Proposal of A Vcsel Datasheet Model for Optical Systems Simulations

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***Abstract*— With the proliferation of voracious bandwidth-intensive multimedia applications, deployed optical sources within optical LANs in data centers must transmit data at very high data rates over short ranges and at a lower cost. To do this, among several optical sources, Vertical Cavity Surface Emitting Laser (VCSEL) is most often used. In this work, we have developed a cosimulation laser model between OptiSystem 7 and Matlab for much more realistic simulations of VCSEL-based links, such as the case of transmission systems within these data centers. After some tests of the modeled component, the chirp phenomena were validated as well as current-power characteristic and component frequency response.**

Keywords—VCSEL, LAN networks, data center, phenomenological model

I. Introduction

The development of new standards for massive online data storage through cloud computing has made possible the proliferation of new applications and services offered to users. Increasingly growing data rates that require applications such as video on demand, interactive gaming, high definition TV, sharing large media files on social networks, become a real constraint for operators, especially those with data centers, whose infrastructure must track the rise in throughput and satisfy the demand. Indeed, between 2015 and 2020, it is estimated that more than three times the global data center data traffic, of which 77% represents the traffic generated between servers within the same data center [1].

To cope with this ever-growing demand, the future interfaces of transmission systems, mainly optical, used within Local Area Networks (LAN) of data centers must not only provide speeds of at least 100 Gb/s, but also be deployed at a low cost, while ensuring good connectivity over ranges up to 500 m [2].

To do this, among several optical interfaces, the 850 nm Vertical Cavity Surface Emitting Laser (VCSEL) coupled with MMF (Multimode Fiber), has been the subject of several studies that have resulted in IEEE 802.3 ba, 802.3 bm, and 802.3 bs specifications, related to short ranges within data centers [3],[4]. Moreover, the low cost of VCSEL (twice as cheap as a DFB laser - Distributed Feed Back), and its low power consumption (a few mW power) make it a very good candidate for bit rate increase in short range transmitters [5].

As the economic factor is paramount in the deployment of optical transmission systems, it is necessary to use system simulations to study the different implementation scenarii for optimal component dimensioning before the real implementation step. Thus, like modeling work carried out under VPITransmissionMaker with the D-EML (Dual Electro-Absorption Modulated Laser) [6] taken with the DFB laser [7], we propose to model with Optisystem 7, VCSEL lasers for the scalability in optical LANs data centers. The purpose of this article is to propose a functional model of VCSEL using basic system software such as Optisystem7 in cosimulation with Matlab2016. We provide a detailed description of the VCSEL, highlighting different phenomena specific to this type of component by mathematical formulations, and we approach its modeling using system simulation based on OptiSystem7 / Matlab.

The work reported in this document is organized in two (02) major parts. In the first part, we present a detailed description of the elaborate model of the VCSEL, as well as its operating principle. The second part presents the results of the system simulations performed.

II. MATERIALS AND METHODS

A. *Presentation of proposed VCSEL model*

OptiSystem software is used as a tool for modeling and simulating the VCSEL optical source, of this work. The available models of this type of lasers in OptiSystem7.0 focuses on the knowledge of intrinsic physical and thermal parameters component, hardly provided in the manufacturers datasheets because under own proprietary data to component machining [8],[9].

The VCSEL model discussed in this article is a new alternative to simulate the realistic behavior of the component, using only parameters often provided by manufacturer's datasheets: as the case for example, of Finisar Photonics VCSEL [10], which is studied in this paper.

Fig. 1 shows the different blocks used for modeling the VCSEL component. These are mainly continuous wave (CW) laser with insertion of Gaussian noise, amplitude modulator (AM), frequency modulator (FM), an electric low-pass filter Bessel modeling the component bandwidth, a block denominated "driver" and a block realizing the transient and adiabatic chirps function of the laser. To make the model more realistic, we introduced the non-linearity of the component through the Rapp model (as presented in section D). The proposed model has an electrical input (input of the driver) and optical output (after the FM modulator).

B. *Continuous wave laser, amplitude modulator (AM) and frequency modulator (FM)*

Continuous wave (CW) laser provides a light signal which serves as an optical carrier at 850 nm. This carrier is amplitude modulated by electrical signal data from the driver through the amplitude modulator block (AM). The linewidth of the laser is modeled by a white Gaussian noise whose realization modulates in frequency way the ideal optical line of the CW laser. The expression of the AM modulator output, implemented with Matlab due to the unexpected operation of the OptiSystem AM block, is given by:

$$E_{AM}\left(t\right)=E_{CW}\left(t\right)\sqrt{\left(1-m\right)+m\cdot d_{AM}\left(t\right)} \qquad (1)$$

This unexpected operation induced wrong static characteristic current-power response of the laser during measurement process. $E_{CW}\left(t\right)$ is the output field of the CW laser, m the intensity modulation index of the laser with $0\le m\le 1$ and $d_{AM}\left(t\right)$ the modulating signal from the electrical driver, which is bipolar signal in our case and has to be unipolar according to the Optisystem AM block specifications. The field $E_{AM}\left(t\right)$ then undergoes non-linearity function before being modulated in frequency (FM) by the $d_{FM}\left(t\right)$ signal coming from the chirps block process. The final resulting optical field is given by:

$$E_{FM}\left(t\right)=E_{AM}\left(t\right)\left(e^{j2\pi\int_0^t \Delta f_{pp}\left(d_{FM}\left(\tau\right)-0.5\right)d\tau}\right) \qquad (2)$$

Where Δf_{pp} represents the peak-to-peak frequency deviation of the FM modulator. According to Optisystem7, the modulation blocks AM and FM are ideally fixed to values: m = 1 and Δf_{pp} = 1 Hz

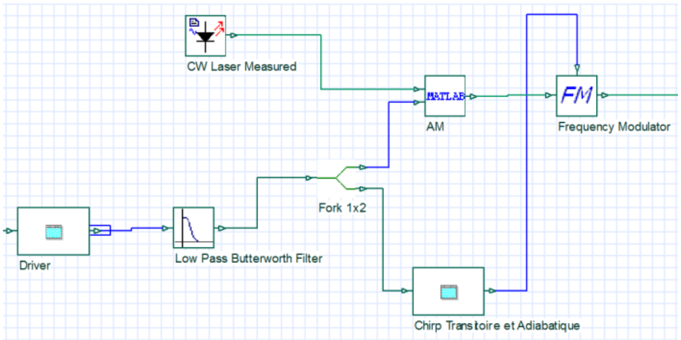


Fig. 1. Simplified blocks diagram of the proposed VCSEL model

C. *Transient and adiabatic chirps block of the laser*

The chirp is a frequency drift ($\Delta\upsilon$) observed during the direct modulation of the laser. This is the result of variation of the refractive index of a medium as a function of the electric field applied to it [6],[7],[11]. This impacts the spectral width of the laser and induced two different effects: one related to modulation phase and the other, frequency modulation. These are called respectively: transient chirp or Henry factor (α_H) and adiabatic chirp (A_d). The adiabatic chirp A_d depends on the thermal effects of the laser, spontaneous recombinations, carriers lifetime, confinement factor and the adiabatic gain of the laser. Their respective impacts depend mainly on the characteristics of the optical source [7]. The Chirp impact of the laser is modeled by:

$$\Delta\upsilon = A_d\cdot P_{signal}+\frac{\alpha_H}{4\pi}\frac{1}{P_{signal}}\frac{dP_{signal}}{dt} \qquad (3)$$

With $\Delta\upsilon$ the optical frequency deviation (Hz) and P_{signal}, the output optical power of the laser (W). In (3), the first term represents the adiabatic chirp and the second one, the transient chirp.

D. *Electrical driver*

The « driver » block converts the electrical signal $v\left(t\right)$ into current form $i\left(t\right)=G\cdot v\left(t\right)$ at the laser input. G represents the transconductance of the laser in (*A/V*). Hence, the output optical power at the AM modulator can be expressed by:

$$P_{AM}(t) = \eta\left(I_{bias} - I_{th} + i(t)\right) \quad (4)$$

With $P_{AM}(t) \geq 0$, η the optical efficiency of the laser (W/A), I_{bias} and I_{th} respectively the bias and threshold currents.

E. *Non-linearity*

The non-linearity function is implemented with Matlab within a block called AM as shown by Fig. 1. This block is used to fully implement in Matlab, the AM modulation followed by the non-linearity function. Note that the non-linearity has been added to take into account the loss of laser gain, due to temperature increase for high polarization currents. Among several models [12],[13] describing the non-linear saturation of lasers, the Rapp model is the most representative model. It is known as one of the best models of non-linearity used to describe the saturation of power amplifiers [7].

It is therefore integrated in the laser model by implementing (5) representing the transfer function of the saturation curve expressed in terms of P_{AM} input power and P_S output power:

$$P_s = \frac{P_{AM}}{\left[1 + \left(\frac{P_{AM}}{P_{Sat}}\right)^{2N_\gamma}\right]^{1/2N_\gamma}} \quad (5)$$

Where $N_\gamma \in ¥^*$ is the parameter describing the fineness of the curve $P_s = f\left(P_{AM}, N_\gamma\right)$, in its transition from the linear to the saturation zone. P_{Sat} represents the saturation power of the laser.

F. *System settings*

Table I presents the parameters of the studied VCSEL used for the proposed model validation.

III. Results and Discussions

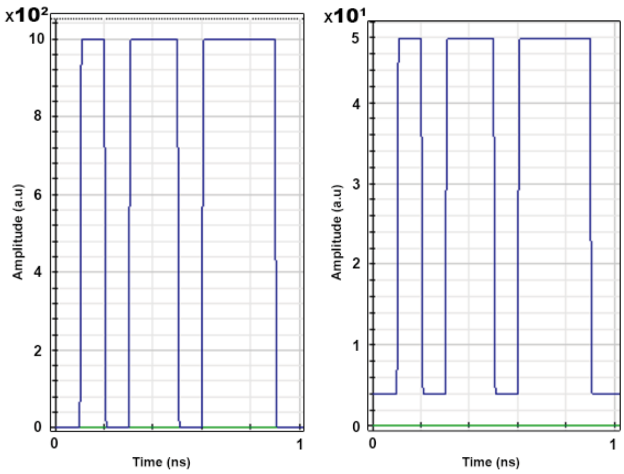
A. *Demonstration of transient and adiabatic chirps*

To validate the chirps effect, the laser has been modulated by an electrical NRZ-OOK signal. Fig. 2 and 3 show the variation of the frequency $\Delta\upsilon$ as a function of time. In Fig. 2 (a), electrical NRZ-OOK signal is presented and in (b), only the adiabatic chirp is taken into account. In Fig. 3 (a), only the transient chirp is considered and in (b), the combined effect of both chirps are shown.

TABLE I. VCSEL parameters from Finisar Photonics[10]

Parameters	Symbols	Values	Units
CW laser			
Wavelength	λ	850	nm
Linewidth	$\Delta\lambda$	10	MHz
RIN	RIN	-128	dB/Hz
RIN measured power	-	1e-005	W
Transient and Adiabatic chirps			
Chirp Alpha	α_H	3,7	-
Adiabatic factor	A_d	10000	Hz/W
Electric driver and bandwith			
Laser slope efficiency	η	0,22	W/A
Laser transconductance	G	0,02	A/V
Threshold current	I_{th}	1,2	mA
Bias current	I_{bias}	0 ~ 15	mA
Laser bandwidth	BW	7	GHz

We can see in Fig. 2 (b) where only the adiabatic chirp is highlighted, that the magnitude range of the signal frequency is 10 times less smaller than in Fig. 2 (a). This contributes to an increase of the group propagation velocity of the signal components, which can induce a time offset of the signal.

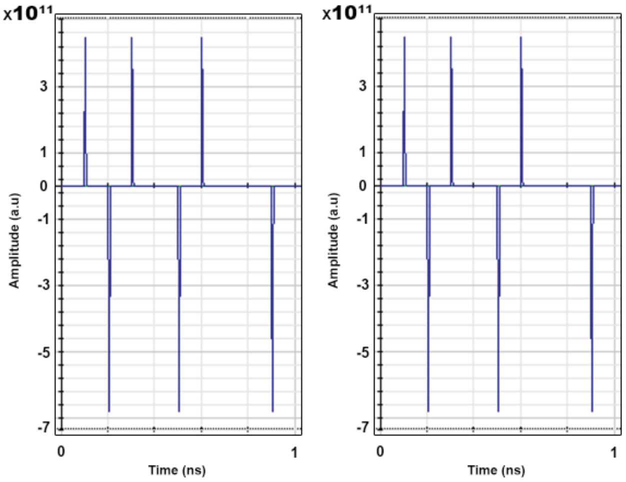


(a) (b)

Fig. 2. Illustration of the output frequency of the laser taking into account the signal (a) NRZ-OOK used and (b) the adiabatic chirp.

In Fig. 3 (a), where only the transient chirp is taken into account, the frequency drift is observed at each rising and falling edge so that the rising edge pulse occurs more rapidly than the rising edge pulse, which produces slower with opposite amplitude values even smaller. Thus, there is a beat on either side of fronts at each level "0" or "1" of the initial signal.

Fig. 3 (b) shows the combined impact of both chirps effect. It is interesting to note on the one hand that the transient chirp is highly sensitive to the transitions between the high level (bit "1") and the low level (bit "0") than the adiabatic chirp, and then, the amplitude values observed for the process transient chirp are larger compared to the adiabatic other, so that the shape shown in Fig. 3 (a) is similar to Fig. 3 (b). These results are similar to those presented by authors in [11].



(a) (b)

Fig. 3. Illustration of the output frequency of the laser taking into account the signal (a) transient chirp, and (d) the combined effect of the two chirps.

B. Validation of the static characteristic function of the laser

To study the static characteristic $P = f\left(I_{bias}\right)$ of the laser, two cases were considered: the linear form obtained from (4) and the nonlinear form based on (5). By driving the laser with a constant continuous signal (DC current for example), the bias current (I_{bias}) of the laser was varied from 0 to 15 mA. And then, we obtain curves in Fig. 4 (a) depending on smoothness values 3, 5 and 7.

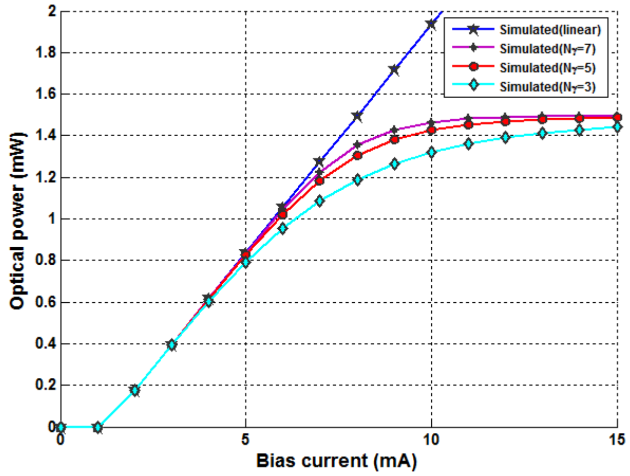
To get realistic model, we used parameters from Table 1 whose experimental measured curve $P = f\left(I\right)$ is shown by Fig. 4 (b).

As shown in Fig. 4 (a), the linear area of the characteristic is observed for bias values between 1.2 mA (threshold current) and 5 mA, while the nonlinearity starts beyond 5 mA until saturation. Also, we see that as N_{γ} increases, the simulated curves have a slope that tends towards the linear curve.

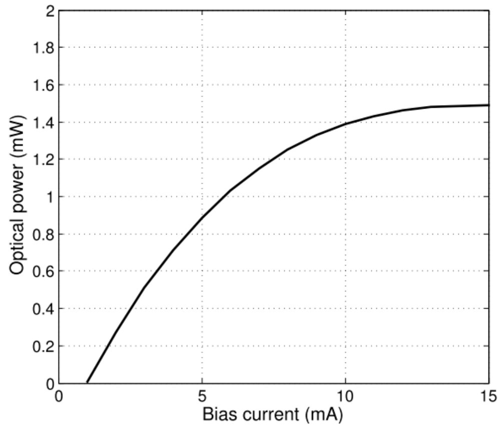
From Fig. 4 (a), it is easy to see that only the red curve ($N_{\gamma} = 5$) better approximates the curve of Fig. 4 (b). In conclusion, this value of $N_{\gamma} = 5$ can be fixed in the model to validate the static characteristic of the VCSEL.

C. Bandwidth validation

We also study the transfer function response of the laser (its bandwith), by testing its frequency response when applying a dirac signal at its input. Bandwidth is modeled in Optisystem7 by inserting an electrical low-pass filter Bessel 4th order.



(a)



(b)

Fig. 4. Static characteristic of the studied VCSEL - (a) Simulated curves - (b) Measured Finisar Photonics curve [10].

As shown by Fig. 5, at -3 dB of the maximum amplitude, the cutoff frequency corresponds to the bandwidth of the laser, as mentioned in Table 1. This confirms that the VCSEL bandwidth is also taken into account by the proposed model.

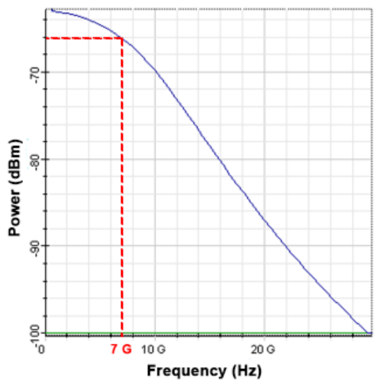


Fig. 5. Frequency response of VCSEL

IV. Conclusion

This paper focused on the implementation of a phenomenological model of VCSEL laser under OptiSystem 7.0 by Matlab cosimulation, for increase data rate context for LAN data centers. The proposed model is based on the modeling of mathematical formulations of phenomena inherent to this type of laser. Following by system simulations and use of component parameters often provided by datasheets, various phenomena such as the transient and adiabatic chirps were highlighted, as well as static characteristics and laser frequency response. In conclusion, this paper proposes a new alternative to model and simulate VCSEL lasers for optical systems.

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