Impact of Intense Modulation on Soliton Power Propagation across Optical Fiber and Optical Wireless Channels

Abstract: The optical pulse generator model in Optisystem 20 is utilized to generate an optical soliton pulse. The performance evaluation of highly modulated soliton power transmission is carried out on both optical fiber and optical wireless communication channels. The evaluation considers a flow rate of 40 Gbps and a link distance, which is not specified in the provided context. Among the proposed modulation schemes, which include CPFSK, FSK, and PSK, CPFSK demonstrates superior performance for both communication channels. Increasing the number of bits per symbol enhances the bit error rate (BER) at the fiber or wireless channel, as received by the optical receiver, for different modulation schemes, except for the CPFSK scheme. Thus, it is evident that the CPFSK modulation scheme is more efficient and outperforms other modulation schemes for various communication channels. Hence, it is evident that the CPFSK modulation scheme exhibits superior efficiency and outperforms other modulation schemes for a variety of communication channels.

Keywords: Modulations schemes, Mach- Zehnder modulator, optical fiber and wireless communication channels.

I. INTRODUCTION

This paper proposes an easy-to-use simulation setup using the Mach-Zehnder Modulator Absorption Phase (MZMAP) to generate perturbation-minimized solitons. By adjusting MZMAP parameters, control over dark soliton characteristics is achieved, resulting in reduced perturbation and improved communication performance.[1] This study examines the performance of a spatial optical transmitter utilizing on-off keying line coding modulation for telecommunication purposes. It assesses key parameters such as encircled flux, fiber mode, signal power, and other variables to evaluate the effectiveness of the system [2]. This study focuses on tackling the problem of signal distortion caused by dispersion in optical communication systems. It highlights the generation of soliton pulses as a promising solution, leveraging their inherent self-shaping and self-focusing properties [3] This paper presents a first-order optical soliton propagation system used to design a ultra-high transmission distances of up to 20,000 Km, with data rates reaching 80 Gb/s [4]. The simulation examines key parameters such as the maximum Q-factor, soliton peak power, and performance at operating wavelengths of 1300 and 1550 nm throughout the entire transmission distance. The limitations of electronic computing in fulfilling the requirements of optical computation and communication traffic are emphasized by the recent advancements in optical computing. This study puts forth innovative proposals for essential components including optical switches, logic gates, and an optical memory system. These proposals leverage the use of non-linear materials to eliminate the dependence on electro-optical elements, opening new possibilities for efficient optical computing and communication [5] This paper provides a thorough investigation into the propagation of optical pulses in an in-homogeneous erbium-doped fiber system [8]. The analysis is based on the nonlinear Schrödinger-Maxwell-Bloch equation, and through the utilization of the Darboux transformation and Lax pair, explicit forms of one and two soliton solutions are derived. The study focuses on examining the effects of loss/gain and external potential, while also exploring the distributed amplification system. By utilising an improved modified extended tanh expansion method, an innovative solution for the perturbed nonlinear Lenells equation was created [9] This study examines high-speed light sources in high-speed passive optical local area communication networks, specifically focusing on the use of directly modulated...
lasers for data rates of 40 Gb/s over a 20 km range. It evaluates the optical output power, signal power amplitude, Q-factor, and data error rates, and incorporates hybrid optical amplifiers, optical filters, and electrical filters to enhance network performance and operational efficiency, achieving a maximum Q-factor of 14.98 and a minimum data error rate of $3.55 \times 10^{-5}$ change sentences. [10] (Esen, 2022). Ozdemir, Neslihan, et al. examined the wave equation which is perturbed in both space and time by kerr nonlinearity, and analysed how this nonlinearity causes pulse dispersion. They desired soliton pulse shaping solution by incorporating self-steepening coefficients in wave equation [11] (Ozdemir, 2022). Wan-Rong Xu et al studied perturbed wave equation to understand the soliton behavior in single mode fiber and formulated new set of solution through integration method [12] (Xu, 2023). Chromatic dispersion effect and its consequence of variation in refractive index were dealt in great deal [13] by analysing perturbed wave equation in cubic-quartic form. Soliton pulse shaping for amplitude and pulse width was done by finding polynomial equation solution (Biswas, 2022). Ming-Yue Wang studied wave solutions, Jacobian solutions, triangular function and rational solutions for all orders of wave equation to formulate solution for soliton pulse shaping [14] (Wang, 2022). The outcomes of Fang, Yin, et al. demonstrated that the pulse dispersion in both spatial and spectral domains is caused by the dispersive effects. When the broadening and nonlinear effects are equal, the shape of the pulse during propagation unaltered [15] (Fang, 2022). Kudryashov et al. studied the traveling wave reduction with arbitrary refractive index and obtained the over determined system of equations as solutions to soliton wave [16] (Kudryashov, 2020). Y. Yakup, et al. recovered the cubic-quartic optical solitons for the dual generalised nonlocal nonlinear Kudryashov’s law [17]. In utilising, the Sardar sub equation and the novel Kudryashov methods, Onder, Ismail et. al. presented soliton pulse solutions of the Kundu-Mukherjee-Naskar (KMN) problem. The KMN equation is crucial for simulating the light bending, rogue waves in the oceans, and fibre pulses in optics [18]. The nonlinear refractive index structure proposed by Kudryashov in this study secures soliton solutions. The two used integration strategies additionally provide additional unique periodic solutions as a consequence [19]. In this study, a comprehensive exploration is conducted on diverse laser source modulation techniques and their applications, employing simulation software to compare the resulting output signals. The investigation incorporates various modulators such as Mach-Zehnder, electro-absorption, and laser rate equation modulators, integrated with an optical link comprising a multimode fiber and a receiver-end photodiode modelled for analysis. The study thoroughly examines the input and output signals utilizing different modulation types, aiming to elucidate their distinctive features and performance attributes [20]. The study simulated the effects of Gaussian pulses on a high data rate fiber communication channel, revealing degraded system performance at 100 Gb/s and 50 km, especially with SPM. Higher-order Gaussian pulses worsen performance efficiency. It is advised to use first-order Gaussian pulses for improved optical communication system efficiency. The study analyses the performance of an FSO link integrating hybrid modulation, predistortion, and cascaded dual EDFA techniques under extreme weather conditions. Leveraging mm Wave propagation benefits, the system enhances visibility range, maintains high Q-factor, and ensures reliable signal regeneration. Experimental results reveal significant Q-factor gains (4x) and increased visibility range (20 m) at 10 Gbps with integrated techniques, while achieving even higher Q-factor gains (5x) at reduced attenuation and extended visibility range (450 m). Many related research articles have also been studied which has been analysed minutely and utilised the different electronics mechanisms that incorporates various modulators to increase its overall gain and system efficiency [21-27].

II. WORKING METHODOLOGY OF MZMAP

The arrangement shown in Fig.1 is used to investigate the MZMAP’s performance. The amplitude of an optical wave is controlled via a Mach-Zehnder modulator. MZMAP in this instance has two equal arms. The electrical signals $v'$ and $v''$ drive two phase shifters to phase modulate the optical input $E_{in}$ is upper and lower modulator arms, which are then combined to create the optical output $E_{out}$. The branching (point "A") divides the incoming signal into two identical halves. Electrical voltage is used to apply the phase shift $\pi$ in one arm of the modulator. We can specify the relationship between the observed attenuation and phase on the applied voltage in the MZMAP. The amplitude modulation of the two waves' phase difference is produced. The output signal is a modulator with equal input and output Y-branch splitting ratios [1].

$$E_{out} = \frac{E_{in}}{1+SR} [SR \exp \left( -\left( \frac{\Delta a}{2} v' + j.\Delta \beta v' \right) L \right) + \exp \left( -\left( \frac{\Delta a}{2} v'' + j. = \Delta \beta v'' \right) L - j\phi_0 \right) ] (1)$$
Fig. 1 Single drive MZMAP operating mechanism

Where splitting radio $SR=p'/p''$

$p'$ ‘Input power of the lower arm at A, $p''$ ‘Input power of the upper arm [13] at B, $v'_b, v''_b$ ‘Bias voltage at the lower and upper arm respectively [16] $v'_m, v''_m$ ‘Modulation voltage at the lower and upper arm respectively [18].

The length influences what phase accumulation this specific wave will accumulate while it travels through a material. Therefore, as it travels farther, it will experience more phases. Let’s examine the impact of this. Thus, this is only the two waves interacting. The ratio of $I_{out}/I_{in}$ is hence 1, and this. Therefore, a phase difference of 0 will have a maximum and go up and down. You will therefore be aware that the pi phase difference will entirely interact destructively. This is a straightforward cosine function, therefore $2\pi$ and $3\pi$ will have something once more. Mach-Zehnder modulator functions in a straightforward manner.

For a normal modulator, $\psi_0$ is regarded as a phase shift of zero radians, while for a phase-shift modulator, the phase shift is $\pi$ radians. The $v'$ is defined as $V'(t) = V'_b + V'_m$, $v(t)$ for the normalised case. $V'_b$ and $V'_m$ Represent the lower arm's The upper arm's $V''(t) = V''_b + V''_m$, $v(t)$, in the normalised state of $V''$, which can be represented as $v(t)$. The normalised modulation waveform $v(t)$ has an average value of 0 and a peak-to-peak amplitude of 1. The normalised electrical input signal is between 0.5 and −0.5. Because there is just one driving modulation in our MZMAP model, $v''_m$ is always equal to zero. The output power signal is given by assuming $SR = 1$.

$$A = \frac{\Delta a}{2} V'_L$$
$$B = (\Delta \beta V'_L)$$
$$C = \frac{\Delta a}{2} V''_L$$
$$D = (\Delta \beta V''_L)$$

$$|E_{out}|^2 = |\psi_{out}|^2$$

$$|E_{out}|^2 = \frac{E_0}{2} \left[ e^{-(A+IB)} + e^{-(C+ID)} e^{-i\psi_0} \right]$$

$$|E_{out}|^2 = \frac{E_0}{2} \left[ e^{-(A)} e^{-iB} + e^{-(C)} e^{-i(D+\psi_0)} \right]$$

$$|E_{out}|^2 = \frac{E_0}{4} \left[ (e^{-(A)} e^{-iB}) (e^{-(A)} e^{+iB}) + (e^{-A+IB}) (e^{-C+ID+\psi_0}) + (e^{-A+IB}) (e^{-C-(iD+\psi_0)}) \right]$$

$$|E_{out}|^2 = \frac{E_0}{4} (e^{-2A} + e^{-2C} + e^{-(A+C)} 2\cos [(B - (D + \psi_0)])$$
\[ |E_{out}|^2 = \frac{\nu_0^2}{4} \left[ e^{-2\left(\frac{\Delta\alpha \alpha' L}{2}\right)} + e^{-2\left(\frac{\Delta\alpha \alpha'' L}{2}\right)} + e^{-\left(\frac{\Delta\alpha \alpha' L + \Delta\alpha \alpha'' L}{2}\right)} \cos \left( (\Delta\beta \psi' L) - (\Delta\beta \psi'' L) - \phi_0 \right) \right] \]

\[ \phi_0 = \pi, \]

\[ \phi_\beta = (\Delta\beta \psi' L) - (\Delta\beta \psi'' L) - \pi \]

\[ |E_{out}|^2 = \frac{\nu_0^2}{4} \left[ e^{-2\left(\frac{\Delta\alpha \alpha' L}{2}\right)} + e^{-2\left(\frac{\Delta\alpha \alpha'' L}{2}\right)} + e^{-\left(\frac{\Delta\alpha \alpha' L + \Delta\alpha \alpha'' L}{2}\right)} \cos \left( \phi_\beta \right) \right] \]

In absence of absorption \( \Delta\alpha \alpha' = \Delta\alpha \alpha'' = 0 \), the output signal is given below:

\[ I_{out} = |I_{out}|^2 \]

\[ I_{out} = \frac{\nu_0^2}{2} \left[ 1 + \cos \left( \phi_\beta \right) \right] \]  \hspace{1cm} (5)

### III. CALCULATION OF SOLITON PARAMETER

Fig. 2 Shown on Proposed model. A balance between the effects of self-phase modulation (SPM) and group velocity dispersion (GVD) leads to the formation of a fundamental soliton. A light pulse that propagates without changing its shape and spectrum and exhibits fundamental characteristics of higher-order solitons. The compensation between the effects of SPM and GVD is not complete for Gaussian pulses since the SPM induced chirp is different from that induced by the GVD. The exact compensation occurs when the pulse shape is that of a fundamental soliton. The peak power necessary to launch a \( N \)-order soliton can be calculated in the following way.

At 40Gb/s the bit slot is 25 ps and the pulse width is

\[ \text{Bit Rate}=40\text{Gb/s}, \text{ Bit slot}=25\text{ ps}, \text{ Width of optical pulse}=0.5 \]

\[ T_{FWHM}=\text{Bit slot} \times \text{ width of optical secant generator pulses}=12.5 \text{ ps} \]

The relation between the \( T_0 \) parameter in (2) and \( T_{FWHM} \) for sech-pulses is:

\[ T_0=T_{FWHM}/1.763=7.0902\text{ps} \]

The values \( n_2 = 2.6 \times 10^{-20} \frac{m^2}{W} \) and \( A_{eff} = 80\mu m^2 \) are used.

Sequence length=8 bits, samples per bit=128 bits

No. of samples= Sequence length \times samples per bit=1024

Time window=sequence length \times Bit slot=3.2 ns

Sampling interval=Time window/No. of samples=0.195 ps

Sample rate=1/sampling interval=5.12 Thz

The power value is

\[ P_N = \frac{n_2 \frac{w_0^2}{\gamma T_0^2}}{\gamma T_0^2} \]

\[ \beta = -20 \text{ps}^2/\text{km} \text{ at } 1.55 \text{ \mu m}, \gamma = \left( n_2 \times w_0 \right) / \left( c \times A_{eff} \right), w_0 / c = 2\pi / \lambda, \lambda = 1550 \text{nm}, \gamma = 1.317 / \text{w}, P_N = 0.3020B/N^2[w] \]

The dispersion length

\[ L_D = \frac{T_0^2}{|\beta|} = 2.5135 \text{km} \]

The quantity \( Z_0 = (\pi \times L_D) / 2 \) is the soliton period and in our case is

\[ Z_0 = 3.9482 \text{km} \]

The pulse remains chirp less, due to the exact compensation that occurs between the SPM-induced and GVD-induced frequency modulation.
IV. DESIGN AND ANALYSIS

A user bit sequence generator generates a sequence of 0’s and 1’s that is sent to electrical modulators and optical sech pulse generators. These components modulate and reshape soliton pulses with a high power level of 0.3 W and an operating frequency of 1550 nm. The modulated electrical signal and the high-power optical soliton signal are sent to an electro-optic modulator such as a Mach-Zehnder modulator for further modulation. The modulated optical signal is split into two paths: the optical fiber channel and the optical wireless communication channel. Both optical signals are converted into light signals using pin diode. The converted electrical signal passes through a low-pass Bessel filter (LPBF) to remove unwanted noise. The output signal from the LPBF is forwarded to a 3R regenerator for retiming, regeneration, and reshaping. At the receiver side, the eye diagram analyzer assesses the maximum Q-factor level, signal-to-noise ratio, and minimum bit error rate.

V. RESULTS

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Table I analysis BER and Q-factor values of the optical fiber and optical wireless channel. Different modulation schemes are utilized for high-power soliton transmission over both the fiber and wireless communication channels. CPFSK Modulation scheme use to optical fiber and optical wireless channel, BER is measure from optical fiber and optical wire-less channel, Increasing the number of bits per symbol enhances the bit error rate (BER) at the fiber or wireless channel, as received by the optical receiver, for different modulation schemes, except for the CPFSK scheme. Thus, it is evident that the CPFSK modulation scheme is more efficient and outperforms the other modulation schemes for various communication channels. Hence, it is evident that the CPFSK modulation scheme exhibits superior efficiency and outperforms the other modulation schemes for a variety of communication channels.
VI. CONCLUSION

Different modulation schemes are utilized for high-power soliton transmission over both fiber and wireless communication channels. The study reveals that among the proposed modulation techniques, the CPFSK modulation scheme exhibits superior performance and efficiency, demonstrating higher bits per symbol, improved electrical received power, and reduced bit error rate (BER). Notably, CPFSK modulation outperforms other techniques in terms of both fiber and wireless communication channels. Furthermore, the proposed modulation techniques enhance the received electrical power in the optical wireless channel compared to the fiber channel. Overall, CPFSK, PSK, MSK, and FSK modulation techniques prove effective in upgrading the Q-factor at the receiver for the fiber channel compared to the wireless channel.

Declaration of Competing Interest

The authors declare that they have no known competing financial AND non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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