White Paper

WDM-PON and CWDM Networks—Function and Measurement Tasks

By Peter Winterling

Although discussion regarding adequate bandwidth for end users is still in the early stages, Digital Subscriber Line (DSL) technology—16 Mb/s with 25 Mb/s asymmetrical DSL downstream rates (ADSL2+)—is no longer considered a viable option. Today's technology buzzword is fiber-to-the home (FTTH), which promises unlimited bandwidth; however, new and economically viable concepts must be developed and delivered to the customer. Clearly, significant increases in profitability of private telecommunications connections cannot be achieved. Economically, this situation requires that test equipment manufacturers must put efficient devices into service to troubleshoot such connections.

FTTH is currently the hottest technology in telecommunications. With optical fiber running from the exchange (switching office) to the home connection, network providers can offer higher bandwidth to their customers than they could with DSL, without its distance limitations. However, optical fiber must be laid within the last mile to complete the future infrastructure, which is an expensive proposition.

In contrast, virtually every household is connected to a copper drop, which requires diligent planning to install. Permits and authorizations must be obtained and, more importantly, trenches must be dug. It is very difficult to economically and viably accomplish this unless the infrastructure is built during the residential development. Therefore, the DSL design—with optical fiber to the street-side distributor cabinet and copper to the home—could be utilized very quickly.

Ultimately, time-to-market is critical toward winning market share. Current transmission speeds are adequate for typical Internet data traffic; however, video transmission stretches the limits for transmitting quality high-definition television (HDTV). Another disadvantage of the current technology: the street-side cabinet contains a Digital Subscriber Line Access Multiplexer (DSLAM), which requires a power supply and cooling unit. In contrast, FTTH opens up completely new possibilities.

FTTH connections are accessed through optical fiber with individual connections to the homes made using passive optical splitters. Figure 1 shows the various types of connections for broadband access using 1:16 and 1:32 splitters. A higher degree of splitting is difficult to achieve because of the division of optical power level. Table 1 shows the different technologies for passive optical networks (PONs).

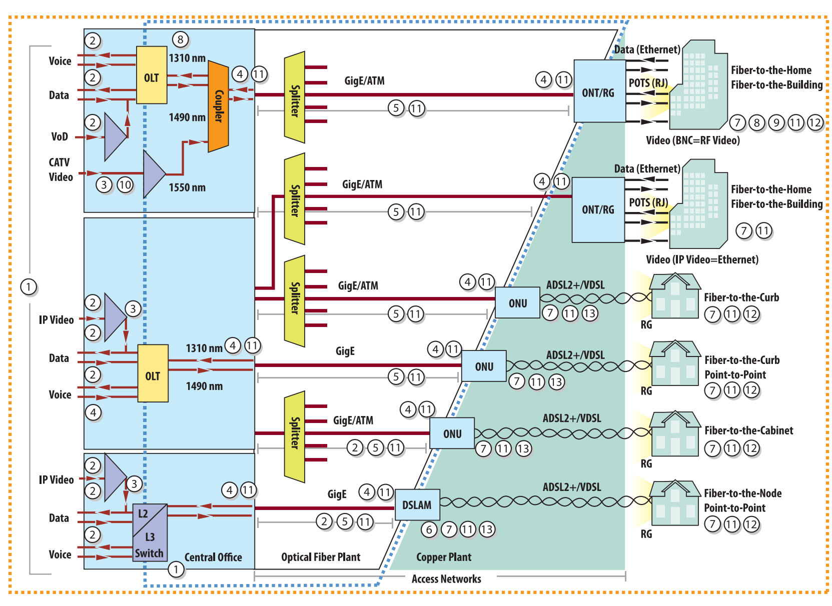

Figure 1   Various FTTx concepts

Common to all is the fact that every subscriber in a PON must adapt to the entire downstream, even though each subscriber only uses a small amount of the available transmission capacity. For example, the interface card inside the optical network termination (ONT) at the customer premises of a Gigabit PON (GPON) system must accommodate 2.5 Gb/s, making it expensive. Broadband PONs (BPONs) do not play a significant role today because of their limited bandwith. Today GPONs are used mainly in various fiber networks (FTTx). Similar to Ethernet PON (EPON) video is embedded as Internet Protocol television (IPTV). Unfortunately, with both of these formats as more subscribers come on line, individual data rates diminish, thus limiting the number of subscribers for each system.GPON and EPON differ in the integration of various services. EPON uses Ethernet technology, which is particularly cost-effective due to its wide distribution, and GPON uses transmission capacity more effectively, which is more flexible than Ethernet resulting in lower overhead costs.[1]

PON Standards	BPON	GPON	EPON
Maximum distance	20 km	60 km	10 km, 20 km planned
Maximum number of subscribers	32	64 (128 under investigation)	32
Bit rate (Mb/s)	Down: 155, 622, 1244	Down: 1244, 2488	Down: 1244
	Up: 155, 622	Up: 155, 622, 1244, 2488	Up: 1244
Wavelength λ Down	1480 to 1500 nm	1480 to 1500 nm	1490 nm
λ Upstream	1260 to 1360 nm	1260 to 1360 nm	1300 nm
λ Video	1550 nm	1550 nm	
Transmission	ATM	ATM, Ethernet, TDM	Ethernet
Standard	ITU-T G.983.x	ITU-T G.984.x	IEEE 802.3ah

Table 1 Overview of various FTTx concepts

A PON-Network consists of an optical line terminal (OLT), a feeder down to the optical splitter followed by a distribution fiber connected to an ONT at the customer premises. No active components are present between the OLT and the ONT. Acceptance measurements on the individual fibers are tested using an optical time domain reflectometer (OTDR). To ensure service reliability and to save costs, the splitter inputs and outputs are spliced, sleeved, and buried underground. Performing the OTDR measurement from the OLT side causes results to be ambiguous, because the back scatter values of the distribution fibers are superimposed as a result of the reflection measurement method. Additionally, due to the coupler, the power splitting introduces a very high loss. The loss for a distribution branch from a 1:32 splitter is at least 15 dB, which puts great demands on the OTDR unit, because closely spaced events require a short dead zone for resolution. This means that the OTDR used must be of a type normally used to measure wide area network (WAN) connections.

Once the FTTH distribution network is operational, troubleshooting a fault can be complex and time-consuming. Faults that occur in only one distribution branch require testing the services and associated signaling. Inability to clearly establish that the cause of a fault occurred on the subscriber side requires checking whether the optical level has dropped below a critical threshold. However, in PONs, checking this involves using a special in-line power meter to eliminate interruptions from the distribution fiber. Or safely deactivate the laser in the ONT if an in-line power meter is unavailable. The JDSU OLP-57 Level Meter enables this and can measure the power level in the distribution branch when used in Through mode. The meter screen displays three optical power levels—two downstream and one upstream—after looping the instrument into the transmission path as Figure 2 shows.

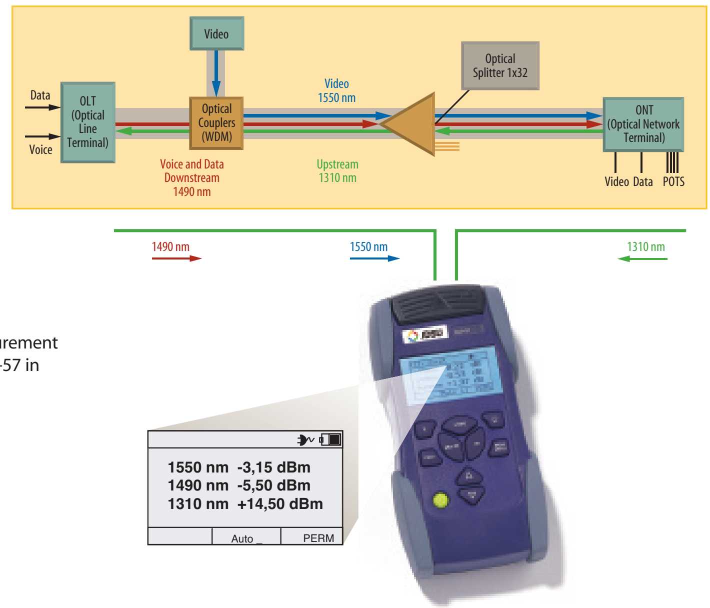

Figure 2 Selective level measurement in PON networks with the OLP-57 in Through Mode

PON networks are basically point-to-multipoint (P2MP) networks, which is best for distributive services. In P2MP networks, the entire transmission capacity is divided among all subscribers for individual Internet access. Misuse is impossible if achieving allocation through time division multiple access (TDMA) or Ethernet packet assembling. The total capacity must be adapted for the ONTs of all subscribers, thus increasing costs for subscriber-side hardware. Additionally, increased splitting can result in lower transmission speeds for each subscriber; however, this can be resolved using point-to-point (P2P) distribution networks. Replacing the splitter with an active Ethernet switch in the street-side cabinet enables higher transmission capacity for the feeder. The splitter capacity for each individual connection is then based strictly on demand, which can be adapted very quickly to the transmission capacity actually required. As with DSL technology, the disadvantage is that active components and all that this entails are required in the distribution region. Applying wavelength division multiplex PON (WDM-PON) technology removes this disadvantage. With WDM-PON, each subscriber in a PON is assigned a separate wavelength as a transmission channel as well as an individual transmission speed that is independent of any protocol. If necessary, one subscriber can be provided with a Gigabit Ethernet signal and another with a synchronous digital hierarchy (SDH) signal. WDM-PON offers the greatest flexibility, because it is a P2P technology and does not require installation of active components in the distribution area as Figure 3 shows. Splitters for GPONs are broadband and, therefore, act as power splitters. Arrayed waveguide grating (AWG) is used as the WDM demultiplexer in WDM-PON, which is already used in wide area communications with DWDM technology[8].For each optical path insertion loss is less than 2 dB, so the splitting factor is limited only by the available number of wavelengths. Systems currently available can address 32 subscribers. The actual limit based on the dense wavelength division multiplexing (DWDM) raster for Metro networks and WANs is approximately 80 wavelengths when using C-Band (1530-1565 nm) for upstream and L-Band (1565-1625 nm) for downstream. The low loss of the demultiplexer allows for extremely long feeder paths. Using dielectric add/drop multiplexers instead of an AWG affords a more linear distribution network architecture structure rather than a star pattern, which is particularly convenient when new locations are added later[6]. It may be necessary to limit the number of subscribers, as the dielectric demultiplexers can only accommodate larger channel spacing. Overall, this technology is very economical, and has proven reliable for use in Metro networks. WDM-PON also allows additional integration of mobile phone or wireless local area network (WLAN) access infrastructure; therefore, offering the greatest flexibility in the access area in comparison to other concepts.

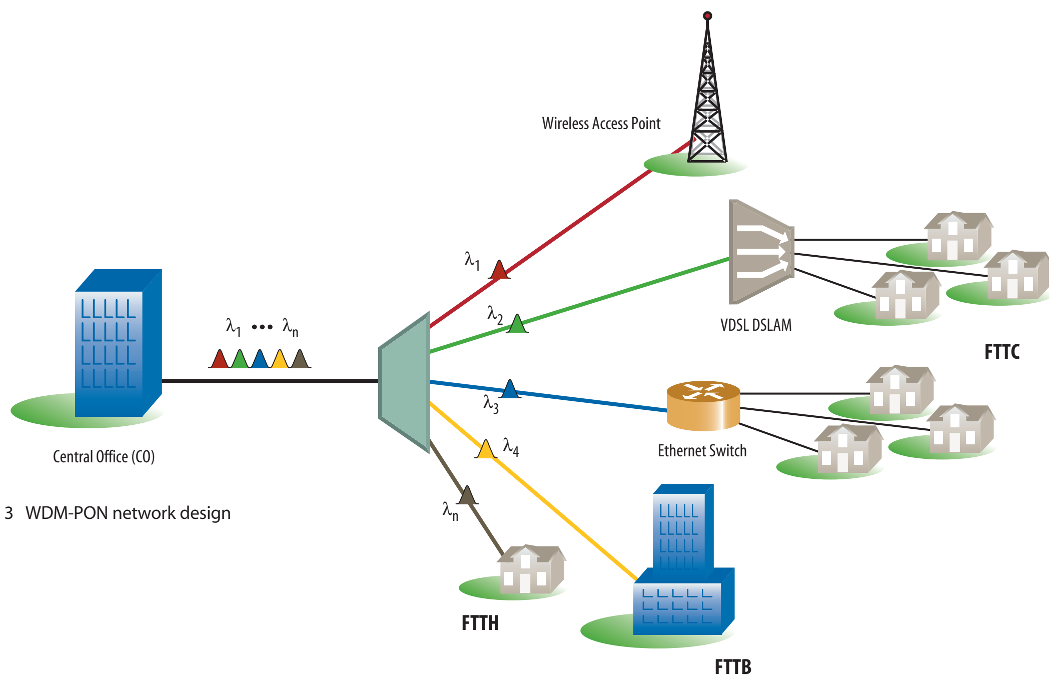

Figure 3 WDM-PON network design

One huge advantage that WDM-PON technology offers is that it can successively replace the currently installed GPON technology, which enables putting off deciding between GPON and WDM-PON for now. WDM-PON also offers choices that allow for optimum adaptation to the area to be connected. The design described previously requires the most investment; however, less expensive solutions can be achieved through increased channel spacing using low-cost splitters. Or, consider the asymmetric bandwidth demand with embedded video distribution that combines WDM-PON for the downstream and GPON architecture for the upstream.

WDM-PON technology extends the multi-channel capability of the Metro network to the subscriber level, thus simplifying the tasks involved with successive expansion and maintenance of the system, as they are already similarly performed in Metro networks. The test and measurement tasks and solutions are also very similar.

When a subscriber experiences a fault, using a handheld tunable laser on site enables taking loss and level measurements without affecting other subscribers, as Figure 4 shows. Attenuation measurements also can be performed on the wavelength assigned to the subscriber from the ONT to the OLT without affecting other subscribers on a distribution branch of a WDM-PON, as long as a standard level meter is used at the subscriber end. Tunable lasers for field use are available for the C- and L-Band that match the International Telecommunications Union (ITU-T) raster. The ITU-T-specified channel spacing of 100 or 50 GHz demands a high degree of frequency stability and the measurement accuracy depends on the relative accuracy of the power level.

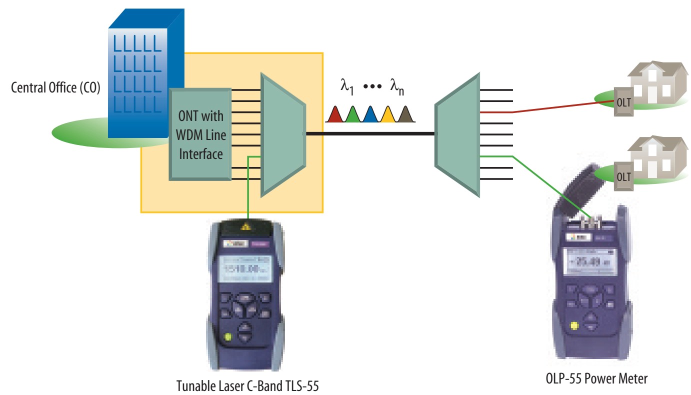

Figure 4 Selective level measurement in WDM-PON networks using tunable laser source TLS-55

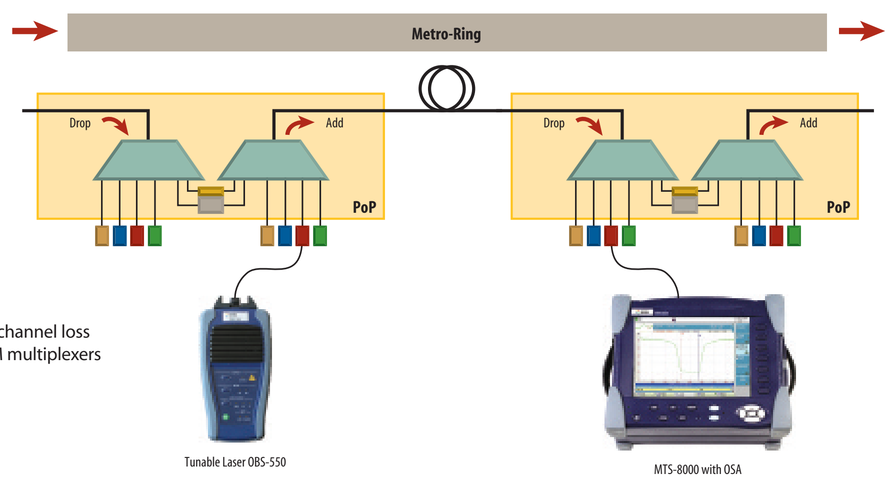

Figure 5 Test setup for channel loss and selectivity of CWDM multiplexers with the MTS-8000

If only a few communications channels are needed in a Metro network, a coarse wavelength division multiplexing (CWDM) system design is employed using the channel raster specified in ITU-T G694.2, allowing for up to 18 communications channels within the 1260 to 1640 nm wavelength range. This option provides an extremely cost-effective, multi-channel solution, because it uses dielectric multiplexers and demultiplexers as in thin-film technology. These less expensive versions also can be used for the laser diodes in the active components, because of increased tolerance in frequency stability for a channel grid with 20 nm spacing. Often, all the connections are spliced in a point of presence (POP) where a spur connects the subscribers through one wavelength each to the Metro ring. Subsequent access to the transmission path is then only possible through selective unconnected wavelength ports. The test setup shown previously in Figure 5 enables measuring the insertion losses for all the connected links at all CWDM wavelengths. Using the Broadband Light Source BBS2 as a plug-in for the JDSU MTS-8000/MTS-6000 (or the OBS-550 if viewing the entire band is unnecessary) and an optical spectrum analyzer with the Attenuation Profile (AP) function fitted in the MTS-8000/MTS-6000 mainframe on the evaluation side will display the CWDM multiplexer filter characteristics. This information is particularly important when the signal path passes through several multiplexer/demultiplexer (MUX/DEMUX) chains, because the individual filter characteristics can become superimposed[7]. It is also possible to analyze whether the necessary decoupling from neighboring channels remains present (shown as a red line segment in Figure 6).

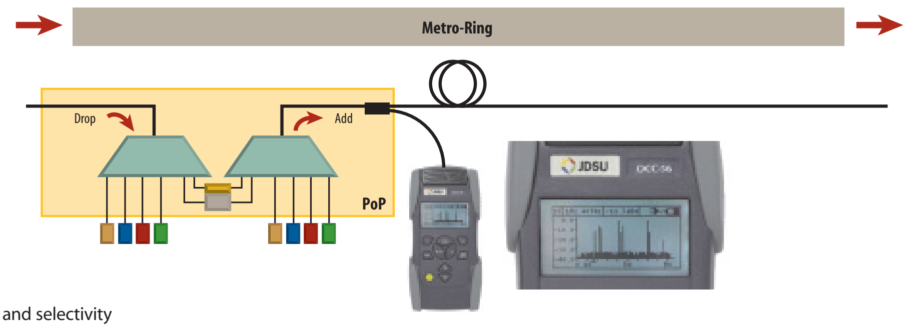

Figure 6 Channel loss and selectivity of CWDM multiplexers with the MTS-8000

Keeping within the link budget for a connection guarantees a corresponding quality of service (QoS) for the service being connected. Also, troubleshooting requires information about the path, all the splices, and plug connections, thus requiring the use of OTDR modules with the wavelengths specific to CWDM. Such devices can select path information for individual wavelengths without deactivating or breaking the Metro ring or the wavelengths carried by it.

An optical spectrum analyzer is an essential tool for turning up and troubleshooting CWDM and DWDM networks. Without this tool, it is impossible to measure the wavelengths and power levels of individual channels in active systems. The increased introduction of multi-channel systems into Metro networks as well as in WDM PONs requires a simpler tool for making selective measurements. Both the Channel Checker OCC-55 for CWDM and the OCC-56 for the DWDM channel grid can be used to measure the wavelengths of the activated channels in active systems and their corresponding power levels (Figure 7).

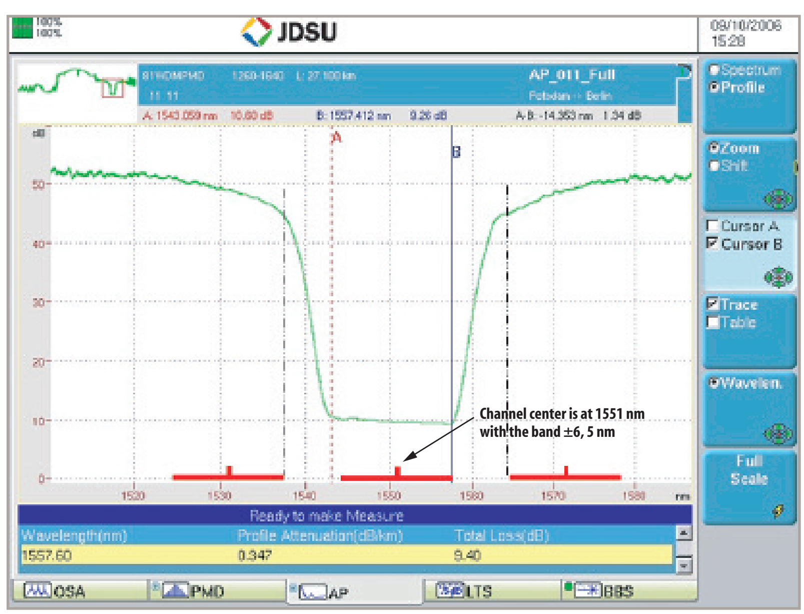

Figure 7 Channel levels in CWDM and DWDM grids with the Channel Checker OCC-56

Summary

In Europe, WDM-PON technology is the next step in a series of steps. In many other countries, broadband coverage currently is provided through a combination of fiber-to-the curb (FTTC) and subsequent copper cabling. As a result of deregulation, isolated applications of FTTH are appearing in Germany, where GPON is more prevalent. As demand for bandwidth increases, WDM-PON will make gradual expansion possible. WDM-PON solutions are already used in parts of Asia and North America, and will eventually enable complete coverage.

Glossary

ADSL2+	16 Mb/s with 25 Mb/s Asymmetrical DSL Downstream Rates
AP	Attenuation Profile
AWG	Array Waveguide Grating
BPON	Broadband PON
CWDM	Coarse Wavelength Division Multiplex
Downstream	Communication from the exchange to the subscriber
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DWDM	Dense Wavelength Division Multiplex
EPON	Ethernet PON
FTTC	Fiber-to-the Curb
FTTH	Fiber-to-the Home
FTTx	Fiber-to-the X (various fiber networks)
GPON	Gigabit PON
HDTV	High-Definition Television
IP Video	Packet-based (IP) video service (IPTV)
ITU-T	International Telecommunications Union
MUX/DEMUX	Multiplexer/Demultiplexer
ONT	Optical Network Termination
OLT	Optical Line Termination
OTDR	Optical Time Domain Reflectometer
P2MP	Point-to-Multipoint
P2P	Point-to-Point
PLC	Planar Lightwave Circuit
PON	Passive Optical Network
POP	Point of Presence
QoS	Quality of Service
ROADM	Reconfigurable Optical Add/Drop Multiplexer
SDH	Synchronous Digital Hierarchy
TDMA	Time Division Multiple Access
Upstream	Communication from the subscriber to the exchange
WAN	Wide Area Network
WDM•PON	Wavelength Division Multiplex PON
WLAN	Wireless local area network
WSS	Wavelength Selective Switch

Peter Winterling is Senior Solution Specialist for the JDSU Fiber Optics and Optical Transport product groups. He has 10 years of experience working in the field of fiber optics technology, where he has acquired extensive technical expertise in optical communications and the corresponding test and measurement solutions. He has published articles on various aspects of measurement technology for both fiber optics and SDH systems.

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