Evolution of Burst Mode Receivers

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Abstract *The paper gives an overview of burst-mode receiver developments. The receiver design challenges associated with high speed TDMA PONs are discussed and recent results of 10Gb/s burst-mode receivers are highlighted.*

Introduction

Worldwide, a passive optical network (PON) is one of the most massively deployed fibre access technologies. Fig.1 shows a typical PON network architecture for FTTx scenarios. From a single optical line termination (OLT) at a service node, it connects up to 64 optical network units (ONUs) at customer's premises. The PON offers a cost-effective optical solution for eliminating the bandwidth bottleneck in the last mile. The burst-mode receiver (BM-Rx) and burst-mode clock and data recovery chip (BM-CDR) located at the OLT are key components of a high speed PON system, and subject to heavy design requirements.

Fig.2[1] indicates the evolution of PONs and the associated BM-Rx's. It took many years for the standardizations of PONs. Finally the first generations of PONs (such as B-PONs, GE-PONs and G-PONs) are now under massive deployment. The G-PONs typically offer 2.5 Gbit/s downstream and 1.25Gb/s upstream, shared between 32 customers over a reach of up to 20km[2-4]. Two types of BM-Rx products are now commercial available. They are the 1.25Gb/s AC-coupled BM-Rx's employing 8B/10B coding[5], and the 1.25Gb/s DC-coupled BM-Rx's with a short overhead[6].

The latest G.984.6 standardizes a long-reach PON, shared between 128 customers over a reach of 60km. To meet higher capacity requirements for HDTV, IPTV, VOD, digital home, etc. future optical access networks are evolving towards 10Gb/s operation. Advanced next generation PON systems are currently subject of standardization by two standard bodies, the IEEE EPON community for a symmetric 10GE-PON (IEEE 802.3av) and the ITU-T FSAN study group for ITU-T XG-PON systems aim at 10Gb/s downstream and 2.5 resp. 10Gb/s upstream. There seems to be significant industry support for aligning the 10G optics (physical medium dependent layer) of ITU XG-PON systems with the optical layer specification of the emerging IEEE 10GE-PON. Therefore, a generic 10Gb/s BM-Rx is one of the most critical and important components for the next generation PONs (NG-PONs). Standards for the next step to 10Gb/s are underway and transparent metro/access systems with symmetric 10Gb/s capacities are also under research[7].

BM-Rx requirements and design challenges

The time-domain multiple access (TDMA) operation of the uplink, and the tree-like topology of the fibre plant, make that a single BM-Rx at the OLT can handle the upstream traffic of all active subscribers. So the OLT cost is shared, and performance is the main OLT design criterion. For NG-PONs operating in burst-mode to support a high splitting ratio (>=32) and/or an extended reach (>=20km), a high sensitivity combined with a wide dynamic range and a fast response time are three important figures of merit for the BM-Rx.

The upstream optical packets sent by all active ONUs are received by the BM-Rx as a rapid succession of bursts, with largely varying signal level and phase from burst to burst. Therefore the BM-Rx and the BM-CDR must perform the amplitude recovery and the data recovery within tens of (or hundreds of)

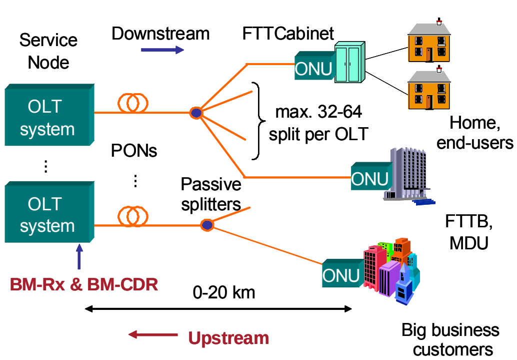

Fig. 1: A typical PON network architecture

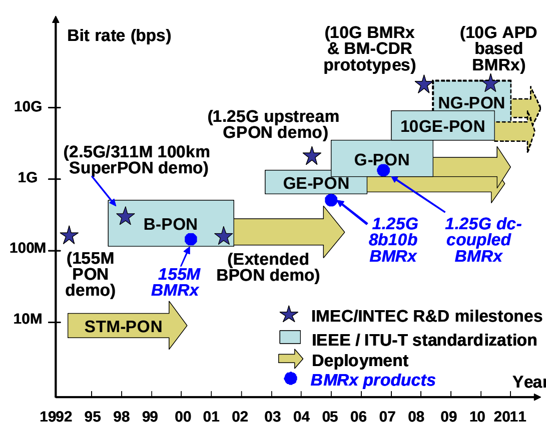

Fig. 2: Evolution of PON's and BM-Rx's

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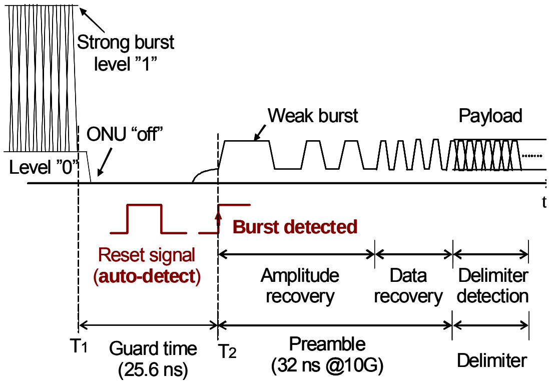

Fig. 3: Timing of the BM-Rx (guard time, preamble, auto reset and burst detection).

nanoseconds, and on a burst-by-burst basis, as illustrated in Fig.3. The slightest receiver non-linearity or memory effect makes that any strong incoming packet is followed by a transient or tail that hinders the reception of a closely following weak burst. So an additional "Reset" signal is required to shorten this tail of the preceding burst, and to erase the threshold that was set for this preceding burst. During and shortly after reset, some unwanted transients occur in the interval between the end of a burst and at the beginning of the next burst. Fig.4 depicts that a blanking signal is usually sent towards the BM-CDR from the succeeding medium access control (MAC), to make the BM-CDR ignore OLT outputs until valid data are received[8].

To achieve efficient network transmission, time-critical control signalling (such as "Reset" and "Blanking" signals) cannot be avoided in DC-coupled GPON systems. For high interoperability however, one prefers to not have time-critical control signals crossing the boundary between the PON physical layer and the MAC layer.

For IEEE GE-PON systems, most BM-Rx are AC-coupled, which requires a longer guard time (up to 512ns) and a longer preamble (400ns) compared to GPON-like BM-Rxs. The AC-coupled BM-Rx's result in lower network efficiency, but allows better receiver

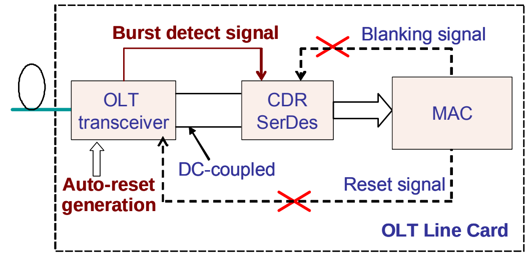

Fig. 4: OLT operation without time-critical control signals from MAC

sensitivity and wider dynamic range. However IMEC/INTEC's design traditionally focuses on DC-coupled BM-Rx's with a very short guard time (25.6ns) and a very short preamble (<30ns in both 1.25Gb/s and 10Gb/s BM-Rx's).

Realization of the 10G BM-Rx for LR-PONs

In the EU-funded FP6 IST PIEMAN project[7], DC-coupled 10Gb/s BM-Rx[9,10] and BM-CDR[11,12] prototypes with a very short overhead (<60ns in total) were developed using a 0.25µm SiGe BiCMOS process, for a 10Gb/s high split (up to 512) long reach (up to 100km) PON (LR-PON) system. Fig.5 depicts the main building blocks of this BM-Rx. The photocurrent received from a PIN photodiode is fed to a BM transimpedance amplifier (BM-TIA). The BM-TIA has two gain settings: high (65dBΩ) and low (55dBΩ). During the preamble, the BM-TIA gain will switch from high to low when the amplitude of the input photocurrent exceeds a certain level. The gain is locked after the gain is set properly, so that it will not toggle due to noise during a burst. From the measured incoming signal level, a coarse threshold level is extracted to compensate for the unilateral deviation caused by the photocurrent, such that a higher swing can be handled to enlarge the dynamic range. Here the speed of the SiGe technology competes with its DC accuracy. In this design, the total preamble time used by the BM-TIA is 6ns. The BM-TIA output signal is then further amplified in the BM limiting amplifier (BM-LA). The BM-LA mainly

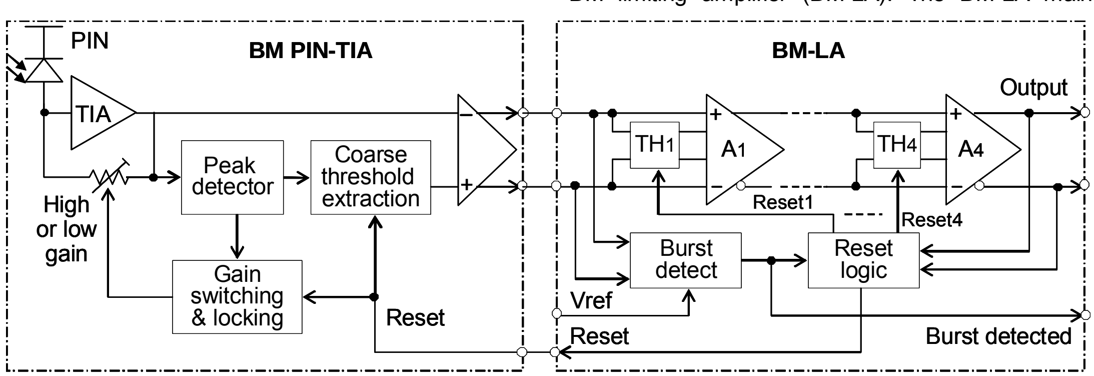

Fig. 5: Simplified BM-Rx building blocks

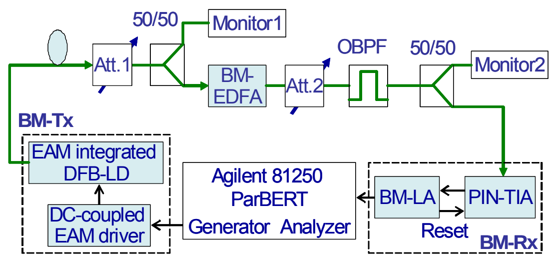

Fig. 6: Experimental set up

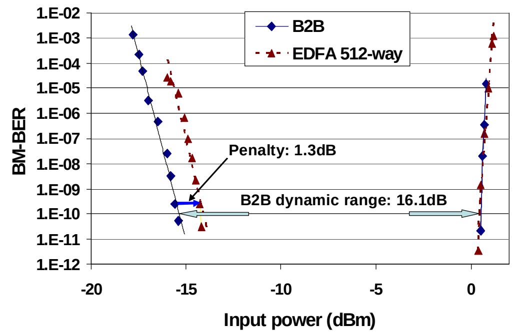

Fig. 7: Measured BER (B2B and with the EDFA)

consists of four stages that successively measure the decision threshold (by a threshold extraction block THi, i=1..4), with gradually improving accuracy. The 'Reset logic' generates a 10ns reset pulse whenever more than 80 consecutive 0s are found in the BM-LA output. So the reset pulse from the MAC to the OLT, shown in Fig.4, is eliminated by auto-reset generation inside the BM-LA. This approach is feasible as the minimum guard time of 25.6ns between bursts is significantly longer than the time corresponding to the longest sequence of consecutive 0s (7.2ns at 10Gb/s). The blanking signal from the MAC to the BM-CDR in the G-PON case is removed too, as the BM-LA generates a so-called "burst detect" signal. The preamble time used by the BM-LA is only about 18ns.

Uplink burst-mode experimental results

In the PIEMAN LR-PON architecture[13] two BM-EDFA's are used, a first one at the Remote Node (RN), to compensate the high optical path attenuation linked to high splitting factors, and a second EDFA at the service node, as a preamplifier in front of the BM-Rx. Due to the presence of the preamplifier EDFA, the PIEMAN 10Gb/s BM-Rx sensitivity requirement is significantly reduced to maximum -11dBm. The first test results were presented in Ref [9], where the measured BM-Rx sensitivity at 10Gb/s was -12.5dBm at a loud/soft ratio of 11.5dB. The back-to-back Rx sensitivity of the second PIN-TIA measured at the IMEC/INTEC premises was -13.5dBm at 10Gb/s, with a dynamic range of 13dB. The generated packets were 1.075µs long and separated by a guard time of 25.6ns. Each packet consisted of a 29.6ns preamble followed by a fixed PRBS 2^{11}-1 pattern. Owing to the very challenging receiver design and the critical uplink integration at 10Gb/s, the PIEMAN DC-coupled BM-Rx prototypes were first integrated at 5Gb/s with the BM-EDFA, as planned in the project. The BM-Rx prototype will be further integrated at 10Gb/s in the final PIEMAN demonstrator, currently being set up within the Photonic Systems Group, Tyndall National Institute.

Fig.6 is the experimental setup where a BM-EDFA provided by Alcatel-Lucent was integrated. The BM transmitter (BM-Tx) was designed in house containing a MITSUBISHI 1.55 µm EA modulator with a DFB-LD module and an off-the-shelf DC-coupled EAM driver. In the setup, attenuator "Att.1" was used to set an input signal power level, in front of the BM-EDFA, which corresponds to a high splitting factor of 512. The second attenuator "Att.2" was used to vary the input signal power in front of the BM-Rx, for Bit error ratio (BER) measurements. An optical bandpass filter (OBPF) with a 3dB bandwidth of 0.3nm was inserted to remove amplified spontaneous emission (ASE) noise generated by the BM-EDFA.

For testing the BM-Rx plus the BM-EDFA at 5Gb/s, the BM-Tx emitted repetitive packets that were 2.15µs long and separated by a guard time of 25.6ns. Each packet consisted of a 25.6ns Rx preamble followed by a PRBS31-1 payload. The BER was measured only during the payload of the packets by the Agilent ParBERT analyzer. No external time-critical control signals (such as a reset pulse) are required, which is a big advantage when implementing and operating the uplink.

As shown in Fig.7 the measured back-to-back BM-Rx sensitivity was -15.6dBm at 5Gb/s. This Rx sensitivity was mainly limited by the wide 3dB bandwidth (> 9GHz) of the BM-TIA (designed for 10G operation). Another cause was the fact that the 10G BM-Rx can only operate error-free for input power levels above -15~16dBm. This is because that the burst detection circuitry was designed for a -16dBm threshold, which was specified for the PIEMAN system. The measured overload was +0.5dBm, thus the dynamic range was 16.1dB.

For evaluating the RX performance in a 512-way split case, the minimum input power of the BM-EDFA was set to -31dBm. The EDFA gain was set to 30dB. By adjusting Att.2 the measured BM-Rx sensitivity was -14.3dBm when BER=10^{-10}. The optical power budget between the output of the EDFA and the input of the BM-Rx was 13.3dB. The penalty caused by the BM-EDFA was 1.3dB for the 512-way split case. The dynamic range was 14.7dB. In this experiment the inter-burst guard times were kept short to show the fast synchronization. However the gap times were too short to allow the EDFA to show a gain excursion, so the EDFA penalty here was only caused by the optical signal noise ratio (OSNR) part. The BM-EDFA gain stabilization technique and its performance will be presented separately at ECOC'09[14].

Recent developments of 10Gb/s BM-Rx's

Recently several papers on the development of 10GE-PON BM-Rx's were published by NTT[15-17]. In Ref [14] a PIN based BM-Rx sensitivity of -16.2dBm, and an input overload over –1.5dB were reported. However an external reset signal was used to initialize the level detection and the condition of offset compensation for each packet. In Ref [15] an APD based BM-Rx was developed to improve the BM-Rx sensitivity, where -24.8dBm sensitivity (M=8.7) and 17.8dB dynamic range were achieved. The guard time and the preamble were 99.3ns and 75ns respectively in both cases. For future coexistence of GE-PON and 10G-EPON systems, NTT further developed a 1.25/10.3Gb/s AC-coupled dual-rate BM-Rx without reset signals. For the 10.3 Gb/s signal, a BM-Rx sensitivity of -30dBm, and a dynamic range of 25.6dB were obtained at a BER of 10^{-3}, where a forward error correction (FEC) is needed to improve the BER from 10^{-3} to 10^{-12}. In this experiment the preamble length is increased significantly to 400ns.

IMEC/INTEC is currently active on the development of the 10Gb/s BM-Rx for future ITU-T FSAN XGPON2 (symmetric 10G) systems where 1.25G/10.3Gb/s coexistence is not a must. Our efforts aim at high performance including a short preamble length for high network transmission efficiency and at the elimination of any external time-critical control signals, for high interoperability. A 10Gb/s burst-mode APD-TIA combining high sensitivity with wide dynamic range is under development within the framework of FP7 ICT MARISE project[18]. And a BM-LA with an advanced feedback approach is being designed too. Moreover, the FP7 ICT EURO-FOS project[19] provides a useful platform to continue our R&D on the integration of 10Gb/s BM-Rx subsystems and the evaluation of their performance on the system level, in parallel with other component design activities. Building on involvement in three EU-funded projects (PIEMAN, MARISE and EURO-FOS) for NG-PON applications, new 10Gb/s APD based BM-Rx prototypes with advanced features are being designed, to tackle the technical challenges and to contribute to the state-of-the-art research in his field.

Conclusions

This paper presents the evolution of the BM-Rx's and the PON trends. The 10Gb/s BM-Rx supports a guard time and a preamble time as short as 25.6 and 29.6ns respectively, which is the shortest ever published. Moreover, to achieve efficient network transmission and high interoperability, an auto reset generation and burst detection were implemented in the 10Gb/s BM-Rx to eliminate any time-critical control signals crossing the boundary between the PON physical layer and MAC layer. The 10Gb/s BM-Rx operates very reliably at 5G/s, and was not critical during the 5Gb/s experiments. However, during the experiments it was found that, for reliable 10Gb/s burst-mode operation, some more optimization is needed, to deal with imperfections caused by a low cost BM-Tx, the OSNR limitation by the BM-EFDA, and/or the BM-CDR. Current research work focuses on the design of a more generic and robust 10Gb/s APD based BM-Rx.

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