Design and conception of optical links simulator for telecommunication applications under Simulink environment

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Abstract: - Optical fibers provide a medium in which microwave signals that modulate optical carriers can be transmitted and distributed with high bandwidth and very low losses. They are involved in many applications such as phased array antennas, CATV, radars and optical communications. In this work an optical link simulator is designed like a platform on which the transmission and optimization of systems could be carried out, this simulator will be developed under Simulink environment (A library will be developed). As case study we will simulate a complete 1,55 µm optical fiber link for the telecommunication applications, based essentially on laser diode modulated at 2,5 Gb/s, optical fiber with a given length and a photodiode with a given sensitivity.

Key-Words: - Simulator, Laser simulation, Photodetector, Optical fiber, Optical fiber Transmission, Optical link, Simulink,.

1 Introduction

The communication can be defined as being a transfer of information between two points. The required technical goal is always to have the best possible quality of the signal, the greatest capacity (flow) as well as the greatest covered distance.

A few years ago one used the coaxial cable for the digital transmission and we reached in these systems a flow of 270 Mbits/s. but with the emergence of new services related to the development of multi-media (videophone, television, Internet,…), a need for a higher rate of information transmission appeared, we needed to find an alternative to the coaxial cable. Thus the optical fibre appeared, its use now, is usual in the telecommunications networks.

Today, the evolution of telecommunications systems always tends towards an increase in the transmissions capacities. The difficulties do not reside any more on the support having a broad band-width and weak attenuations, but on the modules of emission and reception, gathering fast electronics and optoelectronics functions.

In this work a simulator is designed as a platform upon which system transmission and optimization could be performed. The simulator has been developed in stages so as to minimize confusion, errors and ease of implementation. Furthermore a step by step approach allows skill sets pertaining to the simulator to be gradually developed.

The simulator was broken into a number of separate stages mainly, there are three stages. The first stage consisted of the carrier generator, a data stream block to generate modulation data and the modulator (Laser) model itself. Secondly it is the inclusion of a fiber propagation model (linear and non linear model). And finally the receiver blocks (photodetector, amplifier and reconstitution...).

To demonstrate the operation of the Simulink optical simulator an example is incorporated for the simulator of complete 2.5 Gbits/s line transmission and its various components, in order to measure the expected performances of such link .[1][2][3]

2 Problem Formulation

The proliferations of the communications based on the use of optical fibres create an unquestionable need for tools of computer-aided design (CAD) effective for the design of circuits and optoelectronic systems. In the field of electronics, many tools of CAD were developed for the design, the analysis and the simulation of almost each aspect of integration, extending from the process to the device, the circuit to the system. When these tools are properly used, it is often possible to produce realistic designs after only one cycle of design. Being given the saving of time and cost due to the useless revisions of design, the tools of CAD proved to be a priceless asset to the originators of the electronic devices. In order to keep the same philosophy of development in optics as in electronics, equivalent design tools must be developed in the optical field, whereas the limitations of technologies of manufacture and the semiconductors used in electronics became obvious, optical technologies seemed an excellent alternative to conventional electronics and more particularly to the communication systems. These systems have many advantages compared to their predecessors like the speed transmission or immunity to the electromagnetic interferences. However, since the current devices are mainly electronic, a complete conversion into optical system is neither desirable nor realizable. It is then preferable to design devices making the interface between the optical systems and the electronic systems. The systems comprising optical and electronic circuits will be known as optoelectronics. [2]

The first application of optoelectronics is obviously the long distances telecommunications sector based on optical fibres (our objective). These optical fibres systems convert the electric signals into optical signals for the transmission; then again convert them into electric signals at the the reception. In this way, transmission qualities of optical fibres are exploited while compatibility with the existing electronic devices remains maintained. The concept of optical communication can also be applied to smaller scales. Indeed, nowadays, it is not rare to use optical networks between several computers. Whereas the Ethernet networks operate with approximately 100Mb/s, the networks based on optical fibres, represented can go until 10Gb/s. As we see the optical field is vast and become more and so much. For all these applications, it is necessary to use different tools of CAD. Indeed according to the level of integration, we do not need the same precision in the simulation results [2] [3] [5]

At the beginning of the optoelectronics, principal research was axed on the development of the techniques of manufacture of the elementary optical components. Considerable efforts were made during the last decade to improve various optical technologies as well on the semiconductors used for the lasers or the detectors, as for optical fibres and optical guides. These technologies once industrialisables and industrialized made it possible to the researchers to turn to the study of the complete optical systems such as for example long distances telecommunications. One can make a parallel between the field of the electronics of some ten years ago and that of optics today. Indeed as at the beginning of the era of the electronic design, the design of optoelectronic circuit is carried out in a way known as “trial and error”; the circuit is designed then carried out. The designs which do not function correctly are modified then realized again. Often several cycles of design realization are necessary to obtain acceptable results of operation. For the design of circuits and electronic systems, tools of design were developed, thus making it possible to reduce time between the idea and the realization of functioning prototype correctly and an intrinsically the cost necessary to its study. However similar tools were not widely developed for the field of optoelectronics. Indeed often we will find tools simulating the electronic part of the system but without taking account the effects of the optical part and vice versa. It is from this point of view that we want to design this simulator of optical link. [4] [6]

3 Simulator

Because of its flexibility and its low cost, the simulated study of a communication system is often preferred to the direct experimentation. On these considerations it is based the modelling of a numerical link of optical communication with direct intensity modulation/detection. The study is axed on an semi-analytical approach, allowing the numerical simulation of parameters whose complexity is refractory to a purely theoretical analysis, while avoiding the reducing approximations which get a Classic formalism. [5]

An optical link simulator is designed like a platform on which the transmission and optimization of the system could be carried out. The simulator was developed in the form of modules to minimize confusion, errors and to facilitate the design. Moreover an approach step by step allows a whole of competence which in connection with simulation will be gradually developed. This section documents the development of the simulator, by explaining the steps undertaken to conceive it and thus explain how to join the components together in simulation. Complete prototype SIMULINK is shown in fig. 1

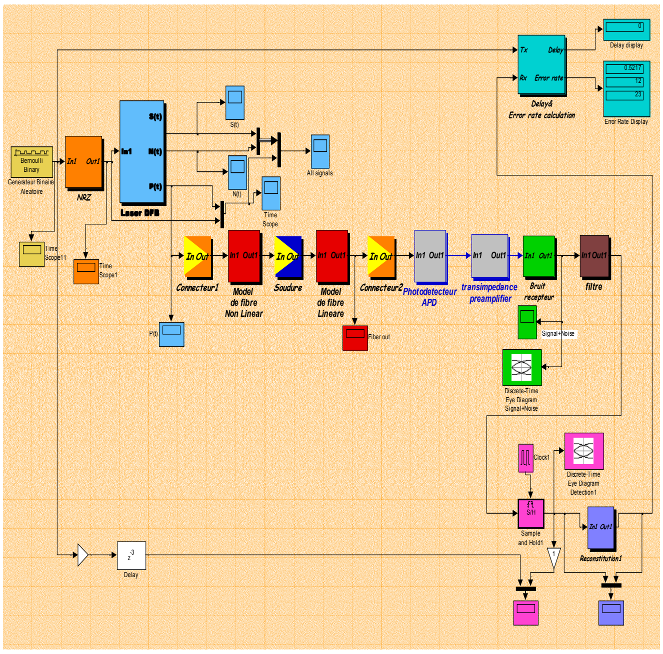

Fig. 1: Complete prototype of the SIMULINK Simulator

3.1 Laser Modeling

It's from the rating equations that an electric model of the laser is established. Several models were established in particular that of Tucker who was the first and whom we will use in our study. These models express the optical power at the output of the laser according to the electrical power input or according to the current of polarization: [7] [8] [9]

$$\frac{dN}{dt}=\frac{I}{qV_{act}}-g_0(N-N_0)(1-\varepsilon S)S-\frac{N}{\tau_n}+\frac{N_e}{\tau_n} \qquad 1$$

$$\frac{dS}{dt}=\Gamma g_0(N-N_0)(1-\varepsilon S)S+\frac{\Gamma\beta N}{\tau_n}-\frac{S}{\tau_n} \qquad 2$$

Parameters	Symbols	Unit
Electrons life time	τ_n	S
Photons life time	τ_p	S
Cavity Volume of the laser	V_{act}	m^3
Gain compression Factor	ε	m^3
Optical compression Factor	Γ	
Emission spontaneous Factor	β	
Différentiel Gain	g_0	m^2
Density at transparency	N_0	m^{-3}

Table 1: Laser Internal Parameters

From these equations, we can construct a block under Simulink which reproduces the behavior of a laser diode and its interface fig. 2**.**

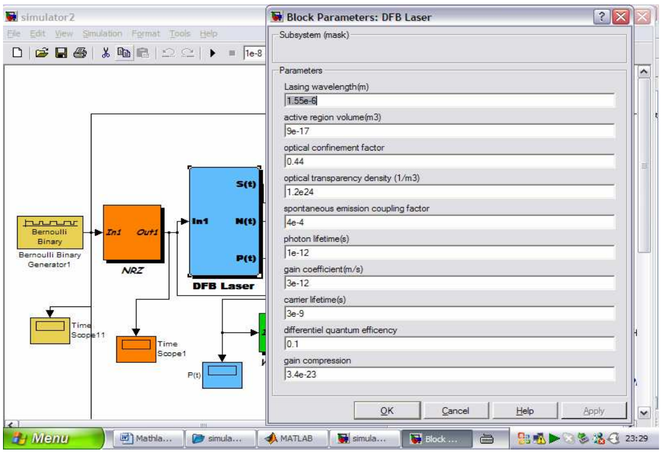

Fig. 2: Simulator Interface of the Laser

3.2 Optical Fiber Modeling

In the optical communications, electric signal carrying information is converted into optical signal which propagate in a silica fibre, to be then reconverted in electric signal. If the fibre used is a single mode fibre, the optical signal can undergo a certain number of distortions due to the properties of the material in which fibre is made up and its geometry. The effects on the optical signal can be divided in two classes:

- Linear Effects: attenuation, chromatic dispersion.
- Non-linear Effects: Brillouin diffusion, Raman diffusion, fluctuations of the refraction index.

The impact of such effects on the signal depends primarily on the operation conditions (wavelength, input optical power, length of the fibre, conditions of manufacture and fibre environment). Under certain conditions, some of these effects can be neglect in front of others to give simplified models allowing a comprehension of the important phenomena and fast numerical calculations

In this work, we have used the transfer function model to model a single mode fibre. The model of the transfer function of the single mode fibre (SMFTF) allows the change of the parameters of dispersion and also makes it possible to effectively model several types of fibre like the SMF (single mode fibre) and DCF (dispersion compensation fibre). The non-linear model of the fibre is also developed thus allowing the change of the type of the fibre by a simple change of the value of Aeff and the curves of attenuation. [5] [10] [11]

3.2.1 Linear model of single mode fibre

The model of the transfer function of a single mode fiber (SMFTF) assimilates optical fibre to a Low pass filter (fig. 3 and 4) [5]:

$$H(f) = e^{-j\pi D \lambda L f} \quad (3)$$

Where D represents dispersion, λ represents the operational wavelength when f it is the frequency of carrying optics and finally L represents the length of fibre.

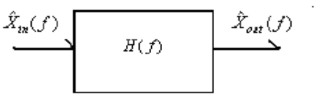

Fig. 3: Functional diagram of the linear model of fibre, an optical LPF

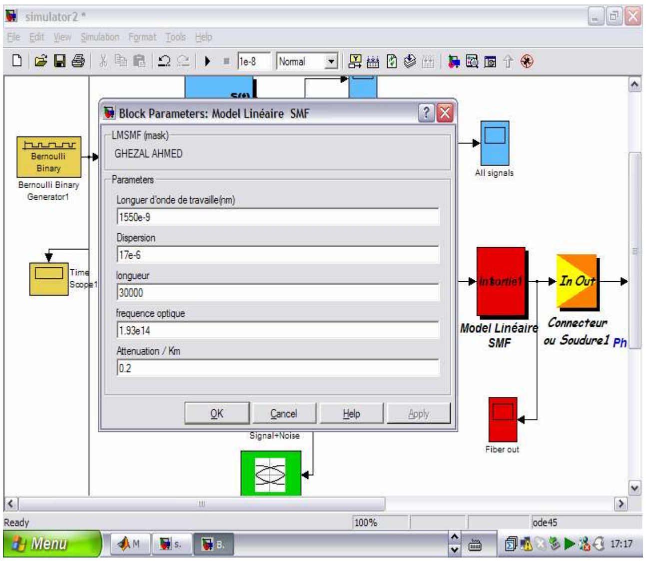

Fig. 4: Simulator Interface of the linear optical fibre model

3.2.1 Non linear model of single mode fibre

We can approximate the nonlinear model by:

$$H(f) = e^{-j\phi_{NL}} \quad (4)$$

Where ϕ_{NL} represents several non-linear effects such as effect Brillouin, Rayleigh and Raman dispersion. This parameter acts like a multiplier and it depends on the power injected from the laser and it is defined by the following equation:

$$\phi_{NL} = \gamma P_{in} L_{eff} \quad (5)$$

Où

$$\gamma = \frac{2\pi \bar{n}_2}{\lambda A_{eff}} \quad (6)$$

$\bar{n}_2$ Represents the coefficient of the non-linear index, for single mode silica optical fibre it is worth generally 10^{-20} m^2/W. Aeff is the effective surface of optical fibre and it is defined by:

$$A_{eff} = \pi r_0^2 \quad (7)$$

r_0 represents the diameter of the fibre core.

$$L_{eff} = \frac{[1-\exp(-\alpha L)]}{\alpha} \quad (8)$$

$$\alpha = \pi D \frac{\lambda^2}{C} L \quad (9)$$

The threshold power, represented by P_{th}, is defined by D.B.S. (Stimulated Diffusion of Brillouin) by approximately 20 kW/cm2 for silica [12]

The nonlinear effect will be negligible for an injected power lower than the threshold power, but in the case where this power is higher than the threshold power the effects nonlinear will considerably affect the propagation

In our simulator, if the level of the optical power is below the predetermined level (threshold power), the non-linear effects of dispersion are considered to be negligible thus our signal goes from input to the output of the model without jamming. However, when the level of the input power is above this predetermined level, the non-linear effects of dispersion are significant and the induced nonlinear dispersion is included (fig. 5). [5][13]

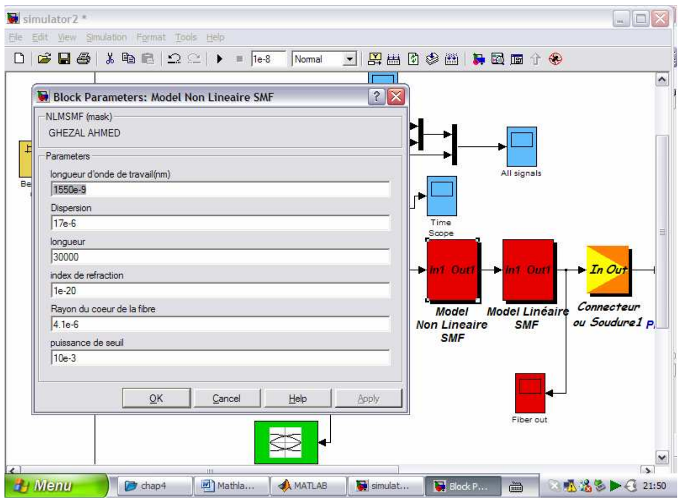

Fig. 5: Simulator Interface of the non linear optical fibre model

4 Case study

In this case study we will simulate a on 60 km link by using 2.5 Gb/s rate. The laser will be attacked by a pumping current of 20 mA and a threshold current of 15 mA

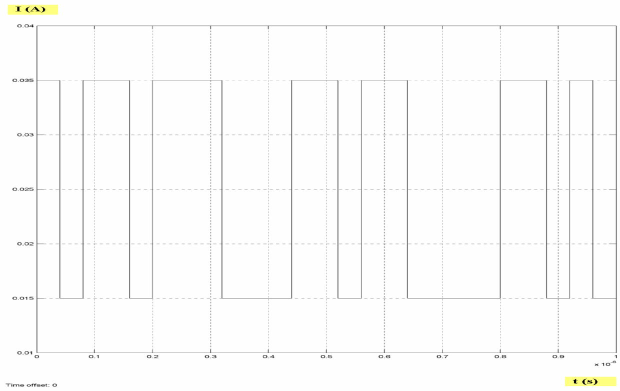

Fig. 6: Signal at the input of the DFB Laser

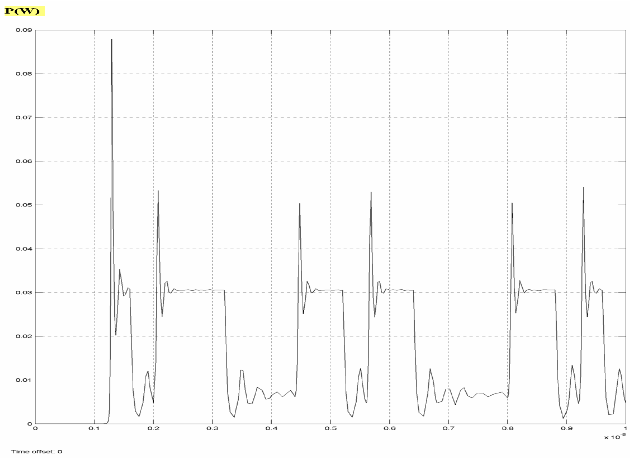

Fig. 7 The modulated signal by the laser

	Attenuation	Number	Length	Value
Connectors	0.5 dB	2	-	**1 dB**
Welding	**0.075 dB**	**30**	**60 Km**	**2.25 dB**

Table 2 : Assessment of the connectors and the welding of the connection

The power of threshold, represented by P_{th}, is defined by D.B.S. (Stimulated Diffusion of Brillouin) which is approximately 20 kW/cm2 for silica [12]

$$P_{th}=10.56 \text{ mW}$$

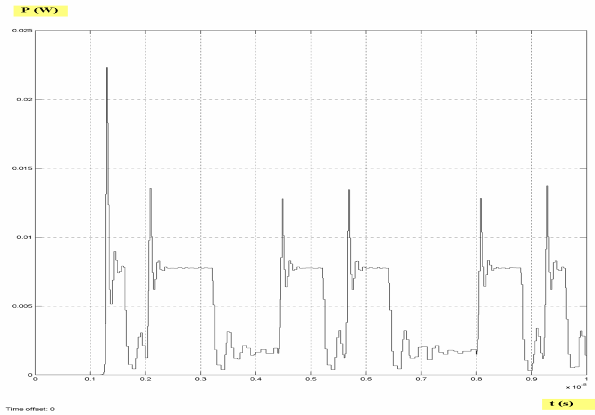

Fig. 8 Photocurrent at the output of the APD photodetector

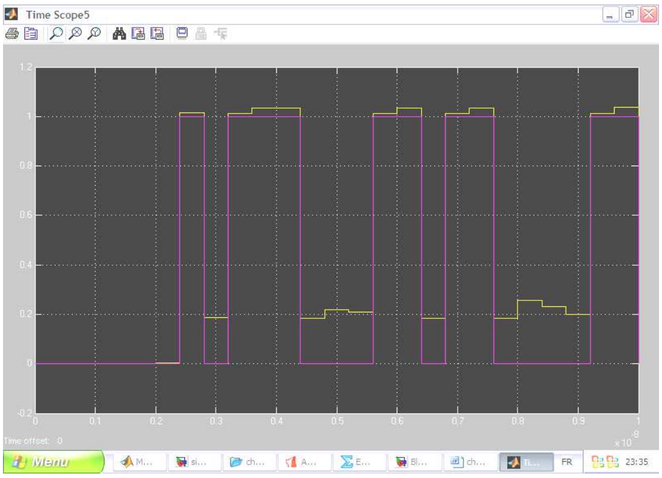

Fig. 9 Comparison between rebuilt signal and the received signal before reconstitution

From the eye diagram we can have

- the ideal threshold value (0.45 in this case) which we will use in the block of detection
- The quality factor Q from it we can compute the BER of the link.

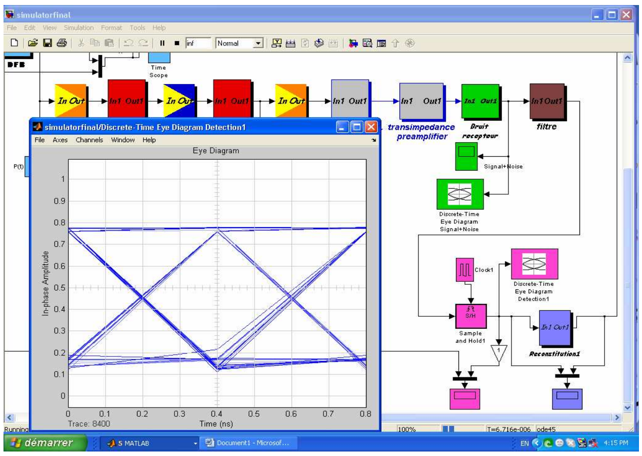

Fig.10 The Eye Diagram at the reception

The quality factor :

$$Q \approx 7.05$$

From Q the BER is less than 10^{-12} which is acceptable.

5 Conclusion

The design of more powerful new systems is an increasingly complex problem, as long as the number of parameters influencing the performances of the link is important. Also, the simulation tools are used more and more. They allow savings of time and money by avoiding the iterative experiments on systems demonstrators. Their utility was described and an exhaustive presentation of our model was written in order to facilitate its knowledge and its control by future users.

The principal objective of this work was to prove the utility of our model for the simulation and its considerable assistance to the communication systems design based on optical fibre. The results obtained made it possible to validate the choices of the techniques and the components used to develop optical fibre link. The methodology employed consist to modify one by one the models necessary to the simulation also highlighted the influence of the various components through their functional parameters, on the total performances of a link such as the error rate and quality factor. This observation can also guide the manufacturers in order to improve their products and more precisely to define the parameters to which their efforts must relate. Our step thus consisted of simulations becoming increasingly complex by the addition of multiple parameters associated with each constitutive block of a system thus making it possible to approach a real connection.

For the future studies one can directs work towards the improvement of the performances and this by creating new block or by using the multiplexing or directing work towards the implementation of degradation laws of the components, this will enable us to determine the lifespan of a communication link, by evaluating the impact of these failures on the performances of the system.

References:

[1] John Crisp., *Introduction to fibre Optics*, Academic, Newnes 2002.

[2] Harry J., Dutton R., *Understanding optical communication*, IBM, September 1998

[3] Carl Nassar, *Telecommunication Demystified*, Eagle Rock Virginia, LLH Technology Publishing, 2001

[4] FRANCE TELECOM, *Les communications optiques du futur*, Mémento Technique n°19, juin 2002.

[5] Michel C. Jeruchim, Philip Balaban, K. Sam Shanmugan, *Simulation of Communication systems: Modelling, Methodology, and Techniques*, Kluwer Academic Publisher, 2002

[6] Barry Elliott. ,Mike Gilmore, *Fiber Optics Cabling*, Newnes 2002

[7] R.S. Tucker & D.J Pope, Large Signal Circuit Model for Simulation of Injection-Laser Modulation Dynamics, *IEEE J. Quantum Electron*, Vol. QE-19, July 1983.

[8] S.A. Javaro & S.M. Kang, Transforming Tucker's Linearized Laser Rate Equations to a Form that has a Single Solution Regime, *Journal of Lightwave Technology*, Vol. 13, No 9, September 1995.

[9] L. Bjerkan, A. Royset, Measurement of Laser Parameters for Simulation of High Speed Fibre Optic Systems, *Journal of Lightwave Technology*, Vol. 14, No 5, May 1996.

[10] Casimer DeCusatis, *Handbook of Fiber Optic Data Communication*, Academic Press 2002

[11] *Characteristics of a single-mode optical fiber cable*, *ITU-T Recommandations G.652*, October 2000.

[12] Z.sidi Ali Mebarek, *Telecommunications optiques*, OPU 2001

[13] Govind P. Agrawal., *Applications of Nonlinear Fiber Optics*, Academic Press 2001.