# A CMOS Burst-mode Up-stream Transmitter For Fiber-optic Gigabit Ethernet Applications

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*Abstract*— **A fully integrated fiber-optic transmitter chip for gigabit Ethernet applications has been implemented in a CMOS technology. For controlling the transmitted optical power so to obtain reliable and constant averaged optical power, the transmitter proposed in this paper uses separated bias and modulation currents control circuits based on the feedback from the monitoring photo-diode (MPD). The chip was fabricated in a mixed-signal analog CMOS technology with 0.18μm gate length and measurements were implemented in a chip-on-board configuration (COB) using pig-tailed FP laser. Under the burst-mode operation of 1.25Gb/s PRBS, measurements show about 0.5dBm transmitted optical power with above 11dB extinction ratio over a wide temperature range. Based on the measurements, this work complies with the EPON IEEE P802.ah standard.**

*Keywords* — **Burst-mode, CMOS analog integrated circuit, Fiber-optics transmitter, Gigabit Ethernet, Up-stream transmitter.**

## 1. Introduction

For multimedia communications, the data transmission capacity of subscriber networks should be increased. As motivated by this increasing demand for a broadband access network, Passive Optical Network (PON) based on Fiber-To-The-Home (FTTH) is considered as an emerging access network technology to solve the last mile problem of communications. Fig. 1 shows a typical PON system such as the full services access network (FSAN). As illustrated in Fig. 1, the PON system is basically a passive PtMP (Point-to-Multipoint) architecture with no active elements in the signal path from the source to the destination. Based on the TDMA, this passive PtMP ability sharing a single optical fiber makes it feasible to implement a cost effective solution for subscriber line that supports broadband voice, data, and even video services [1-4]. Furthermore, in this paper, the increasing demands for the lower cost and higher integration can be sufficiently satisfied with CMOS based implementation of high-speed circuits.

This paper describes a fully integrated CMOS burst-mode up-stream transmitter suitable for use in gigabit Ethernet PON (E-PON) applications. One of the key components requiring real burst-mode operation in the E-PON system is the up-stream transmitter located inside the ONUs at the subscriber end. The general requirements for the transmitter defined in the E-PON IEEE P802.ah standard are summarized in Table 1. As shown in Table 1, together with the stable transmitted optical power under wide temperature variation (-40°C to 80°C), turn-on/off delay is one of the critical performance parameters of the burst-mode up-stream transmitter.

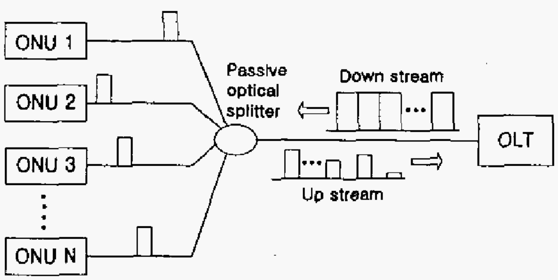


**Fig. 1. Architecture of general PON system**

**Table 1. General Requirements for the E-PON transmitter**

| Specifications | Downstream 1.25Gb/s | | Up-stream 1.25Gb/s | |
|---|---|---|---|---|
| ODN | 10km | 20km | 10km | 20km |
| Ave. Launch Power (max) | 2dBm | 7dBm | 4dBm | 4dBm |
| Ave. Launch Power (min) | -3dBm | 2dBm | -1dBm | -1dBm |
| Extinction Ratio (Min) | 6 dB | | | |
| Transmitter Off State | -39dBm | | -45dBm | |
| Turn-on Time (Max) | N. A. | | 512 nsec | |
| Turn-off Time (Max) | N. A. | | 512 nsec | |

For more detailed description, Fig. 2 shows E-PON timing parameter definitions. Data packet in E-PON allows dynamic or flexible burst length arrangement. As can be seen in Fig. 2, the time gap between the start "$T_{ON}$" and the start of a real packet is defined as a patterned idle signal. So, in order to maximize channel efficiency in one data frame, this gap time should be reduced so far as the system performance of the transmitter guarantees no errors in the OTL receiver. However, in the timing parameter given in Fig. 2, the only controllable feature by the transmitter is the laser turn-on/off time. Receiver settling time or CDR time is dependent parameter on the receiver performances. Therefore, it is important to make an effort minimizing the laser turn-on/off delay for the better up-stream transmitter.

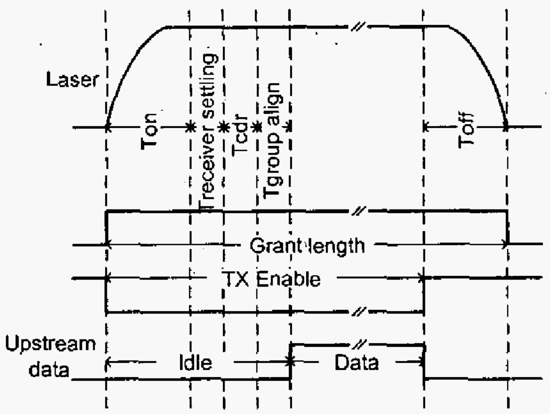


**Fig. 2. E-PON timing parameter definitions**

## 2. Burst-mode Up-stream Transmitter Design

Most optical transmitters are required to stably maintain system performances such as average transmitted optical power and extinction ratio over a wide temperature range (–40 C to 80 C). In order to obtain a reliable and constant transmitted optical power over this wide temperature, the characteristics of laser diode should be confirmed as a function of temperature.

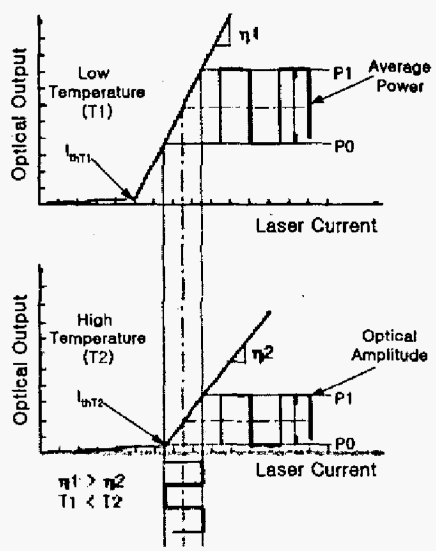


**Fig. 3. Temperature characteristics of a laser-diode as an optical output vs. laser current.**

Fig. 3 shows general transmitted optical power versus laser current characteristics of a typical laser-diode. Although the transmitted power is roughly proportional to the current through the laser above threshold ($I_{th}$), as illustrated in Fig. 3, this relationship varies greatly with temperature of the laser. The increased temperature results the decreased optical gain, which is normally defined as the slop efficiency ($\eta$). As the gain decreases, more laser current should be driven into the laser in order to get a coherent transmitted optical power from the laser. Therefore, these inherent temperature dependencies of laser diode make it essential optical transmitter to adopt temperature compensation circuits.

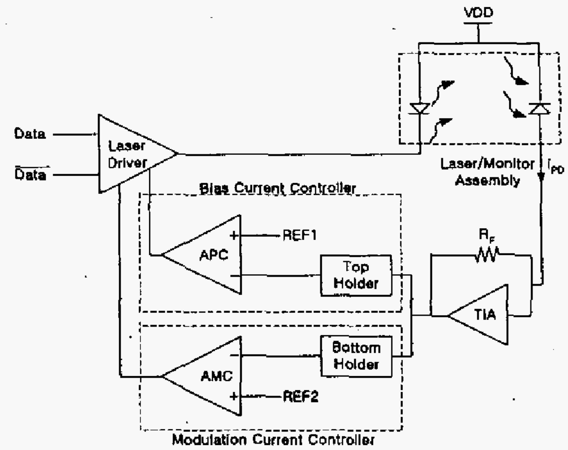


**Fig. 4. Block diagram of the proposed transmitter architecture with temperature compensation for laser-diode.**

Fig. 4 shows the simplified block diagram of the burst-mode optical transmitter architecture proposed in this work. As discussed above, due to the strong temperature dependency of the laser, the transmitter shown in Fig. 4 uses the conventional feedback from the monitoring photo-diode (MPD), which is composed of high-speed transimpedance amplifier (TIA) and top/bottom hold (TH/BH) peak detection circuits. But in order to control the bias and the modulation currents at the same time, the feedback is separated by two independent paths. As can be seen in Fig. 4, together with TH/BH peak detection circuits, the comparator circuits (APC/AMC) control bias and modulation currents of the laser diode respectively. For the given reference voltages, as temperature increases the lower monitoring photodiode current ($i_{PD}$) is fed into the high-speed TIA due to the decreased transmitted optical power of the laser. And then this feedback current generates higher voltage at the output of peak detection circuits, which results in increasing bias and modulation currents of the laser diode. In the next turn, the increased bias and modulation currents rather decrease the output voltage level of the peak detection circuits so that the reliable and constant optical power can be transmitted.

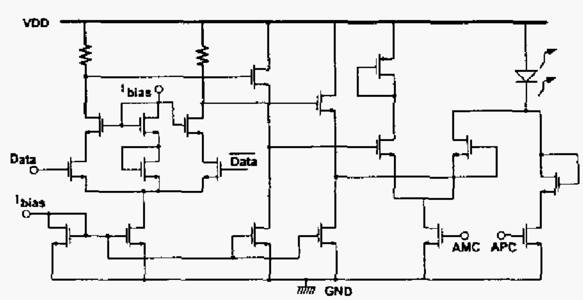


**Fig. 5. Simplified Laser driver schematic.**

Therefore, in this architecture, once the reference voltages of the AMC and APC circuits are determined at the outside, the initial bias and modulation currents for the stable transmitted optical power are automatically installed. Here the initial bias current is usually around the threshold in order to reduce the turn-on delay of the laser. And DC coupling between each functional circuit blocks is required for the burst-mode operation.

Fig. 5 shows simplified schematic of laser driver depicted in Fig. 4. In order to achieve proper DC bias and a compliant 50Ω input matching, the laser driver uses simple LVPECL input interface. And in order to guarantee the enough saturation region of the differential stage, typical DC feedback technique using two diode connected transistors is applied. For the simulation considering the case parasitics of laser-diode, the driver circuit uses the small-signal equivalent laser-diode model shown in Fig. 6.

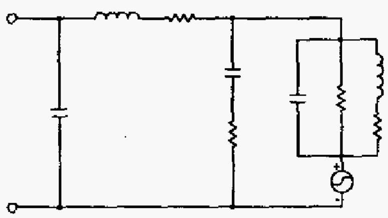

**Fig. 6. Small-signal equivalent laser-diode model.**

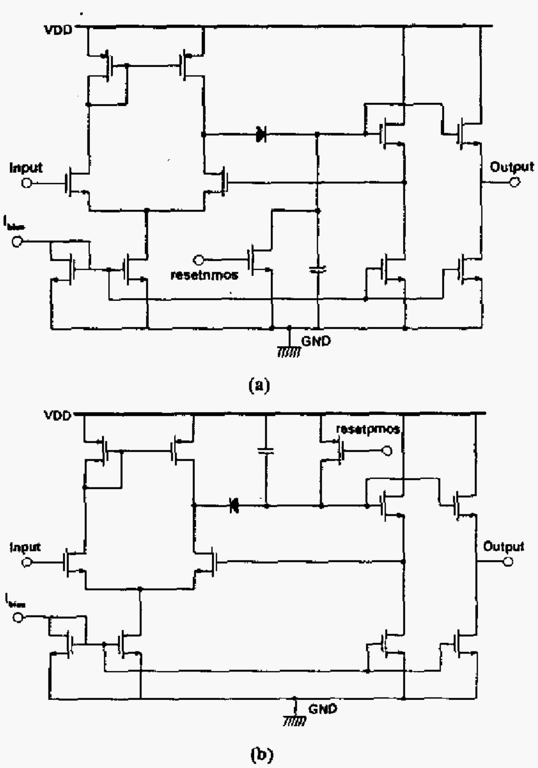


**Fig. 7. Peak detection circuits (a) top hold circuit and (b) bottom hold circuit.**

The peak detection circuits (TH and BH) are depicted in Fig. 7 respectively. As can be seen from Fig. 7, using the rectifying diode and hold capacitor, the hold level is fed back into the negative input of the main amplifier through source follower to make a unity gain feed back loop. The principle and concern on the detailed operation of the TH/BH peak detection circuits was fully discussed in [5-7].

## 3. Performances

The proposed optical transmitter shown in Fig. 4 is being realized with 0.18μm CMOS technology and tested in a chip-on-board configuration. The die microphotograph of the transmitter IC is shown in Fig. 8. With 3.3V supply the transmitter dissipates about 260mW in an area of 0.9x0.75 $mm^2$.

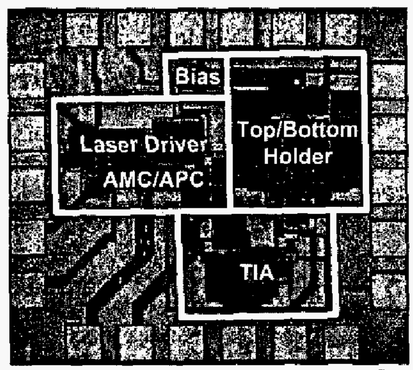


**Fig. 8. Die photograph of the transmitter IC.**

In order to evaluate the performances of the proposed transmitter, we uses HP Parallel BER Tester, which can generate up to 3Gb/s PRBS burst signal. Fig. 9 shows the measured output optical power for 1.25Gb/s burst mode with $2^9 - 1$ PRBS input data. As can be seen in Fig. 9, the proposed transmitter quickly responses with the reset signal.

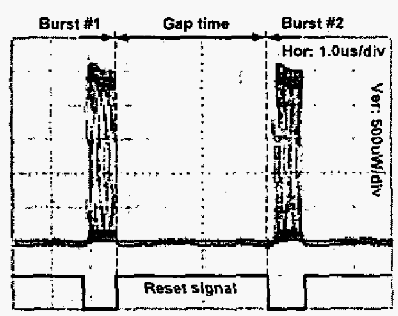


**Fig. 9. Measured waveforms for 1.25Gb/s burst mode with $2^9 - 1$ PRBS**

Fig. 10 shows the transient waveforms of the designed up-stream transmitter. For the simulation, the input PRBS signal with 80-ps rising/ falling time is applied to the transmitter. From the transient waveform of the laser driving current shown in Fig 10, it can be easily converted to the extinction ratio with the practical laser-diode specification ($\eta$ = 0.1 ~ 0.2 mW/mA and $I_{th}$ = 10 ~ 20mA). The designed transmitter shows above 13dB extinction ratio in the real burst-mode operation.

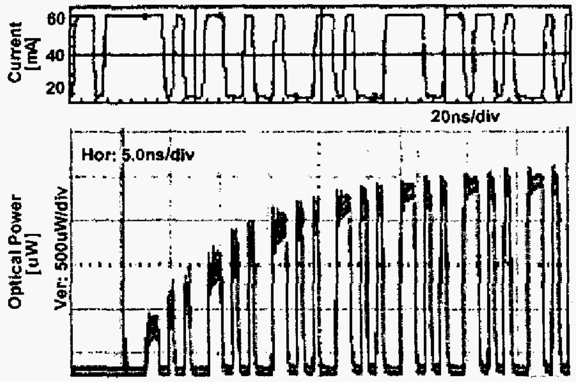


**Fig. 10. Simulation vs. measurement: transient waveforms of the proposed up-stream transmitter.**

In order to meet the E-PON specifications, the laser should be stably turned on within 512nsec with the patterned preamble signal. The proposed feedback, in this paper, controls directly the gate nodes of the current source transistors driving bias and modulation currents of the laser. Therefore, the critical delay comes from the threshold voltage of the current source transistor and the threshold current of the laser. More, these two thresholds are varied with temperature.

Fig. 11 shows the measured laser turn-on/off delay at room temperature. We can see that about 250nsec is required for the stable transmitted optical power. In the other side, as can be seen in Fig. 11, the laser is instantly turned off with reset signal. Also, it can be clearly seen that there is an overshoot of the optical power of the laser. Even so this undesired overshoot can be minimized with the proper filtering and shunt R-C network on evaluation board.

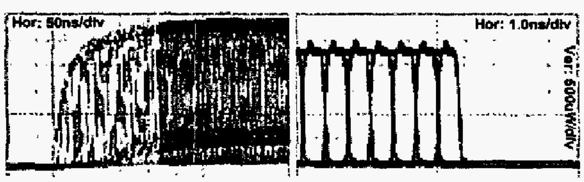


**Fig. 11. Laser turn-on/turn-off characteristics.**

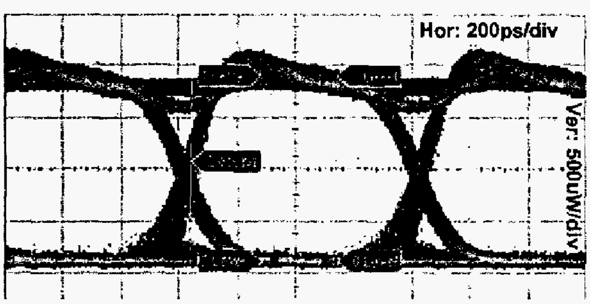


**Fig. 12. Eye diagram of 1.25Gb/s burst mode with $2^7 - 1$ PRBS**

For giving more insights, Fig. 12 provides more detailed description of the eye diagram of one of the two bursts shown in Fig. 9. In the measured eye diagram, the optical power of the center of the vertical scale is 1mW (0dBm). The eye shown in Fig. 12 is clearly opened with PRBS payload data at the room temperature. And it shows above 11dB extinction ratio with about 0.5dBm the averaged transmitted power.

## 4. Conclusions

A fully integrated burst-mode optical transmitter for gigabit E-PON applications has been implemented in a standard 0.18μm CMOS technology. The overall performances of this work are summarized in Table 2. Based on measurements, the proposed feedback mechanism can be available to the burst-mode applications. Now, an improved version is focused on ESD protection circuits.

**Table 2. Performances summary of the proposed work.**

| Specifications | This work | Conditions |
|---|---|---|
| **Data Rate** | 1.25Gb/s | Burst-mode |
| **Averaged power** | About 0.5 dBm | At room temp. |
| **Extinction ratio** | > 11 dB | With feedback |
| **Power dissipation** | About 260 mW | 3.3 V supply |
| **Chip size** | 0.9 0.75 mm$^2$ | 0.18μm CMOS |

## 5. Acknowledgement

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