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IMPROVING THE LIMITATIONS IN THE CAPACITY OF FIBER OPTICS USING MODIFIED NONLINEAR FOURIER TRANSFORM

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Abstract

The central objective of this work is to suggest and develop one simple, unified method for communication over optical fiber networks, valid for all values of dispersion and nonlinearity parameters, and for a single-user channel or a multiple-user network. The method is based on the nonlinear Fourier transform (NFT), a powerful tool in soliton theory and exactly solvable models for solving integral partial differential equations governing wave propagation in certain nonlinear media. The NFT related signal degrees of freedom in such models, in much the same way that the Fourier transform does for linear systems. In this thesis, this observation is exploited for data transmission over integral channels such as optical fibers, where pulse propagation is governed by the nonlinear Schödinger (NLS) equation. In this transmission scheme, which can be viewed as a nonlinear analogue of orthogonal frequency-division multiplexing commonly used in linear channels, information is encoded in the nonlinear spectrum of the signal. Just as the (ordinary) Fourier transform converts a linear convolutional channel into a number of parallel scalar channels, the nonlinear Fourier transform converts a nonlinear dispersive channel described by a lax convolution into a number of parallel scalar channels. Since, in the spectral coordinates the NLS equation is multiplicative, users of a network can operate in independent nonlinear frequency bands with no deterministic inter-channel interference.
Keywords: Vertical cavity surface emitting laser, Data transmission, Fiber optics, Dispersion shifted fiber, Power consumption, Fourier transform

DEĞİŞTİRİLMİŞ DOĞRUSAL OLMAYAN FOURIER DÖNÜŞÜMÜ KULLANARAK FİBER OPTİK KAPASİTESİNDEKİ SINIRLAMALARIN İYİLEŞTİRİLMESİ

Özet

Bu çalışmanın asıl amacı, optik fiber ağlar üzerinden iletişim için basit, birleştirilmiş bir yöntem önermek ve geliştirmektir, tüm dağılım ve doğrusal olmayan parametrelerin değerleri için ve tek kullanıcılı bir kanal veya çok kullanıcılı bir ağ için geçerlidir. Yöntem, doğrusal olmayan Fourier dönüşümü (NFT), çözüm teorisinde güçlü bir araç ve bazı doğrusal olmayan ortamlarda dalga yayılımını yöneten integral kısmi diferansiyel denklemleri çözmek için tam olarak çözülebilir modeller üzerine kuruludur. NFT ile ilgili bu tür modellerde, serbestlik dereceleri, Fourier dönüşümünün lineer sistemler için yaptığı şekildedir. Bu tezde, bu gözlem, darbe yayılımının doğrusal olmayan Schödinger (NLS) denklemi tarafından yönetildiği optik fiberler gibi bütünleşik kanallar üzerinden veri iletimi için kullanılmıştır. Doğrusal kanallarda yaygın olarak kullanılan ortogonal frekans bölmeli çoğullamanın doğrusal olmayan bir analogu olarak görülebilen bu iletim şemasında, bilgi sinyalin doğrusal olmayan spektrumunda kodlanır. Tıpkı (normal) Fourier dönüşümü, doğrusal bir evrişimsel kanalı birkaç paralel skaler kanala dönüştürdüğü gibi, doğrusal olmayan Fourier dönüşümü, bir Lax evrişimi tarafından tarif edilen doğrusal olmayan bir dağıtıcı kanalı birkaç paralel skaler kanala dönüştürür. Spektral koordinatlarda NLS denklemi çarpımsal olduğundan, bir ağ kullanıcıları belirleyici olmayan kanallar arası parazit olmadan bağımsız doğrusal olmayan frekans bantlarında çalışabilirler.
Anahtar Kelimeler: Dikey Boşluklu Yüzey Yayan Lazer, veri iletimi, Fiber Optik, Dispersiyon Değişen Fiber, güç tüketimi, Fourier Dönüşümü

1. Introduction

(Personick, 2013) The underlying principle of fiber technology is the ability of light given that it passes in a specified medium usually glass, has the capacity of carrying a larger amount of information than electrical signals with regard to distance coverage .The glass medium is compared to other media such as coaxial, copper medium or wireless medium through the use of radio frequencies.

(Benzoni & Orletsky, 1989) Modern fiber technology enable the transmission of data or information through signals over hundreds of kilometres without necessarily having to amplify the signals. Optical fiber presents a solution to transmission of signals over long distances because it has superior qualities such as high potential of bandwidth, fewer transmission losses and low interferences.

(Buydos, 1988) When this technology was first proposed, it promised many benefits for the telecommunication sector and it has taken a series of innovations and improvements and products to get the technology where it is currently. The physics principle that glass can be used as a medium became the foundation of fiber optical technology when it was being explored back in the 1960s. Many researchers directed their efforts at exploring the field but the major challenge was developing a pure glass that would have the capacity of retaining 1 percent of light transmitted through after covering a distance of 1 kilometre.

(Kapany, 1967) In more technical terms, this one percent of light for one kilometre covered meant that the glass medium was required to twenty decibels per kilometre.

(Hentschel, 1989) It was not until the ‘70s that this glass property was achieved thanks to the efforts of three scientists namely Dr. Peter Schultz, Dr. Robert Maurer and Dr. Donald Keck. This glass was the considered to the purest glass medium that had ever been created and therefore following studies have been aimed at innovating ways that glass medium can be advanced regarding number of applications and improvement of parameters such as consistency, performance and quality.

One of the fundamental characteristics of fiber optics technology is nonlinearity which poses some form of limitation to the capacity of the same.

(Petersen, 2003) This limitation is explained by the Kerr nonlinearity and therefore there is a need to design more advanced techniques that can mitigate the effects of nonlinearity. Since fiber optics technology was introduced, there has been a significant development that has also contributed to the growth of the internet. Though fiber optics has improved over the years, there is still the issue of limitation that is brought about by nonlinearity.

(Smith, 1998) There are technologies have led to the multiplexing of wavelength division and digital methods of signal processing. Nonlinearity is one of the fundamental aspects of fiber optic cable technology but it also poses some limitations in the transmission of optic signals over large distances. The transmission capacity of the optic cable is reduced with large distances also having an effect on the rate of data transmission of the fiber optic. Nonlinearity is one of the fundamental aspects of fiber optic cable technology but it also poses some limitations in the transmission of optic signals over large distances. The transmission capacity of the optic cable is reduced with large distances also having an effect on the rate of data transmission of the fiber optic.

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2. Problem Description

The fiber optics cable enables transmission of data through a large distance. Its high transmission capacity enables large amounts of data to be transmitted over long distances. Distance for this mode of communication is a very important and key aspect to put into consideration. The transmission of data over long distances is however affected by a number of limiting factors. The signal via which the fiber optics cable uses might become too weak when large distances are involved.

Solving The Limitations Fiber Optics Technology Several different methods have been proposed over the recent years on dealing with limitation factors to proper efficiency of the fiber optic cable technology. The methodologies proposed entail the process of using an all optical signal processing. They include the nonlinear Fourier transform and eigenvalue communications, and the nonlinearity-tailored detection method, Summary of light sources the digital back propagation method, & the optical phase conjugation process, we used the non- linear transform to solve the limitation in the capacity of fiber optics, The BER; bit-error rate are the units in which the observations of the encoding of the periodic nonlinear Fourier transform together with data are encoded. The observations are shown for the various techniques in modulation and the different sizes in clusters against the distance used in propagation. The observations are also presented using the bit-error rate units.

The non-linear transform for the fiber optic communication; eigenvalue communication is preferred method used in the mitigation of the factors limiting the effectiveness of the fiber optic technology. This method of mitigation basically uses the technique of communication systems that are based on the PNFT; periodic nonlinear Fourier transform, It also increases the transmission capacity of the fiber optic cable as discussed below. The channel mode and the main spectrum corresponding to PNFT signal decomposition is as follows. When an ideal Raman amplification is assumed, the master model of the NLSE is used. It is used with the ASE noise being put into account.

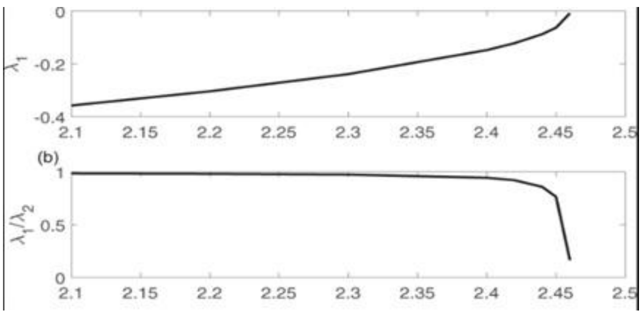

Figure 1. Covariance matrix Eigenvalues (Clark & Hester 1988).

In terms of the transmission speed, both the FP and the VCSEL have high speed transmission. The LED has a slow transmission speed with the DFB having a very high speed of transmission. Where the transmission frequency is concerned, the LED has a wide spectral width and the FP has a wider spectral width. The FP has wider spectral width and the DFB has a narrow spectral width. Where the costs are concerned; the LED has the low cost, with the FP having a moderate cost. The FP has a medium cost.

Table 1. Summary of Light Sources (Linden, 1997).

Light source	LED	FP	DFP	VCSEL
Transsmition direction	Short Range	Medium Range	Low Range	Medium Range
Transmition Speed	Low Speed	High Speed	Very high Speed	High Speed
Transsion Frequency	Wide Spectral	Medium Spectral	Narrow spectral	Narrow Spectral
Cost	Low Cost	Moderate Cost	High Cost	Low Cost

3. Results

A scheme displayed here in Fig. 2 on OptiSystem software is shown. Various signals in the shape of square waves are produced. The eight color from VCSEL change these signals to modulate light. The intensity modulation method is employed in this specific project, i.e., the output light strength varies based on the input signal amplitude. The output light from these multiple colorful LEDs merge passive optical systems such as lenses with white light. This is called multiplexing or multiplexing of color splitting optical wavelength division. It is transferred in free space by multiplexing signal. The transmission range is restricted and LOS route is needed, but the data rate is very big. In this situation, the scheme for indoor environments is simulated here at a range of 1500 m. Each color light is segregated from the white light of the recipient by distinct color filters.

The system was initially tested in a back-to-back (B2B) configuration, where the transmitter output has been directly connected to the receiver, in order to obtain the best performance achievable by the system in the sole presence of the intrinsic transceiver distortions (e.g. transmitter front-end distortions, detectors noise, etc.) and added additive white Gaussian noise (AWGN) as commonly done for linear coherent systems. The OSNR was swept by varying the noise power added to the signal at the receiver input. The adopted metric for measuring the performances allows a direct comparison with standard coherent transmission systems. The OSNR range considered is the region of interest where the system performance is around the HD-FEC threshold. The measured average BER is shown in Figure. 2. A visible effect is the fact that the BER is not the same for the four different constellations, but it is worse for the two constellations associated with the eigenvalue with a higher imaginary part. This effect can be related to the dependency of the noise variance of both the eigenvalues and the corresponding scattering coefficients on the imaginary part of the eigenvalues themselves; an analysis of the noise distribution for the various eigenvalues and scattering coefficients is provided in the Supplementary Material.

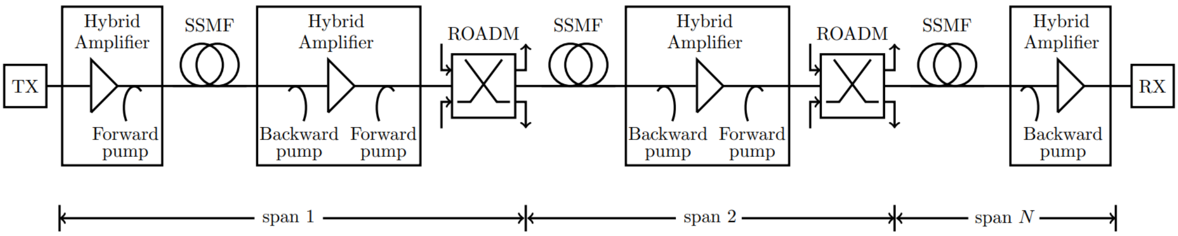

Figure 2. The general view of the fiber optical system.

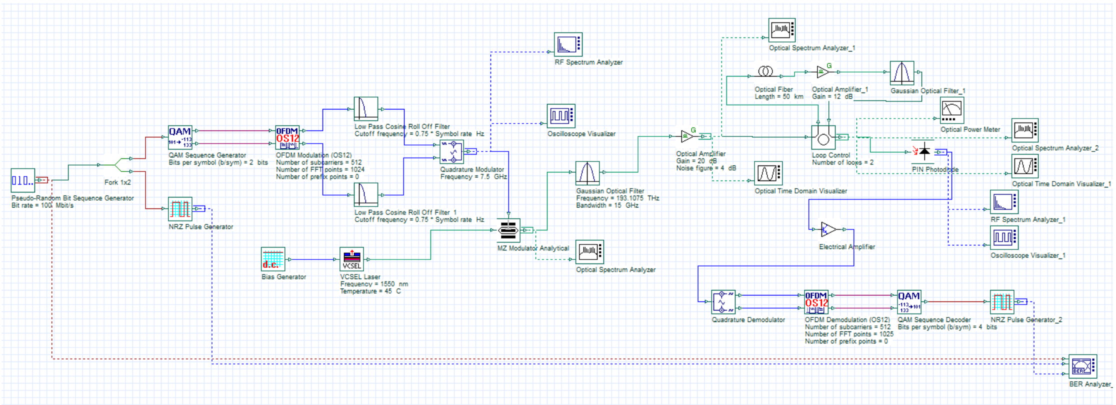

Figure 3. Structure of the modified nonlinear Fourier transform in Optisystem.

This scheme has 100 Mbps with BER below FEC boundaries, i.e. the range from 3, 8 till 10−3 for the range between 100 and 1700 m, which can be achieved. As shown below Fig. 4. with all the color wavelengths, the white light range is:

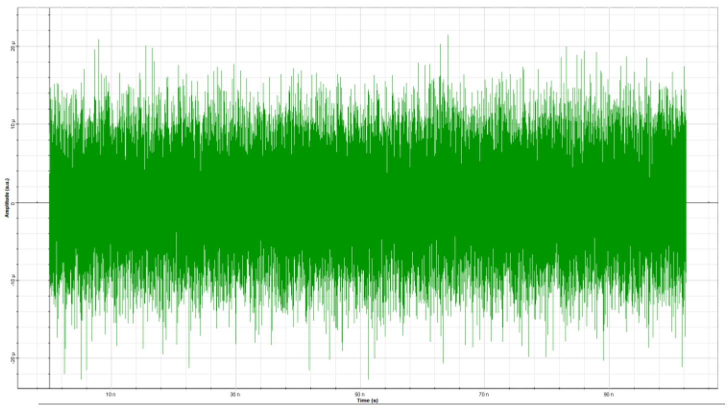

Figure 4. Spectrum of white light.

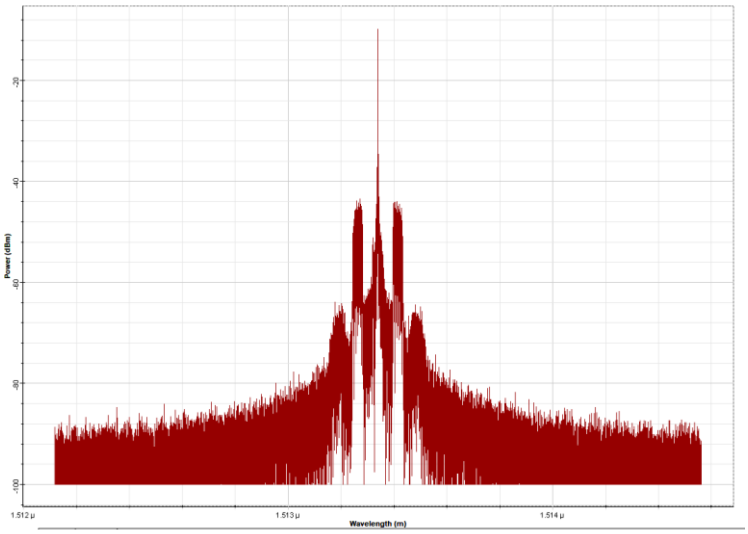

Figure 5. Spectrum of light.

We applied the system according to the figure that we explained using Optisystem 14 simulator. In this work we had 4 Quadrature Amplitude Modulation based (QAM) based Orthogonal frequency-division multiplexing (OFDM) signal from 100 Mbps pseudo random signal that applied on 4x1 WDM to process the signals into one signal to a 2000 m fiber optical cable. The output of the 4x1 WDM is connection OFDM demodulator and QAM demodulator and ends with a pulse generator to check the signal characteristics.

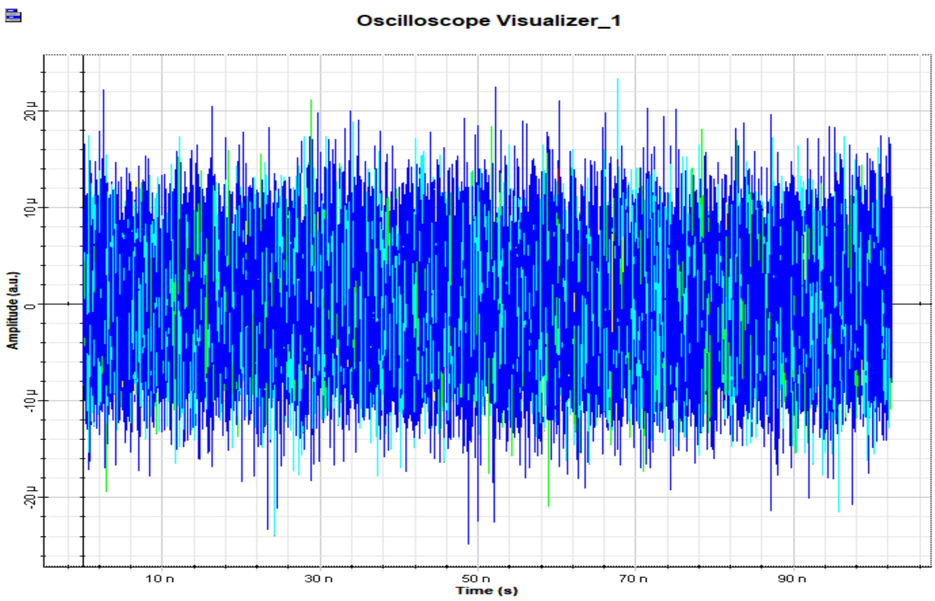

Figure 6. The demodulated output signal.

4. Conclusion

The rate of data of 100 mbps is very low when compared to the limit of previous errors with a maximum bit error rate of $3x10^{-8}$. This scheme is used for 1500 m transmitting range. The LED arrays may increase optical power levels, thus increasing the transmission distance. It can also be improved with pointed laser diodes that provide monochromatic light of high intensity, which also improves the rate of information. By enhancing modulated methods the data rate can also be improved. OFDM with QAM modulation is one of the best methods for the nonlinear Fourier transform technique. With the 4-QAM OFDM modulation technology, the data rate is 10 Gbps, a further increase can be made with 512 QAM OFDM signal.

References

Personick, S. D. (2013). Optical Fiber Transmission Systems. Springer Science & Business Media.

Benzoni, J.F., & Orletsky, D.T. (1989). Military Applications of Fiber Optics Technology.

Buydos, J. F., & Library of Congress Science and Technology Division Reference Section. (1988). Fiber optics. Science Reference Section, Science and Technology Division, Library of Congress.

Kapany, N.S. (1967) Fiber Optics: Principles and Applications. Academic Press.

Hentschel, C. (1989). Fiber optics handbook: an introduction and reference guide to fiber optic technology and measurement techniques (3rd ed). Hewlett-Packard.

Petersen, J. K. (2003). Fiber optics illustrated dictionary. CRC Press. https://doi.org/10.1201/9781420040357.

Smith, B. M. (1998). Careers in fiber optics. Rosen Pub. Group. https://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=20014.

Clark, R. J. H., & Hester, R. E. (1988). Advances in non-linear spectroscopy. Wiley.

J, L. K., Society of Photo-optical Instrumentation Engineers., & United States. Advanced Research Projects Agency.

(Eds.). (1997c). Laser diode and LED applications III: 10-11 February, 1997, San Jose, California. Bellingham, Washington: SPIE.