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Technology to the rescue of next-generation 10G PON networks

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Overview

Current next-generation PON technologies are too expensive for widespread deployment. Advances in 10-Gbps electronic dispersion compensation and "super" TIA technology can reduce such costs.

While standardization processes move ahead at great pace, commercial roll-out of next-generation 10-Gbps fiber-to-the-home networks is still a long, long way from being reality.

This is not a popular view among the many vendors striving to demonstrate how their latest technology will lead the way for these networks. But it is clear that 10G PON equipment right now is based on expensive technology and faces some major challenges if it is to ensure viable mass deployment. This article will show that recent developments in 10-Gbps technology can help address these challenges.

Some background

First let's start with some background on next generation PONs — why are they needed? The drivers often quoted are the increase in bandwidth demand, mainly due to high user uptake of video services (such as Joost, Hulu, and iPlayer) and online gaming. While Internet video clearly needs to be supported by higher bandwidth per customer, this is not the only concern. It is also important to note that the streaming nature of video means that the bandwidth demand per customer will be much more constant.

To understand why this is a problem, it is useful to look at current network bandwidth provisioning. Currently an access network can offer 32 customers a 100-Mbps Ethernet service using a 1-Gbps access network speed. This is possible due to the statistical nature of the bandwidth requirements of the customers; not everybody will need the full 100 Mbps at the same time.

Video, however, changes this, as people usually watch TV/video in the evening, say between 8 pm and 10 pm. The video data stream is also near constant. This means that telcos will not be able to share a single bandwidth pipe among as many customers as they are used to, and more overall PON bandwidth will need to be provided to service the same number of users.

Next-generation PONs aim to address this increased bandwidth demand by providing a 10-Gbps downstream connection, which can be shared among 32 or more optical networking units (ONUs). Each ONU can service many more customers, located for example in apartment buildings or other "multiple dwelling units" (MDUs).

The IEEE and FSAN/ITU are addressing these requirements in the 10GEPON standard (IEEE 802.3av) and NG-PON work (split into XG-PON1 and XG-PON2), respectively. The IEEE began before FSAN and has already arrived at an initial approved standard. The NG-PON work is progressing well in FSAN, with initial specifications now drafted by the ITU.

Challenges in next-generation PONs

While 10-Gbps networks have been around for quite some time now, and technology has significantly reduced the cost structure, it should be clear that a 10G PON will be more expensive than the current GEPON and GPON implementations. This is not just due to the lower volumes of 10-Gbps components, but also because of more fundamental issues.

First, there is the problem with "backwards compatibility." Next-generation PONs are expected to be implemented as upgrades to the existing PONs, and will be run over the same fiber plant. This means that, since the losses in the fiber plant will remain the same, the 10G PONs will require at least the same overall power budget (difference between transmit power and receiver sensitivity).

This is not easy, as optical receivers at 10 Gbps are generally 4X (or 6 dB) less sensitive than 2.5-Gbps receivers, putting the burden on the transmitter, which will have to be 6 dB more powerful. To make things worse, at 10 Gbps there will be additional losses, such as path penalties caused by chromatic dispersion (CD).

Some of this power budget problem can be addressed by increasing sensitivity through the use of forward error correction (FEC) in each receiver. This can provide more than 3-dB gain. Still, to enable the 10G PON to use the existing GEPON or GPON fiber plant, more exotic high-sensitivity receivers have to be used, and these are very expensive.

Second, there is the cost of the optical transmitters. When choosing a high-powered laser a tradeoff must be made. Directly modulated distributed feedback (DM-DFB or DML) lasers are lower cost than externally modulated lasers (EMLs) and have a higher output power. However, DMLs also have a higher line-width (broader spectrum) than EMLs, which results in higher CD over standard singlemode fiber. This dispersion results in a path penalty, even over the short fiber lengths present in a legacy PON (20 km).

The path penalty for a DML over 20 km can be as much as 4 dB, completely negating the higher output power it can give compared to an EML. Some illustrative numbers for DMLs and EMLs are given in Table 1.

Table 1: A comparison of DML and EML

Transmitter Type	Power	Cost	Path Penalty 20 km	Path Penalty 60 km
DML	9 dBm	100%	4.1 dB	8.6 dB
EML	4 dBm	200%	0.5 dB	2.4 dB

Fortunately, there are a number of emerging technologies available to system suppliers that can help reduce the costs of 10G PON equipment, such as electronic dispersion compensation (EDC) and "super transimpedance amplifiers" (super-TIAs).

EDC

EDC can help in a few different ways. If EDC is used in the ONU, much of the CD path penalty can be compensated, resulting in a net gain. Up until recently this option has been discounted, as conventional wisdom holds that EDC is expensive and power hungry, rendering it unsuitable for use in ONUs where cost is of prime concern. This view is true for traditional EDC designs as used in extended-reach singlemode fiber systems, where the EDC alone can require several watts of power and costs tens of dollars. These EDCs are usually based on very high performance analog-to-digital converters combined with extremely fast digital signal processors running Viterbi or maximum likelihood sequence estimation algorithms.

There are, however, alternative EDC implementations designed to be smaller and take less power, while still providing significant benefit in terms of reduction of the path penalty. Such EDCs, as shown in Figure 1, use analog and mixed signal implementations of feed forward equalizers (FFEs) combined with decision feedback equalizers (DFEs).

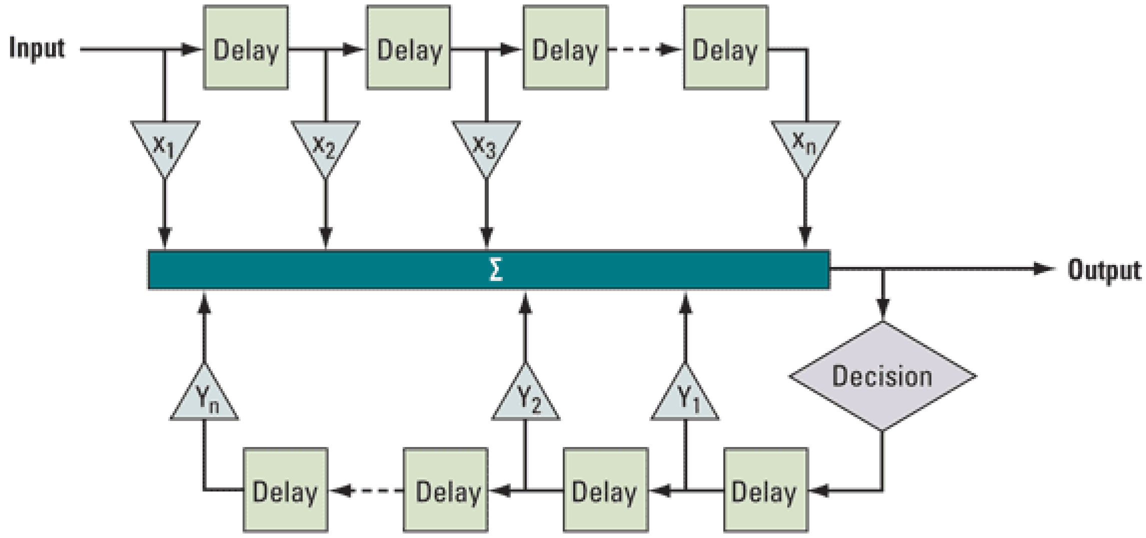

FIGURE 1. EDC implementations based on FFE and DFE.

An important additional consideration for this latter type of EDC is that it is commonly implemented in standard CMOS, which means that it could be integrated in the PON MAC chip. This approach, illustrated in Figure 2, would mean that the EDC part could be added to the ONU at very little additional cost, both in square millimeters and power (200–300 mW). Thus EDC becomes highly cost-effective, enables use of DMLs, and helps substantially reduce total system cost.

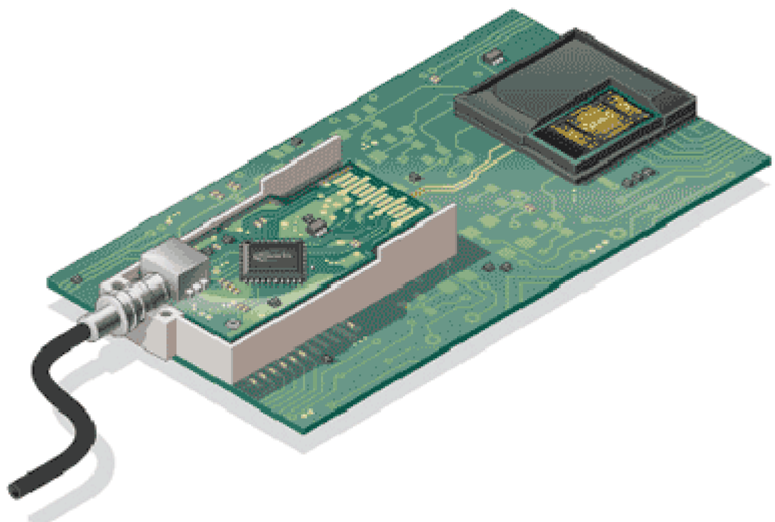

FIGURE 2. ONU of the future: SFP+ module with integrated EDC.

Another consideration is that in extended-reach PONs, with link lengths of 60 km, even EMLs would incur a significant path penalty due to CD. In this case it is likely that EDC will have to be used in the ONU to reduce this penalty and achieve the required receiver sensitivity.

Super-TIA

Even when using high-power transmitters in the OLT, the ONU receiver still has to achieve very high sensitivity. Traditionally this requires the use of an avalanche photodiode (APD) instead of a PIN, even in GPON Class B+ systems (required ONU sensitivity of -27 dBm).

APD-based receivers are much more expensive than PIN-based ones, due to a number of reasons. APD chips are more expensive to manufacture, with much lower yields compared to PINs, due to the difficulty in the ion implantation process while maintaining low capacitance. APD-based receivers also require accurate control circuits to provide over-temperature bias voltage compensation, which has to be set up at module manufacturing time. Finally, APD receivers require hermetic packaging and burn-in time to ensure reliability. All of these factors combine to make APD-based devices at least 3X the cost of PIN-based receivers.

Recently, super-TIAs have been developed for 2.5-Gbps (GPON) applications with an extremely low input referred noise (IRN) of under 100 nA rms. In the GPON markets, PIN-based receivers with this type of super-TIA have been called “APD killers” because of their ability to totally remove the requirement to have APD-based receivers to implement GPON Class B+ compliant equipment. The option to use a PIN-TIA optical receiver opens the door to large cost savings.

Moving to 10 Gbps in XGPON and 10GEPON, the sensitivity requirement becomes even tougher. As already explained, carriers want to be able to use the same fiber infrastructure as existing PONs, which means the overall link budget must remain the same. Traditional thinking would mandate the use of 10G APD receivers to enable the receiver sensitivity to be around -28 dBm (pre-FEC, BER=1e-3). For comparison, traditional 10-Gbps PIN TIAs only provide about -22 dBm at this bit error rate.

However, with the recent developments in super-TIAs, this assumption should be further examined. A direct calculation using the 2.5-Gbps super-TIA number of 100 nA rms and translating this to a 10-Gbps receiver with 4X the bandwidth takes the total IRN to 400 nA. This would theoretically give a 10-Gbps PIN TIA receiver with a sensitivity of -26 dBm at 1e-3 BER.

There are additional impairments in the practical implementation of such a receiver, as well as further penalties for the lower extinction ratio at 10 Gbps. However, such an approach shows that, with leading-edge design techniques and the use of the right technology, it looks very possible to make 10-Gbps PIN-based receivers that can achieve a sensitivity of at least -24 dBm.

It should be noted that, even with super-TIA technology, the transmit power will have to be increased to enable systems with PIN-based receivers that can co-exist on the current fiber infrastructure. The advantage is that with these leading-edge, super-TIA receivers, the OLT transmit power can stay under the eye safety limit of 10 dBm.

Also, the use of an optical amplifier at the OLT may be required. However, the additional cost of the amplifier is offset by the cost savings of not having to use the APD at the ONU. Modern EDFAs are available at a cost that is less than the savings of 10 PIN-based ONUs.

Alternatively, the use of low-cost DMLs will be possible, as these can transmit the required output power without amplification. This latter approach would require EDC at the ONU.

Examples of link budget implementations and relative costs for a 20-km, 32-ONU system are shown in Table 2.

Table 2: Link budget implementations and relative costs for a 20-km, 32-ONU system

Property	Unit	IEEE 802.3av PR20/PRX30	PIN TIA	Super-TIA	Super-TIA + EDC	Comments
OLT Tx power	dBm	2–5	10–12	8–10	8–10	
OLT Tx technology		EML	EML+EDFA	EML + SOA	DML	
Eye safety issue[1]		No	Yes	No	No	
ONU Rx power min.	dBm	-28.5	-20	-22	-22	Includes 1-dB filter penalty
ONU Rx technology		APD	PIN	PIN	PIN + EDC	
Path penalty	dB	1.5	1	1	4.1	DFB option requires EDC
Systems optics cost (1 OLT, 32 ONUs)[2]		100%	60%–80%	<50%	<40%	

[1] Does the transmitter power exceed 10 dBM?

[2] Assumes cost of APD is 3X PIN; cost of EDFA is offset by the cost savings of using 10 PIN receivers; cost of SOA is 20% lower than EDFA; DML is 50% the cost of EML.

As significant cost can be taken out of the ONU by using a PIN TIA receiver, system companies are actively investigating how to structure the power budget to enable this, even if this requires higher-power transmitters.

Conclusions

While the IEEE has recently approved the specification for 10GEPON networks, many companies are still struggling to arrive at cost-effective implementations. The FSAN/ITU community is still in a good position to structure the power budgets in such a manner that the total cost of a XGPON system is viable, while ensuring that carriers can deploy it over their current fiber infrastructure.

Nevertheless, developments in EDC and super-TIAs have made it clear that these technologies can significantly reduce the cost of next-generation PONs. Such technologies will ensure that next-generation PON systems will not just remain in technology labs and field trials, but will see mass deployment in the near future.

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Links to more information

Lightwave Online: Verizon Tests XG PON 10G GPON with Huawei Equipment
Lightwave Online: Alloptic Intros 802.3av-Compliant 10G EPON for FTTH
Lightwave e-Conference: Market Forecasts for High-Speed and Access Networks

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