EasyChair Preprint

№ XXX

Performance of Effect for XPM and FWM in Fiber Optics

Mohammed Salah Abood, Mustafa Hamdi, Bakr Taha,
Ahmed Shamil Mustafa and Emad M. Alsaedi

EasyChair preprints are intended for rapid
dissemination of research results and are
integrated with the rest of EasyChair.

June 7, 2021

Performance of effect for XPM and FWM in fiber optics

Mohammed Salah Abood[1], Mustafa Maad Hamdi[2], Bakr Ahmed Taha[3], Ahmed Shamil Mustafa[2], Emad M. Alsaedi[4]

[1] School of Information and Electronics Engineering, Beijing Institute of Technology, Beijing, China.
[2] Department of Computer Engineering Techniques, Al-Maarif University College, Al-Anbar, Iraq.
[3] UKM—Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Bangi 43600, Malaysia.

[4] Department of Computer Sciences University of Technology Baghdad, Iraq.

`mohammedsalah81@gmail.com,meng.mustafa@yahoo.com,p103537@siswa.ukm.edu.my,ahmedshamil90@gmail.com,emadcio@gmail.com`

Abstract. Optical fiber technologies have revolutionized telecommunication. The need for extensive transmission capability has spurred the production of fiber optics. This study aims to include a definition of XPM and FWM and how they influence the optical signal transmitted through nonlinear dispersive fibers. Consequently, Nonlinear fiber optics plays a significant role in implementing high-capacity optical networks. In this work, we evaluate the effect of XPM and FWM in fiber optics based on OptiSystem simulation results in this paper. We found the Nonlinear optics deals with the behavior of laser, Nonlinear effects in the optical fiber occurring due to nonlinear refractive index are Cross-Phase Modulation (XPM) and Four-Wave Mixing (FWM). In summary, Nonlinear effects are essential for inventing lasers, amplifiers, switching, multiplexing devices, and demultiplexers.

Keywords: OptiSystem, simulation, XPM, FWM, fiber optics.

1 Introduction

Chromatic dispersion, fiber-free nonlinearity, and noise from optic or cross-connections in the field of optical communication networks can rapidly degrade signal quality before signals arrive at their destination. The binary signal logic '0' and '1' is difficult to define, giving rise to transmission errors. Corrupted signals must be substituted for the precision of the original signal to reduce the bit rate. In general, signal recovery strategies can be dividing into three categories: reamplification, restoration, and retiming (3R)[1]. Various optical 3R regenerating methods have been published, e.g., using Semiconductor Optical Amplifier (SOA) using cross-grain or cross-phase modulation [2]Electromagnet modulation, the internet's exponential expansion, contributes to the quantum leap in the optical fiber network's delivery capabilities. They were due to improved information packing performance of a single pull (more than 2 bits/symbol) than traditional binary modulation (1 bit/symbol). The approach to significantly increasing the effective use of spectral bandwidth in existing optic amplifiers and transmission lines is multi-level modulation [3].

Large cross-phase (XPM) modulation is a cross-phase modulus analysis model (XPM) developed in the first-order perturbation principal framework, based on the dispersion-managed coherent fiber optic systems. For random pulse forms, the XPM variance determined analytically. The number of Gaussian times shift pulses is ideal for the non-Gaussian pulse and gives a robust non-Gaussian pulse approximation and even an explicit XPM variance derivation. The XPM variation is calculated analytically in line with the numerical simulations. So, in specific quantum information systems, XPM is essential for two single-photon pulses. Electromagnetically Induced Transparency (EIT) has achieved significant nonlinearity with minimal losses when XPM is applied. The N-type four-level system is a simple, proven EIT-based XPM scheme [4]. There has also been a demonstration of an updated XPM scheme based on the N-type system[5]. XPM is one of the most noticeable nonlinear effects when several SCM signal carrying wavelengths co-propagate in a dispersive fiber. Moving power from one channel to another creates crosstalk that is counterproductive to authentic communication and should have retained the lowest possible degree in the wavelength domain [6]. So, to reach higher performance, the enormous traffic growth needs continued improvement in optical transmission systems. Increasing capability while retaining the same accessibility requires specialized strategies to eliminate linear and nonlinear impairment of transmission. Compensation of the linear impairments such as CDs and PMD is affordable with optical equalization. Digital equalization CDs are cheap (e.g., fractionally spaced finite impulse response filter). However, it is also difficult to reduce nonlinear Kerr-induced impairs (i.e., self-phase modulation (SPM), XPM, and FWM). Current nonlinear equalizers need a wide range of optical parameters and trigger heavy calculations. Moreover, quasi-static transitions to more dynamic optical networks make transmission systems more complex [7].

FWM to phase conjugation (PC) and plasma diagnosis has applied. The methodology was consisting of a nonlinear reaction to an applied optical field by bonded electrons in the material at longer wavelengths (infrared 10 μm to radio wave 10 m) and showed great potential as a plasma diagnostic[8]. FWM can cause significant errors in multi-wavelength transmission systems using dispersion-shifted fibre (DSF) in the zero-dispersion wavelength (λ0) region. Thus, this phenomenon leads to system loss, although frequency generation use [9]. The effectiveness of this nonlinear interaction depends significantly on the correspondence of phases. A significant parameter for the optical fiber phase misalignment is chromatic dispersion. Different dispersion-shifting and non-dispersion-shifted fibres, where a non-zero chromatic dispersion level, one ps/km/nm in the dispersion-shifted fibre, being treated, were investigated as a feature of FWM efficacy [10]. The challenges lie to deliver a clear idea of the impact that cross-phase modulation (XPM) and four-wave mixing (FWM) facilities have on the propagation of optical signals in a nonlinear dispersion fiber using OptiSystem.

This study aims to include a definition of XPM and FWM and how they influence the optical signal transmitted through nonlinear dispersive fibers. On the other hand, we examine various factors to increase the results of XPM and FWM. The capabilities of OptiSystem can also be improved by easily interacting with a wide range of devices. However, the results showed that the XPM and FWM effects' dispersion in a lossless fiber would reduce. To be successful, it is essential to use a higher bit rate because it results in a higher time value.

2 Literature Review

This section describes works of literature research of XPM and FWM effects in an optical fiber system. Different types of studies have been doing for addressing and optimizing the required Bit rates. However, few methods of analysis have been developing to increase the bit rate and wavelength. The change of wavelengths with all-optic modulation has studied in a fiber powered by two pump waves. The operational mechanism is examined with a modulating all-optic step with two parallel / cross-polar pomp waves to produce a precise up-/down-mounted replica of the optical signal. The conversion efficiency was measure with a 300-m high-linear fiber [11, 12]. Another research [13, 14]shows effective XPM modulation based on a closed-loop double-digit framework. By changing phases of the optical fields, the properties of the dual medium have controlled. This phase based XPM system provides significant phase modulations at low light intensities without the need for laser beam cavities or closes focus. The system detects a phase level transition with two pulses consisting of eight photons, all in cool ferrocene. This research [15] proposed an easy solution with Nonlinearity Splits and a reciprocal recovery step algorithm for reducing the cross-phase effect (XPM). The method used designed to reduce the effects of the wavelength (WDM) system. Also, in [16, 17], a comprehensive four-wave mixing (FWM) study and its required matching phase conditions are reported in graded-index multimode optical fibres. When fiber length is on the order of a meter or less, and the signal and idler produce at broad frequency distances from a pump, the study is mainly essential for spontaneously frequency conversion and photon pair generation through FWM. An empirical expression has obtained to measure the phase misalignment that results from the distribution of the online waveguide between pump, signal, and idler beams.

Thulium (Tm)-doped laser with all fibre wavelengths; an experimental demonstration has made of four-wave mixing (FWM) of strongly Germanic highly nonlinear (HG-HNLF). With the advantage of a high nonlinearity of the HG-HNLF, the FWM-based intensity-dependent gain is integrated into the laser cavity to reduce the competitiveness of gain in Tm-doped fibre. The room temperature is at a range of 0,86 nm in wavelength due to 50-m HG-HNLF, 9, 22, and 36 lasing lines about 10-dB, 20-dB, and 30-dB [18]. Finally,[19, 20], these studies aim to develop birefringent fibres (BF) dipole and combo optical solitons along with the four-wave mixing effect (4WM). Two kinds of raw mediums, Kerr law and parabolic law, are used. The Choudhury approach method has extended to obtain dark soliton solutions in the light (dipole) optical pulse with sparkling backgrounds. Li's technique used to achieve soliton combo solutions that deliver solitary light waves and dark solitary waves.

3 Methodology

This section describes the methodology of XPM and FWM effects in optical fibre communication based on Opti-System simulation tools. We can examine multiple factors responsible for increasing XPM and FWM results, enables nearly any form of optical communication to be built and different optical network evaluations. It also offers a library of active and passive modules to install and monitor fibre optic communication networks' outcomes. As shown in Figure 1, a method for XPM analysis have built. The optical Gaussian Pulse Generator's operating wavelength is 1551 nm, and its capacity is different from 20 mW. The fibres are 100 km long. The fiber has an effect of self-phase modulation. The resulting XPM input pulse spectrum attributable to the fiber output is displayed using an Optical Spectrum Analyzer.

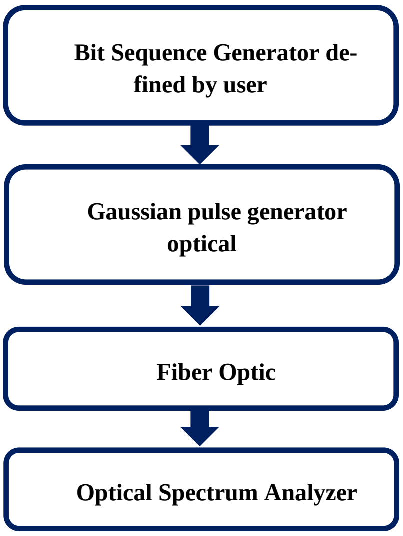


Fig.1. A simulation model for SPM analysis

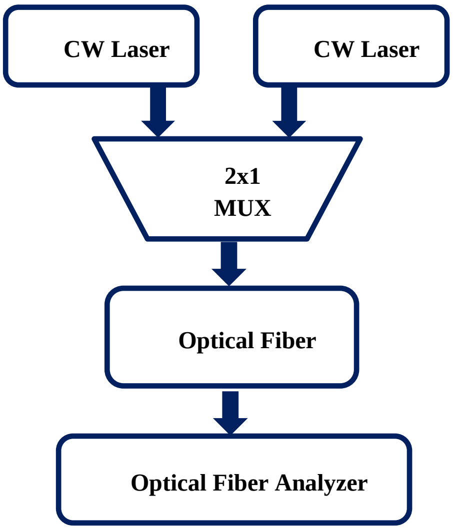


Fig 2. A simulation model for FWM analysis

The two-channel WDM system shown in Figure 2 is considered for FWM research. At 1551 nm and 1549 nm wavelengths, two Continual-Wave Lasers (CW) produce the required light signal. The two-channel WDM multiplexer multiplexes two signals. The fiber is supplied with a multiplexed signal. The machine is initially operated by 0 dBm. The productive fiber area is 64 square meters, and its range is 100 kilometers. The fiber end output of the FWM method is seen by the Optical Spectrum Analyzer.

4 Simulation Tools

This section describes the simulation of XPM and FWM effects in optical fibre communication based on Opti-System simulation tools. To begin, the layout was created and designed, as shown in Figure 3. You can see the Numeric tab of the Total Field Non-linear Dispersive Fiber component shown in Figure 4. The output signal here is many orders of magnitude below the soliton regime since the step size used to simulate soliton propagation is so much smaller. However, it still occupies the (BW) occupied by the signal is more significant and a small enough step size is needed to accurately calculate the 4-wave mixing products resulting from the interaction of the input signals [24]. The step size is determined in this case, rather than nonlinear, by the coherence length of the FWM process (associated with the self-phase modulation process).

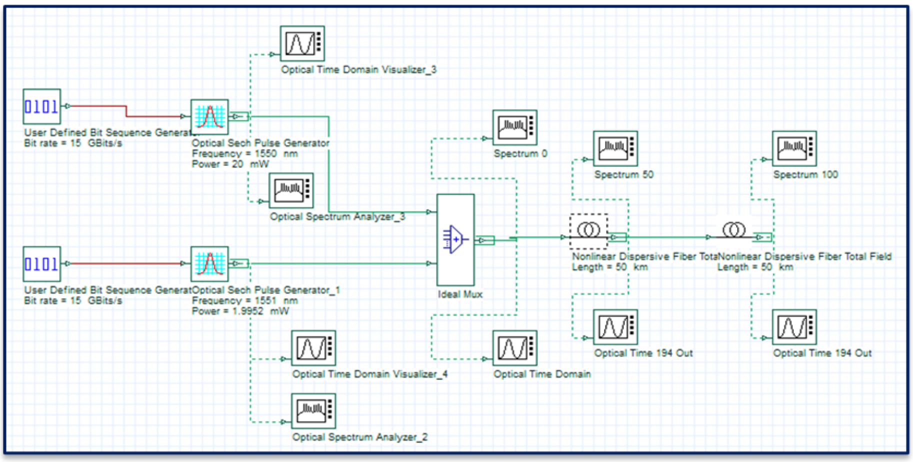
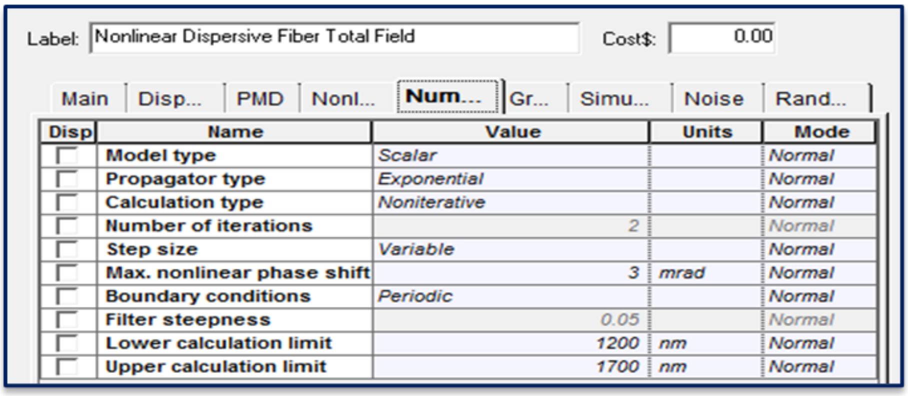


Fig.3. Create and design layout


Label: Nonlinear Dispersive Fiber Total Field

Cost$: 0.00

Disp	Name	Value	Units	Mode
☐	Model type	Scalar		Normal
☐	Propagator type	Exponential		Normal
☐	Calculation type	Noniterative		Normal
☐	Number of iterations	2		Normal
☐	Step size	Variable		Normal
☐	Max. nonlinear phase shift	3	mrad	Normal
☐	Boundary conditions	Periodic		Normal
☐	Filter steepness	0.05		Normal
☐	Lower calculation limit	1200	nm	Normal
☐	Upper calculation limit	1700	nm	Normal

Fig.4. Nonlinear Dispersive Fiber Total Field Properties dialogue box-Numeric tab

OptiSystem is a comprehensive software architecture suite allowing users in the current optical network transmission layer to design, validate and model visual communications. It is, however, a device-level simulator that focuses on realistic fiber-optic networking simulation. An advanced graphical user interface manages the design of the optical component, network list, models of modules and graphics (GUI). Furthermore, in the physical layer, it simplifies almost any kind of optical connectivity and analyzes a wide variety of lengthy, metropolitan and local networks (LANs). OptiSystem supplies a wide library of prototype optical (OSD) design or simulation and planning data. The OptiSystem capabilities can also be improved by incorporating user elements that interact with a wide range of instruments easily. Any apps like this are available [21]

Thearchitecture of the physical layer optical communication networks to the part level.

- CATV or TDM / WDM / CDM network design.
- Passive optical networks (PON) based FTTx.
- Free space optic (FSO) systems and Radio over fiber (ROF) systems.
- SONET / SDH ring design.
- Sender, channel, amplifier, and configuration of the receiver.
- Scatter map concept.
- BER assessment and device punishments for multiple receiver models.
- Expanded BER structure and budget relation calculations.

5 Results

This section describes the results and discussion of XPM and FWM effects in optical fibre communication based on Opti-System simulation tools. The input consists of two Gaussian pulses (800 ps) separated in time and (1 nm) in frequency, as in figure5.

The fiber dispersion is =16 (ps/nm)/km

The simulation (BW) is about three times greater or higher than the input signal. This is achieved to avoid the FWM products from being aliased when the two pulses communicate non-linearly.

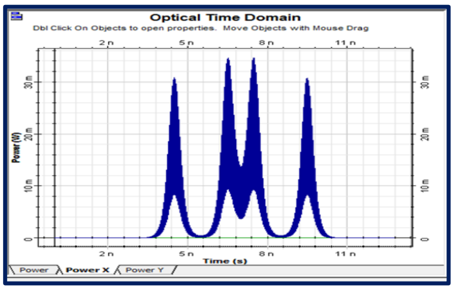


Fig.(5A). Input pulses and their spectrum(Time)

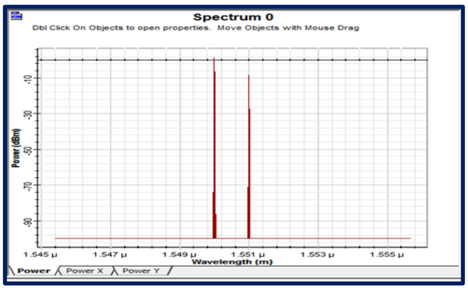


Fig.(5B). Input pulses and their spectrum (Wavelength)

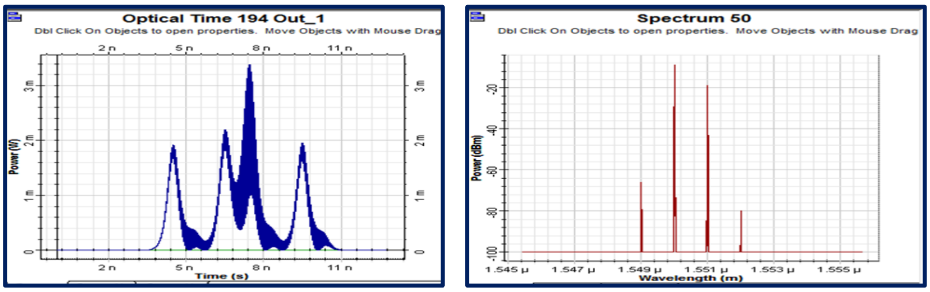


Fig.6. Pulses and their spectrum in a lossless fiber 50 km after propagation.

The pulse at (1551 nm) has a maximum of 2 mW power, which means that the pulse at 100 km is insignificant for SPM. However, the pulse (1550 nm) contains 20 mW peak intensity, and for this pulse, the impact of SPM is significant. The XPM would be too big at (1551 nm) pulse. However, the two pulses converge after (50 km) transmission, and the pulse spectra are extended to 1551 nm and back to display figures 5. The influence of XPM is responsible for this extension. The spectral expansion of the pulse (1550 nm) is more interesting. The increase is due to SPM for this pulse. The expansion of the pulse (1551 nm) (Cause of XPM), however, because of the presence of GVD, is less. The edge of the stronger pulse moves through, the smaller pulse decreases the gap times and increases the spectral expansion. In (50 km), products from four waves will certainly be mixed at (1549 and 1551 nm). So, the BW signal is the input signal three times. Where both the signal and false frequencies are not appropriate for simulating BW, the FWM papers have been converted to the BW.

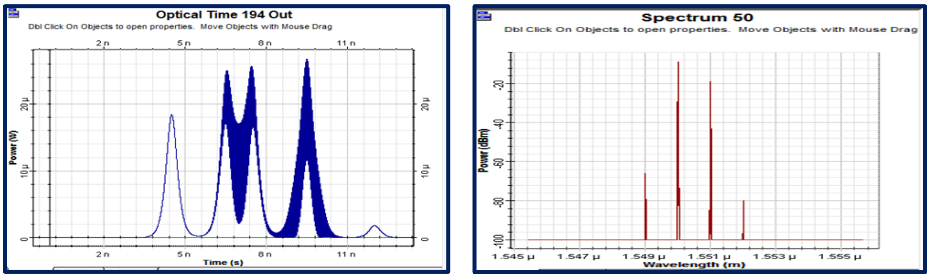


Fig.7. After 100 km of propagation pulses and spectrum

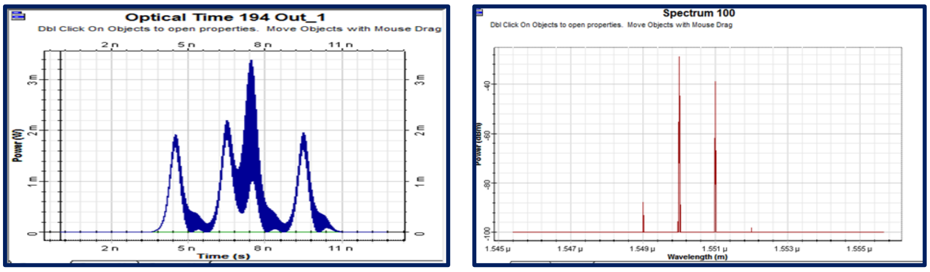


Fig.8. Including fiber loss

At (100 km, when pulses have ceased to overlap and FWM is absent. Even the XPM caused the pulse spectral enhancement (1551 nm). This is attributed to the symptoms associated with pulse increase. The overlap is opposite to pulse separation-related. The interfering pulse with declining amplitude contributes to a frequency transition from the opposite sign to the previous signal from the increasing edge. This paper demonstrates that the dispersion in a lossless fiber will decrease XPM and FWM effects. As pulses begin to overlap in a loss fibre, there is no further symmetry that allows the false waves to disappear, then when they start splitting, and waves that are fake don't disappear. Observed influences and changes in fiber using graphs pulses and their spectrum. The 50 km as in fig 6 and 100 km as in fig 7 lengths used for our experiment was post-propagation.

Finally, in this flowchart below, I reflect Microsoft's time and bitrate values, as Figure 9 shows. We can also see that when the bit rate is higher, the time value is higher.

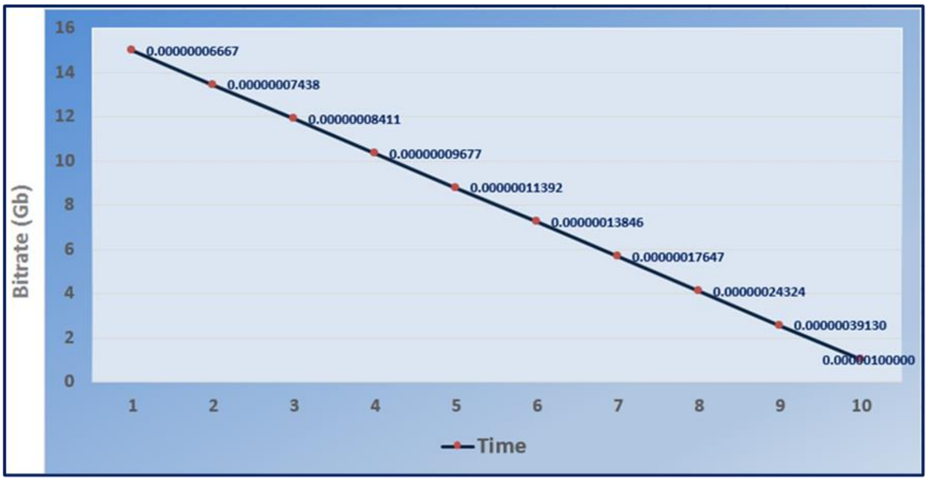


Fig.9. Time and Bitrate

6 Conclusion

Nonlinear effects require a significant interest when designing optical fiber communication systems. Given the above, we conclude that increasing the input power leads to increase XPM and FWM impact at a constant channel spacing. Simultaneously, fibre influences and changes were monitored via graphs, pulse measurements, and the spectrum. The paragraphs showed noticeable results and changes in the fiber. For our experiment, we used 50 km and 100 km lengths after post-propagation. OptiSystem is a useful tool to examine the balancing of nonlinear effects. Furthermore, techniques have been presenting for the simultaneous broadband conversion of all-optical simultaneous wavelength by taking advantage of the four-wave mixing (FWM), combined with simultaneous measurement of the nonlinear and Chromatic dispersion component. Finally, nonlinear effects can be useful in solitons generation, pulse compression, amplifiers, lasers, wavelength converters, multiplexing devices, and demultiplexers.

References

1. Hsieh, H.-S., K.-M. Feng, and M.-C.M. Lee, *Study of cross-phase modulation and free-carrier dispersion in silicon photonic wires for Mamyshev signal regenerators.* Optics express, 2010. **18**(9): p. 9613-9621.
2. Leclerc, O., et al., *All-optical signal regeneration: from first principles to a 40 Gbit/s system demonstration.* Comptes Rendus Physique, 2003. **4**(1): p. 163-173.
3. Leclerc, O., et al., *Optical regeneration at 40 Gb/s and beyond.* Journal of Lightwave Technology, 2003. **21**(11): p. 2779.
4. Shiau, B.-W., et al., *Low-light-level cross-phase modulation with double slow light pulses.* Physical review letters, 2011. **106**(19): p. 193006.
5. Catanese, C., et al. *A Survey of Neural Network Applications in Fiber Nonlinearity Mitigation*. in *2019 21st International Conference on Transparent Optical Networks (ICTON)*. 2019. IEEE.
6. Mohammed, M.J., Hamdi, Mustafa Maad , , *Hybrid Tow Feature Extraction Descriptor for Shape Pattern Recognition.* Australian Journal of Basic and Applied Sciences, 2018. **12**(7).
7. Singh, V., S. Kumar, and P.K. Dimri, *Comparative study of XPM-induced crosstalk due to 3OD parameter in SCM-WDM transmission system.* Optik, 2019. **186**: p. 177-181.
8. Federici, J.F., *Review of four-wave mixing and phase conjugation in plasmas.* IEEE transactions on plasma science, 1991. **19**(4): p. 549-564.
9. Hamdi, M.M., Mohammed, Mohammed Jabbar, *BER Vs Eb/N0 BPSK Modulation over Different Types of Channel.* Australian Journal of Basic and Applied Sciences, 2018. **12**(5).
10. Inoue, K., *Four-wave mixing in an optical fiber in the zero-dispersion wavelength region.* Journal of lightwave technology, 1992. **10**(11): p. 1553-1561.
11. Watanabe, S., et al., *Wavelength conversion using fiber cross-phase modulation driven by two pump waves.* Optics express, 2019. **27**(12): p. 16767-16780.
12. Abood, M.S., et al. *Fuzzy Logic Controller to control the position of a mobile robot that follows a track on the floor*. in *2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*. 2020. IEEE.
13. Hamdi, M.M., et al. *Coarse WDM in Metropolitan Networks: Challenges, Standards, Applications, and Future Role*. in *Journal of Physics: Conference Series*. 2020. IOP Publishing.
14. Liu, Z.-Y., et al., *Large cross-phase modulations at the few-photon level.* Physical review letters, 2016. **117**(20): p. 203601.

15. Zheng, Q., et al. *XPM mitigation in WDM systems using split nonlinearity compensation*. in *Asia Communications and Photonics Conference*. 2019. Optical Society of America.
16. Nazemosadat, E., H. Pourbeyram, and A. Mafi, *Phase matching for spontaneous frequency conversion via four-wave mixing in graded-index multimode optical fibers.* JOSA B, 2016. **33**(2): p. 144-150.
17. Abood, M.S., M. Ismail, and R. Nordin. *A quiz management system based on P2P near-field communication on Android platform for smart class environments*. in *2016 International Conference on Advances in Electrical, Electronic and Systems Engineering (ICAEES)*. 2016. IEEE.
18. Huang, T., et al., *All-fiber multiwavelength thulium-doped laser assisted by four-wave mixing in highly germania-doped fiber.* Optics express, 2015. **23**(1): p. 340-348.
19. Raza, N. and A. Zubair, *Dipole and Combo Optical Solitons in Birefringent Fibers in the Presence of Four-Wave Mixing.* Communications in Theoretical Physics, 2019. **71**(6): p. 723.
20. Marcuse, D., A.R. Chraplyvy, and R. Tkach, *Effect of fiber nonlinearity on long-distance transmission.* Journal of lightwave technology, 1991. **9**(1): p. 121-128.
21. Yang, X. and Y. Hechao. *The application of optiSystem in optical fiber communication experiments*. in *Proceedings of the Third International Symposium on Computer Science and Computational Technology (ISCSCT'10)*. 2010. Citeseer.