WDM-PON: A VIABLE ALTERNATIVE FOR NEXT GENERATION FTTP

AN ENABLENCE ARTICLE WRITTEN BY
DR. MATT PEARSON, VP TECHNOLOGY
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Most of the Fiber-to-the-Home deployments in recent years have been based on industry standard technologies such as Gigabit Ethernet Passive Optical Networks (GEPON) and Gigabit PON (GPON). The success of these deployments has led to significant innovation in both system architecture and the components that are used to build these systems, and the next generation of passive optical networks will inevitably be far more advanced than what is typically deployed today.

At the forefront of PON development there have been two separate approaches that appear to compete for next-generation systems: 10 Gbps PON (be it 10G EPON or 10G GPON), and WDM-PON. Each approach has its own advantages and its own issues, but the progress with both new technologies has accelerated in recent years. In this article we will focus on WDM-PON, and examine some of the challenges and new technologies that are making this technology a very viable competitor for next-generation platforms.

While WDM-PON has already had early success in Korea, its adoption in other parts of the world has been slowed by relatively high costs compared to GEPON and GPON technologies. That seems to be changing as WDM-PON competes head-to-head with 10G PON and Point-to-Point systems for next-generation FTTH deployments.

The system architecture in a WDM-PON network is not significantly different from that of a more traditional GEPON or GPON system, although exactly how the network operates is entirely different. While we will not discuss all the technical details in this article, the end result of WDM-PON is a wavelength to each subscriber.
That is contrary to more traditional PON architectures where one optical feed is shared among 32 or more users. In that case each home operates at the same wavelength, and is allotted a 1/32nd time slot on the main fiber. In WDM-PON each home is assigned its own wavelength and has continual use of the fiber at that wavelength. A very high-level view of a WDM-PON network is illustrated in Fig. 1.

In a standard PON system, a single fiber runs from the central office to a neighborhood, at which point a passive 1x32 splitter splits the optical signal to 32 different homes. Virtually all PON technologies rely on some form of wavelength division multiplexing (WDM) to enable bi-directional communications. For example, in a typical GPON system, the upstream communication runs at 1310 nm wavelength, while the downstream traffic runs at 1490 nm. A third wavelength at 1550 nm is used for video overlay. So the utilization of WDM in PON systems is already very commonplace. However in a typical GPON or GEPON system all subscribers use those same common wavelengths. This means they have to share the fiber infrastructure, which is done through time division multiplexing (TDM). Each of those 32 homes transmits over the same fiber, but the time in which they are allowed to “occupy” the fiber is allocated by the optical line terminal (OLT) at the central office. While the equipment in each home is capable of transmitting at over 1,250 Mbps, it can only do so during its allotted time on the fiber, and therefore it is not uncommon for each subscriber in a legacy PON system to only achieve sustained data rates of around 30 Mbps.

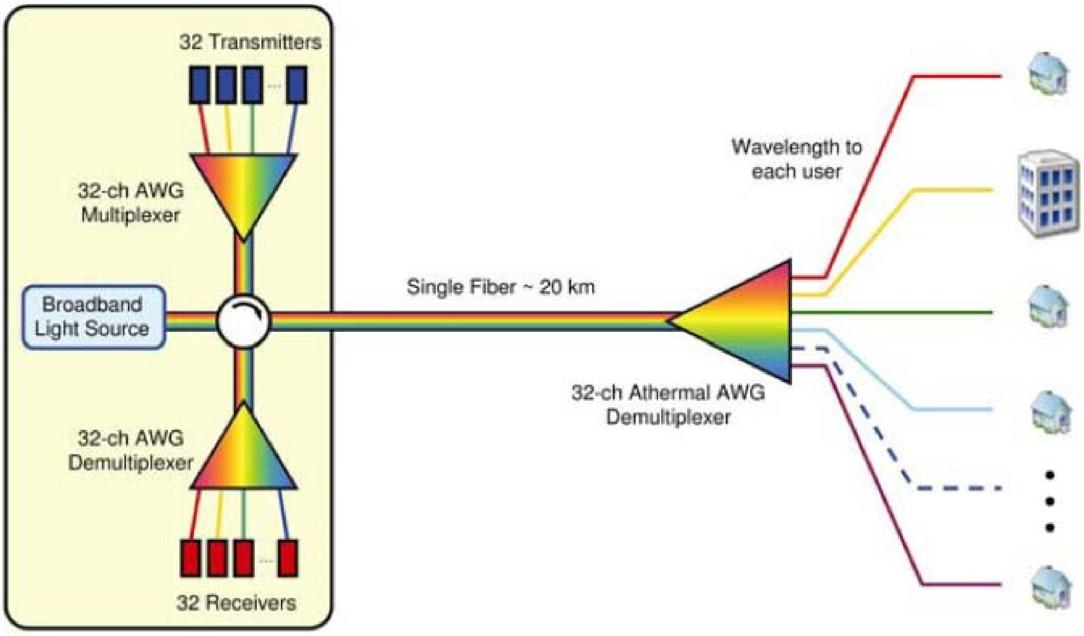

Fig1: Schematic representation of a simplified WDM-PON system.

This concept of many users sharing a common fiber helps minimize the fiber infrastructure required in an FTTH deployment. However, this sharing of fiber is one of the main factors limiting higher data rates to subscribers. WDM-PON allows for effectively the same fiber infrastructure to be used, while allowing each subscriber to access the full 1,250 Mbps available to them. There are several changes to the network that are required to enable that change. The first requires that the passive 1x32 power splitters be replaced by passive 1x32 channel demultiplexers, typically athermal arrayed waveguide gratings (AWGs), as shown in Fig. 1. This allows for 32 different wavelengths to be transmitted down the common fiber, and then each home is allocated its own wavelength.

There are several advantages to the WDM-PON architecture over more traditional PON systems. Foremost of course is the bandwidth available to each subscriber. Second, WDM-PON networks can typically provide better security and scalability, since each home only receives its own wavelength. Third, the MAC layer in a WDM-PON is simplified, since WDM-PON provides Point-to-Point (P2P) connections between OLT and ONT, and does not require the Point-to-Multipoint (P2MP) media access controllers found in other PON networks. Finally, each wavelength in a WDM-PON network is effectively a P2P link, allowing each link to run a different speed and protocol for maximum flexibility and pay-as-you-grow upgrades.

The main challenge with WDM-PON is cost. Since each subscriber is assigned his own wavelength this suggests that the OLT must transmit on 32 different wavelengths versus one shared wavelength as found in more traditional PON systems. Likewise, it requires that each of the 32 homes on a link operate at a separate wavelength suggesting that every ONT requires an expensive tunable laser that can be tuned to the correct wavelength for a particular home. This would be very cost prohibitive, particularly in initial set-up costs, and was a major hurdle in early design of WDM-PON systems.

The ability to passively integrate diode lasers to a PLC platform is a result of several innovations in wafer processing and optical design. In the past, only custom lasers were compatible with most PLC hybridization processes. This limited the number of vendors, and

Most modern WDM-PON systems now rely on a technique called laser-injection locking, which allows relatively inexpensive Fabry-Perot-type lasers to operate at virtually any desired wavelength. Every laser has a certain range of wavelengths, or “gain profile”, over which it can transmit. If a laser is directly modulated it will transmit data at whatever wavelength within its gain profile has the most feedback. This feedback may be internal, such as that from a grating in a high-performance DFB laser, or it may come from an external reflector. Injection locking is a way to force a laser to operate at a particular wavelength by providing it with a wavelength locking signal, or “seed” wavelength, which is effectively an artificial feedback signal that locks the laser to the desired wavelength. When used in this configuration, these externally seeded lasers are called reflective semiconductor optical amplifiers (R-SOAs).

In most WDM-PON systems, a broadband light source at the central office sends a broadband seed signal into the OLT transmitters to lock their transmission to the correct wavelength as their data are transmitted down the main fiber. At the 32-channel AWG demultiplexer in the field, this signal gets split into 32 different fibers, one wavelength going to each fiber. Each fiber leads to a separate ONT, where the seed wavelength locks the R-SOA to its correct wavelength. This architecture requires no tunable lasers at the ONT site, making the ONTs very cost competitive, and in fact functionally very similar to more traditional GPON ONTs. And since the wavelength of each ONT is determined by the seed wavelength coming from the OLT and AWG, there is no need to stock an inventory of ONTs at different wavelengths. All ONTs in a WDM-PON network are identical.

The largest system change compared to other PON architectures comes at the OLT. A WDM-PON OLT is quite complex compared to its GEPON or GPON counterparts. Since each subscriber gets the benefit of a full wavelength to their home, this also requires that each subscriber has their own dedicated transceiver in the OLT as well. Once again, injection locking makes this feasible. The OLT chassis includes a broadband light source that passes through a 32-channel AWG, and thereby seeds each of 32 separate R-SOAs in the OLT. These R-SOAs are directly modulated at 1.25 Gbps, each allocated to a particular subscriber. This creates what is effectively a highspeed Point-to-Point system, using a relatively inexpensive PON fiber plant.

While R-SOAs and injection locking help minimize the costs of WDM-PON, there is no question that WDM-PON components remain more expensive than the standard components used in GEPON and GPON networks. However, none of the existing PON infrastructures can offer nearly the same data rates to each subscriber, so this comparison is not completely fair. At present the most comparable PON alternative would be next generation 10G PON, but even 10G PON cannot match the data rates obtainable with WDM-PON, since that 10 Gbps is shared among 32 users. On a cost-per-Mbps basis, WDM-PON is perhaps already the most inexpensive option for next-generation systems.

Simply tweaking existing components to reduce the costs of WDM-PON systems will not be sufficient to make WDM-PON competitive with other next-generation PON solutions. It required completely new component technologies. A lot of focus now is being placed on Planar Lightwave Circuits (PLCs) as a means of shrinking the size and lowering the costs of WDM-PON ONTs and OLTs.

The use of PLC technology in PON applications is not new. Virtually all PON systems rely on PLC-based 1x32 power splitters in the outside plant, due to their low cost, small size, and simplicity. These passive optical splitters require no power and operate over a very wide range of temperatures. They are relatively simple PLC products, requiring only optical waveguides and packaging. The use of PLC-based transceivers has also helped lower the costs of GEPON and GPON ONTs by collapsing all the upstream and downstream transceiver functionality onto an optical chip. These PLCs are much more complex than passive splitters, and contain WDM filtering along with lasers, detectors, amplifiers, and capacitors, all hybrid integrated on a common PLC substrate. The many advances in PLC integration technology over the past decade have truly revolutionized what functionality is achievable on an optical chip.

WDM-PON networks start by replacing the 1x32 power splitter with a 32-channel athermal AWG. Rather than splitting the optical power between 32 different homes, the athermal AWG splits one wavelength to each home. These are of course also PLC-based components, and their athermal design requires no power. This allows the athermal AWG to replace the 1x32 power splitter in the same outside enclosure, so that the fiber infrastructure in a WDM-PON deployment is identical to that in a more traditional PON system.

The PLC-based AWGs that are used in these systems are important, since they actually perform three functions simultaneously: First, they take a single fiber from the OLT and demultiplex it to send one wavelength to each of 32 users. Second, this same function acts to seed the laser at each of those 32 ONTs, locking each to its appropriate wavelength. And third, it turns out that a C-band AWG can also be designed to operate equally well in the L-band, and this allows the same AWG to receive all the upstream traffic from 32 users and multiplex it onto the same common fiber back to the OLT. And since this is an athermal AWG, all these functions happen passively with no power going to the module.

While the use of PLCs in this splitter node on any PON system is common, in fact the norm, the use of PLCs in other parts of a WDM-PON network is growing increasingly important. For example, each 32-port OLT includes an AWG coupled with 32 separate receivers, and a similar transmitter side that includes an AWG and 32 separate R-SOAs. This requires a large footprint, so the broadband light source used for seeding is usually included on a second card, so that each 32-port OLT requires two slots in the chassis. PLCs can significantly shrink the size of the OLT optics, allowing all components to be moved to a single board, effectively doubling the density of WDM-PON OLT modules.

PLC technology has matured in recent years to deliver functionality that was previously not possible in such a small size. For WDM-PON applications, the main focus is on collapsing the 32-channel transmitter and receiver components into compact integrated modules that allows all the OLT functionality to fit on a single OLT blade.
PLC technology allows for 32 photodiodes, TIAs, capacitors, and other sub-components to be hybrid integrated on an AWG chip with very-high yields. This can be done on a silicon chip that is only approximately two inches long. The packaging and electronics add to this footprint, but the end result is double the port density in the OLT. Fig. 2 shows how some of this chip-based optical integration looks in practice.

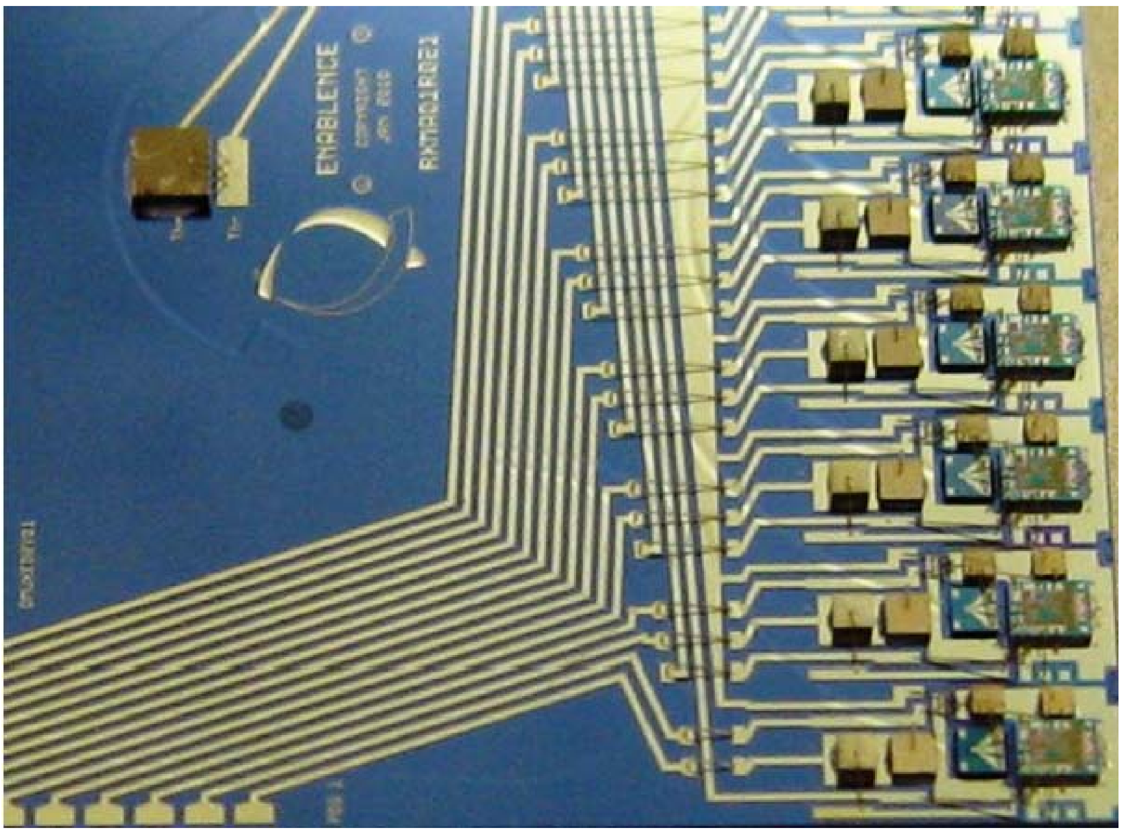

Fig. 2. Close-up view of a Planar Lightwave Circuit that integrates WDM functionality, along with hybrid receiver photodiodes, transmipedance amplifiers, capacitors, thermistors, and other sub-components on a silicon chip.

Similarly, PLC-based transmitter modules combine all 32 channels of WDM filtering, along with 32 R-SOA transmitters, and matching optical power monitors for each channel. This level of integration was simply not feasible even just a few years ago, but now enables some of the next-generation WDM-PON networks to compete on a cost and port-density basis with 10G PON.

From a service level perspective, no other PON technology, including 10G PON, offers the same bitrate to each home that WDM-PON can provide. The 1,250 Mbps per-user bandwidth is comparable only with point-to-point systems, but WDM-PON leverages a lower cost PON fiber plant. The main challenges that have impacted WDMPON deployments, namely cost and port density, are now starting to be addressed through lower-cost integrated components based on Planar Lightwave Circuits.

Perhaps the largest remaining challenge to WDM-PON deployments is arriving at a WDM-PON standard, similar to the IEEE and ITU standards that cover GEPON and GPON, respectively. While 10G PON solutions will provide continued significant cost pressures, adoption of an industry standard for WDM-PON will help focus development efforts and drive down the costs of WDM-PON components. As the early challenges in initial setup costs and OLT port densities are addressed, WDM-PON deployments will continue to rise. This will present a very viable standards-based alternative to 10G PON and other next-generation FTTH solutions.

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