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PERFORMANCE IMPROVEMENT OF OOFDM SYSTEMS BASED ON MODIFIED A-LAW COMPANDING TECHNIQUE

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ABSTRACT

Optical Orthogonal Frequency Division Multiplexing is a bandwidth efficient multicarrier modulation where the available spectrum is divided into subcarriers, with each subcarrier containing a low rate data stream. However, the Peak-to-Average Power Ratio is a major drawback factor of multicarrier transmission system such as Optical Orthogonal Frequency Division Multiplexing. Various methods have been proposed to reduce this factor and one of these methods called Companding Technique and due to their flexibility and low complexity, the Companding Technique is gained great attention. A comparison between the original, companded, and modified companded signal has been implemented in Intensity Modulation/Direct Detection Optical Orthogonal Frequency Division Multiplexing. The proposed Modified A-law Companding technique is guarantees the improved performance in terms of Bit Error Rate and Quality Factor while reducing Peak-to-Average Power Ratio effectively and efficiently by modifying the amplitude of Optical Orthogonal Frequency Division Multiplexing signals. The simulation results allow an optimum companding based on the use of both of (a and A) parameters to be chosen in relation to acceptable or desired Peak-to-Average Power Ratio, Bit Error Rate and Quality Factor requirements. The proposed modified companding scheme can offer better Peak-to-Average Power Ratio reduction, Bit Error Rate, and Quality Factor at A=30 and 87.6 where a=1. The simulation results at the transmission link=900Kmshow that A at 87.6 is the best value measured in term of Peak-to-Average Power Ratio= 5dB at a Complementary Cumulative Distribution Function nearly 1×10^{-3}compared with the original, Quality Factor is 12 and Bit Error Rate is1×10^{-3}.

Keywords: optical orthogonal frequency division multiplexing, peak-to-average power ratio, complementary cumulative distribution function, quality factor,bit error rate.

1. INTRODUCTION

An Orthogonal Frequency Division Multiplexing (OFDM) has been using in the optical communication systems because of the following advantages: immunity to Inter-symbol Interference (ISI), high spectral efficiency, co-channel interference and impulsive parasitic noise, lower implementation complexity compared with the single carrier solution [1] [2]. The intensity Modulation/Direct Detection Optical OFDM (IM / DD OOFDM) system has been widely investigated in high-speed optical Communications, short-range and the cost-sensitive [3]. As well as its many advantages, OOFDM systems have also several disadvantages such as ISI and Peak-to-Average Power Ratio (PAPR), which it will focus in this paper. This high peaks to average power ratio set high power as input to the Power Amplifier at the transmitter [2]. The high power amplifier (HPA) working in the nonlinear section, therefore, In-band and out-of-band interferences are increased due to this nonlinearity. Reducing the PAPR will enhance HPA performance, reduce power consumption, reduce signal distortion by HPA and improve bit error ratio (BER) performance. The performance of the transmitter is enhancing by using PAPR reduction techniques [4]. Multiple PAPR reduction techniques are offered for multi-carrier systems such as Clipping and pre-distortion [5][6][7], Partial Transmit Sequence, Selective Mapping [8][9][10], nonlinear companding[11][12][13], Tone Injection, Tone Reservation [14][15][16], etc. Of all those PAPR reduction systems, the increasing in bandwidth and large memory with complexity in these techniques, so that the clipping and Companding technique is useful for PAPR to overcome this constraint [4][5].

The clipping process is the easiest system to use but this processing leads to distortions and causes an increase in the BER of the system [7]. Therefore, The other way using the companding techniques that give better performance than clipping techniques because the companding transformation is done at the transmitter to attenuate the high peaks and increase low peaks and an inverse companding transform is done on the receiver end to reduce the distortion of signals and pick up the original signal, before transmission [6][11].

The OOFDM signal involves severally modulated subcarriers that may provide a large PAPR once value-added up coherently. An OOFDM signal features a massive PAPR that is terribly sensitive to the non-linearity of the high peak [3]. Blocks of the symbol in the OFDM are selected with every symbol modulating one from a set of subcarriers and these subcarriers are recognized to be orthogonal [8]. The representation of complex OFDM signals are given in (1) and (2) respectively:

$$x(K) = \frac{1}{N}\sum_{n=0}^{N-1} X_n\, e^{\frac{j2\pi nk}{N}} \tag{1}$$

Where$K = 0,1,2, \dots, N-1$ (2)

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2. PEAKS TO AVERAGE POWER RATIO (PAPR)

The PAPR for a signal x(K) is outlined as the ratio of maximum instantaneous power to the average power as insulated in (3) [3]:

$$\text{PAPR}=10*\log\left(\frac{\max|x(K)|^2}{\text{Avg}|x(K)|^2}\right) \tag{3}$$

Reduction of PAPR is simply shown the probabilities that the PAPR of data block exceeds a given threshold value. The expression of Complementary Cumulative Distribution Function (CCDF) is given in (4)[2]:

$$\text{CCDF} = \text{Probability}\ (\text{PAPR}>\text{PAPR}_{th}) \tag{4}$$

Where PAPR_{th} represents the Threshold level.

3. MODIFIED A-LAW COMPANDING TECHNIQUE

Due to low complexness regardless of the number of subcarriers, therefore the Companding technique has been using for PAPR reduction in OFDM systems [2]. The A-law using at the transmitter as a compressor after Inverse Fast Fourier Transform(IFFT) and an expander before Fast Fourier Transform (FFT) at the receiver. A-law has a non-zero value and it has mid risen at the origin point [17] as shown in Figure-1.

As explained in equation (5) the high-level inputs the characteristics are logarithmic segmented and for low-level inputs, the characteristics are linearly segmented [8].

$$y(x) = \begin{cases} y_{max}\dfrac{A\frac{|X|}{X_{max}}}{(1+A)}\,\text{sign}(X) & 0 < \dfrac{|X|}{X_{max}} \le \dfrac{1}{A} \\[2ex] y_{max}\dfrac{\left[1+\log_e\left[A\frac{|X|}{X_{max}}\right]\right]}{(1+\log_e A)}\,\text{sign}(X) & \dfrac{1}{A} < \dfrac{|X|}{X_{max}} \le 1 \end{cases} \tag{5}$$

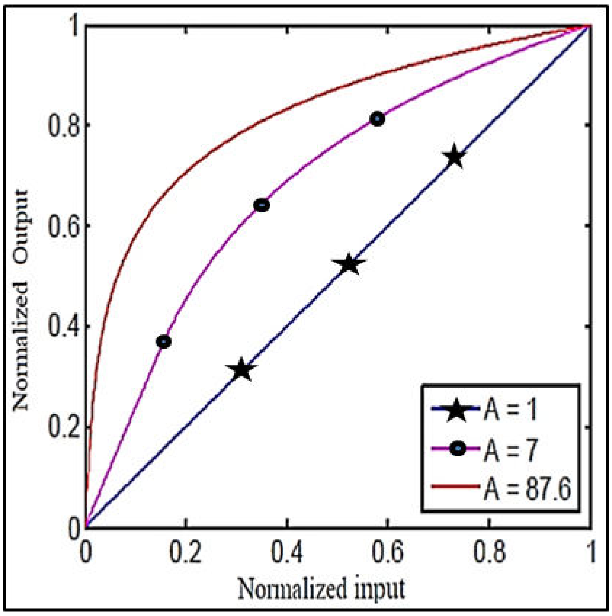

Figure-1. Characteristics of A - law compressor [5].

We propose a new modify of the A-law technique based on the logarithmicsection of the originalA-Lawby addition square root of power a and β paprmeter to maintain the input and output signals at the same average power level, the modified companded function is givenin equation (6):

$$y = \sqrt[a]{\beta * \log(1 + A(\frac{|X|}{X_{max}}))} * sign(x) \tag{6}$$

β: Parameter calculated as below:

$$\beta = \left(\frac{E(x^2)}{E\left(\sqrt[a]{\log(1+A(\frac{|X|}{X_{max}}))}\right)}\right)^{a/2} \tag{7}$$

Finally, the de-companding of modified A-law is given below:

$$x = \frac{X_{max}}{A}\left(\exp\left(\frac{y^a}{\beta}\right) - 1\right) * sign(x) \tag{8}$$

4. THE PROPOSED MODELING SYSTEM OF OOFDM

Firstly, the traditional configuration of OOFDM system without using companded technique is showing in Figure-2.

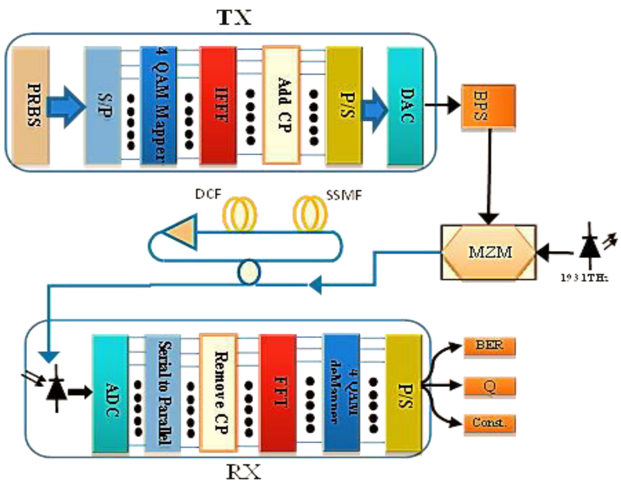

Figure-2. The traditional OOFDM system.

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The proposed modeling system using modified A-Law companding technique is shown in Figure-3and compared with the traditional system, the A-Law transform applied in transmitter and receiver as shown in Figure-3 after Fourier in the transmitter and before Fourier in the receiver.

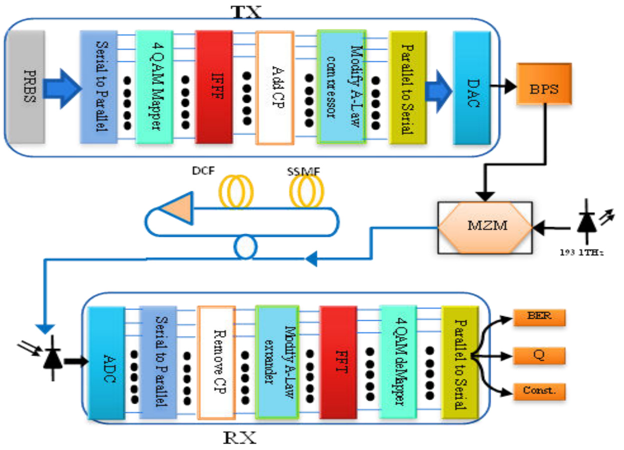

Figure-3. The proposed OOFDM system with modified A- Law transform.

The transmitted digital bit streams are originated in VPI Transmission Maker software package from the Pseudorandom binary sequence (PRBS) at (2^{13} -1) and then OFDM data decoded with and without A-Law transform by MATLAB software package, then optical modulation and opticalupconversion and transmission are done by VPI Transmission Maker. The companded signal transmitted through the optical link which length equal to 900Km (60Km*15 loops). The Fiber link contains a Standard Single Mode Fiber (SSMF), a Dispersion Compensation Fiber (DCF), and an optical amplifier. The SSMF is 50km length with 0.2dB.km^{-1} attenuation coefficient and 16ps. nm^{-1}.km^{-1} of Chromatic Dispersion (CD) coefficient. The DCF has a CD coefficient of -400ps.nm^{-1}.km^{-1}. For compensating the fibers losses, the optical amplifier has a gain and noise figure of 12dBm and 4dBm respectively. Finally, in the receiver, the reverse operation occurs after detection to restore to the original signal.

5. SIMULATION RESULTS

The coded OFDM signal (real and imaginary part of companded OFDM) is up-converted at 7.5GHz an Intermediate Frequency (IF) as shown in Figure-4.

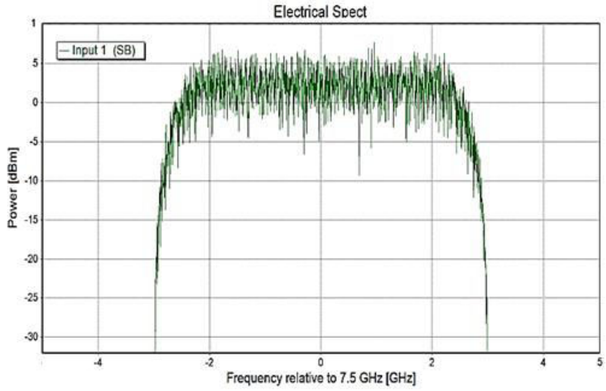

Figure-4. Electrical proposed modified A-Law OOFDM spectrum at IF=7.5GHz.

The output spectrum power from MZM will contain an optical carrier which in this case is targeted at 193.1THz and two side-bands targeted at 7.5GHz of the optical OFDM signal as shown in Figure-5.

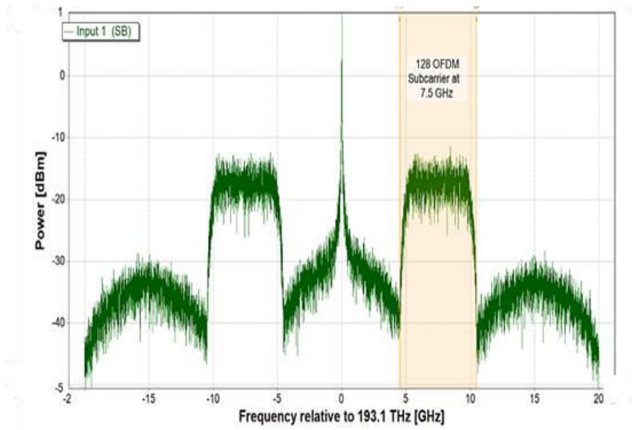

Figure-5. Spectrum of the proposed modified A-Law OOFDM.

An optical filter is then responsible for suppressing the lower sideband by 18GHzbandpass optical filter, the filtered modified OOFDM single is shown in Figure-6.

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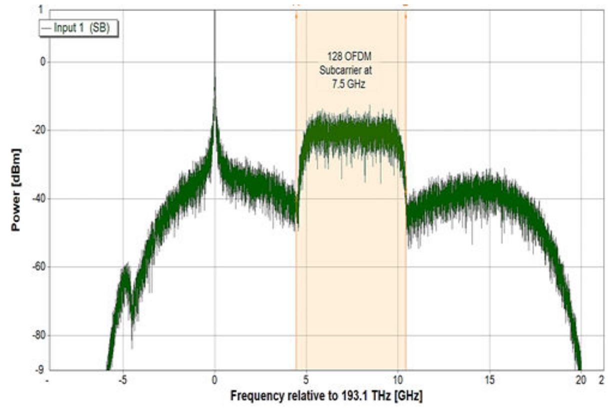

Figure-6. Spectrum of the proposed modified A-Law OOFDM after Filtering.

The PAPR performance of the proposed OOFDM transmitter is significantly more improved. At the CCDF of $\approx 10^{-3}$ shown in Figure-7, the PAPR of the proposed modified A-law technique is reduced with 3.7dB at A=30 and 5dB at A=87.6 as compared with the original signal, and about 3dB at A=30 and same reduction 5dB at A=87.6 when compared between the A-law and the original signal.

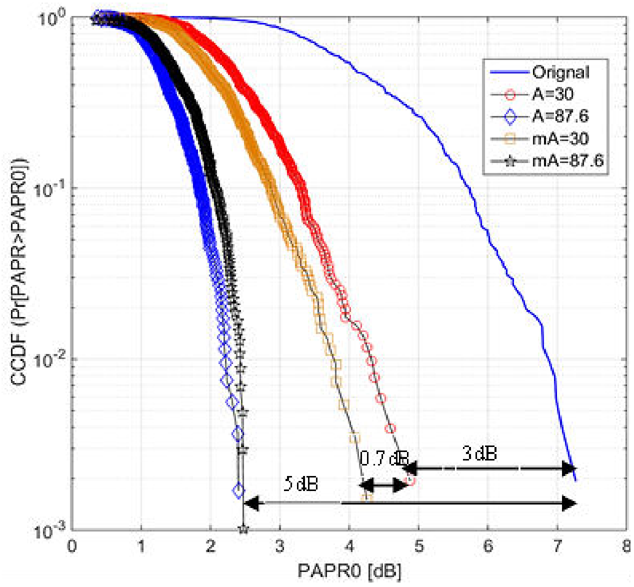

Figure-7. CCDF plot showing a-law with modified a-law PAPR reduction.

After the fiber length at 900Km (60Km*15) with 4QAM modulation format The Quality Factor(QF), BER and constellation diagram at the receiver end are showing in Figure-8, Figure-9 and Figure-10 respectively. The degradation observed in the original system without companded technique used is shown in Figure-8, Figure-9 plotted with marker cross black the measured QF is 2dBm, BER is 7.3×10^{-2} and non-uniform constellation diagram in Figure-10(a). The degradation is the maximum because of increasing of the chromatic dispersion when increasing the transmission length.

The proposed modified A-Law algorithm that plotted with marker red color clearly improves the OOFDM system performance described as QF, BER, and constellation. As shown in Figure-8, Figure-9 and Figure-10, two values of A at 30 and 87.6are proposed, the value A at 87.6 is more enhancing the all system in term of QF at 8.9dBm and BER at $6.1*10^{-5}$ than that using A at 30 which QF = 6dBm and BER= $1.5*10^{-2}$.

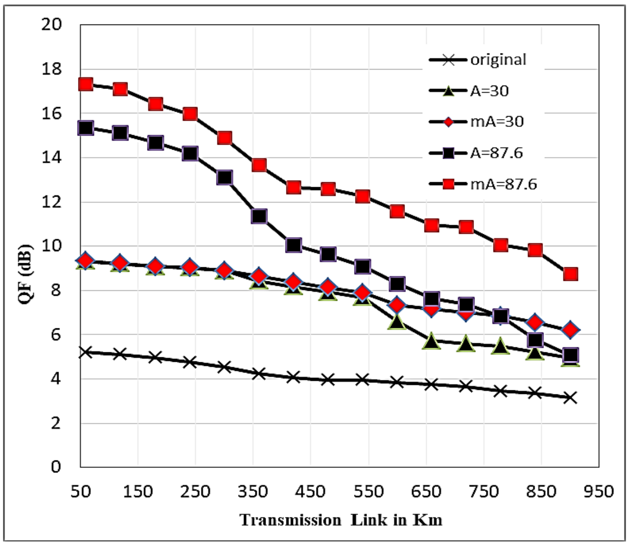

Figure-8. QF vs Transmission length.

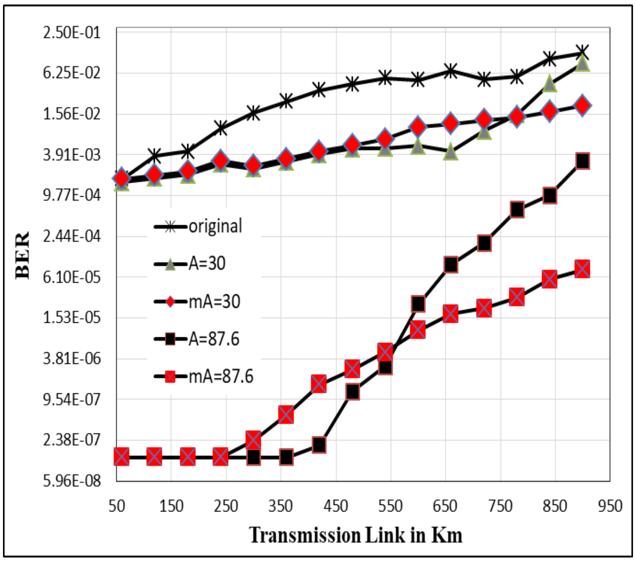

Figure-9. BER vs Transmission length.

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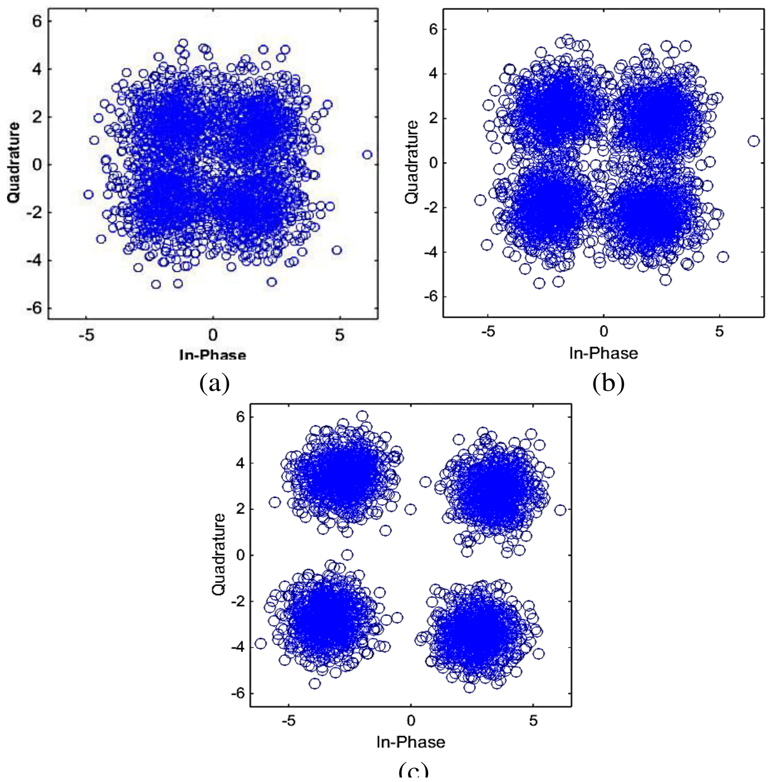

Figure-10. Constellation diagram of modified OOFDM system at the receiver end after 900Km at(a) original without companded (b) Proposed companded at A=30 (c) Proposed companded at A=78.6.

6. CONCLUSIONS

The proposed IM/DD OOFDM transmitter system with modified A-Law companding algorithm have been implemented to reduce the PAPR of OOFDM systems implemented based on the sequence of operation shown in Figure-3.The simulation results show the A=87.6 is a best one to reduce the PAPR and the system performance improved more than A=30. All simulation results of QF, BER and constellation have been presenting by combination VPI Transmission Maker with MATLAB software package. In future, the performance of transceiver systems can be more improved by proposing anew value for a.

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