split



Cascaded Split



Splitter	Typical Insertion Loss
1 : 2	3-4 dB
1 : 4	8-9 dB
1 : 8	10-11 dB
1 : 16	12-13 dB
1 : 32	16-17 dB

PON Network ISP/OSP Elements

Optical Line Terminal

Optical Line Terminal (OLT)
- **Provides two main functions:**

1. Conversion of electrical signals to optical
2. Coordination and multiplexing of CPE ONU/ONTs
- **Located in the Headend**

Fiber Distribution Hub (FDH)
- **Houses the optical splitter(s)**
- **Provides fiber management**
- **Located in the OSP**

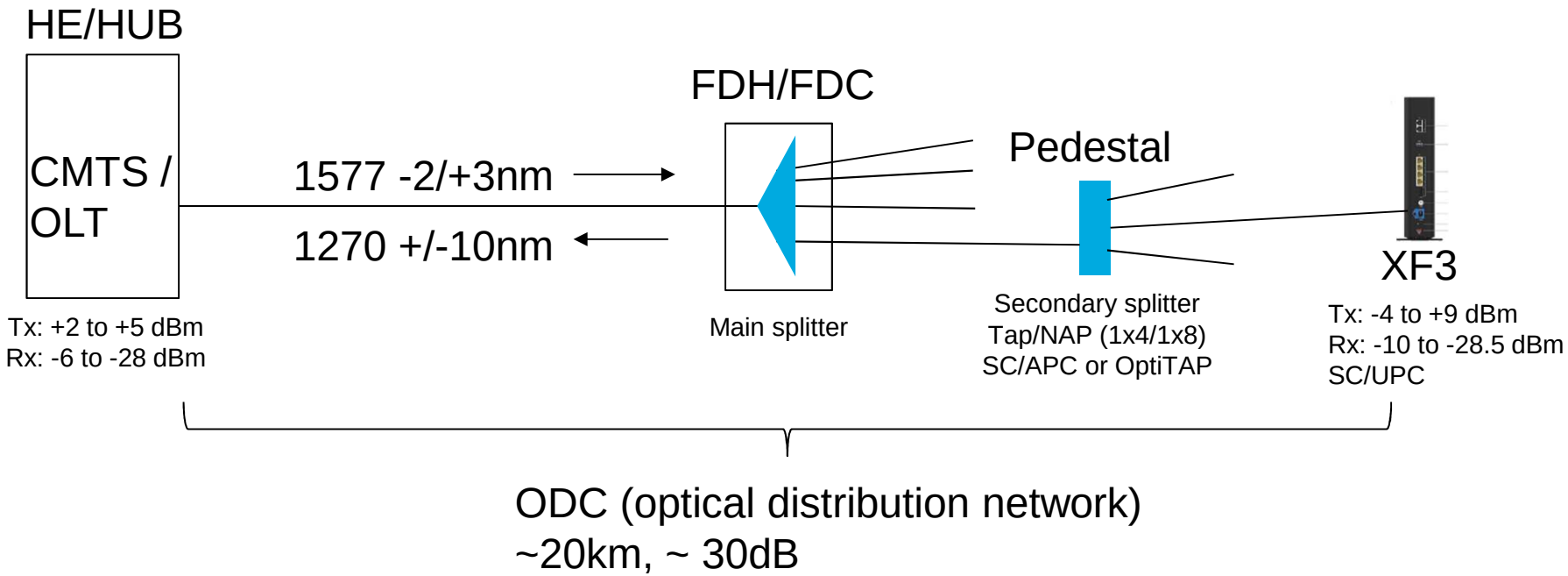
Optical Network Terminal (ONT)
- **Optical termination point**
- **Located at customer premise**

Optical Splitter
- **Passive component**
- **Typically a 1x32 split**

Drops
- **Distribution to customers**
- **Pre-terminated or field-built**

Comcast EPON Deployment

- Up to 1x128 splits
- OLT moving to Nodes in 2019
- Downstream: OLT broadcast using Logical Link ID (LLID) – XF3 only accepts its LLID
- Upstream: TDMA



EPON Technology Acronyms & Installation Terminology

FTTx Technology Acronyms

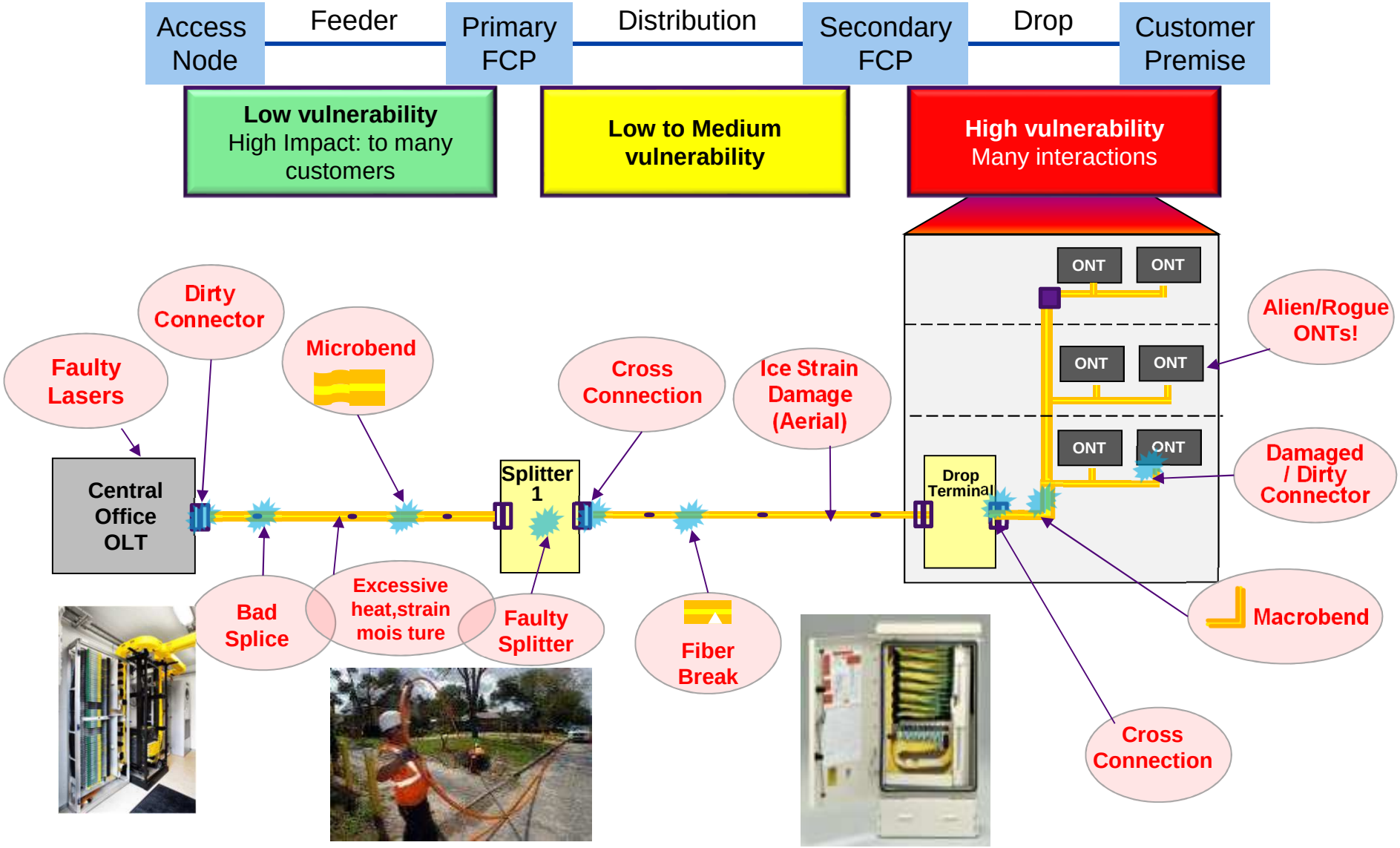
- RFOG – RF Over Glass
- PON – Passive Optical Network
- EPON – Ethernet Passive Optical Network
- OLT – Optical Line Terminal
- ONU – Optical Network Unit
- ODN – Optical Distribution Network
- FDC – Fiber Distribution Cabinet
- APC – Angle Polished Connector
- UPC – Ultra Polished Connector

EPON Installation Terminology

- Greenfield – Greenfield deployment designs are the installation and configuration of a new PON network where none existed before. New Developments.
- Brownfield – Brownfield deployment designs, in contrast, is an upgraded HFC network over to PON.
- GRAM – All-IP service delivery option that allow us to deliver our Video content via a stand-alone Gateway configuration. Eliminating the need for any QAM/Docsis Set-Top Devices; allowing the gateway to serve as the video controller.

Decisions & Challenges in Deployments

What Could Possibly Go Wrong?

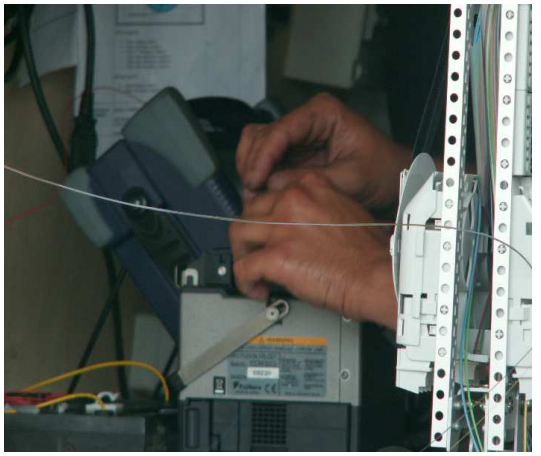


More Fiber = More Challenges

- Limited fiber expertise - traditional experience is with coax
- More fiber = more optical connections
  - 80% of all issues from dirty/damaged connectors
- Ribbon fiber and MPO/MTP connectors
  - 12, 24 or more fibers per ribbon/connector
- Not just simple point-to-point transmission
  - Multiple wavelengths
    - Standard broadband power meter inot able to measure service specific power levels
  - Point-to-multi-point with high loss optical splitters
- Bursty signals in upstream
- Managing multiple work groups both internal & contractors

***Be proactive**: your service is only as good as the highway it travels over. Implementing testing procedures and solutions may add more cost upfront but it will pay off in the long run!*

Connectorized vs. Spliced Network



- Connectorized
  - Lower cost, fewer technicians to deploy
  - Easier to test with many test access points
  - Easier to maintain and add/remove customers

Spliced Approach		Hardened Drop Connector Approach	
Hand-Hole Costs	$ 10,000.00	Hand-Hole Costs	$ 11,194.00
Cable Costs	$ 15,000.00	Cable Costs	$ 1,538.00
Cable Placing Costs	$ 75,000.00	Cable Placing Costs	$ 56,650.00
Splicing Costs	$ 9,072.00	Splicing Costs	$ 2,988.00
Terminal Costs	$ 0.00	Terminal Costs	$ 16,072.00
Total Costs	**$109,072.00**	**Total Costs**	**$ 88,442.00**
Cost/ Home Passed	**$ 568.08**	**Cost/ Home Passed**	**$ 460.63**

Specific cost model based on a phased project for a 192 home subdivision, featuring eight homes per block.

Source: ADC

Number of ports	Insertion loss
2	3 dB
4	6 dB
8	9 dB
16	12 dB
32	15 dB
64	18 dB

- Spliced
  - Lower loss
  - More rugged (connector is the #1 issue on FTTH)
  - More secure
  - More difficult to test with fewer test access points

➔ **Both methods are valid and are used worldwide**

Fully Configurable vs. Pre-configured Cabling

- Fully configurable cable
  - Very flexible but more expensive to install
    - Was used by most of the first FTTH players
  - Complete acceptance testing required

- Pre-configured cable
  - Cost effective solution but less flexible
  - More inventory required (different lengths)
  - Most of the testing performed at the factory

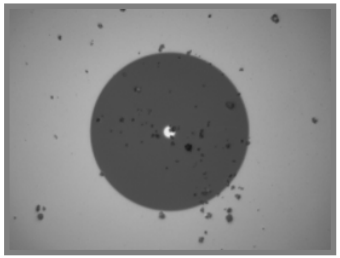
➔ **Both methods are valid and are used worldwide**

Tight Loss Budgets

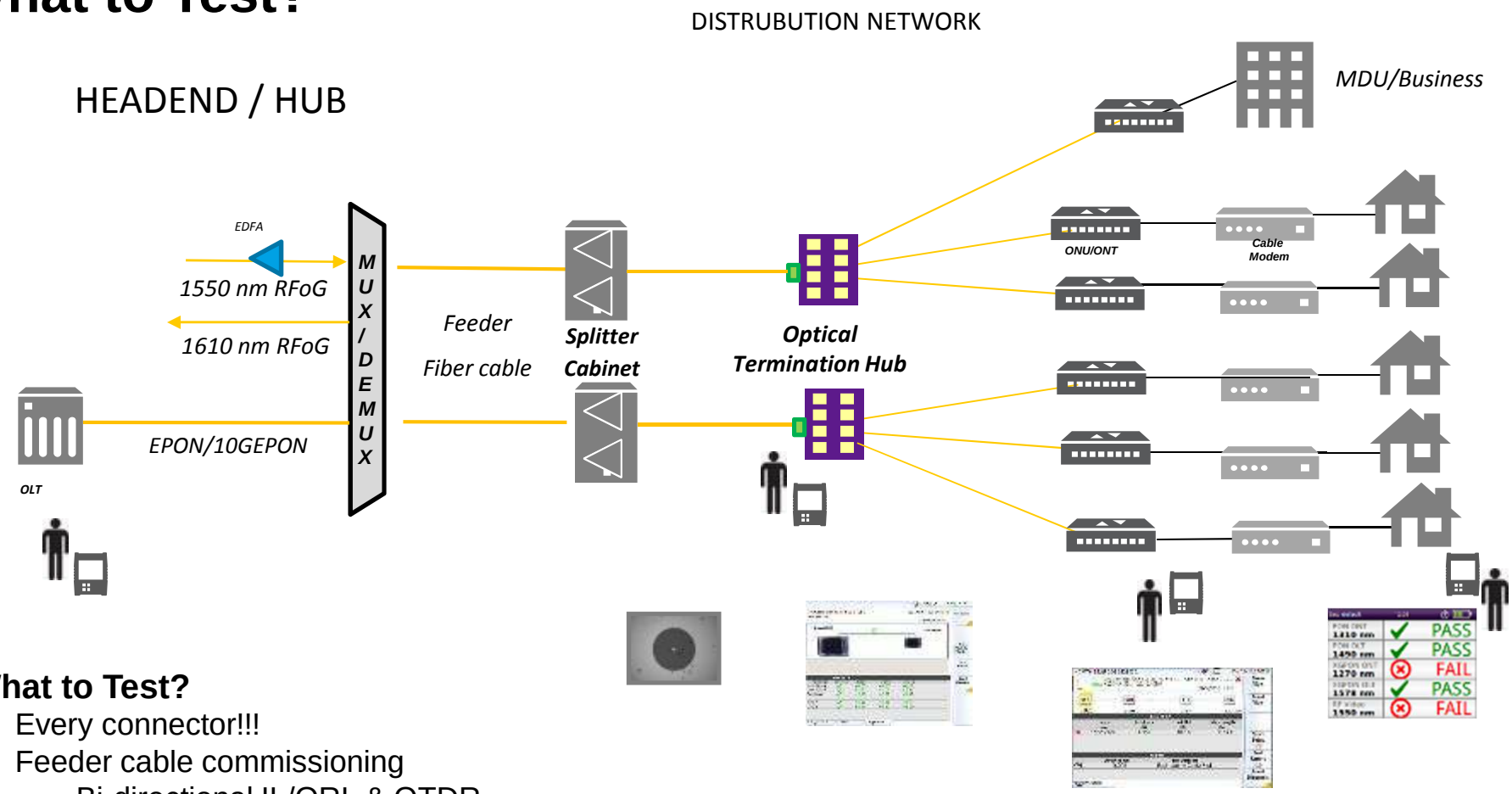
Loss Budget Calculation Analysis		Qty	Total
OLT SC/APC Adapter	0.25dB	1	0.25
ODF SC/APC Adapter	0.25dB	1	0.25
ONT SC/APC Adapter	0.25dB	1	0.25
Splitter SC/APC Adapter	0.25dB	1	0.25
Splice loss	0.1dB	3	0.3
Splitter Loss 1:8	9.5dB	2	19.0
Fiber Loss @ 1550nm (15Km Typ.)	0.21dB/Km	15km	3.15
Total Link Loss			**23.45dB**
Typ. Max Allowed in GPON			**25dB**
Budget Head Room			**1.55**

1 bad splices = 2 dB
1 dirty connector = 5 dB!

Back Reflection = **-32.5 dB**
Total Loss = **4.87 dB**



What to Test?



What to Test?

- Every connector!!!
- Feeder cable commissioning
  - Bi-directional IL/ORL & OTDR
- Power levels for service activation
- Live troubleshooting with Filtered, out-of-band OTDR

Where to Test?

- End-to-end feeder fiber
- At termination hub or House
- Troubleshooting at customer prem or termination hub

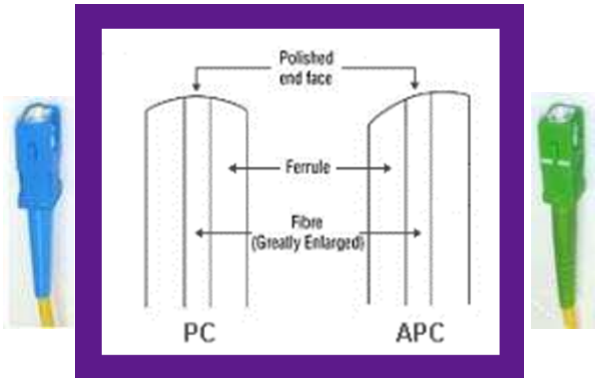
Typical Values

- **Attenuation Loss (dB/km)**
  - 1310nm (single mode) 0.35 dB/km
  - 1550nm (single mode) 0.2 dB/km
  - 1625nm (single mode) 0.25 dB/km
- **Event Loss (dB)**
  - Fusion splice 0.05 dB
  - Mechanical splice 0.3 dB
  - Connector pair (FOTP-34) 0.5 dB
- **Reflectance (dB)**
  - PC connector -55 dB
  - APC connector up to -65 dB
- **ORL (dB)**
  - 20's are bad
  - >30dB ok, often >40 to 45dB
- **Macrobend**
  - varies w/ degree of bend and wavelength
  - **Longer wavelengths are more sensitive to macrobends**
- **Typical Splitter Losses**

Split	Typical Insertion Loss
1 : 2	**3-4 dB**
1 : 4	**8-9 dB**
1 : 8	**10-11 dB**
1 : 16	**12-13 dB**
1 : 32	**16-17 dB**

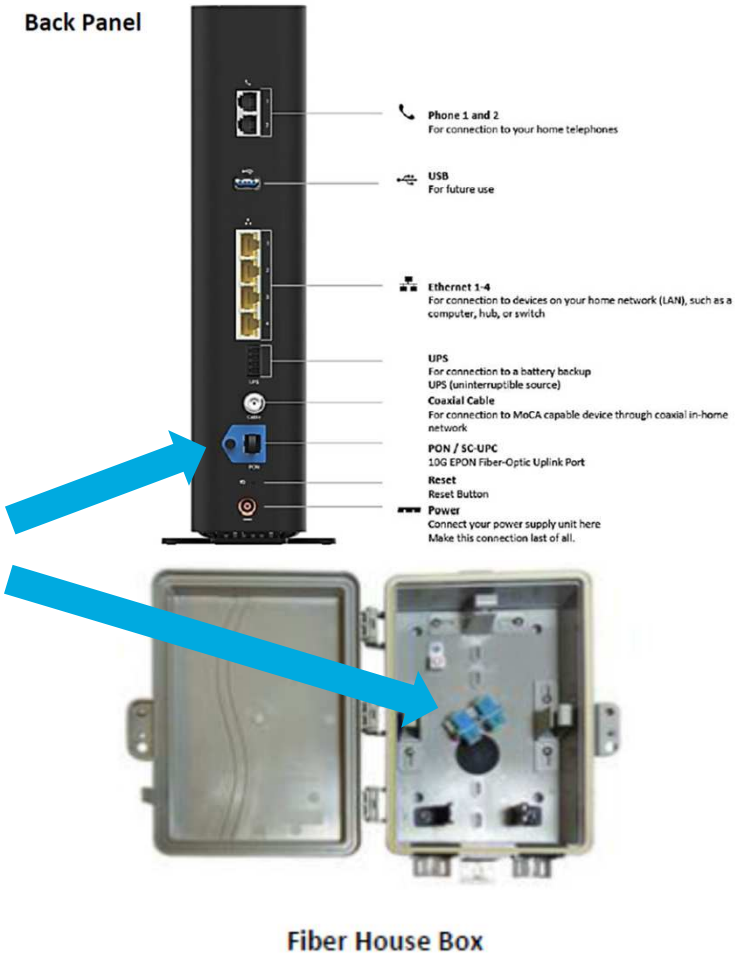
Connector Inspection
All Phases

Connectors



Blue = SC/UPC
Green = SC/APC
Blue ≠ Green!

SC/UPC



Fiber House Box

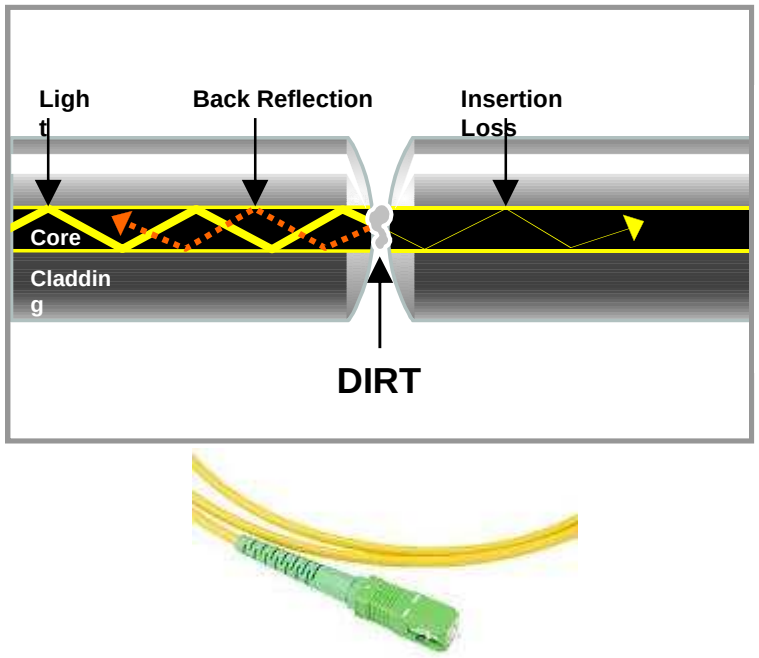
DROP CABLES

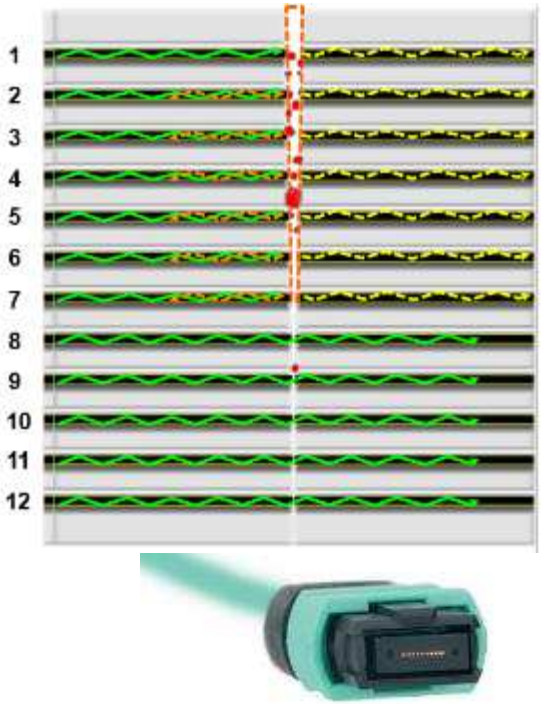
OptiTap

Plug & Play or Plug & Pray?

CONTAMINATION is the #1 source of troubleshooting in optical networks.

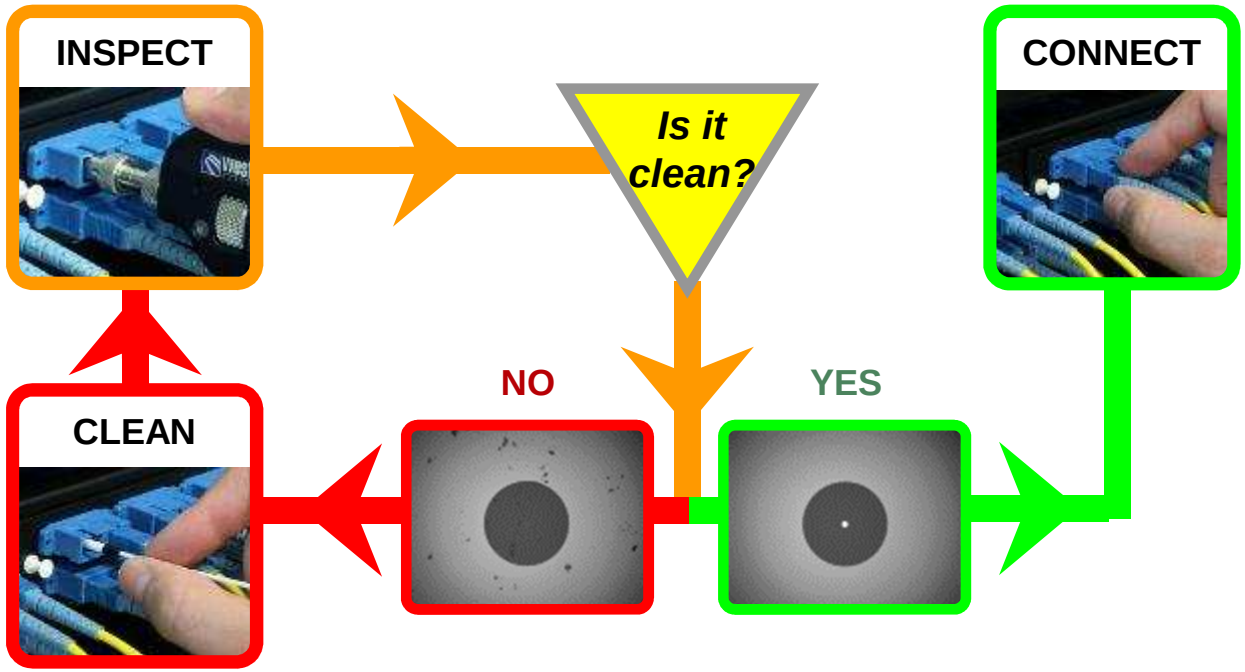
Responsible for around 80% of failures





Inspect Before You Connect

Fiber connectors are widely known as the **WEAKEST AND MOST PROBLEMATIC** points in the fiber network.



Inspecting <u>BOTH</u> sides of the connection is the **ONLY WAY** to ensure that it will be free of contamination and defects. A simple process with big benefits.

Inspect Before You Connect

Direct View Scopes (aka “Eyeball” Scopes) – NOT RECOMMENDED

- **Potential safety hazard**
  - eye damage if tech mistakenly connects a live fiber
- **Incomplete Inspection**
  - Allows inspection of Patch Cord side only
  - Leads to cross-contamination- even if patch cord side is cleaned when connected into dirty bulkhead fiber both sides of fiber connection become dirty

Inspecting <u>BOTH</u> sides of the connection is the **ONLY WAY** to ensure that it will be free of contamination and defects.

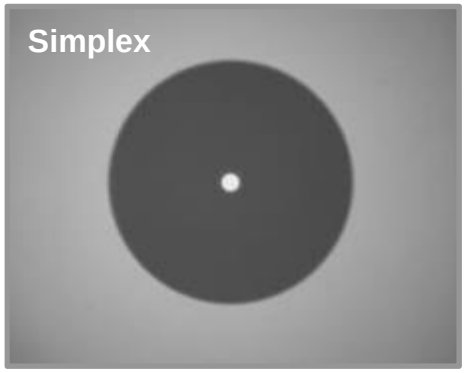
+

Fiber House Box

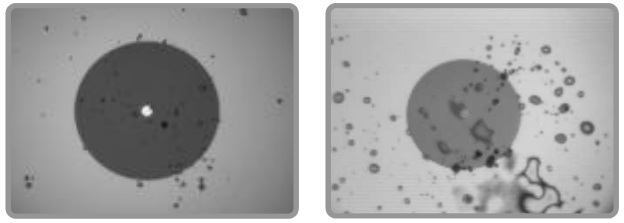
OR

Types of Contamination

A fiber end-face **should be free of any contamination or defects,** as shown below:

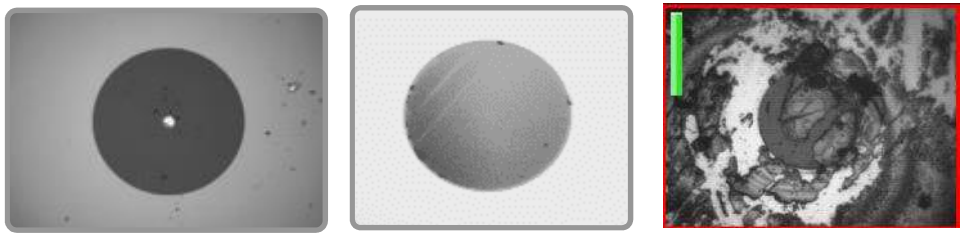


Common types of contamination and defects include the following:



Dirt **Oil**

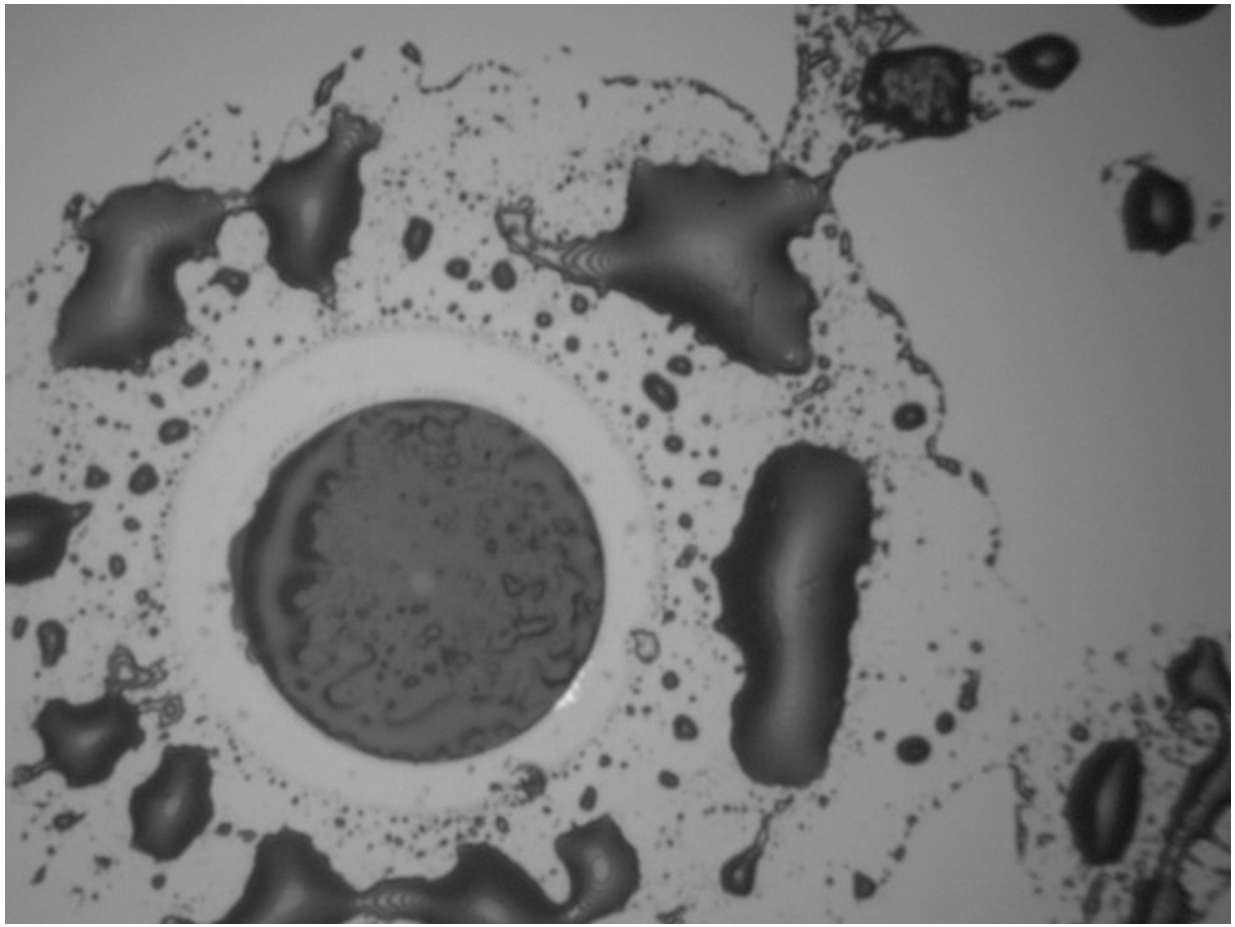
Can be proactively cleaned



Pits & Chips **Scratches** Burned on contamination from EDFA

The damage is already done

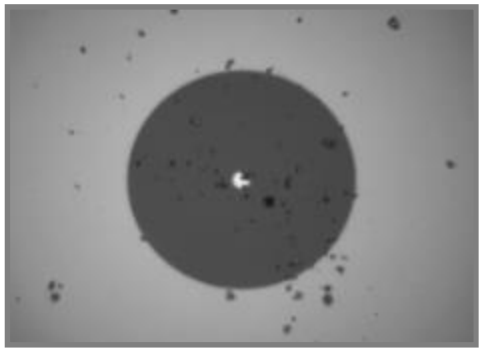
Oil Transfer



When a clean fiber is connected to a contaminated fiber, note the transfer of dirt and the ring just outside of the cladding showing the 200 micron contact area.

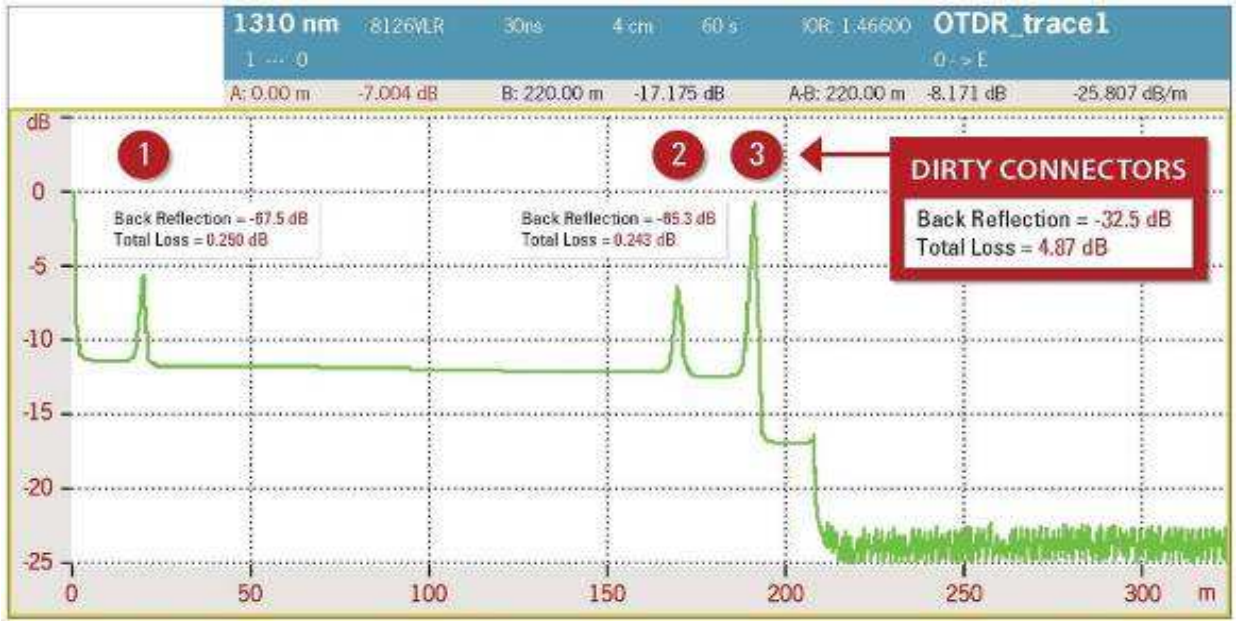
Contamination and Signal Performance

Back Reflection = **-67.5 dB**
Total Loss = **0.250 dB**



Back Reflection = **-32.5 dB**
Total Loss = **4.87 dB**

Fiber Contamination and Its Affect on Signal Performance



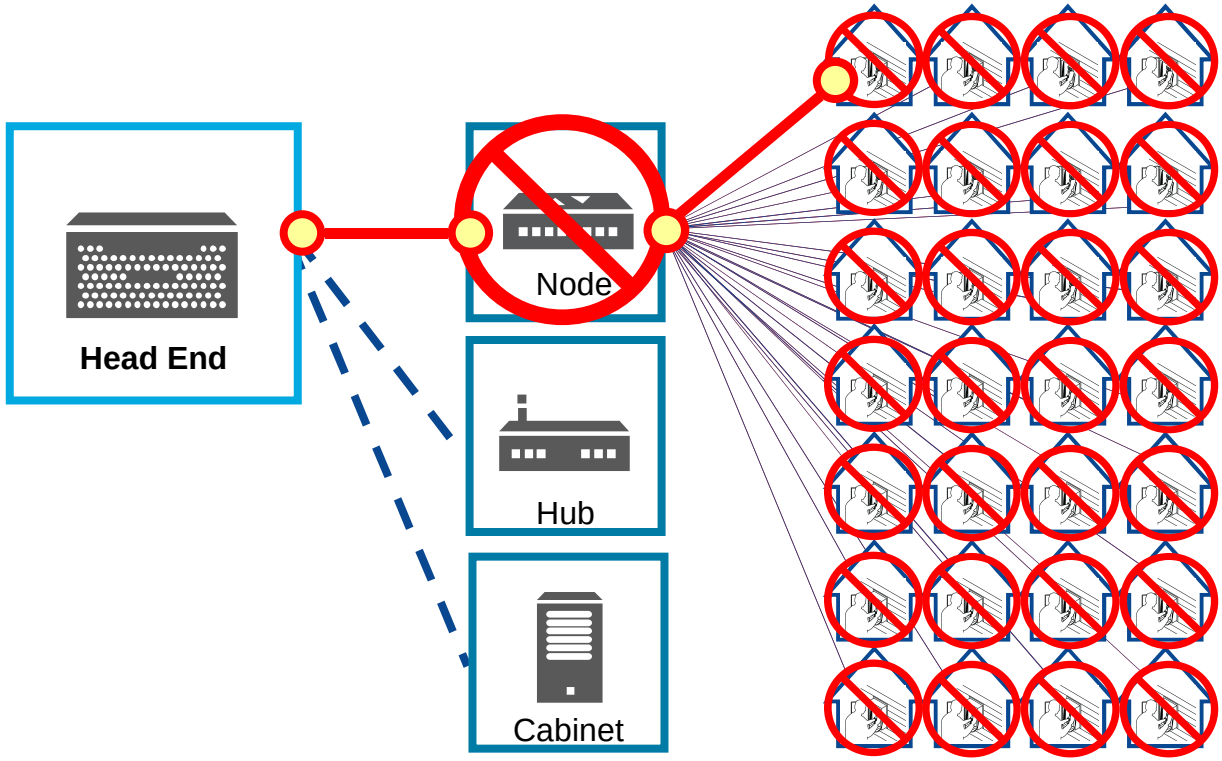
Clean Connection vs. Dirty Connection

This OTDR trace illustrates a significant decrease in signal performance when dirty connectors are mated.

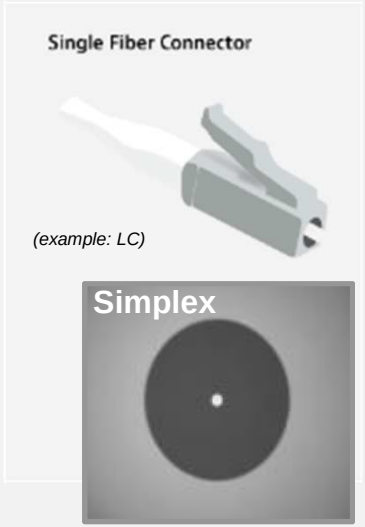
Don’t Forget Your Test Set Ports and Launch Cables!!

Potential Impact of a Dirty Connector

If **CONTAMINATION** is present at the HE or Hub, the impact can be exponential and much more problematic.

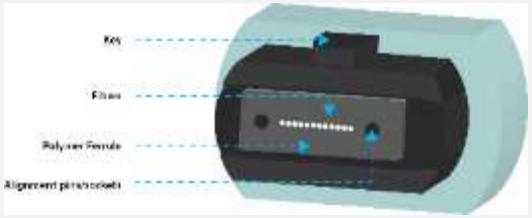


Single Fiber vs. Multi-Fiber Connectors



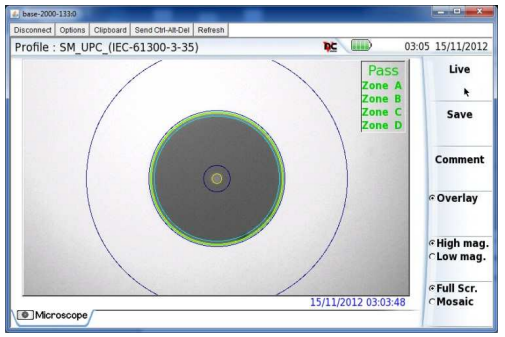
- White ceramic ferrule
- One fiber per connector
- Common types include SC, LC, FC, and ST

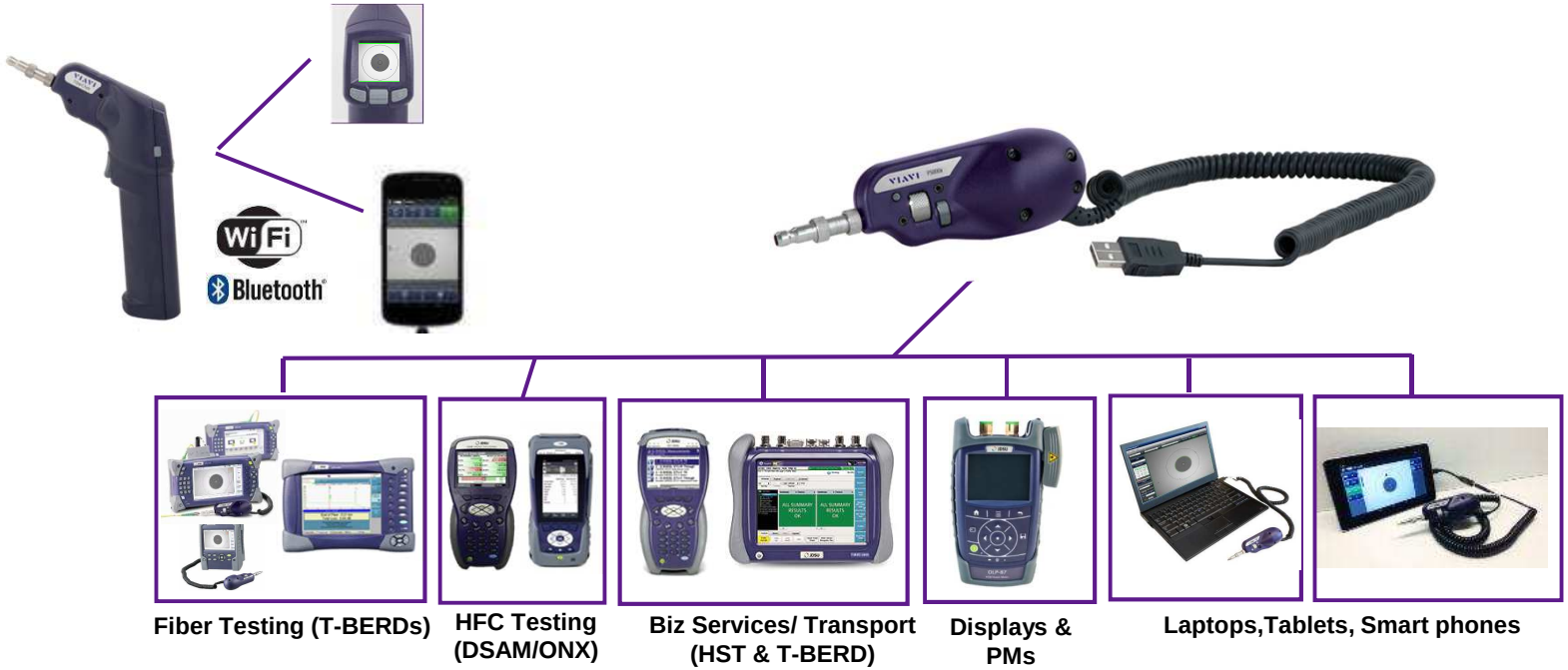
- Polymer ferrule
- Multiple fibers in linear array (for example, 8, 12, 24, 48, and 72) in single connector providing high-density connectivity
- Common type is MPO or MTP®



Selecting the Right Fiber Inspection Tools

- Save time and frustration with **AUTO-FOCUS** and **AUTO-CENTERING** of the Fiber
- **AUTOMATED PASS/FAIL** results
- Certifies to **INDUSTRY STANDARDS SPECIFICATIONS (IEC61300-3-35)**
  - Ensures everyone gets the same results
- **WIDE RANGE OF TIPS** to cover different connectors and access requirements
- Fast and Easy Report **DOCUMENTATION**

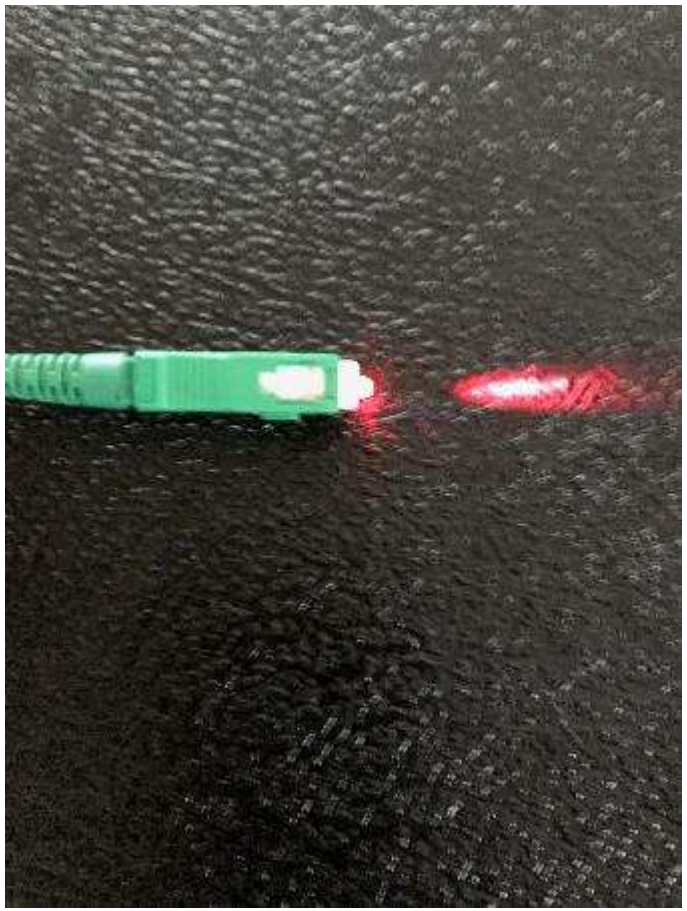


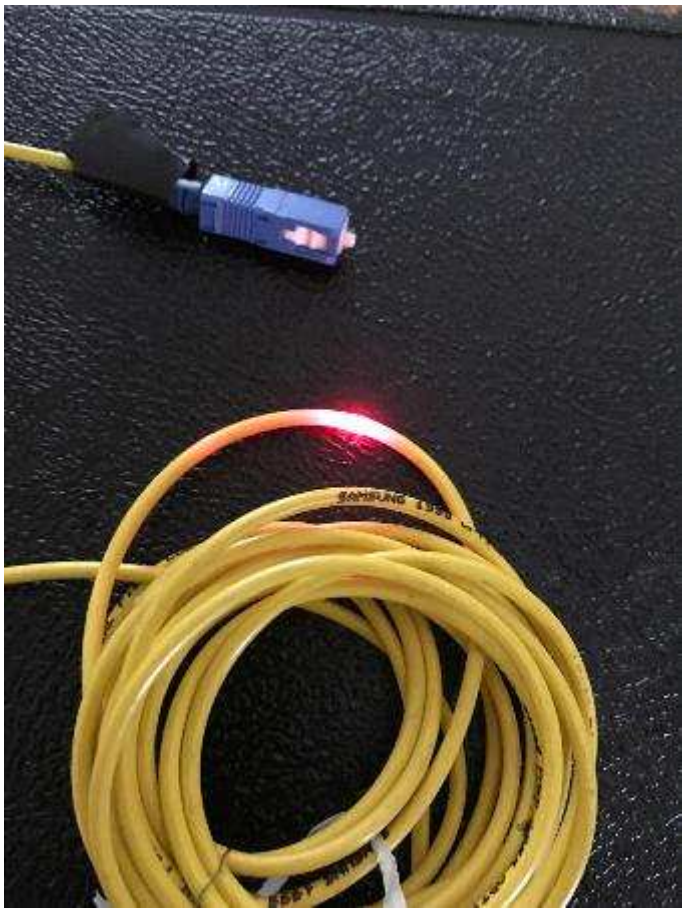


Power Meters for PON/FTTH

- Construction
- Turn-up / Service Activation
- Maintenance

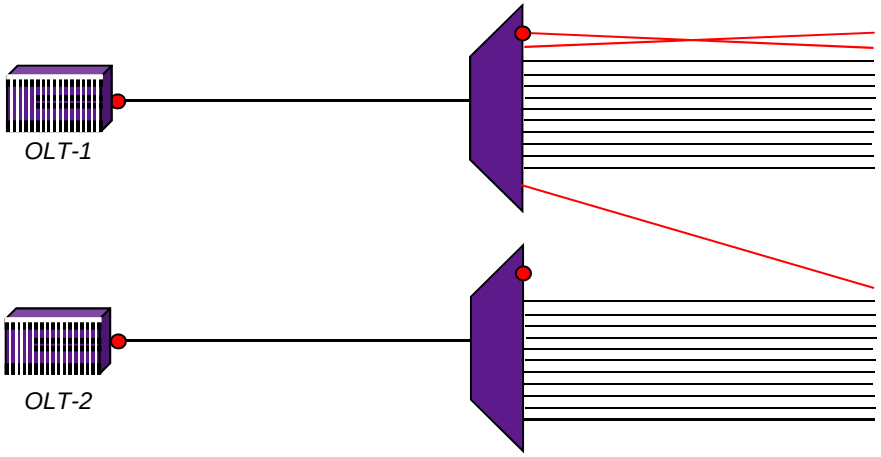
Visual Fault Locator (VFL)





Useful for verifying field-installed connectors and continuity

Patching Customers Correctly



Issue with Customer ID by field tech…

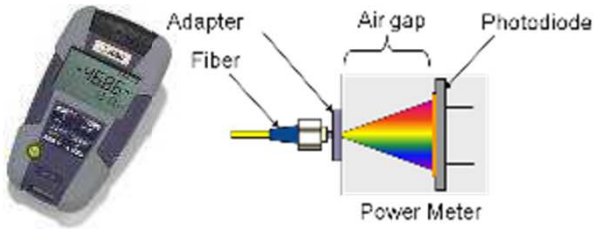
Implement a continuity test during installation phase

VFL

- If continuity is not checked during installation phase:
  - Incorrect connections will not be found until ONT is turned-up -> dispatch
  - A customer who has been patched incorrectly might be brought down-> customer dissatisfaction
- Continuity tests reduce OPEX and customer dissatisfaction
- Use a **Visual Fault Locator (VFL)** for quick verification of continuity during installation (avoid cross connects)

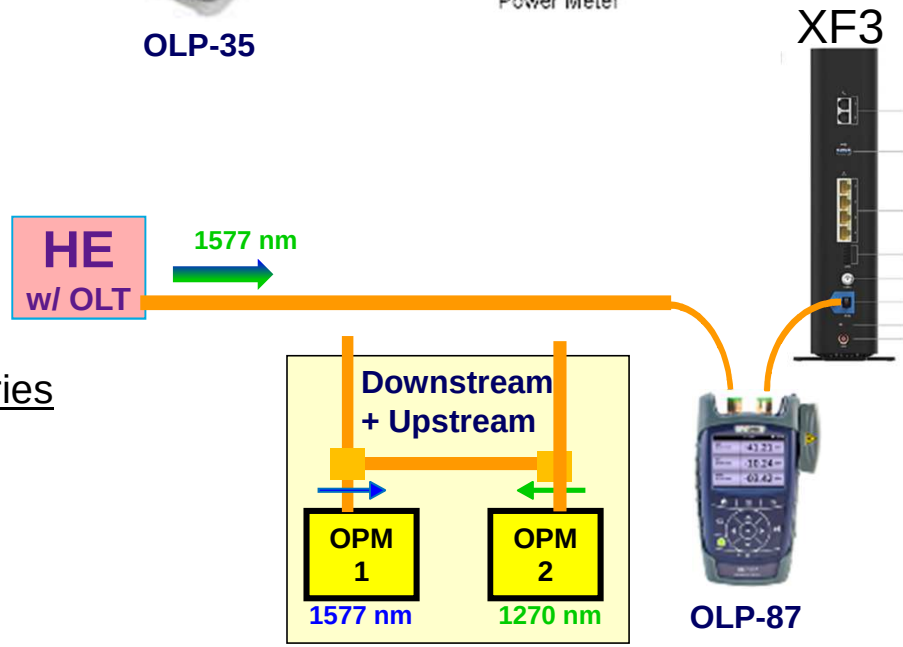
Selecting the Right Power Meter for the Application

- **Broadband Power Meter**
  - Only 1 wavelength can be on fiber
  - Good for downstream measurement only
  - Measures average peak power



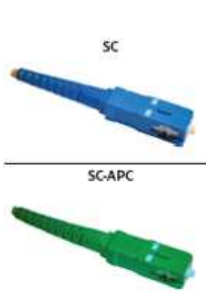
OLP-35

- **PON Power Meter**
  - Performs two functions:
    1. Has ability to isolate and measure multiple downstream wavelengths simultaneously
    2. Has the ability to be inserted in-series to measure downstream and upstream signals
       - Upstream signal is TDM and requires BURST measurement capability



OLP-35 Power Meter

- **Broadband** Power Meter
  - your “traditional” power meter
  - Runs on AA Batteries
  - Screw on/off Universal Push/Pull (UPP) interface adapters
    - 2.5 mm interface standard (for SC, ST, FC)
    - 1.25 mm interface available (for LC)
  - Ability to customize and store 5 wavelengths
    - 1578nm for EPON

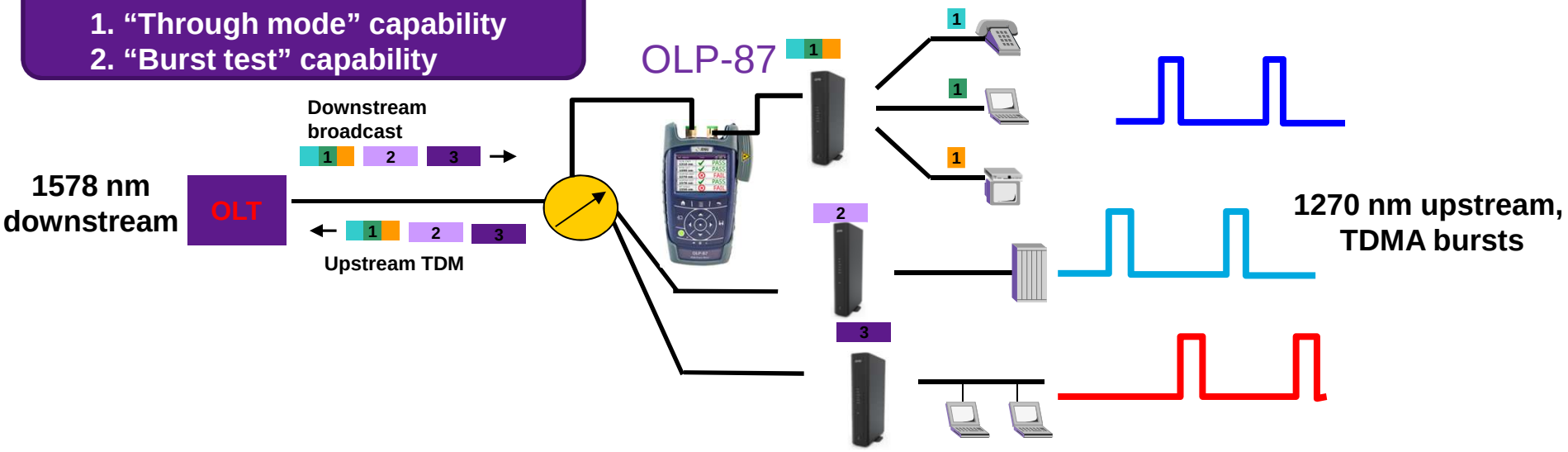


UPP

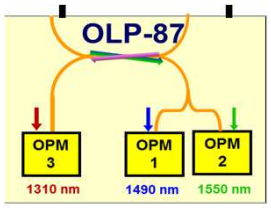
2.5mm

Verifying Upstream Power Level (XF3)

Advanced PON Power Meters:
1. “Through mode” capability
2. “Burst test” capability

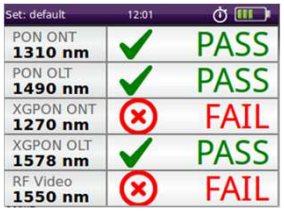


- **The XF3 MUST see the downstream 1578 nm wavelength before activating the upstream wavelength(s) at 1270nm**
  - A PON PM w/ through mode allows OLT ⇔ XF3 communication to be established so the upstream wavelength(s) will activate
- **Upstream signal active only in predefined time slots (framed)**
  - Must be able to accurately measure power level for a BURSTING upstream laser (intermittent on/off)



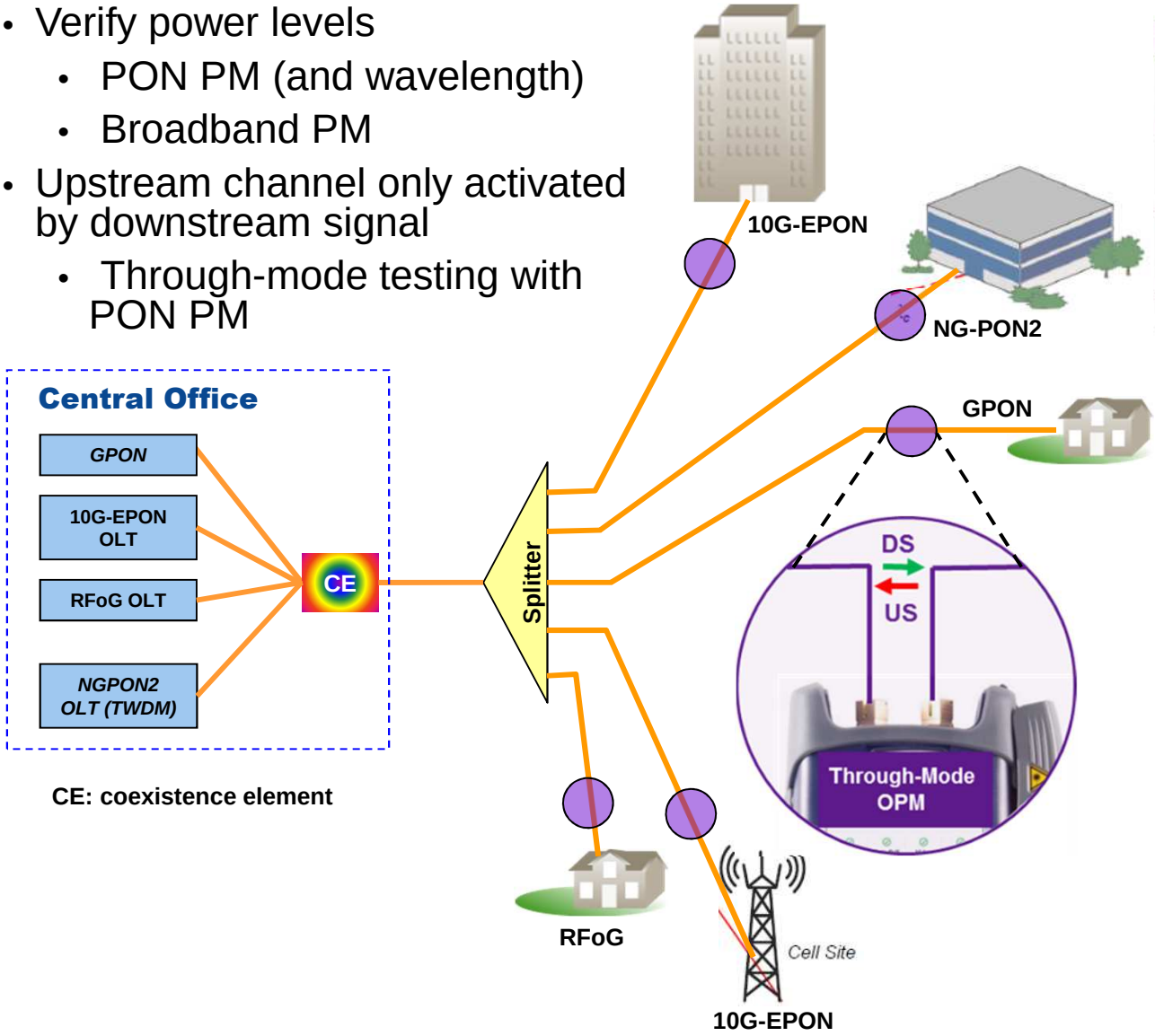
FTTx power meter shows average peak level

Standard power meter shows average level

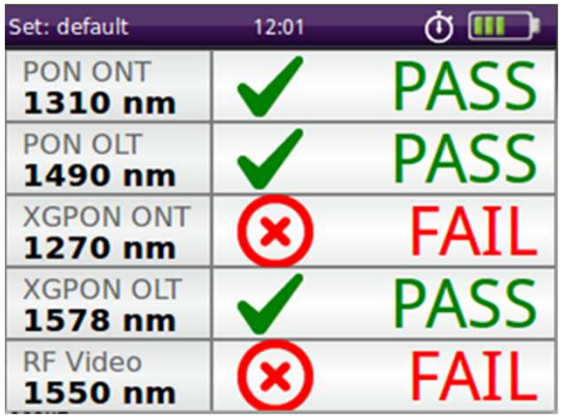


PON Service Activation Testing

- Verify power levels
  - PON PM (and wavelength)
  - Broadband PM
- Upstream channel only activated by downstream signal
  - Through-mode testing with PON PM



CE: coexistence element



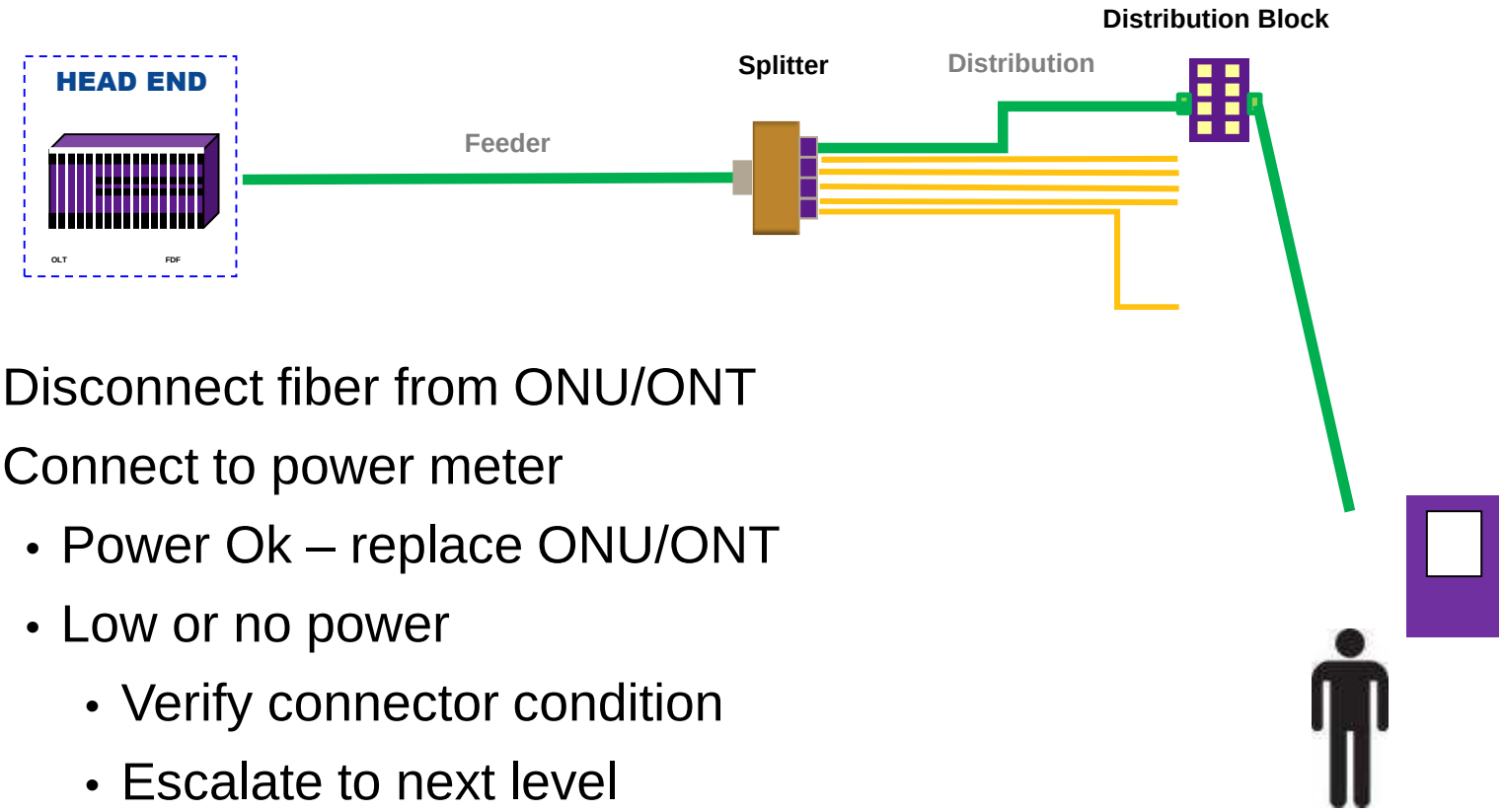
FTTH Maintenance

- **Level 1:** Verify power level at ONU/ONT
  - Connector microscope
  - *Broadband power meter*

- **Level 2:** Verify individual service power levels and ONU/ONT operation
  - Connector microscope
  - PON power meter

- **Level 3:** Troubleshooting no power and fiber issues
  - Connector microscope
  - PON OTDR with 1650nm

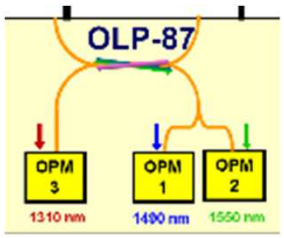
Level 1: Maintenance – Verify Power Levels at ONU/ONT



- Disconnect fiber from ONU/ONT
- Connect to power meter
  - Power Ok – replace ONU/ONT
  - Low or no power
    - Verify connector condition
    - Escalate to next level

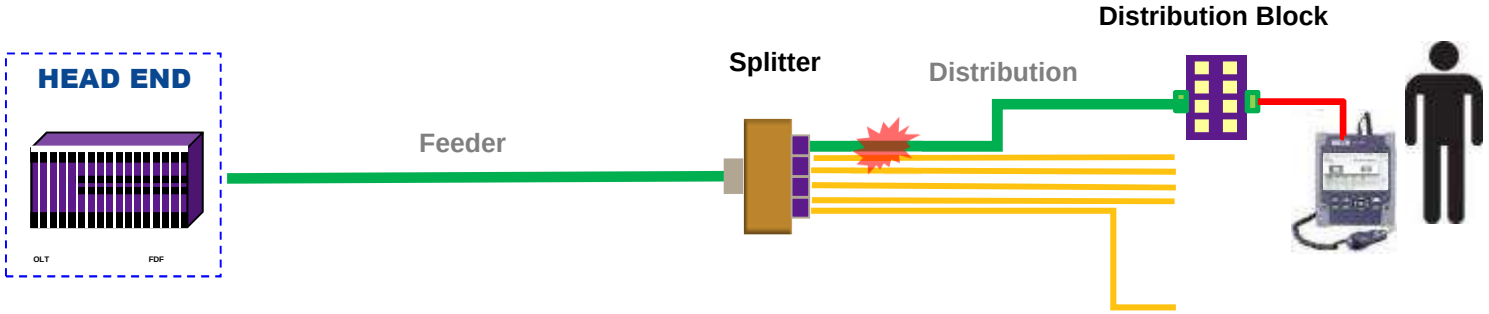
Level 2: Maintenance – Verify Individual Service Power Levels and ONU/ONT Operation

Block Diagram

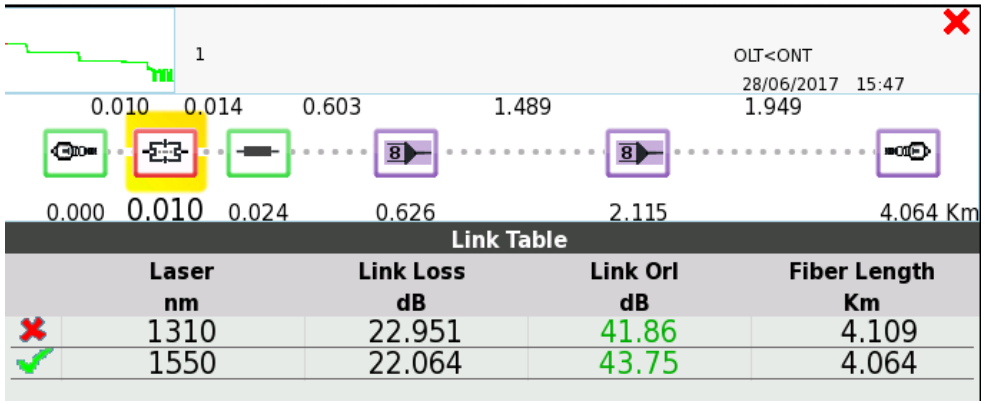


- **ONU/OLT <u>MUST</u> see downstream wavelength <u>before</u> activating upstream wavelength(s)**
  - A PON PM w/ through mode allows OLT ⇔ ONU/OLT communication to be established so the upstream wavelength(s) will activate
- **Upstream signal active <u>only</u> in pre-defined time slots (burst)**
  - Must be able to accurately measure power level for a BURSTING upstream laser

Level 3 Maintenance – Troubleshooting No Power and Low Power Scenarios



- Connect OTDR from customer premise to find the break or cause of low power
  - If low power, 1650 nm filtered OTDR is required
  - If no power, any OTDR will work
  - *Note: if testing through the optical splitter, a PON optimized OTDR is required*



- *1625nm filtered OTDR modules are available (traditionally used for PON) but can be too close to the 1610nm upstream used in RFOG. 1650nm filtered can be used for BOTH RFOG and PON troubleshooting…as well as NG PON

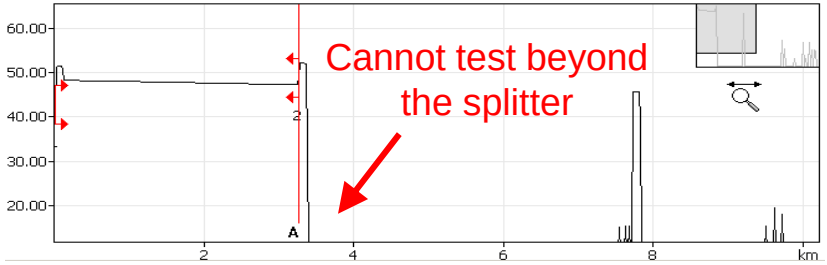
OTDRs for PON/FTTH

- Construction
- Maintenance

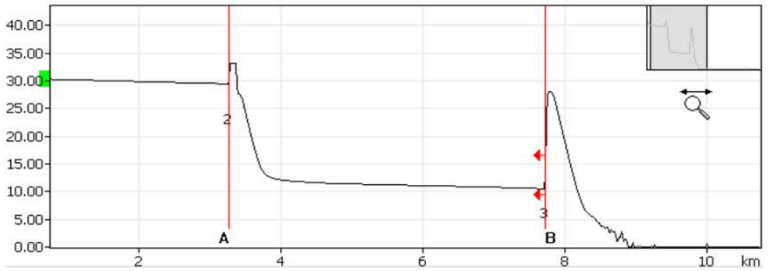
Selecting the Right OTDR for PON Testing

- High dynamic range:
  - Typically >37 dB
- Short dead zones:
  - Required to characterize closely spaced events
- Short Recovery:
  - Must be able to see events after the splitter (high loss)
- Optimized software to correctly identify optical splitters

Standard OTDR:



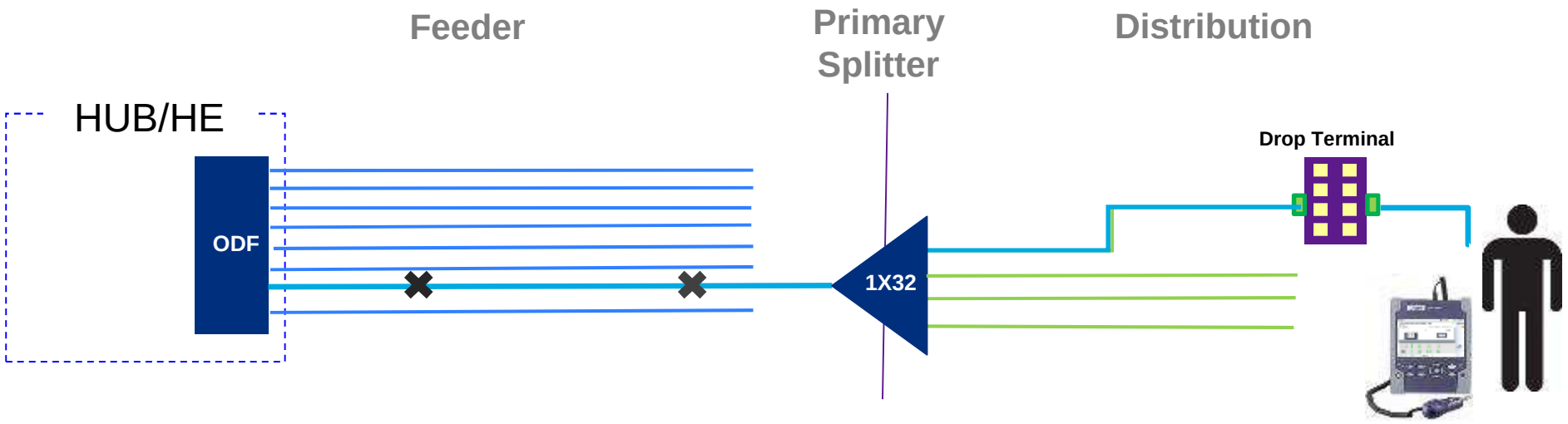
PON-optimized OTDR:



Selecting the Right OTDR for PON Testing

- Wavelengths:
  - Construction: 1310/1550nm
  - In-Service Maintenance:
    - Filtered OTDR port
    - Out-of-band 1625nm or 1650nm (preferred)
    - Does not disrupt other customers
- Ability to generate pdf reports

Testing from the Customer Premise

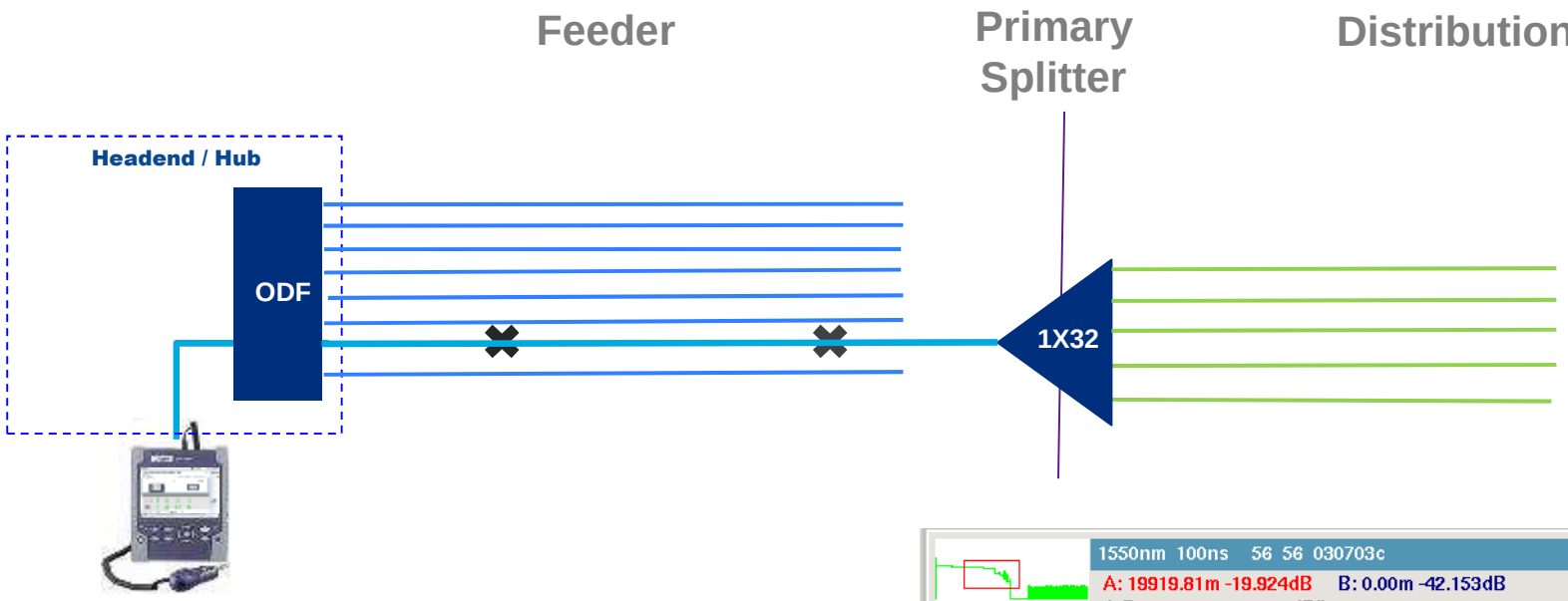


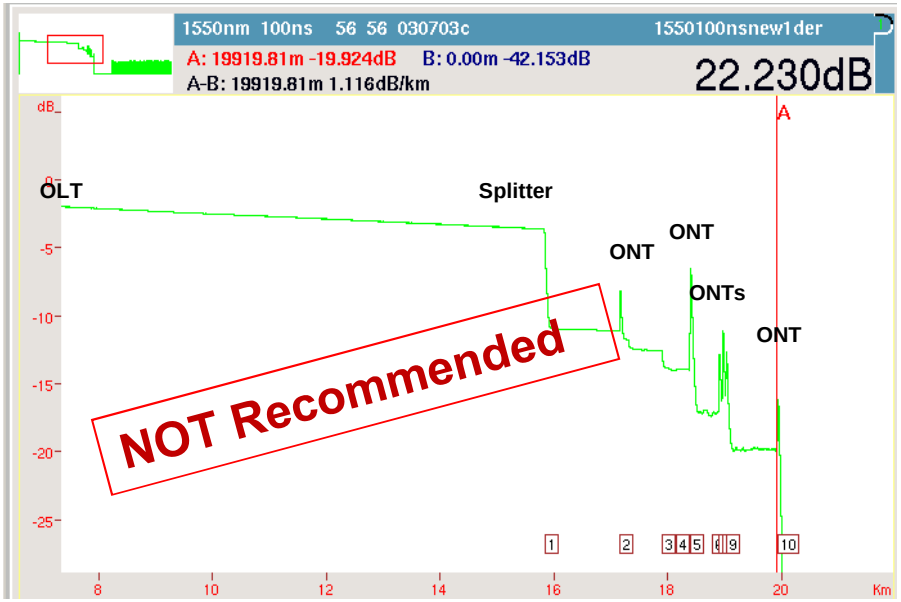
ADVANTAGES

- Each leg seen as a “point-to-point link”
- Recommend 1650nm filtered OTDR
- No CO/HE access required
- Most useful for single customer outages

1650nm filtered OTDR

Can I test from the OLT?





Challenges

- Multiple legs difficult to differentiate
- Difficult to troubleshoot faults due to multiple legs
- Low reflectance connectors at the Drop Terminal/ONT
- Most useful for Feeder fiber faults

Is 1490nm Testing Required?

- Recommended for IL/ORL but not essential.
  - Some Service providers just use IL values at 1550nm (loss at 1490 is typically < 0.02dB/km higher)

- Absolutely not needed for OTDR.
  - Although there are OTDRs with 1490nm, this laser is more expensive and…
    - Optical budget is equivalent to 1550nm
    - 1490nm is not bend sensitive, so can´t be detected so its better to user 1550nm
    - **OTDR trace with 1490nm does NOT provide additional data or parameters to the ones measured with 1310/1550nm**

Service Verification:

- PON
- Ethernet
- Wifi

Challenges with GPON

Residential & Small Business PON

Service Provider Perspective	Test Requirements	Ideal Solution
Light Is Not Enough • A red LED on a CPE is helpless at Service Activation or Troubleshooting • Customer experience can still be down	Clear multiple sources of issues • Enough light • Sync with OLT & on the **right PON ID** • Get an IP address (PPPoE/VLAN right) • Access the internet	**Test All Layers** **Test Anywhere** • ONT Emulation • For demarcation e.g. GPON, Ethernet, WiFi
Customer Complaints Cost Customer expects speed they purchased • Expensive incoming calls • Very expensive dispatches & repeats • Hugely expensive churns	Performance vs Web connectivity • Speed Test (TCP Throughput) and verify all equipment well configured (profiles = what purchased)	**TCP Throughput Test** (on all access points) • Service Performance over GPON, Ethernet, WiFi
WiFi Impacts Total Experience #1 Issue • WiFi = customer experience • GPON right but customer complains	Emulate WiFi devices & Test • WiFi Coverage (in each room) • Service performance (over WiFi in each room)	**WiFi coverage** **Service Performance over WiFi** • WiFi Performance up to high end 3x3 antenna devices

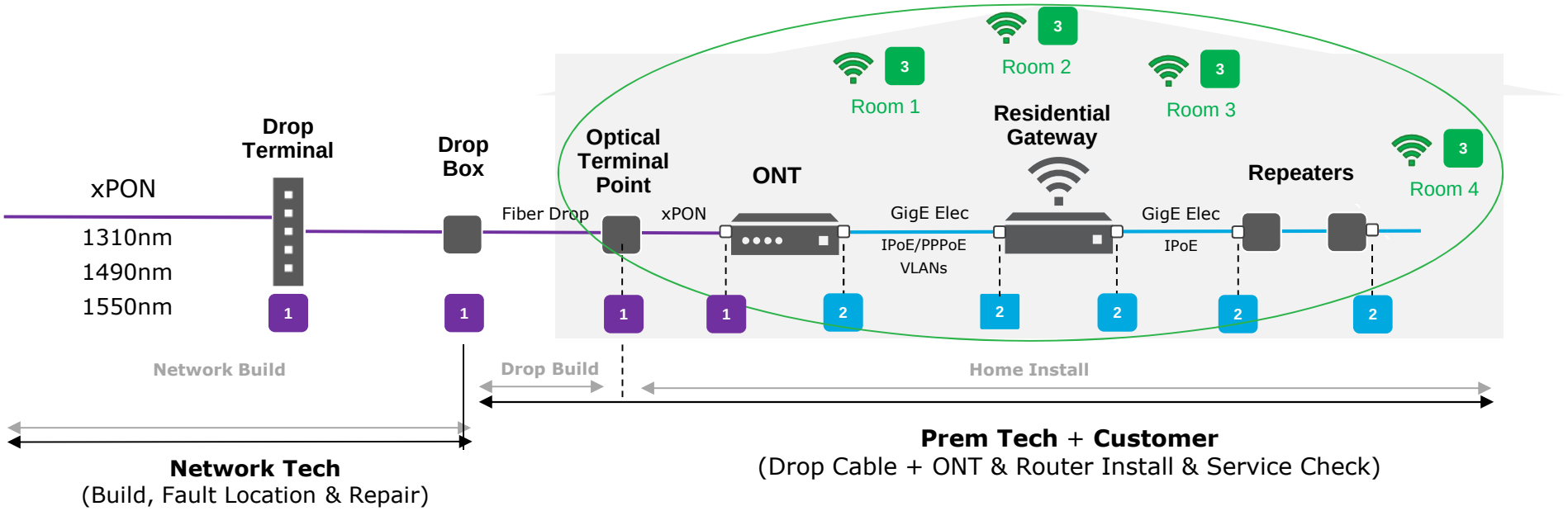
Challenges with GPON

Residential & Small Business PON

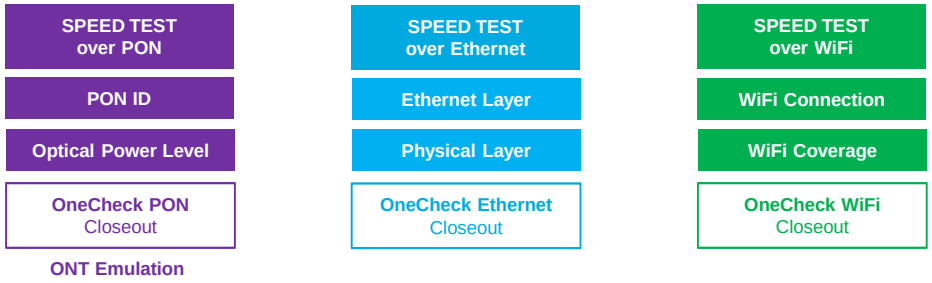
Service Provider Perspective	Test Requirements	Ideal Solution
Unskilled Techs Must Deal with Multiple Technologies • FTTH ramp up • New techs, workforce consolidation • Turnover • OPEX reduction trend (less skilled workforce)	Automation and Speed • Fully automated, guided tests • Fast tests, fast understanding (simple results analysis)	**1-button OneCheck Tests** **1-screen Test Results** • OneCheck PON (1 minute) • OneCheck Ethernet (1 minute) • OneCheck WiFi (1 minute per location) • Closeout Tests with Date / Time / Geolocation
Providers Need to Drive Compliance • Difficult to ensure all tech /contractors follow the process; everything works right the first time • Multiple techs / contractors working on PON doesn't help (miscommunication)	Work Tested Work Compliance Traceable • Simple & Fast Closeout Tests • Every time a Tech leaves a site • All recorded & accessible from a central point	**OneCheck Closeout Tests Central Server** • Date / Time / Geolocation recorded • Requirement for all dispatches • At both (Physical) Network & (Customer Experience) Service levels

Service Verification (Customer Perspective)

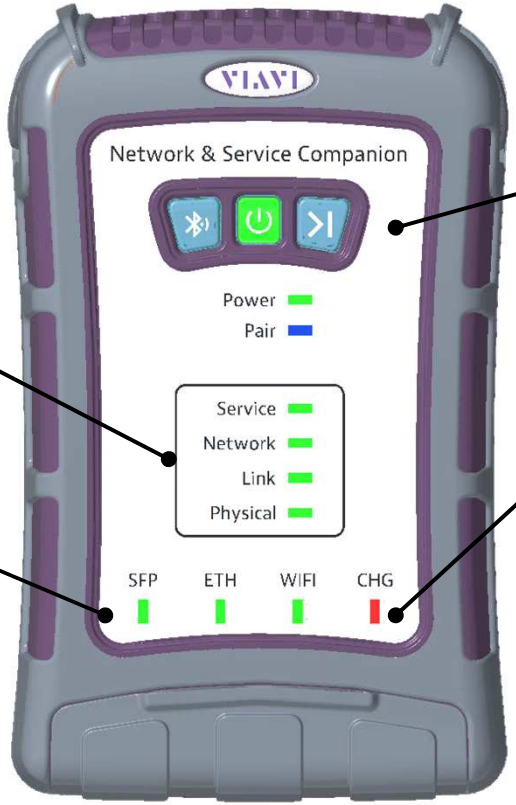
Residential & Small Business - **PON**



- Connectors
- Optical levels
- **PON ID** **(**i.e. connected to right OLT port)
- Performance (i.e. Speed Test)
- In-home (i.e. WiFi)



Network & Services Companion (NSC-100)



Bluetooth Pairing
On / Off Button
Start / Stop Test Button

Test Result Summary

Charging

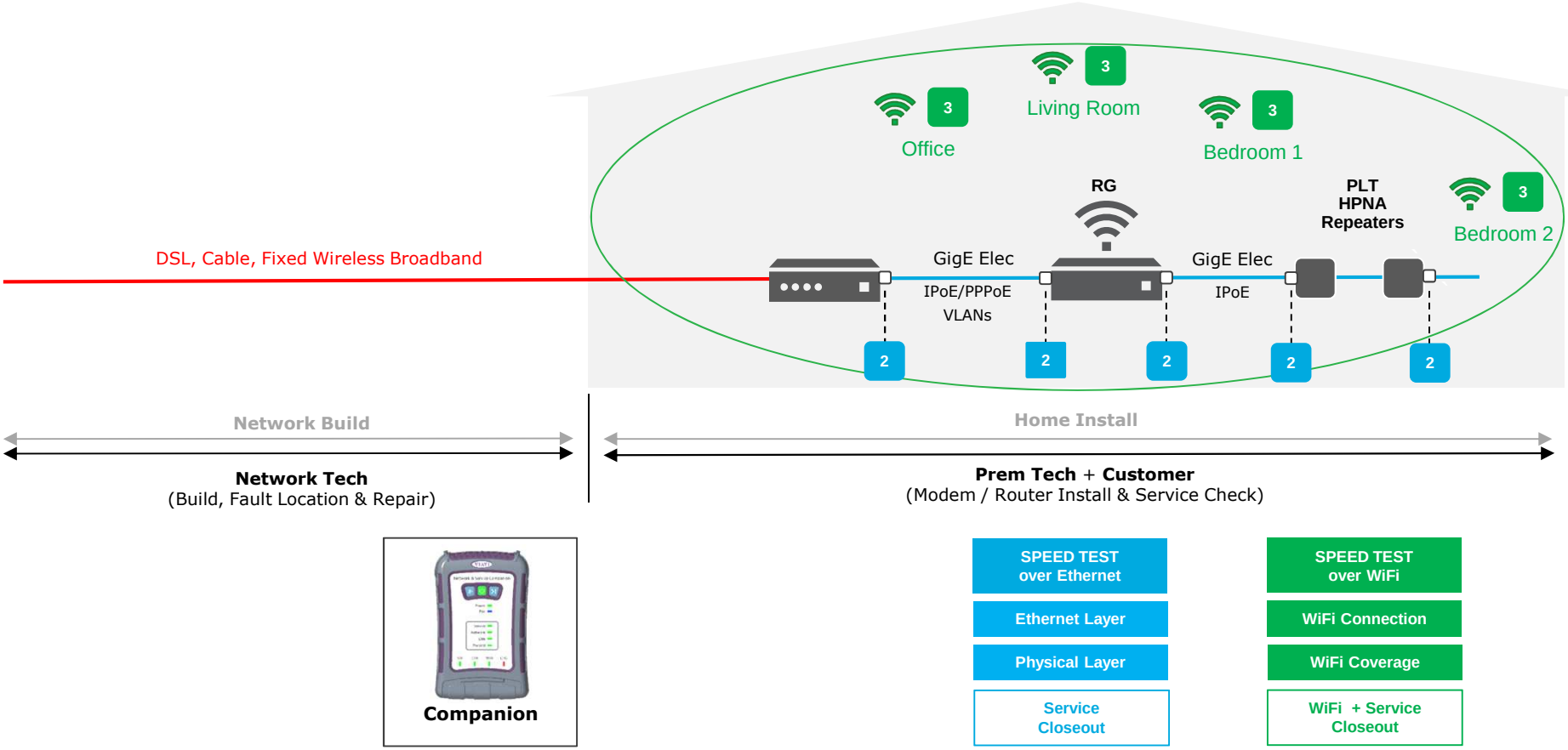
Active Test Interface

Field Replaceable Battery

SFP+
Ethernet
USB A Host
USB C Charging

Network & Service View

Residential DSL, Cable & FWBB



FTTH/PON Test Tools

Inspection	Power Meter PON ID	OTDR	Service Performance
			
FiberCheck Probe	OLP-88	SmartOTDR	Companion
Ensure Clean Connectors	Measure Power Levels PON ID	Identify & Locate Breaks, Bad Splices, Bad Connectors or Bends	Identify & Segment Service Performance Issues on PON & In-home interfaces

Tests and Tools by Workgroup

Measurement type	Construction	Turn-up	Maintenance
Fiber inspection (& cleaning)	☑	☑	☑
Insertion Loss (Light Source & Power Meter) 1310/1550nm (PON) or 1310/1550/1625 (RFoG/NGPON2)	☑		
Power Level - PON selective power meter (1490 / 1550 & 1310 for PON/RFOG) - Broadband power meter (1490 only / 1610 RFoG) - 10G PON power meter (1270/1578)		☑	☑
ORL meter 1310/1550nm	☑		
OTDR 1310/1550nm (PON) or 1310/1550/1625 (RFoG/NGPON)	☑		
In-Service OTDR Filtered 1625 (PON) or Filtered 1650 (RFOG /NGPON)		☑	☑
Remote Provisioning, Monitoring, & Troubleshooting Optical Network Monitoring System (ONMSi)			

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