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A Novel Scheme for Orthogonal Frequency Division Multiplexing-Radio over Fiber Based on Modulator and Dithering Technique: Impact of Self Phase Modulation and Group Velocity Dispersion

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Abstract: Nonlinearity characteristic in OFDM (Orthogonal Frequency Division Multiplexing)-RoF (Radio over Fiber) system which causes the frequency shift of light and has a high electrical field on medium transmission. We begin by discussing SPM (Self Phase Modulation) and GVD (Group Velocity Dispersion) are part of nonlinear characteristic. SPM induced spectral broadening will be degrade performance of light wave and GVD will be impact on duration pulse of optic. The impaired information signal reduces the power and later affects the quality of signal. This research aims to focus on the improvement of two external modulator LiNbO3 MZM (Lithium Niobate-Mach Zehnder Modulator) and applying of frequency dithering techniques to reduce the existing nonlinearity of the optical fiber purposely to enhance the receiving power for the lower input power with the length of fiber up to 100 km. Finally, the result shows an average of 18.5% increase in the power level for linewidth of 1 MHz, 3 MHz, and 7 MHz across 50 km distance with the log BER (Bit Error Rate) -2.407, BER 0.003, and SNR (Signal to Noise Ratio) 43.8, across 100 km of optical fiber the value of log BER -2.471, BER 0.003, and SNR 49.14.

Keywords: MZM $LiNbO_3$, SPM, GVD, Dithering, Nonlinearity.

1. Introduction

Laser has a Nonlinear optics (NLO) property for the basic operation of the generation of laser involves several nonlinear mechanisms such as threshold current, stimulated emission and spontaneous emission. Nonlinear is the arm of optical fiber that portrays the conduct of light in nonlinear media. That is media responds nonlinearity effect from the dielectric polarization (P) to the electric field (E) of the light. Nonlinearity is high interest area in optical fiber technology, which have impact to the wavelength, amplitude, energy and phase. SPM and GVD are the part of nonlinear, nonlinear characteristic is one of parameters in which reduce affect the performance of optical fiber. Many ways solution to solve nonlinear, among others are to modified component on optical systems. Recently, a novel scheme based on MZM dual drive to combine hybrid coupler and double parallel MZM an optical single side band that has been conducted [1,2]. Investigated Direct Modulation (DM) and External Modulation (EM), and direct modulator on QAM (Quadrature Amplitude Modulation) has exhibits to mitigate SBS (stimulated Brillouin scattering) and optimization nonlinear compensated for LTE (Long Term Evolution)-RoF with varied launch power for enhanced power budget [3]. Another line of research is aimed to demonstrate of the nonlinear compensation LTE-RoF based on DMFD (Direct Modulation Frequency Dithering) and EMFD (External Modulation Frequency Dithering) also to mitigate SBS including analysis of QPSK (Quadrature Phase Sift Keying), 16 QAM, and 64 QAM scheme [4]. On the other hand, was investigated to optimized launch power for the

Direct Detection Orthogonal Frequency Division Multiplexing (DD-OFDM), that showed analytically DFB (Distributed Feedback) laser induced PFC (Positive Frequency Chirp). That system achieved the longest transmission span with a requirement of higher SNR. The maximum link achieved DFB is ~68 km at an SNR ~29 dB, ~88 km at an SNR ~32 dB used DE (Dual Electrode)-MZM and SNR ~26 dB for 79 km used SE (Single Electrode)-MZM [5]. The other elaboration to mitigate output pulse of characteristic impact spectral separation, including the effect of SPM, GVD, dithering, and optical OFDM. Design has been proposed to provide design guidelines and resulting outputs of a self-pulsating source based on regenerative self-phase modulation and offset band-pass filtering and modelling time domain travelling wave including effect of GVD and SPM [6,7]. A previous works to optimize RoF used dithering technique and coherent detection based on varied modulation was mentioned in [8,9]. Meanwhile, the authors in [10] used modelling post, pre, and symmetric compensation technique to reconfigure bandwidth.

There is worth noting of the aforementioned works, the optimization performance RoF has only extensively investigated under the assumption linewidth value and optical receiver power on coherent detection are fixed on solitary frequency dithering and single modulator dual drive. Nonlinearity is correlated with quantum process in laser, due to of these characteristic, linewidth laser is important parameter beside those mentioned parameters early. Therefore, there is interesting to design system based on dual modulator and high frequency dithering using varied value of linewidth, optical launch power, and optical receiver power on coherent detection. There are inevitable parameters on the systems due to mitigate determine how strong the linewidth, and those models on difference between optical launch power and optical receiver power affects.

Contrast with previous works, the state of the art research and to fit the gap in this area, we used high frequency dithering to combine compulsion signal from modulators $LiNbO_3$ MZM dual drive scheme model combines high frequency dithering (f_d) sinusoidal wave technique to reduce nonlinearity strong point SPM and GVD, and to mitigate varied values of linewidth, OLP (Optical Launch Power), and ROP (Receiver Optical Power) affects in coherent detection. Furthermore, in high frequency case the dither signal is assumed to have a frequency much higher than the maximum frequency component of the input signal. Finally, contribution of this works will enhance the output level power for the lower input power and a longer optical fiber in the length of fiber up to 100 km to achieving of reliability system condition.

The paper is organized as follows: Section II describes the proposed system model. The result of measurement and analysis detailed in Section 3. Finally, the conclusion and future works up in Section 4.

2. Proposed System Model

Fig. 1 exhibits the proposed design OFDM-RoF system. In the transmitter, two modulators $LiNbO_3$ MZM have injected signal $S_{RF}(t)$ composed from CW (Continuous-Wave) laser. CW laser used to produce a continuous wave optical signal. Signal from CW laser direct to process by using 16 QAM component modulation and OFDM 12 modulators with a data rate 10 Gbps and frequency of 193.1 THz. Signal optic from modulators will combined to the analog signal of dithering technique. The source of system dithering is sinusoidal wave signal with the high frequency of 200 THz and modulated in the frequency deviation of 100 GHz. It is selected causes high frequency uses to long span transmission. Dither was used to control the signal high amplitude of a frequency modulator.

In a receiver, Local Oscillator (LO) power and varying linewidth to mitigate effect of linewidth and power receiver to systems. The simulation of proposed scheme here used Optisystem version 13.0.

2.1 $LiNbO_3$ MZM Basic Model

The application of an electrical signal is to controls the degree of interference at the output optical branch, therefore it can control the output intensity. The equations that describe the behaviour of the modulator can modelled as:

$$E_o(t) = \frac{E_{in}(t)}{10^{\left(IL/20\right)}} \cdot \left[\gamma . e^{\left(j\pi v_2(t)/V_{\pi RF} + j\pi v_{bias2}/V_{\pi DC} \right)} + (1-\gamma) . e^{\left(j\pi v_1(t)/V_{\pi RF} + j\pi v_{bias1}/V_{\pi DC} \right)} \right] \quad (1)$$

where $E_{in}(t)$ refers to optical signal input, IL refers to insertion loss parameter, $v_1(t)$ and $v_2(t)$ input electrical voltage upper (1) and lower (2), $v_{bias1}(t)$ and $v_{bias2}(t)$ are the setting of Bias voltage 1 and Bias voltage 2 respectively, V_{RF} switching modulation voltage, V_{DC} as the switching

Bias voltage, and γ denoted the power splitting ratio is inclusion from parameter of phase and amplitude modulation. Mathematical formula of output modulators is formulated by:

$$A = \frac{E_0}{2}\cos(\omega_t + \Delta\theta_0) + \frac{E_0}{2}\cos(\omega_t) \quad (2)$$

where A is information signal from modulator output, E_0 is carrier of signal, ω_t and $\Delta\theta_0$ each are modulation based on time function and adjustment of phase. Based on the same systems and component inclusion signal of two modulators, which is formulated as:

$$A_{Total} = 2\, E_0\, cos\, \frac{1}{2}(2\omega_t + \Delta\theta_0)\cos\frac{1}{2}(\Delta\theta_0) \quad (3)$$

A_{Total} is total signal compulsion information two modulators, and E_0 is carrier of signal from two signal, ω_t and $\Delta\theta_0$ each are modulation based on time function and adjustment of phase.

2.2 Dithering Technique

Dithering is the process of injection into the periodic signal for linear or nonlinear system to get some purpose of which is to add a linear characteristic of the open/close system.

The occurrence of a nonlinear framework is depicted with a general information of input-output nonlinear operator $y = f_{NL}(x)$, block diagram nonlinear process has shown in Fig.2. The output information equation of the system is presented as follows.

$$y = h_1(t)\,.\,f_{NL}\big(x(t)\big) = h_1(t)\,.\,f_{NL}(r_g(t) + d(t)) \quad (4)$$

Where $h_1(t)$ is the impulse response of the filter $H_1(j\omega)$, $d(t)$ is the signal of time dithering, $x(t)$ is the input signal $h_1(t)$ is the impulse response of the filter $H_1(j\omega)$, $r_g(t)$ optical signal source, and $y(t)$ is the output signal of the nonlinear system having a mathematical description of the single-input single-output $f_{NL}(.)$ we could find the output response to any desired input.

2.3 Self-Phase Modulation

One of causes nonlinearity is diversity of phase wavelength to time function, the other causes are from silica and have nonlinearity condition between electrical polarization and electrical field. Self-phase modulation occurred due to the phenomenon of both Y-branch waveguides. Output one modulator dynamic of wave phase to function of time is formulated by:

$$\theta = \frac{2\pi}{\lambda} nL \quad (5)$$

where θ phase by an electrical field (E) over fiber, L is fiber of length, λ is wavelength of optical pulse propagation in fiber of refractive and n is refractive index. Fiber high transmitted expressed formula becomes:

$$\theta = \frac{2\pi}{\lambda} n_{eff} L_{eff} \quad (6)$$

where λ wavelength of optical pulse propagation in fiber of refractive, $n_{eff}L_{eff}$ is effective refractive index and fiber length.

2.4 Group Velocity Dispersion

Group velocity dispersion is the phenomenon that the group velocity of light in a transparent medium depends on the optical frequency or wavelength. In mathematical numeric of fiber dispersion, will calculate using donate Constanta expansion of β (propagation mode), and parameter β_2 is derivative from group velocity, we can be expressed function group velocity dispersion becomes.

$$\beta_2 = \frac{1}{(v_g)^2}\frac{\partial v_g}{\partial \omega} \quad (7)$$

β_2 is derivative of velocity group, v_g and ω are group velocity and frequency canter. The group velocity dispersion is mostly defined as a derivative with respect to wavelength (rather than angular frequency). The other usual expression parameter to be calculated from the above-mentioned GVD parameter is thus formulated as:

$$D = -\frac{2\pi C}{\lambda^2}\beta_2 \quad (8)$$

where D or β_2 is the parameter of dispersion, λ is light of wavelength optical fiber and c is speed of light. (For waveguides, it is replaced with the phase constant of β_2). This abundance is usually specified with units of ps/(nm km). The spatial resolution including the effect of the GVD in optical fiber is formulated as:

$$\frac{\Delta_z}{2} = \frac{0.88c}{2v_{BW}}\sqrt{1 + (1.133\lambda^2 Dz v_{BW}^2/nc)^2} \quad (9)$$

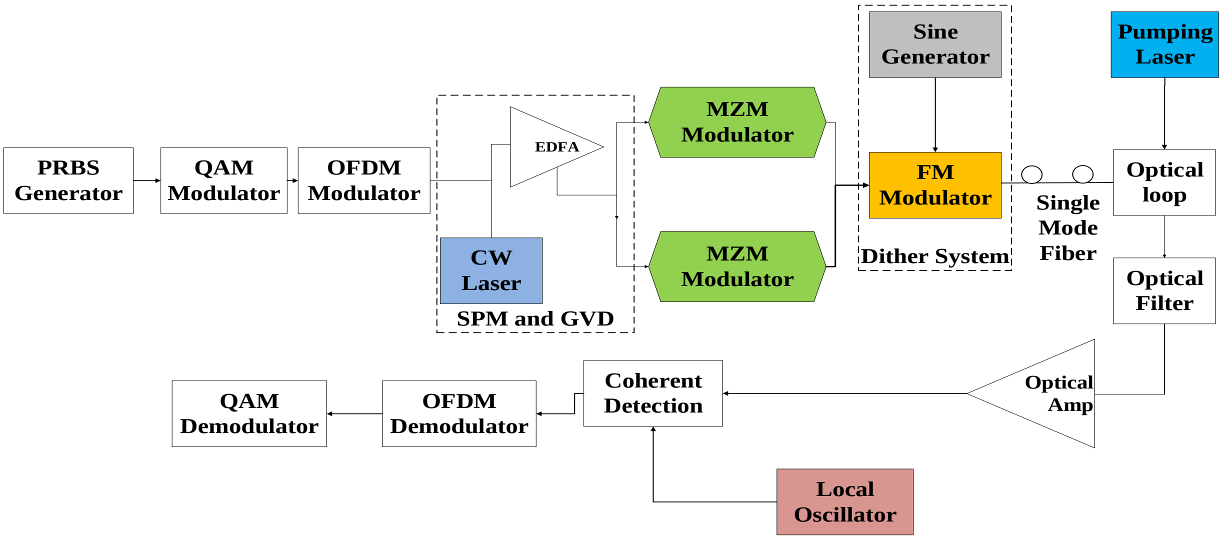

Figure.1 Scheme modified of OFDM-RoF using dual modulator and high frequency dithering

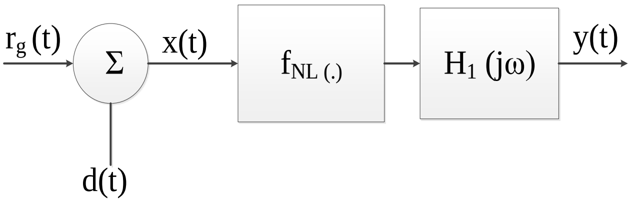

Figure.2 The output of the nonlinear using high and single frequency f_d component

λ is the light wavelength =1.55μm, n and c are velocity of light and the refractive index of the fiber =1.46, D is the GVD = 17.7 ps/nm/km, and different frequency-chirp ranges v_{BW} is 75 GHz and 49 GHz.

3. Measurement and Analysis

Laser linewidth in a typical single-transverse-mode He-Ne laser (at a wavelength of 632.8 nm), in the absence of intracavity line narrowing optics, can be of the order of 1 GHz. Smaller of linewidth value will be make narrow of pulse duration. On the other hand, the laser linewidth from stabilized low-power continuous-wave lasers can be very narrow and reach down to less than 1 kHz [11]. External modulation of a single frequency seed could achieve broadening linewidth.

Fig. 3 until Fig. 5 exhibits the results of the received power based upon the varied linewidth, ROP (Receiver Optical Power), and OLP (Optical Launch Power). Fig. 3 shows the optical received power where the transmitted power is varied from -8 dBm to 8 dBm to observe the system's performance subjects to the nonlinearity with respect to effect of SPM and GVD. The dithering scheme is applied in the optical fiber in the length of 50 km and linewidth of 1 MHz, 3 MHz, and 7 MHz. For each linewidth, the received power is to approximate the transmitted level. For 1 MHz linewidth where the transmitted power 8 dBm the received power level is 137.213 dBm. For 3 MHz linewidth where the transmitted power is also 8 dBm, the received power level achieved 137.211 dBm and 7 MHz achieved 137. 209 dBm. In the other transmitted power of -8 dBm the received power level is 122.414 dBm, and 122.410 dBm and 122.414 dBm dBm in each on 1 MHz, 3 Mhz, 7 MHz linewidth. For 1 MHz linewidth where the transmitted power is 6 dBm and 4 dBm the received power level each are 135.655 dBm and 133.941 dBm. For 3 MHz linewidth where the transmitted power is also 6 dBm, the received power level achieved are 136.654 dBm and 132.125 and 7 MHz achieved are 135. 652 dBm 133.938 dBm. In the other of lower transmitted power -6 dBm the received power level is 122.414 dBm, and 122.410 dBm and 122.414 dBm in each on 1 MHz, 3 Mhz, 7 MHz linewidth, and for -4 dBm the received power level is 126.366 dBm, 126.363 dBm and 126.363 dBm. Fig. 3 shows used power generate composite systems will be boost signal, to achieve enhancement of power output and compose a signal robust against noise than conventional systems.

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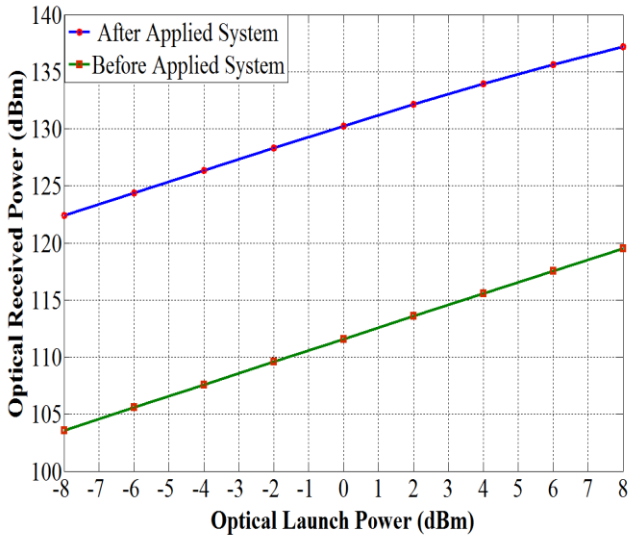
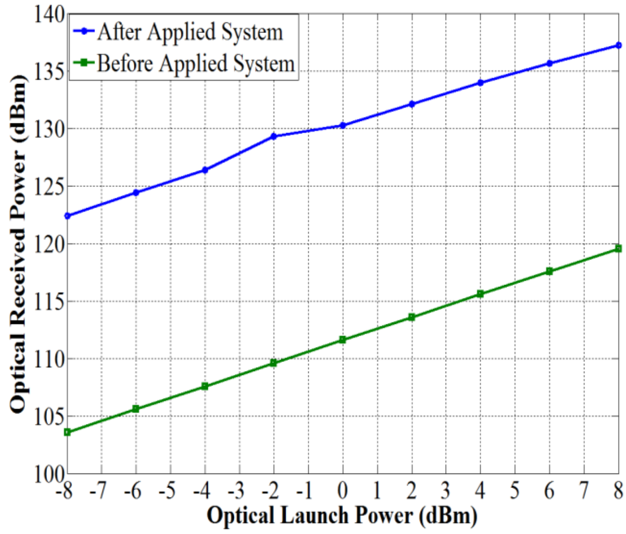
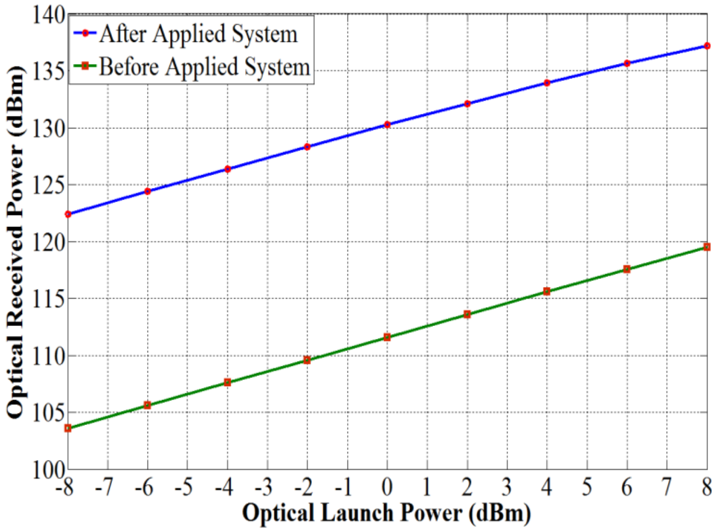


(a)



(b)



(c)

Figure. 3 Optical received power after and before the application of the proposed power increasing system based on (a) 1 MHz (b) 3 MHz and (c) 7 MHz linewidth

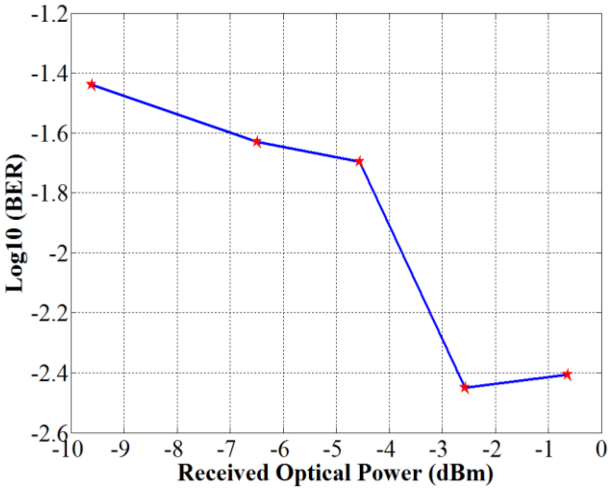


Figure.4 Systems with varied receiver power based on Log BER

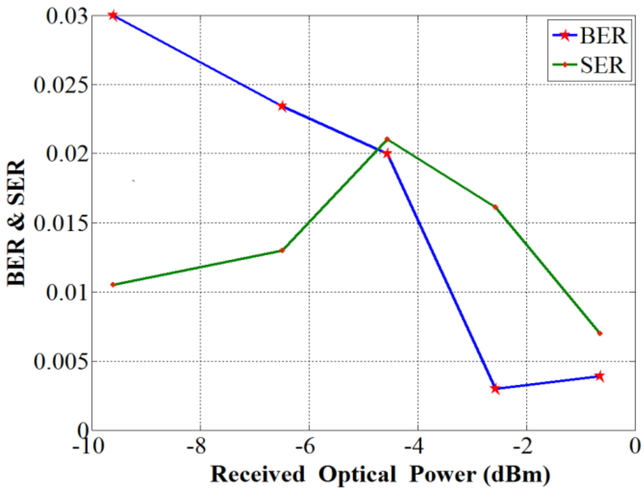


Figure.5 Systems with varied linewidth based on BER and SER

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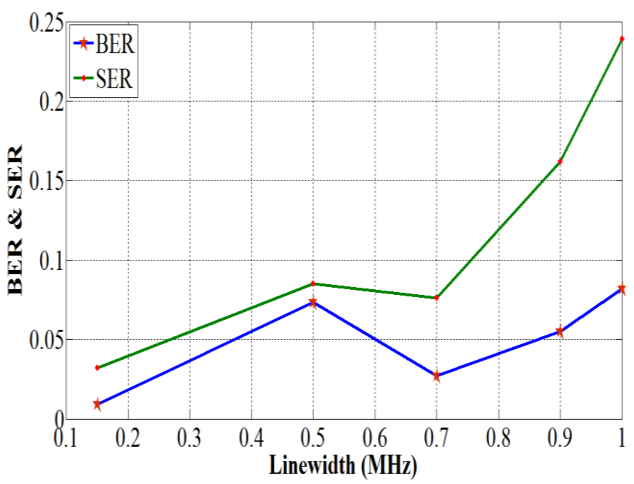


Figure.6 Systems with varied receiver power based on BER and SER

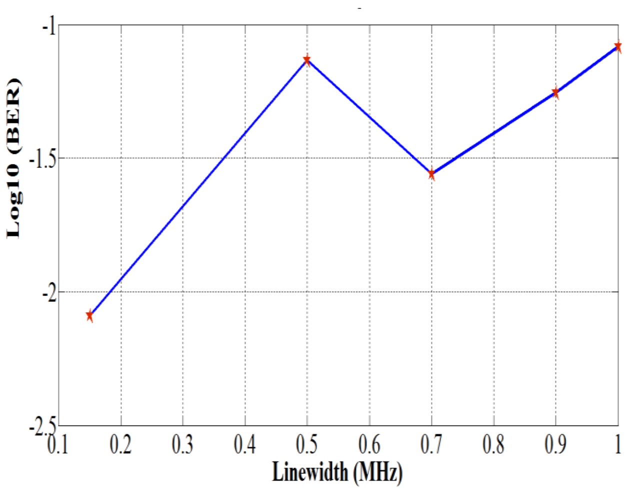
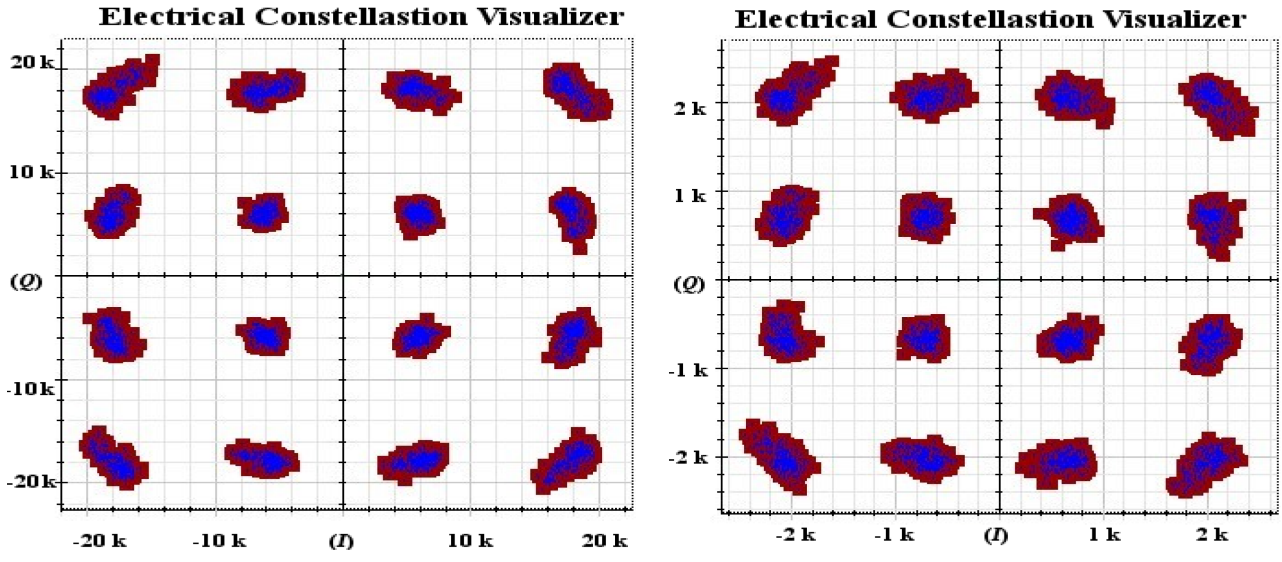


Figure.7 Systems with varied linewidth based on Log_{10} (BER)

Fig. 4 and Fig.5 depicts the systems with OLP -8 dBm and varied ROP of 10 dBm, 13 dBm, 15 dBm, 17 dBm and 19 dBm after and before applied systems. This simulation is intended to determine how much influence the suitability between OLP and optical receiver power based on Log BER, BER, and SER (Symbol Error Rate). On receiver power 10 dBm, 13 dBm, 15 dBm, 17 dBm and 19 dBm, achieved log BER each other are -1.44, -1.926, -1.696, -2.449, and -2.407. The value achieved of simulation shows between OLP and receiver power has influential, the best condition achieved when the value of receiver power more then to the OLP. That will be make a easy to synchronisation power and phase with a high power in receiver. The simulation shows the best log_{10} BER found was -2.407 on power received 17dBm. The best BER and SER achieved 0.003 on power received by 17 dBm and 0.007 on 19 dBm.

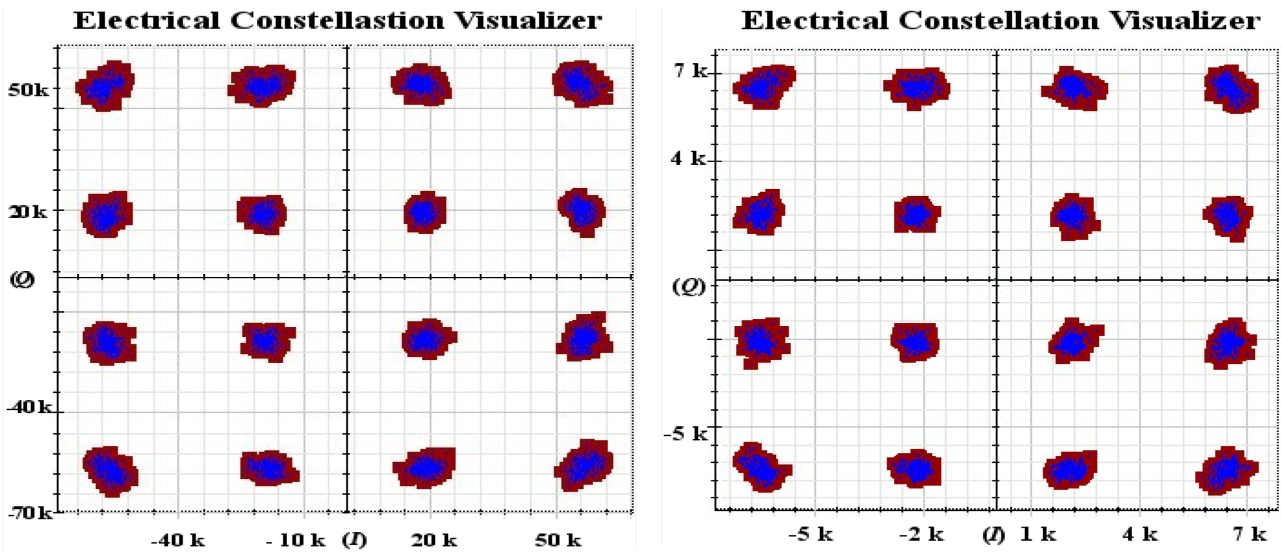
Fig. 6 and Fig. 7 shows BER, SER and log BER based on the varied linewidth with the constant transmission and received power. The best BER and SER achieved on 0.15 MHz linewidth were 0.009 and 0.012, while the value of the best log BER was -2.388. Small value of linewidth will be make lasers approaching to coherent condition, so that if the modulated signal will be more stable. The analysis results based on a varying linewidth indicates certain relation between linewidth and coherent length in an opposite way, and system would be responded if there is a change linewidth and power receiver. The proposed system exhibited an increase power approximately in the acceptance level by 18.5%. The overall engagement of dithering technique, and modulator gained a significant increase in the output power, while reduced the effect of SPM and GVD with the lower input power.

Fig. 8 and Fig. 9 depicts the signal constellation after and before injected proposed system applied an optical fiber of length 50 km and 100 km. Fig. 8 and Fig. 9 exhibits the signal constellation after and before injected proposed system applied an optical fiber of length 50 km and 100 km. Fig. 8 (a) shown the constellation the maximum and minimum amplitude achieved on 20k (a.u) and -20k (a.u), it means the power maximum amplitude increases after injected proposed compared by the Fig. 8 (b) whereas the maximum and minimum amplitude is reached only in 2k (a.u) and -2k (a.u). Even if an increase in signal power is also proportional to the increase in noise power, but based on the Fig. 8 (a) and (b) exhibits the constellation obtained is very clearly. On the other simulation result, has shown on Fig. 9 (a) depict the maximum and minimum amplitude achieved on 70k (a.u) and -70k (a.u) after injected proposed, while in Fig. 9 (b) the maximum and minimum amplitude is reached only in 5k (a.u) and -5k (a.u) for fiber of length 50 km. The amplitude unit (a.u) used proposed in the system on optical fiber of length 50 km and 100 km achieved better results. Improve value of receiver power occurs of linewidth is directly to proportional, the smaller linewidth used will be obtained a better of BER value. Increased uses linewidth will be not affect receiver power that will be only effects on the transmitter side. Based on measurement of constellation, the constellation signal changed by the amplitude and also based on the phase. The clearly constellation of noise means the signal modulated have been to a little energy chance. Constellation is representative from signal respond of system, based on depicts of Fig. 8 and Fig. 9 all of constellation are classified to the canonical characteristic, these means harmonic of coordinate transformation.



(a) (b)

Figure.8 Diagram constellation based on amplitude unit (a.u): (a) OLP -8 dBm length fiber 100 km with proposed system and (b) Diagram constellation OLP -8 dBm of length Fiber 100 km without proposed system



(a) (b)

Figure.9 Diagram constellation based on amplitude unit (a.u): (a) OLP -8 dBm fiber of length 50 km with proposed system and (b) Diagram constellation OLP -8 dBm fiber of length 50 km without proposed system

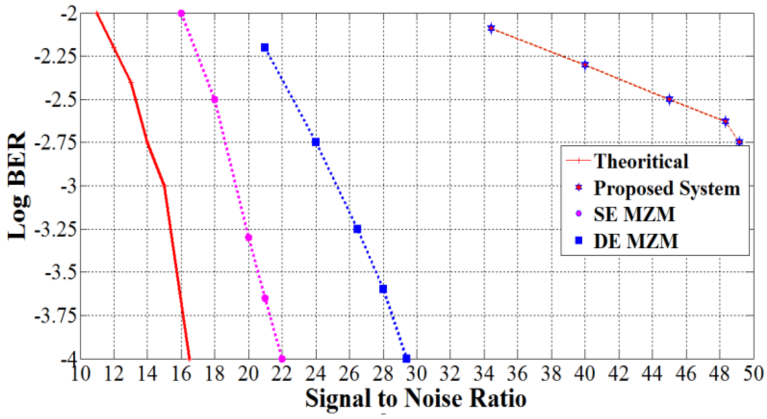


Figure.10 Comparison proposed components and method to DD-OFDM based on achieved of SNR

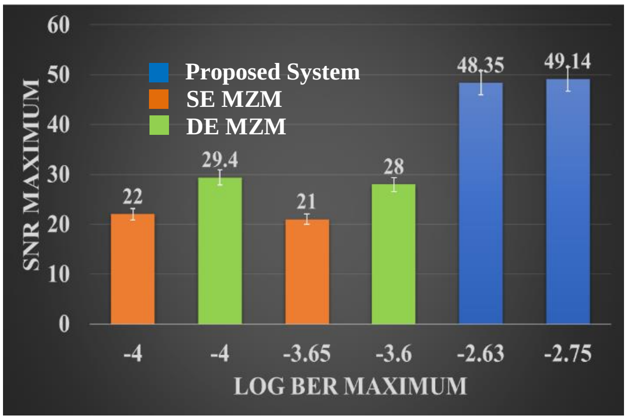


Figure.11 Comparison proposed components and method to DD-OFDM based on maximum achieved of SNR

In the last analysis in Fig. 10 and Fig. 11, respectively presents comparison data between proposed method and improve components to the other method based on maximum of optical fiber span and SNR achieved. We investigated system based on SNR and log BER parameters. We analysis affect varied of OLP and linewidth on optical fiber of length 100 km during this part of analysis. To emphasize the difference with the other work, we adopt conductivity with previous work DD-OFDM method based on modulators of SE (Single Electrode)-MZM and DE (Direct Electrode)-MZM to compares of data. Fig. 10 showed of SNR value achieved of theoretical, single electrode modulator MZM, dual electrode modulator MZM, and proposed method. Fig.10 depicts detail the values of each SNR for power consumption -8 dBm, -4 dBm, 0 dBm, 4 dBm, 6 dBm, and 8 dBm are 15.72, 22.5, 34.42, 48.35, and 49.14. The best achieved of SNR is 49.14 on upper power 49.14 with log BER -2.75 and 15.72 on lower power -8 dBm for log BER -1.95. Based on the measurement of SNR results under the proposed system the EVM (Error Vector Magnitude) values has been obtained. Each value of EVM on -8 dBm, 0 dBm, and 8 dBm are 0.25, 0.17, and 0.14. EVM is also a direct related function to the SNR, accordingly the ability of the receiver to perform reliable. These of parameters can be used to showed the ability of transmission.

Meanwhile, achieved of SNR maximum also can be simplify plotted in Fig.11 based on those methods, modulators proposed to DE MZM and SE MZM compares. Furthermore, there are achieved transmission of span 62 km and 71 km with the best SNR each other 22 and 29.5 for SE-MZM and DE-MZM, while for proposed method and modulators the best of SNR maximum achieved 49.14 and 48.35 dBm with log BER maximum each other are -4 and -2.75, respectively.

Finally, solid purpose of this paper demonstrated performed of dual modulators is superior than single modulator, that will support covers up weakness superposition of nonlinearity characteristic. Furthermore, combined dual modulators and dithering technique could be covered to solve problem of nonlinearity distortion using noise effect for high transmission. In laser occurred reaction between atom and photon, that's caused the diversity energy in the laser transmitted. Nonlinear impact could change energy reactive and wavelength, using this technique will be reduce loss of energy reduction and wavelength changes. Improvement in the transmission by using the technique of dithering and additional types of modulator MZM $LiNbO_3$ as a follow-up to reduce the harmonization that arise due to nonlinear effects.

The characteristic of SPM is induced chirp, and creates new frequency and leads to spectral broadening. Also in GVD, the characteristic that will be spread signal from resource signal and victim of amplitude. On condition pulse propagation is affected by the phenomenon of GVD and SPM, widened pulse of propagation will be faster. If condition $\beta_2 > 0$, in case the widening of SPM phenomenon reaction in increased pulse rate to compared if the pulse is affected by the phenomenon of GVD. This occurs because of the phenomenon SPM chirp due to the phenomenon of positive and negative GVD to condition $\beta_2 < 0$.

Dither used add noise to the index that is applied to the numerically controlled oscillation. We add the dither signal to the accumulator phase values before further quantization of the accumulated result. Integrated modulators optical device used electro optic to using digital signal modulation, that's modulator uses wide bandwidth and high speed up third order to compensate nonlinear phenomena, hence could produce high output power and SNR for long span transmission.

4. Conclusion

In this paper, we have discussed and analysed features of a good communication systems. Scientific contribution of used dual modulator could resolve of phase sift, frequency and amplitude. While, dithering technique is very useful for the system to have a higher power to deliver a bit rate that is faster and more resistant to noise, and assist in the process of quantization. The proposed system has improved the quality of the output by enhancing the receiving power up to 18.5%. The simulation indicates that the laser linewidth effects strongly on the receiving abilities and the application effects strongly on the coherent length which appear as a polychromatic light. The coherent length is inversely to the linewidth parameter and directly proportional to the speed of light. Therefore, the higher coherent length causes to lower value of linewidth. The ideal system is a system that has a high of coherent length, hence that the laser will be one polarization, phase and frequency. Accordingly, a feasible system is a system with lower linewidth, these conditions will be produce narrow spectral width. Hence, this case is feasible to high speed data transmission.

Dithering technique provides variation amplitude and frequency to achieving a good dithering signal characteristic to provide random signal distribution. The proposed system scheme contributes to reduce SPM and GVD to enhance the amplitude unit (a.u), and optical fiber span. We have deployed effective system with lower OLP to optimize maximum range transmission of fiber and performance system based on SNR and constellation. The proposed system provides the predominant effect is increased power output and durability of signal to noise described by constellation and reaches a maximum range of optical fiber span.

Highly recommendation in case long fiber transmission using high frequency dither system and double external modulator to keep quality of signal. In the future works, probably to deploy and optimize of dither system using phase dithering technique combining a single pumping laser to reduce nonlinear impact. The observe nonlinear impact on optical fiber used of those component and technique proposed should be done using the other tools.

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