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Reduction of the Nonlinearities by decreasing Peak to Average Power Ratio (PAPR) for Coherent Optical OFDM-WDM system using Exponential Compading

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***Abstract*—To improve the efficiency of optical channel, the idea of Wavelength Division Multiplexing (WDM) was evolved in which multiple optical signals on different wavelength were sent through the fiber simultaneously. Later on, the Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) has been introduced into WDM. This increases bandwidth, improves data rates, and provides high spectral efficiency without increasing the cost or the complexity of the system. In this paper we examine the effectiveness of reduction of Peak to Average Power Ratio (PAPR) using Exponential Companding technique on OFDM for coherent optical medium while working on WDM. The simulation results show that the technique effectively reduces nonlinearities of the optical fiber, and improves the overall system performance.**

Keywords—CO-OFDM; PAPR; WDM; Exponential Companding technique

I. Introduction

In current era, high data-rate is essential for every aspect of communication. This is required because the demand of high bandwidth has increased, whereas the available bandwidth is limited for use, which leads to evolution of optical fiber communication. The fiber provides high bandwidth with immunity against electromagnetic interference. High bandwidth in turn gives high data rate, which makes this communication medium favorable for current scenario [1].

WDM is an attractive technology, which maintains high data rates during transmission through an optical fiber with various wavelengths simultaneously, containing distinct user information. Therefore, the channel capacity of the transmission can be extended by forming number of small channels virtually inside single physical channel using multiple band-pass filters. Each virtual channel works on different wavelengths and permits the transmission of data simultaneously [2,3,4].

OFDM is an advance modulation technique that can deliver high spectrum efficiency and one of the best schemes to counter against chromatic dispersion and Polarization Mode Dispersion (PMD) [1,5,6,7,8]. Thus, the application of CO-OFDM system with WDM enhances the efficiency of the spectrum as well as the range of the transmission. High PAPR of OFDM signal makes Digital to Analog Converter (DAC) and Mach-Zender Modulator (MZM) to work in nonlinear region [9,10]. Thus, to reduce the nonlinearities from the system, it either requires reducing the effect of PAPR or increasing the dynamic range of these devices. However, cost and complexity of system increases by increasing dynamic range of devices. Hence, various work has been reported in past to reduce the PAPR of OFDM signal, in order to further reduce the nonlinearities [9,10].

Since, the channel is affected by noise, attenuation and dispersion, hence if the nonlinearities are introduced before the transmission through channel, then it is increased while passing through the channel. Thus, it introduces disturbances in actual signals. In optical fiber, effective refractive index is directly proportional to the intensity of light which causes nonlinearity inside fiber [6,7]. Thus, it requires reduction of PAPR before sending the signal through optical fiber. To reduce the problem of PAPR, number of techniques such as clipping and filtering [11], scrambling [12] and Companding technique [13,14] etc., were already reported in the literatures.

In order to address these issues, a method is presented in this paper which focuses on reducing the hardware complexity and computational complexity of the PAPR reduction techniques by using Exponential Companding technique [14] and applying them for CO-OFDM with WDM system. Hence, the inherent potential of the optical transmission is utilized. The basic idea behind Exponential Companding technique is to expand small signals and compresses the large signals as a result decreases the PAPR of the OFDM signal. According to the simulation results discussed in this paper, the Exponential Companding and decompanding technique can work successfully in CO-OFDM with WDM. The performance of these proposed reduction schemes are evaluated by using the OptiSystem 13.0.1 and MATLAB R2014b softwares.

The system model is explained in Section-II and the proposed model has been discussed in Section-III. The simulation results have been presented and analyzed in Section-IV and the conclusion is given Section-V.

II. System Model

The system model explains the CO-OFDM system and WDM model for the system.

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A. CO-OFDM [1]

Figure 1 shows the complete process for single channel CO-OFDM system. This modulation technique has been used to reduce the chromatic dispersion and Polarization Mode Dispersion produce in the optical fiber. In this system, data bits are generated using pseudo random sequence generator (PRBS). Later, generated bits are mapped to get complex data symbol with the help of 4-QAM digital modulation scheme and the process is known as constellation mapping. This constellation mapping provides phase as well as amplitude for each symbol. This complex symbol is modulated using OFDM modulator. Then MZM is used on OFDM modulated signal which convert the low frequency Companded electrical signal into high frequency optical signal and then the high frequency optical signal is transmitted over optical fiber [9].

At the receiver side, the electrical signal has been retrieved using coherent detector, and then the signal is demodulated using OFDM demodulator. Then constellation de-mapping is done to retrieve original data. A local oscillator used in the CO-OFDM method to produce optical signals at a specific wavelength [1,6].

B. Peak to Average Power Ratio (PAPR)

The system with multicarrier suffers with distortion because they are sensitive to nonlinearity this is the main problem of such system. Non linear distortions results the degradation of BER performance of the overall system and also cause interference to the neighboring frequency spectrum, due to the interaction of in-band and out-of-band power. The key factor of distortion is nonlinearity at the transmitter side of system specially on the MZM and on optical amplifier. In comparison with the customary single-carrier systems, the OFDM modulation has very large variation in the instantaneous output. For this reason, linear dynamic range of the devices like MZM, ADC, optical amplifiers and DAC should be large. If in any case the linearity is not pursue, it causes large number of unwanted interference and this in turn make the device to operate in the non-linear region for that part of signal. When the signal peaks are being operate in non-linear region cause distortion due to high out of band radiation and inter-modulation. Therefore it is necessary to apply PAPR reduction techniques for optical OFDM systems.

The PAPR, described by the ratio of the signal peak power to its average power, evaluate the fluctuations in the amplitude of the signal [1,9].

$$\text{PAPR} = 10 \log_{10} \{\max [|x_n|^2] / E[|x_n|^2] \} \quad (1)$$

where, P_{peak} is the Peak output power, $P_{average}$ is the Average output power, E[.] is the expected value, x_n is the Transmitted OFDM signals, and X_k is the Mapped input symbols. Mathematically, x_n is expressed as,

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k W_N^{nk} \quad (2)$$

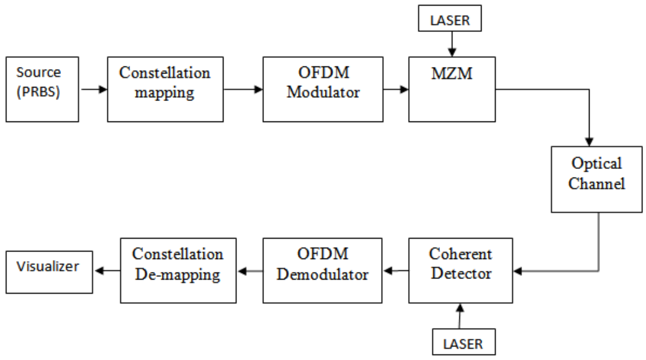

Fig.1. Block diagram of CO-OFDM

In case of signal processing for multicarrier system, high PAPR occur when large numbers of subcarriers form the constructive interference. For an optical OFDM system with N number of subcarriers that are having same phase values, the peak power of signal being received would be N fold of the average power of signal. The PAPR attain its theoretical maximum for the baseband signal, when PAPR (dB) = 10logN [1,12].

C. Exponential Companding

Exponential Companding technique is a nonlinear method to decrease the PAPR of OFDM signal [13,14]. This method converts the original Gaussian-distributed OFDM signal into uniform-distributed (Companded) signal efficiently without varying the DC power level. Unlike the μ-law Companding method, that primarily concern with the expansion of small signals and compression of large signal, the Exponential Companding scheme used to regulate small as well as the large signals without providing biasing in order to provide better performance in terms of PAPR reduction. This scheme decreases the phase error for OFDM systems while keeping the input average power and output average power of signals at the same level.

Exponential Companding at the transmitter can be given as [14],

$$h(x) = \text{sgn}\langle(x)\rangle * \sqrt[d]{\alpha \left[1 - e^{-\left(\frac{x^2}{\sigma^2}\right)}\right]} \quad (3)$$

where, sgn() is known as the signum function, d is the degree of method, σ is the standard deviation of input signal. Here, α is the Positive constant, and it gives the average output power of signals, and can be described as,

$$\alpha = \frac{E[s(n)^2]}{E\left[\sqrt[d]{\left[1 - e^{-\frac{s(n)^2}{\sigma^2}}\right]}^{\,2}\right]} \quad (4)$$

The exponential expander at receiver is mathematically given by,

$$h^{-1}(x) = sgn\langle(x)\rangle * \sqrt{-\sigma^2 * \ln\left(1 - \frac{x^d}{\alpha}\right)} \quad (5)$$

In Fig.2, we can see that the actual signal without Companding is a ramp signal, and as the Companding factor 'd' increases from 1 to 100, the Companding of signal increases which can be observed as the unit ramp signal converses toward a straight line that is at y=0.5. This indicates about the increment in the amount of signal compression and expansion. Increase in Companding factor d also leads to decrease in the value of PAPR, but it simultaneously disturbs the orthogonality among the transmitted signals.

III. Propsed Method of Companding

The block diagram in Fig.3 describe a multi-user WDM system which consist of 4 channels, where each channel is having distinct set of input data, generated by PRBS. Data bits from each channel are now mapped using 4-QAM mapping scheme in order to improve the spectrum utilization having less Euclidean distance. Mapped symbol is now modulated using OFDM. To reduce the PAPR, the Exponential Companding is applied at each channel on OFDM modulated signals. After Companding, all the signals are up-converted with different laser wavelengths by MZM. Each signal having different wavelengths is transmitted simultaneously by using 4x1 MUX. During transmission, dispersion factor of optical fiber is added with symbol. Since OFDM can reduce the chromatic dispersion of the channel, therefore it can improve the throughput of the system.

The reception process is just opposite of the transmission process. After retrieving the electrical signal using coherent detector, signal is expanded with same factor that has been used for Companding at the transmitter side. Then the signal is demodulated using OFDM demodulator and then de-mapping is done.

IV. Simulation Results And Analysis

All the simulations are performed using the OptiSystem 13.0.1 and MATLAB R2014b softwares. The parameters used in these simulations are given in Table I.

The Fig.4(a) and (b) shows the spectrum that has been transmitted and received respectively through the optical fiber without Companding. The received spectrum contains the original spectrum along with considerable amount of nonlinear cross products arise due to Four Wave Mixing (FWM), Self

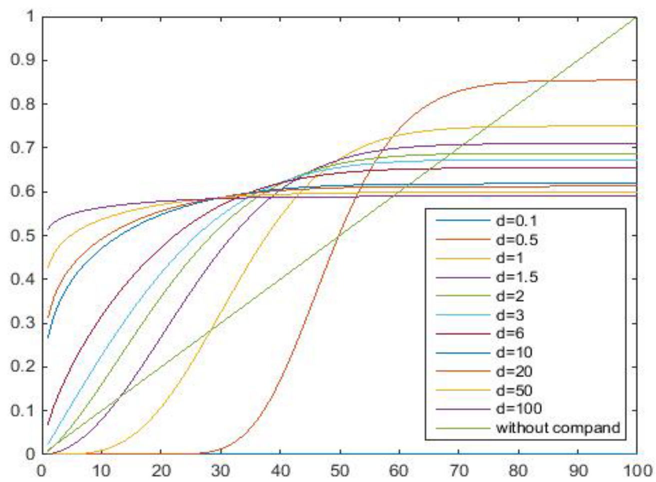

Fig.2. Variation of Companding factor for exponential Companding

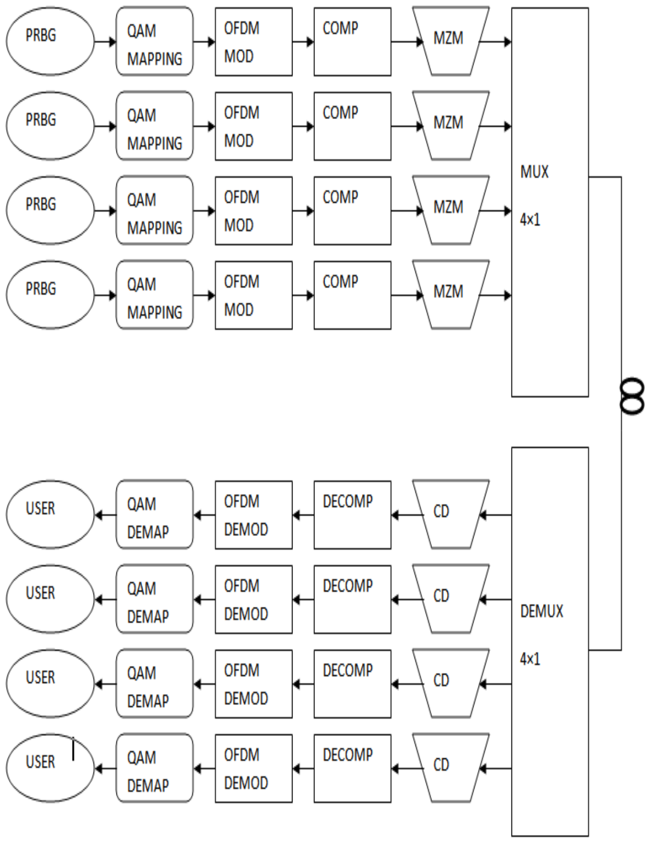

Fig.3. OFDM with Companding technique for WDM

Phase Modulation (SPM) and Cross Phase Modulation (XPM). Spectrum width of each channel has been increased due to XPM, and some extra products also introduced in the spectrum because of FWM. The design of WDM is not practically fruitful due to generation of side spectrum because of nonlinearities.

Figure 5(a) shows the spectrum of 4-channel WDM that has been transmitted through the optical fiber after applying the Companding of d=1. Figure 5(b) shows the received spectrum, where we can observe that the received spectrum contains only spectrum of 4-channel without any nonlinear products. This also confirms that neither any extra cross product due to FWM nor any widening of spectrum occurs due to SPM or XPM. Thus, we can say that reduction of PAPR also decreases the nonlinearities present in the system.

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Bit Rate	10 GHz
Number of FFT points	256
Number of subcarriers	64
Power	10mW
Channel-1 Frequency	193.05 THz
Channel-2 Frequency	193.1 THz
Channe-3 Frequency	193.15 THz
Channel-4 Frequency	193.2 THz

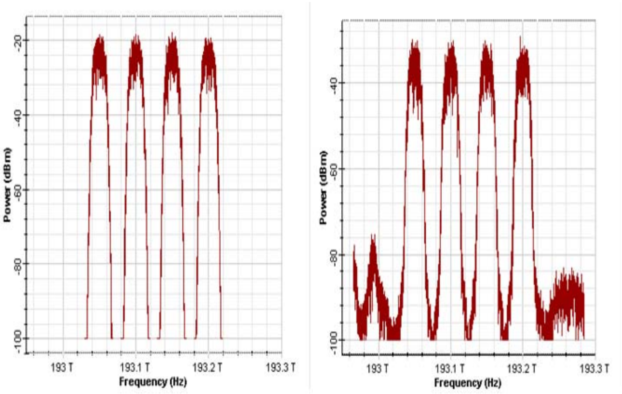

Fig.4(a). Transmitted and (b). Received spectrum without Companding technique for CO-OFDM WDM

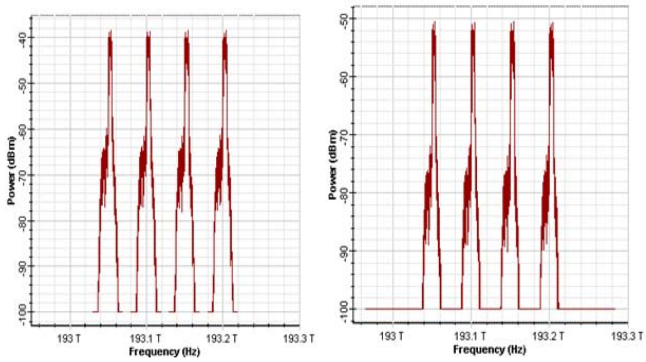

Fig.5(a). Transmitted and (b). Received spectrum with exponential Companding technique (d=1) for CO-OFDM WDM

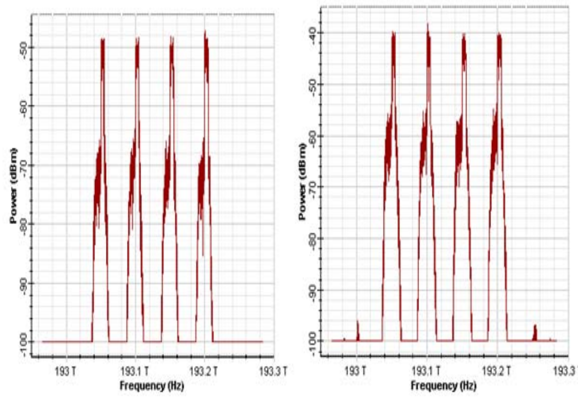

Fig.6. Received spectrum with exponential Companding technique for (a) d=2 (b) d=3

Figure 6(a) and (b) shows the received spectrum for additional two values of Companding i.e., d=2 and d=3 respectively. We can observe that as the Companding increases from d=2 to d=3 with step size of 1, the nonlinearities also increase as visible from the side peaks in Fig.6.(b). To get the optimum (maximum) value of Companding factor 'd' for which the nonlinearities (side lobes) are just started to arise, we have simulated the same system model for the step size of 0.1 between d=2 to d=3, and found that d=2.4 is the upper cut-off for the considered system model.

V. Conclusion

The main motive of this paper was to deliver effective solution for nonlinearities present in optical channel while working with WDM technology along with the CO-OFDM with Companding technique. The resulting data validate the efficiency of the OFDM with Companding technique for WDM system in which it provides the significant reduction in nonlinearities. We are also able to find the threshold value of Companding under assumed conditions and parameters, which indicates its maximum value, and beyond which, the affect of nonlinearities start increasing and are visible by the side lobes present in the received spectrum.

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