



RESEARCH ARTICLE

OPEN ACCESS

SIMULATION OF AN ULTRA-FREQUENCY CARRIER GENERATOR IN TWO REGIMES (NON-LINEAR AND DISPERSIVE) FOR DIGITAL TRANSMISSION IN THE FIELD OF ADVANCED TELECOMMUNICATION

Amar Hamouda¹, Nabil Laiche², Laid Gasmi³

¹Department of material Sciences, Faculty of exact sciences and natural and life sciences, Oum El Bouaghi University, Algeria.

²Dynamical Systems and Control Laboratory. Oum El Bouaghi University, Algeria.

³Laboratory of Mathematics Modeling and Applications, University of Adrar, Algeria.

¹<https://orcid.org/0000-0002-6244-8092>, ²<https://orcid.org/0000-0003-3392-1300>, ³<https://orcid.org/0000-0001-8925-0089>

E-mail: amarhamouda@univ-ueb.dz, nlaiche2020@gmail.com, lai.gasmi@univ-adrar.edu.dz.

ARTICLE INFO

ABSTRACT

Article History

Received: February 14, 2026

Reviewed: March 14, 2026

Accepted: March 10, 2026

Published: June 30, 2026

Keywords:

Electromagnetic waves,
Imbalance, dispersive, nonlinear.

Optical Pulses.

Nonlinear Dispersion.

Optical Communications.

Our work consists in realizing by simulation a generator of electromagnetic waves (train of optical pulses) as carrier of the information signal in two different regimes (dispersive and non-linear) based on the technique of imbalance condition between the nonlinear effect and the dispersive effect: that the nonlinear effect is greater than the dispersive effect and vice versa, in order to decrease the temporal width of the optical pulse. In addition, to increase the power and improve the quality of the information signal to be transmitted by optical fiber, or in free space, against additive white Gaussian noise, in advanced telecommunications systems.



Copyright ©2026 by authors and Galileo Institute of Technology and Education of the Amazon (ITEGAM). This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

I. INTRODUCTION

With the advent of the Internet, bandwidth requirements have become increasingly important in order to reliably convey the growing mass of information on the various networks while preserving a good quality of service. Indeed, this has necessitated the development of a communication system that is powerful and reliable enough to interconnect a constantly growing number of users across the globe. At the present time, the most efficient and widespread technology for fiber optic transmission systems, at very long distances or without wires, is based on techniques for generating information carriers at very high frequency and at high power in different regimes (dispersive and nonlinear) [1] [2]. Indeed, this technique makes it possible to exploit the spatial dimension (multiple antennas) to separate the different users who share the same frequency band. This is a very strong asset for the quality of the generated signal (stable and jitter-free, protected and secure against additive white Gaussian noise). It is in this context that our research work carried out within the Laboratory of Studies and Research of Instruments and Communications of Annaba (LERICA) is part of the aim of producing by simulation a 160 GHz information carrier in two transmission regimes (dispersive and nonlinear). With the emergence of new services related to multimedia development, a need for a higher information transmission rate has arisen. An alternative to the coaxial cable had to be proposed in order to compensate for disadvantages such as losses, short transmission distances, and performance limitations. Optical fiber has emerged as the transmission medium to overcome these problems [3]. Its use fullness is unavoidable in telecommunications networks. Nowadays, the development of the Internet is leading to an evolution of telecommunications systems towards an increase in transmission capacities [4]. The rate limitation is due to the transmission and reception modules integrating electronics and optoelectronics functions and no longer being on the medium, which has a high bandwidth and low attenuation values. The first observation of laser pulses was made in 1963 by Gurs and Muller [5] on a ruby laser and in 1964 by Statz and Tang [6] on a HeNe laser.

Digital transmission systems convey information between a source and a recipient using a physical medium such as cable, optical fiber, or propagation on a radio channel. The signals transported can be either directly digital, as in data networks, or analog (speech, image, etc.) but converted to a digital form. The task of the transmission system is to route information from the source to the recipient, as reliably as possible [7]. With the rapid evolution of telecommunications services available to users, such as multimedia services enriched by very high-speed Internet, IPTV (Internet Protocol Television), video telephony, high-definition television and home networks will soon have to be able to carry data streams of up to gigabit per second. This demand for very high speeds goes far beyond the possibilities offered by coaxial cable-based solutions (ADSL, VDSL, etc.) [8]. Object-oriented programming enables complex applications to be carried out by cutting them into simple subsystems. The "software bricks" created evolve easily and independently of one another and are designed through rigorous functional and methodological analysis, process optimization, and processing factorization to become irreplaceable in calculations and logical operations, the processing, and transmission of information, the manipulation of images, and the control of robots, which covers all design and programming techniques for computerized systems with an industrial vocation [9] [10]. The new technology of very long-distance optical fiber transmission and wireless transmission is based on increasing the frequency produced by the transmitter and decreasing the temporal width of the signal to be transmitted in order to ensure the three main parameters ensuring good quality of service: a larger number of users, spectrum to the frequency spectrum that can be used, better spectral efficiency (in bits/s/Hz), i.e., a better ratio between bit rate and bandwidth, and better security (advanced data encryption possibilities [11]. Because of the "magical" side of radio communication, since the electromagnetic waves that propagate in the air are invisible to the naked eye, the realization of systems using wireless transmission and optical fiber transmission is a challenge for researchers in the fields of optical fiber physics and laser diodes.

II. THEORETICAL STUDY

II.1 SCHEMATIC DESCRIPTION OF THE CARRIER GENERATOR

This generator consists of four blocks (modules) integrating electronics and optoelectronic functions, each of which has a well-defined role (see Figure 1).

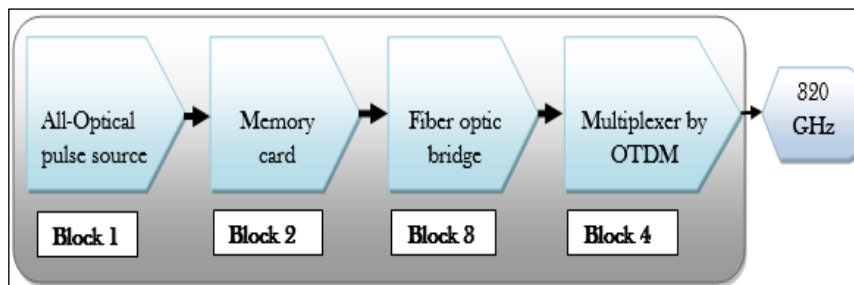


Figure 1: Descriptive diagram of the generator.
Source: Authors, (2026).

II.1.1 Block 1

This block (see Figure 2) is a source of short pulses at a rate of 40 GHz with a duty cycle of 1/5. It consists of a laser source (CW laser) delivering a continuous power equal to 7.65 dBm at the wavelength 1555 nm. This power passes through the first polarization controller thus optimizing the power level of the harmonics at the output of the isolator which completely eliminates the Brillouin effect. Thesecond polarization controller is used to adjust the polarization on the axis of the Mach-Zehnder modulator which is driven by a 20 GHz very high frequency generator (Figure 2). One obtains at the output of this modulator a train of pulses at 40 GHz which is amplified by EDFA1 and EDFA2. The resulting train is injected into the 2.1 Km compression fiber. The signal thus delivered is a train of pulses clocked at 40 GHz is stable, without jitter and having a duty cycle of 1/5 (see Figure 2) [12-14].

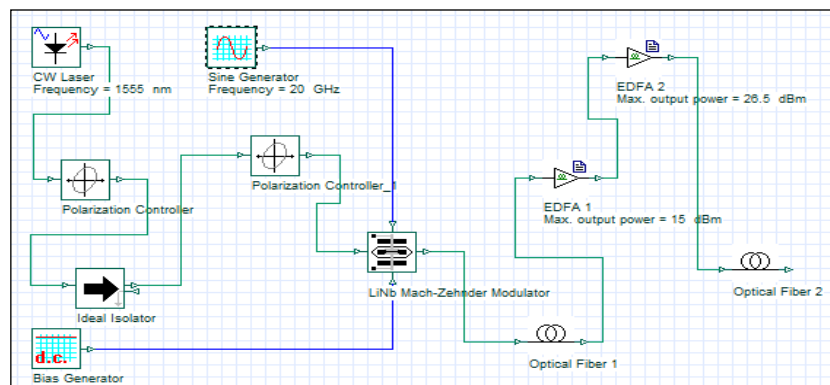


Figure 2: Source of pico-second optical pulses (under Opti system).
Source: [12].

II.1.2 Block 2

This part of the generator behaves to a RAM type memory card containing a program whose role is to switch between position 1 (end of the fiber that ensures the nonlinear effect) and position 2 (end of the fiber that ensures the dispersive effect) (see Figure 3).

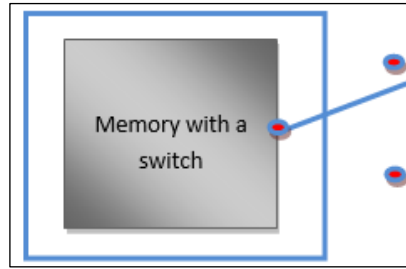


Figure 3: Memory card with a switch.
Source: Authors, (2026).

This block contains two optical fibers in parallel (see Figure 4), the first of which had the property of imbalance between the chromatic dispersion of order 2 [15-17] and the effect of nonlinearity [18-20], so that the first is higher than the second, and vice versa in the second optical fiber.

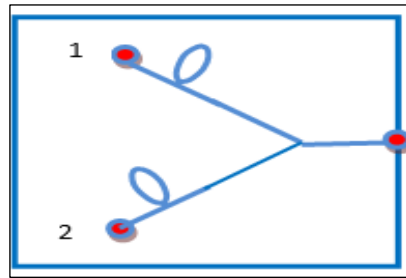


Figure 4: Fiber optic bridge.
Source: Authors, (2026).

II.1.3 Block 3

This block is composed of cascaded elementary multiplexer trios by the Optical Time Domain Multiplexing (OTDM) method [21] [22], each containing a Mach-Zehnder modulator (MZM) at the input for pulse train coding, and two branches of two other MZMs. The first branch of the first elementary multiplexer contains an optical pulse self-timer with $t = \tau_1$, the second element is equivalent to the first element with $t = 2 \tau_1$, the third element is equivalent to the previous element with $t = 3 \tau_1$ (τ_1 : is the time width of the optical pulse) (see Figure 5).

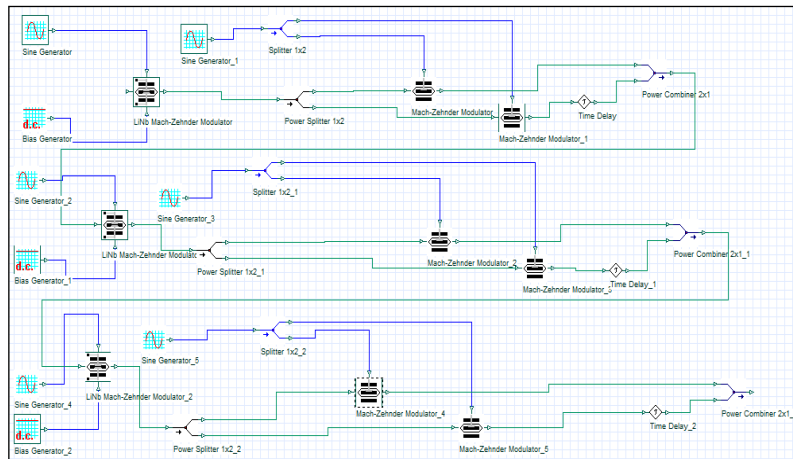


Figure 5: Multiplexer by OTDM method (under Opti system).
Source: Authors, (2026).

II.2 EFFECTS PRODUCED BY THE OPTICAL FIBER TRAVERSED BY AN ELECTROMAGNETIC SIGNAL

II.2.1 Optical Fiber Losses

Let P_0 be the power injected into an optical fiber of length L , only the power P_T will actually be transmitted, and therefore, we can express it as a function of P_0 in the following form:

$$P_T = P_0 \cdot \exp(-\alpha_L L), \quad (1)$$

II.2.2 Chromatic Dispersion of Order Two

This phenomenon is considered harmful in the field of optical telecommunications, because it induces a temporal enlargement of the impulses (the information to be transmitted) during their propagation [23], which subsequently causes them to overlap. β_2 , it is responsible for the temporal enlargement of the pulses also known as the dispersion coefficient of the group velocity GVD (Group Velocity Dispersion), it reflects the variation in speed compared to frequency [24] [25].

$$\beta_2 = \left(\frac{\partial^2 \beta}{\partial \omega^2} \right)_{(\omega=\omega_0)} = \frac{1}{V_g^2} \frac{\partial V_g}{\partial \omega} = \frac{1}{c} \left[2 \frac{\partial n}{\partial \omega} + \omega \frac{\partial^2 n}{\partial \omega^2} \right], [24] \quad (2)$$

Where V_g is the group velocity and n is the refractive index of the propagation medium and n is the nonlinear refractive index of the fiber. The chromatic dispersion, denoted D , represents the difference in the arrival time of two pulses of different central wavelengths of 1 nm and sent in a fiber of 1 km of length. This quantity can be expressed as a function of β_2 , (in ps.nm⁻¹.km⁻¹).

$$D = -\frac{2\pi c}{\lambda^2} \beta_2, \quad (3)$$

With c is the speed of light and λ is the wavelength. L_D is the dispersion length, corresponding to the propagation distance at the end of which the initial pulse, from a temporal width to $1/e$ of T_0 , has widened or spread by a factor $\sqrt{2}$. It is important to know the length for which the effect of dispersion, of order 2, becomes important, or:

$$L_D = \frac{T_0}{|\beta_2|}, \quad (4)$$

II.2.3 Kerr Effect (NONLINEAR EFFECT)

This phenomenon of birefringence provoked [26] [27], discovered by Kerr (in 1875), is known as the Kerr effect:

$$\gamma = \frac{\omega_0 \cdot n_2}{c \cdot A_{eff}}, \quad (5)$$

with ω_0 : is the frequency of the carrier, A_{eff} : corresponds to the effective area of the optical fiber.

$$\text{Or } n_2 = \frac{2n_{NL}}{\epsilon_0 c n}, \quad (6)$$

n_2 : represents the nonlinear index, n_{NL} the nonlinear refractive index. We can set the L_{NL} parameter, as in the case of dispersive effects, the length of fiber for which nonlinear effects become important:

$$L_{NL} = \frac{1}{\gamma P_0}, \quad (7)$$

P_0 : is the peak power of the fundamental soliton ($N = 1$) [28] connected to the parameters of the optical fiber by the criterion $L_D = L_{NL}$.

The solitonic regime is carried out for:

$$L_D = L_{NL} \quad (8)$$

We are talking about a non-linear regime for:

$$L_{NL} \gg L_D, \quad (9)$$

Is carried out dispersive regime for:

$$L_{NL} \ll L_D, \quad (10)$$

II. 2.4. Parameters Of the Optical Fibers Used

From equations (1,,10), one can find the values and parameters of the components of the assembly (see Table. 1 and Table. 2).

Table 1: Properties and characteristics of the four optical fibers.

Optical fibers	Chromatic dispersion of order 2 (β)	Kerr effects (γ)	Fiber length (L)
Fiber 1	17 ps/(nm.Km)	1.7 W ⁻¹ .Km ⁻¹	2.18 Km
Fiber 2	17 ps/(nm.Km)	1.95 W ⁻¹ .Km ⁻¹	1.95 Km
Fiber 3	17 ps/(nm.Km)	0.85 W ⁻¹ .Km ⁻¹	1.44 Km
Fiber 4	-100 ps/(nm.Km)	1.3 W ⁻¹ .Km ⁻¹	1.4 Km

Source: Authors, (2026).

Table 2: Values and parameters of the components of the simulated assembly.

component	parameter	symbol	value
Laser source	Wave length	L	1555 nm
	The power	P	6.95 dBm
Mach-Zehnder 1 modulator	Extinction voltage	zU_{ext}	23 V
	Bias voltage	V_b	9.5 V
Mach-Zehnder 2 modulator	Extinction voltage	U_{ext}	29 V
	Bias voltage	V_b	4.68 V
EDFA 1 amplifier	Maximum output power	$P_{s,\text{max}}$	13 dBm
EDFA 2 amplifier	Maximum output power	$P_{s,\text{max}}$	28 dBm

Source: Authors, (2026).

II.3 MODELING THE PROPAGATION OF LIGHT PULSES

A light pulse, of slowly variable envelope $A(0,t)$, propagating in an optical fiber can be described by the following general nonlinear Schrödinger equation.

$$\frac{\partial A}{\partial z} + i \frac{\beta_2}{2} \frac{\partial^2 A}{\partial t^2} - \frac{\beta_3}{6} \frac{\partial^3 A}{\partial t^3} + \frac{\alpha_L}{2} A - i\gamma |A|^2 A + i\gamma T_r \frac{\partial |A|^2}{\partial t} A + \frac{\delta}{\omega_0} \frac{(\partial |A|^2)}{\partial t} A = 0, \quad (11)$$

Propagation, Chromatic dispersion, Attenuation, Kerr effect, Raman effect and Stiffening. Self-steepening is a higher-order non-linear effect that occurs when an ultra-short (FWHM < 1 ps) and energetic light pulse propagates in an optical fiber. This phenomenon, called a shock term, results in an accelerated propagation of the wings of an impulse with respect to its center where the power is maximum (peak power). As a result, the intensity profile becomes asymmetrical depending on the propagation distance. It is possible to model the propagation of a pulse, ultra-short and energetic (a few ps), by the equation "NLSE". In our case, we neglected the chromatic dispersion effects of order 3, the Raman effect and the effect of self-stiffening. This gives the following equation:

$$\frac{\partial A}{\partial z} + i \frac{\beta_2}{2} \frac{\partial^2 A}{\partial t^2} + \frac{\alpha_L}{2} A - i\gamma |A|^2 A = 0, \quad (12)$$

II.4 GENERATOR MEMORY CARD ALGORITHM AND PROGRAM

The automation of this multi-speed generator is carried out according to a program from this algorithm (see Flowchart of the algorithm). Algorithm for automating the two-speed generator.

1. Set Constants

'LD = 2.18', 'P = 0.58'

2. Read input

Get value for ' γ ' from user

3. Calculate

'LNL = 1 / ($\gamma \times 0.58$)'

4. Display

Show the value of 'LNL'

5. Compare

- If 'LNL > 2.18' → print "reg_dipse"

- If 'LNL ≤ 2.18' → print "reg_nolin"

End

Comments

The flowchart implements an automatic control algorithm for a two-speed generator, selecting between linear and nonlinear operating regimes. It first defines constants LD = 2.18 and P = 0.58, then reads a variable γ .

Using γ and a fixed P_0 , it computes $LNL = 1 / (\gamma \times P_0)$. If LNL exceeds LD, the generator operates in the “dipse” (likely nonlinear/transient) regime, and the output reg_dipse is written. Otherwise, it defaults to reg_nolin (linear regime). The decision hinges on a threshold comparison: when the computed nonlinearity parameter LNL is large enough, the system switches to the dipse mode, suitable for high-demand or unstable conditions. This logic ensures efficient power management, engaging nonlinear behavior only when necessary, thus optimizing generator performance across varying loads or speeds.

Program construction (multi-regime)

```
Const
LD ← 2.18; P0 ← 0.58;
Var
γ, LNL: real;
reg_nolin, reg_dispers: string of characters;
Begin
readln(γ);
LNL := 1/(γ* P0);
Writeln(LNL);
If LNL > LD then Writeln(reg_nolin);
else
writeln(reg_dispers);
end,end,end.
```

III. DIGITAL SIMULATION

Faced with the increasing complexity of the architectures and systems developed, and simulation tools have acquired an important role; they are, increasingly, used to optimize the parameters involved in the realization of a system. Also, they make it possible to predict results expected experimentally. They now also make it possible to use during a simulation, experimental elements such as signals recorded with measuring devices or curves characteristic of real components. In all that follows, the simulation tool used is the OPTISYSTEM version 7 [29] [30]. Optisystem is an optical communication system simulation package for the design, testing, and optimization of virtually any type of optical link in the physical layer of a broad spectrum of optical networks, from analog video broadcasting systems to intercontinental backbones with a rich library and a simple interface that is easy to make edits (see Figure 6).

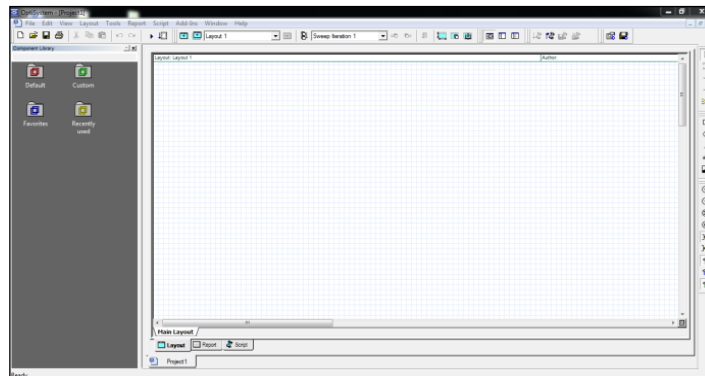


Figure 6: Interface of Opti System.

Source: Authors, (2026).

IV. RESULTS AND DISCUSSION

From the work [12] Breves generator of pulses at different flow rates (40 GHz, 80 GHz and 160 GHz, it was carried out in solitonic regime according to the equilibrium condition between the dispersive effect and that of the nonlinearity within the main optical fiber (see Figures 7, 8 and 9). This is checked for the relationship ($L_D = L_{NLN}$).

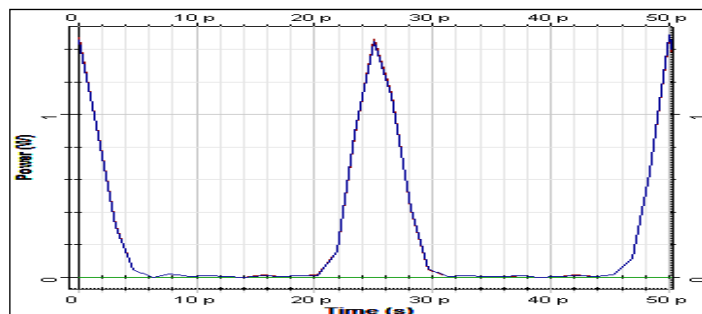


Figure 7: Pulse train at 40 GHz at the output of the generator according to condition of the solitonic regime

Source: [12].

The peak pulse power is of value 1.43W and the temporal width of the pulse is of the order of 2.5 ps.

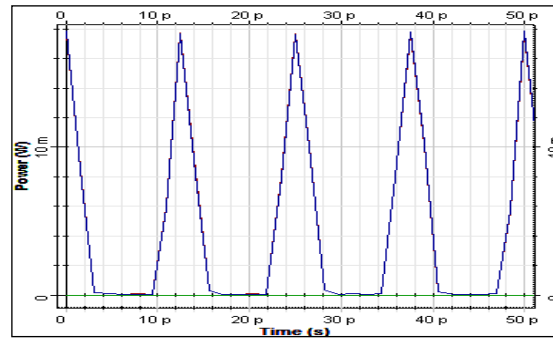


Figure 8: Pulse train at 80 GHz at the output of the generator according to the solitonic regime.
Source: [12].

The output frequency is 80 GHz, the peak pulse power is of value 10.65 mW and the time width is 2.3 ps.

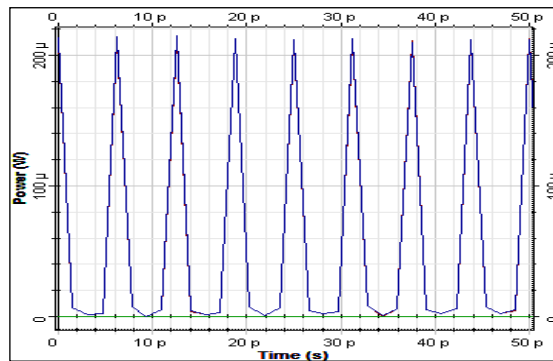


Figure 9: Pulse train at 160 GHz at the output of the generator according to the solitonic regime.
Source: [12].

The output frequency is 160 GHz, the peak pulse power is of value 200.12 μ W and the time width is 2 ps. The replacement of this fiber by another that verifies the condition ($L_D < L_{NLN}$) makes it possible to produce a train of light pulses in non-linear mode is the semilariton form (see Figures 10, 11 and 12) after the multiplexing by the OTDM method [31-33].

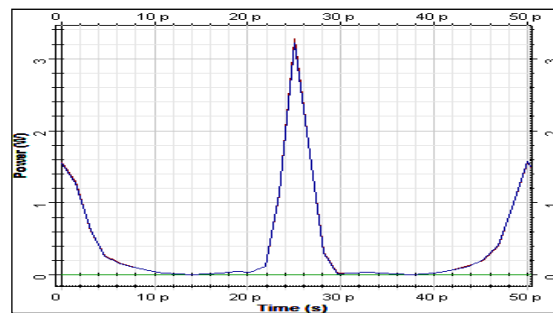


Figure 10: Pulse train at 40 GHz at the output of the generator according to the second condition.
Source: Authors, (2026).

The peak pulse power is of value 3.25W and the temporal width of the pulse is of the order of 2.2 ps. (see Figures 10).

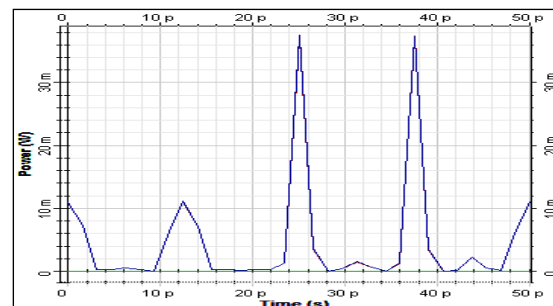


Figure 11: Pulse train at 80 GHz at the output of the generator according to the second condition.
Source: Authors, (2026).

The peak pulse power is of value 30.40mW, as well as the temporal width of the pulse decreased from 2.3 ps to 2.1 ps (see Figures 11).

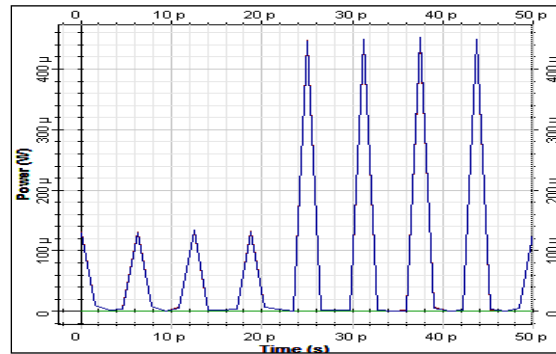


Figure 12: Pulse train at 160 GHz at the output of the generator according to the second condition.
Source: Authors, (2026).

The peak pulse power is of value $400.45 \mu\text{W}$, as well as the temporal width of the pulse decreased from 2 ps to 1.6 ps (see Figure 12).

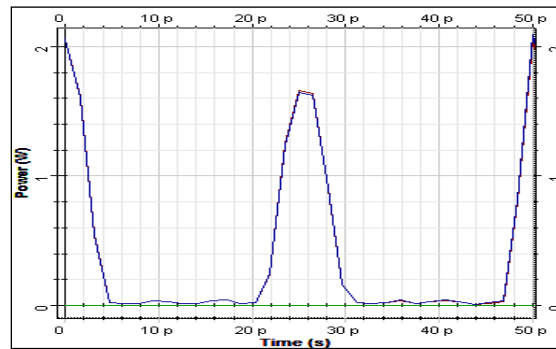


Figure 13: Pulse train at 40 GHz at the output of the generator according to the third condition.
Source: Authors, (2026).

The peak pulse power is of value 2.09 W and the temporal width of the pulse is of the order of 2.2 ps. (see Figures 13).

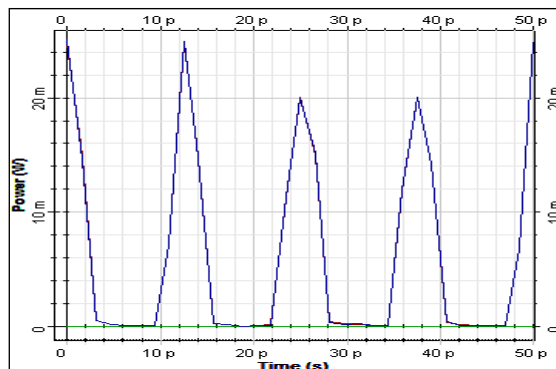


Figure 14 Pulse train at 80 GHz at the output of the generator according to the third condition.
Source: Authors, (2026).

The peak pulse power is of value 20.45 mW , as well as the temporal width of the pulse decreased from 2.3 ps to 2.1 ps (see Figures 14).

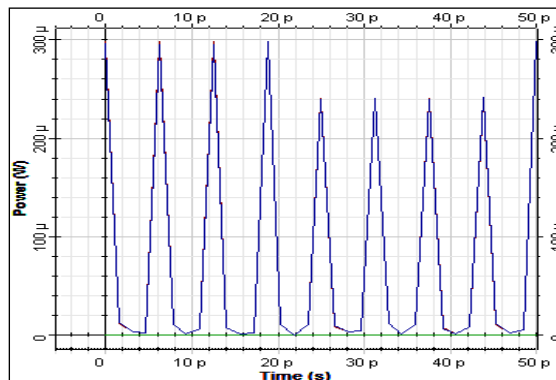


Figure 15 Pulse train at 160 GHz at the output of the generator according to the third condition.
Source: Authors, (2026).

The peak pulse power is of value $300\mu\text{W}$, as well as the temporal width of the pulse decreased from 2 ps to 1.6 ps (see Figure 15). From the results obtained in the work [12] in order to improve the performance of the generator (quality factor and stability of the signal), it was possible to reduce the temporal width and increase the peak pulse power of the pulse (see Table. 3).

Table 3: Comparison of results (Temporal width and peak pulse power) between [12] and (dispersive and non-linear) regimes.

Generator	Temporal width (ps)			Peak pulse power		
	40	80	160	40	80	160
[12]	2.5	2.3	2.0	1.43 W	10.65 mW	200.12 μW
Dispersive regime	2.2	2.1	1.6	2.09 W	20.45 mW	300 μW
Non linear regime	2.2	2.1	1.6	3.25 W	30.40 mW	400.45 μW

Source: Authors, (2026).

The compression of a sinusoidal beat by four-wave mixing is relatively simple to implement to obtain a train of ultra-short pulses at high cadence and high quality. On the other hand, in addition to the bandwidth limit, this technique is expensive depending on the frequency f of the RF signal that drives the Mach-Zehnder modulator [34]. Moreover, to find a compromise between cost and system stability controlling the modulator at its zero-transmission point is by the $f/2$ frequency of the RF that allows us to generate a sinusoidal beat at the rate f qualified as "frequency doubling". Again, the second fiber which ensures the nonlinear regime ($L_D < L_{NLN}$) was changed by a third that checked the inverse of the previous condition ($L_D > L_{NLN}$), this provided a train of optical pulses in dispersive regime (see Figures 10 and 13). The start of the train would be increased after passing through the multiplexer [35] had become a self-modulated signal (see Figures 12 and 15). The switching from one of the two optical fibers to the other is performed automatically according to a program recorded in the memory card inserted in the generator assembly (see Figures 1 and 3). From the same operating principle of the generator of ultra-short light pulses in solitonic regime (power 1.23 W at a temporal width of 2.5 ps) [12], we realized by simulation another generator train of ultra-short optical pulses in non-linear regime (power 3.25 W, at a time width of 2.2 ps) of the same repetition rate 160 GHz and in dispersive regime (power 2.09 W at a time width of 2.2 ps) and the same repetition rate. In these two speeds, the generator is more stable and without jitter of good quality than the previous one in order to improve the performance of the transmission of the information signal. This generator is made by simulation by electronic and optronic components cheaper and easy to implement from the values of the parameters mentioned above in Tables 1 and 2.

V. CONCLUSION

This work is based on the development and improvement of the generator [12]. The latter is responsible for carrying out the pulse train in solitonic regime by the balance between nonlinearity and chromatic dispersion of order two within the optical fiber. Meanwhile two other fibers of the same types and properties were added, the first providing the train in nonlinear mode according to a very precise condition at the level of the equilibrium of the two effects within this optical fiber, and the second fiber ensures the inverse of the previous condition to produce the train of pulses in highly dispersive regime. Also, the start-up of one of the two optical fibers is carried out thanks to a program in a memory card inserted in the assembly of the previous generator. Furthermore, improving the performance of the generator [12] requires developing the characteristics (spectral efficiency, noise protection and security against signal piracy) from the properties of the material constituting the optical fiber which depend on the increase in the frequency of the signal, and subsequently the decrease in the temporal width of each pulse and self-modulation (see results in Figures 7, 8, 9, 10, 11, 12, 13, 14 and 15), as well as the regulation of the spectral distribution of the signal and subsequently the increase in the average power. In addition, this generator operates in two regimes (non-linear and dispersive). The techniques of remodeling the initial signal in an optical fiber by non-linear effects are methods that have proven their effectiveness in generating this type of generators such as adiabatic compression [12, 13]. The compression of a sinusoidal beat, in an abnormal chromatic dispersion fiber, via the process of multi-wave mixing (MFWM: Multiple Four Wave Mixing), is a relatively simple technique to implement experimentally and which makes it possible to generate ultra-short pulse trains, of high quality, in Fourier limit and without pedestal [12]. In this approach, it is possible to generate the initial sinusoidal beat by coupling two continuous laser diodes (CWs), whose frequency deviation is equal to the desired frequency. Last but not least, the main advantage of this technique is to reach very high frequencies far exceeding those delivered by electronic systems (limited to 40 GHz) [13].

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Amar Hamouda.

Methodology: Amar Hamouda.

Investigation: Amar Hamouda.

Discussion of results: Amar Hamouda.

Writing – Original Draft: Amar Hamouda, Nabil Laiche.

Writing – Review and Editing: Amar Hamouda.

Resources: Amar Hamouda.

Supervision: Amar Hamouda.

Approval of the final text: Amar Hamouda, Nabil Laiche and Laid Gasmi.

VII. ACKNOWLEDGMENTS

The authors would like to thank the editor and the anonymous referees for their careful comments and valuable suggestions that led to a substantial improvement of the presentation of the paper.

VIII. REFERENCES

- [1] B. Eliasson, G. M. Milikh, T. C. Liu, X. Shao, K. Papadopoulos, « Simulations of the Generation of Energetic Electrons and the Formation of Descending Artificial Plasma Layers During HF Heating at Arecibo », *Journal of Geophysical Research : Space Physics* 123(12), December 2018.
- [2] K. Singh Gill, «RUBY LASER», *International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET)*, Volume 11, Issue 4, April 2022.
- [3] A. Chen, E. Murphy, "Broadband optical modulators: Science, technology, and application", 2016.
- [4] S. Zhu, X. Chen, X. Liu, G. Zhang, P. Tian, "Recent progress in and perspectives of underwater wireless optical communication", Volume 73, September 2020.
- [5] S. Gorche, «Transmission Techniques for Digital Communications», Academic press Library in mobile and wireless communications, book pages 523-558, 2016
- [6] E. Kredens, F. Rio, «Études de communication», Université de Lille, book 2015/1 (n° 44), Pages 192, 2015.
- [7] M. Wenhan, "Research on the application of digital signal processing technology in the communication field", *Electronic World*, 552 (18): 124-127, 2018.
- [8] E. Planas, J. Cabot, "How are UML class diagrams built in practice? A usability study of two UML tools: Magicdraw and Papyrus", *Computer Standards & Interfaces*, 67, 1-13, 2020.
- [9] A. Khudhair Abbas, Y. I. Al Mashhadany, M. J. Hameed, Sameer Algburi, "Review of Intelligent Control Systems with Robotics", (*IJEEI*) 10(4), November 2022, doi: 10.52549/ijeei.v10i4.3628
- [10] P. Bozek, Y. L. Karavaev, A. A. Ardentov, and K. S. Yefremov, 'Neural network control of a wheeled mobile robot based on optimal trajectories', *Int. J. Adv. Robot. Syst.*, vol. 17, no. 2, pp. 1–10, 2020, doi:10.1177/1729881420916077
- [11] A. Hamouda, » Study and design of an all-fiber ultra-high-throughput picosecond pulse generator» Badji Mokhtar University of Annaba, 2017.
- [12] A. Hamouda and K. Saouchi, "Breves generator of pulses at different flow rates (40 GHz, 80 GHz and 160 GHz)", *journal of JNTM* 7 27-32, 2017.
- [13] A. Hamouda and K. Saouchi, "Simulation d'une source tout optique débitant des impulsions à ultra-haut débit (320 Gb/s) », *Rev. Sci. Technol., Synthese* 35 224-232, 2017.
- [14] R. Parikh, N. Pithadia, R. Petkar, "Simulation of Fibre Optics using MATLAB Fibre Optics Simulation ", *IJERT*, Vol 1, 5, 24-04-2018.
- [15] X. Luo, M. Pu, Y. Guo, X. Li, X. Ma, «Electromagnetic Architectures: Structures, Properties, Functions and Their Intrinsic Relationships in Subwavelength Optics and Electromagnetics», *Materials Science, Advanced Photonics Research*, 2021.
- [16] D. S. Abraham, D. D. Giannopoulos, "A Convolution-Free Mixed Finite-Element Time-Domain Method for General Nonlinear Dispersive Media", *IEEE Transactions on Antennas and Propagation*, vol.67, no.1, pp.324-334, 2019.
- [17] T. Hirooka, K. Tokuhira, M. Yoshida and M. Nakazawa, "440 fs, 9.2 GHz regeneratively mode-locked erbium fiber laser with a combination of higher-order solitons and a SESAM saturable absorber", *Opt. Lett.* 1 24 (21), pp. 24255-24264, 2016.
- [18] J. Li, C. Wang, L. Pei, T. Ning, J. Zheng, R. He, Y. Li, «Generation of an optical triangular-shaped pulse train with variable symmetry by using an I/Q modulator», *Opt Lett*, 45(6):1411-1414, 2020.
- [19] F. Ali, Y. Khan, S. S. Qureshi, S. Ahmad, M. Waqas, "Effect of fiber optics nonlinearities in long-haul and ultra-high speed DWDM optical transmission networks at 10, 40 and 100 Gb/s ultra-high speed data rates", *J. Opt. Commun.* 2018.
- [20] F. Ali, S. Ahmad, F. Muhammad, Z.H. Abbas, U. Habib, S. Kim, "Adaptive equalization for dispersion mitigation in multi-channel optical communication networks", *Electronics* 8, 1364, 2019.
- [21] Hacene F. Karim, "Design of a novel passive optical line protection for fiber to the home networks", *Opto-Electronics Review*, Vol 29, pp 33-38, 2021, doi:10.24425/opelre.2021.135826.
- [22] G.P. Agrawal, «Applications of Nonlinear Fiber Optics», book 3rd Edition - August 11, 2020.
- [23] S. Kumar, R. Herrero, M. Botey and K. Staliunas, «Taming of Modulation Instability by Spatio-Temporal Modulation of the Potential», *Sci Rep* 5, 13268, 2015, doi.org/10.1038/srep13268,
- [24] Guangxue Zheng, Shengchun Piao, Shengchun Piao, Shengchun Piao, "Group velocity dispersion curves estimation based on joint processing of sound pressure and vertical particle velocity", *JASA Express Lett*, Vol. 4, Issue 12, 2024, doi.org/10.1121/10.0034610
- [25] Wang, H., Rui, D., and Kun-De, Y., "Bayesian geoacoustic parameter inversion based on dispersion characteristics of normal mode water wave and ground wave," *Acta Phys. Sin.* 72(5), *Acta Phys. Sin.* 72(5), 2023, doi.org/10.1016/j.apacoust.2023.109390.
- [26] Y. Song, X. Shi, C. Wu, D. Tang, H. Zhang, «Recent progress of study on optical soliton in fiber lasers», *Applied Physics Reviews* 24 May 2019.
- [27] Q. Li, Z.x. Jia, Z. r. Li, Y. d. Yang, J. l. Xiao, S. w. Chen, G. s. Qin, Y. z. Huang, and W. p. Qin, "Optical frequency combs generated by four-wave mixing in a dual wavelength Brillouin laser cavity", *AIP Advances* 7, 075215, 2017.

- [28] Z. Zhang, S. Zhang, S. Wang, X. Hu, H. Zhang, G. Feng and S. Zhou, "Wavelength and duration tunable dissipative soliton resonance fibre laser", *Laser Physics*, Volume 30, Number 3, 2020.
- [29] B. Barza, A. P. Anisha, "Simulative Analysis and Compensation of Dispersion in WDM Optical Systems", *International Journal of Engineering Research & Technology (IJERT)* Volume 04, Issue 01, January 2015.
- [30] H. Hu, F. Qian, X. Xie, T. Duan and H. Feng, «Demonstration of flexible optical time-division multiplexing system for high-speed free-space optical communications», *Journal of Optics* volume 45, pages1–6, 2016.
- [31] C. Sun, Y. Yu, M. Ye, G. Chen and X. Zhang, «An ultra-low crosstalk and broadband two-mode multiplexer based on adiabatic couplers», *Scientific Reports* volume 6, Article number: 38494, 2016.
- [32] T. Komljenovic, L. Liang, R. L. Chao, J. Hulme, S. Srinivasan, M. Davenport and J. E. Bowers, «Widely-Tunable Ring-Resonator Semiconductor Lasers», *JournalsApplied Sciences* Volume 7 Issue 7, 17 July 2017.
- [33] S. Lin, Z. Wang, J. Li, S. Chen, Y. Rao, G. Peng, A. Gomes, "Nonlinear dynamics of four-wave mixing, cascaded stimulated Raman scattering and self Q-switching in a common-cavity ytterbium/Raman random fiber laser", *Optics & Laser Technology*, Vol 134, February 2021.
- [34] R. Amin, J. K. George, S. Sun, T. Ferreira de Lima, A. N. Tait, J. B. Khurgin, M. Miscuglio, B. J. Shastri, P. R. Prucnal, T. El-Ghazawi, and V. J. Sorger, «ITO-based electro-absorption modulator for photonic neural activation function», *APL Materials* 7, 081112, 2019.
- [35] P. NagaSiva Kumar, A. Sangeetha, G. Srikanth, "Analysis of Optical Time Division Multiplexing Using Packet Interleaving Scheme", *International Journal of Scientific and Research Publications*, Volume 3, Issue 4, April 2013.