Theoretical and experimental study of laser turn-on delay in a GigaPON system with pre-biasing bits

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This paper presents a study of the turn-on delay for a burst mode gigabit laser transmitter with a variable number of pre-biasing bits. We theoretically derived the delay from the rate equation for carrier density and filled in the constants for a 1.24 Gb/s PON system with a Mitsubishi FU-445SDF laser diode. The simulation was performed in OptSim, and the result fits the theoretical calculation. A gigabit burst mode laser driver was designed using a commercially available continuous mode laser driver and extra discrete components for bias current switching. The experiments agree with both the calculated and the simulated results.

Introduction

In a Gigabit Passive Optical Network (GigaPON) one fiber is shared among a number of Optical Network Units (ONU's). To avoid collisions of the upstream data sent from different ONU's, the traffic is combined in a Time Division Multiple Access (TDMA) scheme. In a particular timeslot, only one ONU sends upstream data while the other ONU's are prohibited to transmit any light into the fiber. So all the ONU's are required to work in Burst Mode (BM).

A guard time provides enough distance between two consecutive packets to avoid collisions. It has to cope with the turn-on delay of a laser diode, the tail light of the previous packet, and the time granularity of the ONU delay equalization. A guard time of 4 bytes was proposed for the 1.25 Gb/s upstream transmission. Although an ONU must not launch optical power during the guard time of slots that are assigned to it, it may launch some light during the last n bits for laser pre-biasing. The ONU is also allowed to apply some bits immediately following the assigned packet for laser turn-off [1], [2]. The launched power level during laser pre-bias and laser turn-off must be less than one tenth of the "1" level. Minimum 10 dB extinction ratio is required to not penalize the data decision in the receiver.

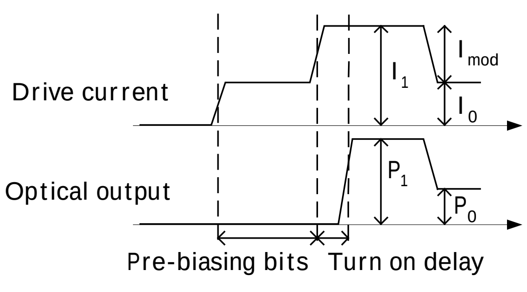

Figure 1: Drive current and optical output timing diagram

For operation at gigabit speed, the ONU laser diode must be biased well above its threshold, to avoid turn-on delay and to keep the duty cycle balanced. Conversely no transmission, and even no bias power, is allowed in the timeslots that are reserved for any other ONU, as this might interfere with the ongoing traffic.

Therefore the Burst-Mode laser Driver (BMLD) has to drive the laser diode from a state where it transmits no power at all to a state where the diode is well biased and ready to transmit data with a minimum of duty cycle distortion. The ONU will start to bias its laser diode by sending n pre-biasing bits.

This paper presents the study of the turn-on delay of the first bits after the guard time depending on the number of pre-bias bits applied and the launched power at the ONU; this is illustrated in Figure 1.

Theoretical Study

A calculation of the turn-on delay when the laser diode current starts from I_{off} below threshold and rises to I_{on} above threshold can be found in the literature [3]. I_{th} is the threshold current and τ_e is the carrier lifetime:

$$t_d = t_e \cdot \ln \frac{I_{on} - I_{off}}{I_{on} - I_{th}} \qquad (1)$$

This turn-on delay is derived from the rate equation for the carrier density expanded around the threshold carrier density n_{th}:

$$\frac{dn}{dt} = \frac{I - I_{th}}{eV} - \frac{1}{t_e}(n - n_{th}) \qquad \text{for } n < n_{th} \qquad (2)$$

Stimulated recombination is neglected in this equation because this term has little contribution below threshold. When there are n pre-bias bits, the laser diode current initiates at I_{off}, below threshold, and goes up to I_0, above threshold, for a time $t_{pre} = n \cdot t_{period}$. Finally the current increases from I_0 to I_1 as drawn in Figure 1. We derived the turn-on delay after the pre-bias from rate equation (2):

$$t_d = t_e \cdot \ln \frac{I_1 - \left((I_{off} - I_0) \exp\left(t_{pre} / t_e \right) + I_0 \right)}{I_1 - I_{th}} \qquad (3)$$

If the pre-bias bits are enough to drive the laser diode above threshold this formula gives a negative turn-on delay. In this case it is no longer valid and the turn-on delay can be neglected. Assuming a GigaPON system with a Mitsubishi FU-445SDF laser diode (t_{period} = 800ps, τ_e = 1.6 ns and I_{th} = 7.7 mA) expression (3) is used to predict the delay after the guard time in this system. Figure 2 displays the calculated values of t_d for different numbers of pre-bias bits and at different launch powers, P_1.

Simulations

In the OptSim simulation software a more complex model of the Mitsubishi FU-445SDF laser diode is included. This made OptSim a good environment to perform accurate simulations of the turn-on delay after a number of pre-biasing bits.

The rate equation mathematical model for a laser simulation requires physical parameters that can't be obtained directly from the vendors' datasheet. A tool named "best-fit laser" helps to fit physical parameters to recursively find a set of given datasheet parameters.

Since the datasheet parameters are typical values, the "best-fit laser" tool is also needed to modify the physical parameters to fit measurement data of a particular laser. In our study it is used to fit the threshold current and relaxation oscillation peak frequency with measurement data.

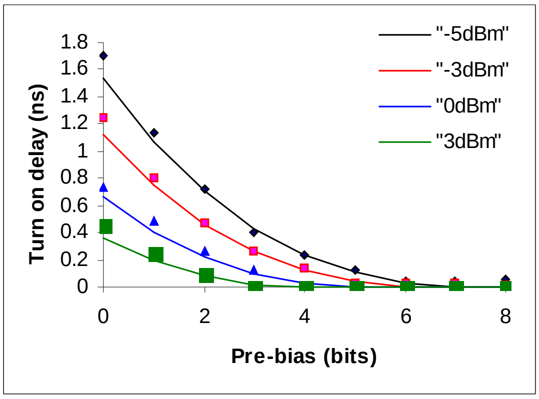

Figure 2: Calculated (lines) and simulated (dots) turn-on delay versus number of pre-biasing bits

To emulate the BM laser driver, a new compound model is made in which bias and modulation current can be driven separately. The driver output can have "off", "zero" and "one" states. Moreover, this model can be developed further to simulate a realistic BM laser driver designed in the lab. Figure 2 shows the simulated results together with the calculations. The calculations are a little bit more optimistic than the simulations because we neglected the stimulated recombination. Still there is a good agreement between both.

Measurements

The measurement of the turn-on delay after a number of pre-biasing bits can only be done with a BMLD that is able to transmit at three output states: "off", "zero" and "one". A survey of the market shows there are no BMLD chips available for 1.25 Gbit/s and for which the user can set the bias and modulation current.
A commercial Continuous Mode (CM) laser driver, the MAX3850, was selected for the design of a gigabit BMLD. With discrete components an extra differential pair had to be added to perform the BM functionality. The schematic diagram of the BMLD design is presented in Figure 3. Inaccurate loading of the modulation output circuit can cause reflections and ringing, and degrade the quality of the optical waveform. The shunt capacitance associated with the bias current source and differential pair results in parasitic effects at the modulation output that are function of the frequency. In order to minimize the effect of this impedance variation, an isolation inductor is placed between the bias current source and the differential pair. This impedance has no effect on the speed performance of the bias circuit and makes the bias circuit behave as a high impedance for the modulation output.
The turn-on delay is defined as the delay between the laser current and the optical output current (Figure 1). It is difficult to measure this because both at the electrical side as at the optical side there are extra delays caused by the control circuits and the interconnections. We assumed the turn-on delay to be negligible when the laser diode is well biased and used this as a reference. The discrete points in Figure 4 are the measured values. The lines represent the theoretical calculated values, and agree with the experimental results.

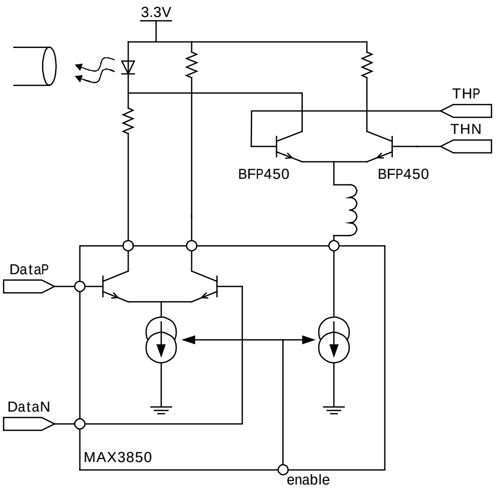

Figure 3: Schematic diagram of the burst mode laser driver

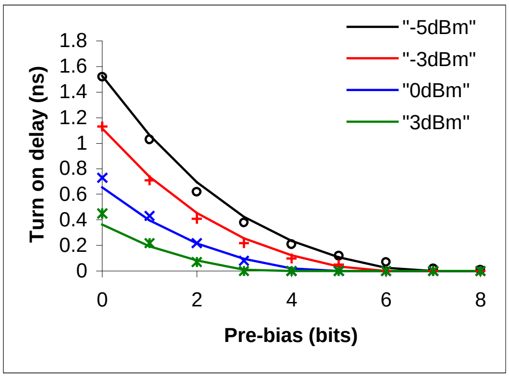

Figure 4: Measured (dots) and calculated turn-on delay versus pre-biasing bits

Conclusion

Both the simulated and measured results agree with the theoretical calculations. Equation (3) can be used to determine the number of pre-biasing bits needed and to calculate the penalty on the duty cycle of the first data bit for different laser diodes.

The presented study is part of the IST GIANT (GIgapon Access NeTwork) project. The requirement of minimum 8 pre-bias bits has been contributed to the ITU-T recommendation G.GPON.pmd (draft version). Taking different implementation methods and worst-case conditions into account, 16 pre-bias bits at 1.25 Gb/s should be enough for stable operation.

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