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Research paper

FPGA implementation of modified PAPR reduction technique for OOFDM system

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Abstract

Orthogonal Frequency Division Multiplexing (OFDM) has been widely adopted in optical communication systems. However, the Peak-to-Average Power Ratio (PAPR) is considered one of the major drawback factors of communication system, so various methods have been proposed to reduce this factor. The modified logarithmic companding technique is used for reducing this factor in current paper. In addition, the main goal of this paper is the field-programmable gate array (FPGA) implementation of this modified companding technique. The software package called LabVIEW is used for programming the FPGA hardware. All results of Quality Factor (QF), Bit Error Rate (BER) and constellation diagram have been presented by combining the VPI Transmission Maker, MATLAB, LabView, and FPGA hardware. That is to say, the proposed implementation of the modified companding can offer a better PAPR reduction, BER, and QF at control parameter y at 0.1. To put it another way, the PAPR is reduced by 6.2 dB at 1×10^{-3} Complementary Cumulative Distribution Function (CCDF). Accordingly, getting 3.8 dB improvement of QF in comparison with the original system and the BER is 4.8×10^{-5}.

Keywords: *Orthogonal Frequency Division Multiplexing (OFDM); Field-Programmable Gate Array (FPGA); Peak-to-Average Power Ratio (PAPR); Quality Factor (QF); Bit Error Rate (BER).*

1. Introduction

Generally, an Orthogonal Frequency Division Multiplexing (OFDM) has been used in the optical communication systems as a result of different advantages such as: immunity to Inter-symbol Interference (ISI), high spectral efficiency, co-channel interference and impulsive parasitic noise, lower implementation complexity in comparison with the single carrier solution [1], [2]. On the logical ground, the intensity Modulation/Direct Detection Optical OFDM (IM / DD OOFDM) system has been widely investigated in high-speed optical Communications, short-range as well as the cost-sensitive [3].

It has been illustrated that in addition to their various advantages, OOFDM systems have also several disadvantages such as ISI and Peak-to-Average Power Ratio (PAPR), which will be illustrated in this paper with FPGA as a hardware implementation. Moreover, the high peaks to average power ratio sets high power as an input to the Power Amplifier at the transmitter [4]. The High Power Amplifier (HPA) is working in the nonlinear section. Therefore, in-band and out-of-band interferences are increased due to such nonlinearity. There is no doubt that reducing the PAPR will enhance HPA performance, reduce power consumption, reduce signal distortion by HPA and improve Bit Error Ratio (BER) performance. In other words, the performance of the transmitter can be enhanced by using PAPR reduction techniques [4], [5].

Basically, multiple PAPR reduction techniques are offered for multi-carrier systems such as Clipping and pre-distortion [6-8], Partial Transmit Sequence, Selective Mapping [9-11], nonlinear companding [12-14], Tone Injection, Tone Reservation [15-17], etc. In all those PAPR reduction systems, the increase occurs in bandwidth and large memory with complexity in these techniques, so that the Clipping and Companding techniques are useful for PAPR in order to overcome this constraint [5].

To give an illustration, the clipping process is entirely considered 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 is using the companding techniques that have the ability to give a better performance than clipping techniques due to the fact that the companding transformation is done at the transmitter to attenuate the high peaks. On the other hand, increasing low peaks and an inversing companding transform are done on the receiver end in order to reduce the distortion of signals and pick up the original signal, before transmission [6] [12].

The OOFDM signal involves several modulated subcarriers that may provide a large PAPR once value-is added up coherently. An OOFDM signal features a massive PAPR that is terribly sensitive to the non-linearity of the high peak [3]. To illustrate this point, 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 is given as:

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

Where:

$$K = 0,1,2,\dots,N-1$$

The main goal of this paper is the FPGA implementation of the proposed modified logarithmic technique in [18] that has the abil-

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ity to reduce the PAPR effect efficiently and effectively. Furthermore, the previously mentioned technique has been implemented by using MATLAB and VPI transmitter maker software package. In this paper, the proposed hardware implementation is used depending on NI MyRIO-1900 with Xilinx FPGA board hardware and LabVIEW software package. The rest of the paper is arranged as follows: Section 2, a brief description of PAPR in an OFDM system has been presented. In Section 3 offered the definition of modified logarithmic companding technique. In Section 4, a brief detail of FPGA (NI MyRIO) has been given and in Section 5, descriptions of the proposed system by the way of using the FPGA implementation of modified logarithmic technique. While, in Section 6 the results and discussion of the proposed system are illustrated. Finally, a conclusion is presented in Section 7.

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 illustrated in (2) [3]:

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

Furthermore, the reduction of PAPR simply shows the probabilities that the PAPR of data block exceeds a given threshold value. The expression of Complementary Cumulative Distribution Function (CCDF) is given in (3) [2]:

$$\text{CCDF=Probability (PAPR>PAPR}_{th}\text{)} \quad (3)$$

Where PAPR_{th} represents the Threshold level.

3. Modified logarithmic companding technique

The logarithmic technique is used in communication system at the transmitter as a compressor that is illustrated in equation (4). Then again , this occurs after Inversing Fast Fourier Transform (IFFT) and an expander before Fast Fourier Transform (FFT) at the receiver side that is described in equation (5) [2]:

$$f(x) = \log(1 + (k * |x|)) * \text{sgn}(x) \quad (4)$$

$$f(x)^{-1} = |(\exp\left(\frac{|x|}{k}\right) - 1)| * \text{sgn}(x) \quad (5)$$

Where:
sgn: sign function
k: is a positive number for controlling the amount of companding.
What's more, the proposed modified logarithmic companding technique has been used for PAPR reduction in OOFDM systems due to low complexes regardless of the number of subcarriers is published in [18]. The modified companding and de-companding function are given in equation (6) and equation (7) respectively:

$$f(x) = \log(1 + (k * |x|)^y) * \text{sgn}(x) \quad (6)$$

$$f(x)^{-1} = |(\exp\left(\frac{|x|}{k}\right) - 1)^{1/y}| * \text{sgn}(x) \quad (7)$$

Where:
sgn: sign function
k: is a positive number for controlling the amount of companding
y: positive number range (0.1 to 1)
The proposing parameter (y) is also controlling the amount of companding as well as maintaining the input and output signals at the same average power level.

4. FPGA (NI MyRio-1900)

Significantly, the programming phase of FPGA is much more difficult at first. In FPGA programming, the Hardware Description Language (HDL) is used which is seen to be very complicated than conventional C programming. Nevertheless, the programming of FPGA with LabVIEW FPGA Module, a product of National Instruments have become much useful than HDL.
Notably, the NI MyRIO-1900 has been used in this paper as illustrated in Fig. 1, which is a portable and programmable device that can be used in systems such as control, robotics, and mechatronics [19].
The NI myRIO-1900 has analog input (AI) and analog output (AO) in the range of 0 to 5 V and 2 to ± 10 V. With this in mind, the number of channels that can be used as digital input and output (DIO) is 40. Moreover, the device with Xilinx Z- 7010 processor has terminals that output, +5.0 V, +15.0 V and -15.0 V. The NI myRIO-1900 is connected to a host computer via USB or wireless. Then again, the NI myRIO-1900 is connected to a host computer via USB or wireless [20].

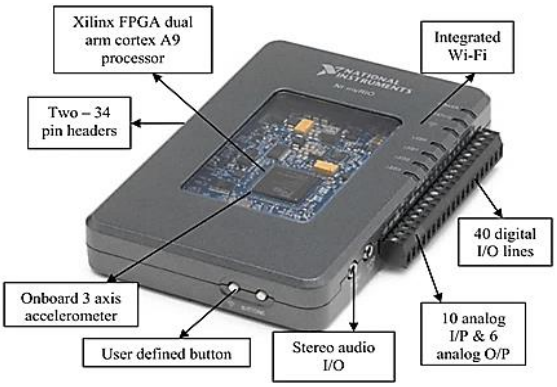


Fig. 1: NI MYRIO Device.

5. Proposed FPGA hardware implementation of modified companding technique

For the first time, the modified logarithmic technique has been implemented on the proposed FPGA (NI myRIO) by the way of using LabView software tools and the data processing as illustrated in Fig. 2.
Generally, the process has been divided into the following steps. Firstly, a random bit stream is generated from the Pseudo-random binary sequence (PRBS) at (2^{13}) the software and then the bit stream is modulated in Matlab in order to realize the mapping of 4QAM and by 128-point FFT transform. That is to say, the OFDM baseband signal is generated with Matlab.

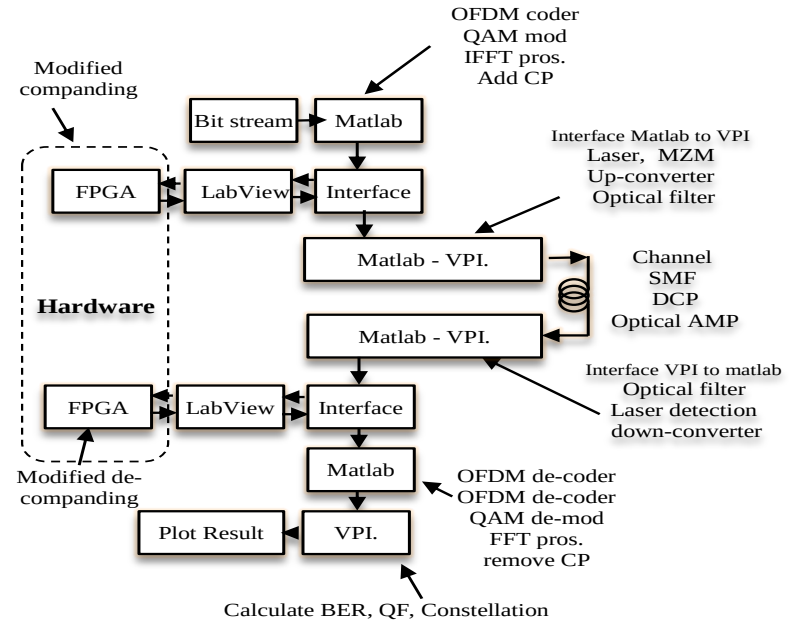


Fig. 2: The Main Process of the Proposed System Using Modified Companding Scheme with Proposed FPGA Hardware Implementation.

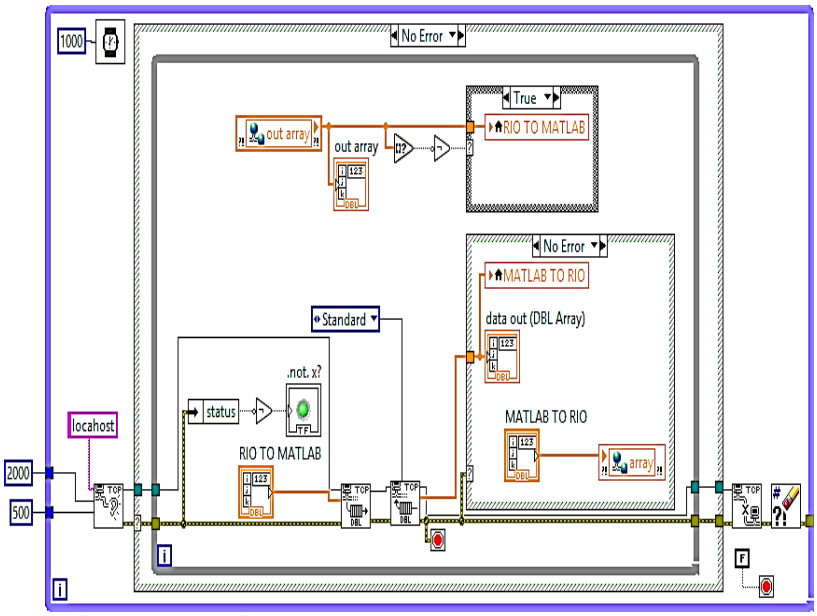


Fig. 3: Interface Transceiver of Signal Processing Between Matlab and Myrio FPGA Using Labview.

Secondly, the LabVIEW programming environment running on the computer has been used in order to compile interface transceiver processing between Matlab and myRIO, and this is done by using the connection in Fig. 3.

Additionally, the signal is transmitted from software to hardware. In other words, the OFDM data is transmitted through a LabView interface to realize conversion to the FPGA hardware (myRIO). Furthermore, the same myRIO can be used as a transmitter (companding) and as a receiver (de-companding). The implementation of the companding technique utilizing LabView and FPGA (myRIO) are illustrated in Fig. 4 and Fig. 5, which show the meaning of the processing of data.

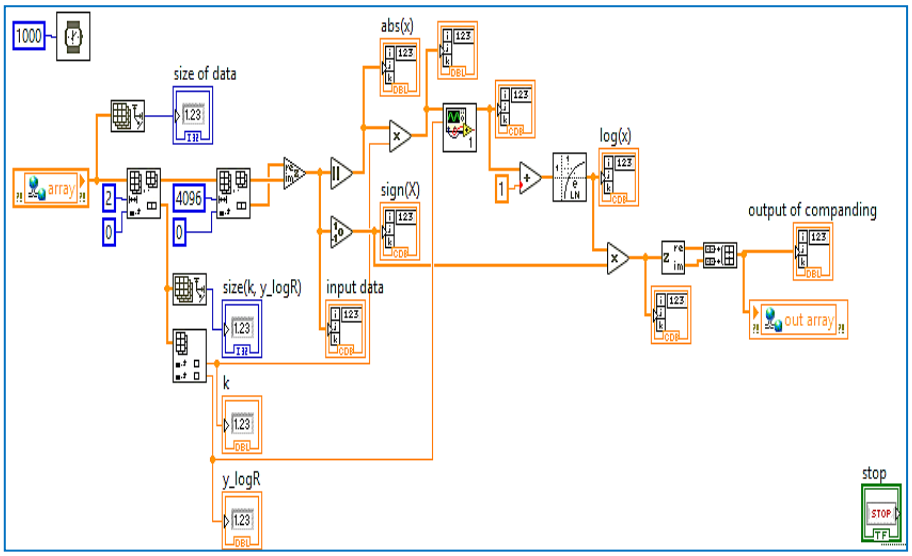


Fig. 4: Implementation of Modified Companding Technique at the Transmitter Side.

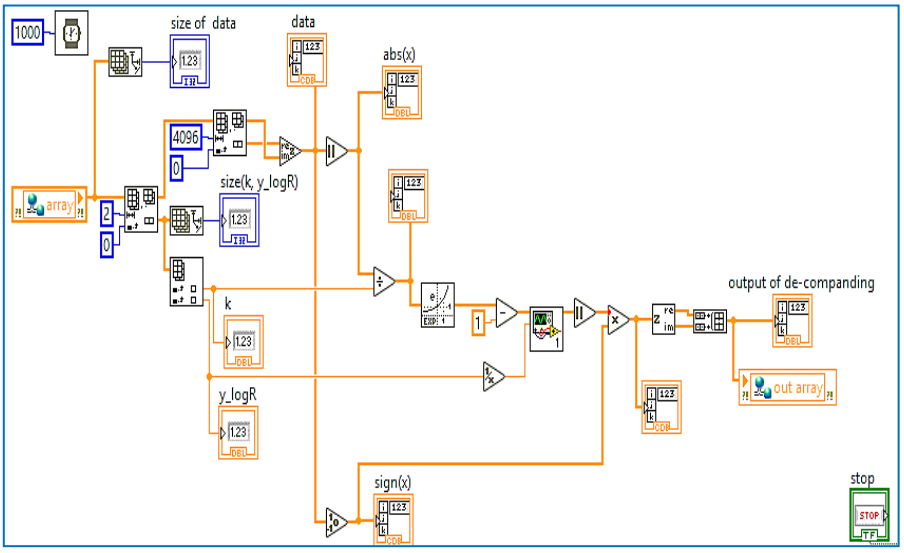


Fig. 5: Implementation of Modified De- Companding Technique at the Receiver Side.

The I/Q baseband signals are transmitted to the myRIO through USB port (8000:500). The I/Q baseband signals are synthesized by the companding transform that is implemented on fig. 4 in order to reduce the PAPR as well as mitigate the nonlinear effects. To give an illustration, VPI Transmission Maker does the optical modulation and optical up-down conversion and transmission link. The resulting companded signals are mixed with a specified optical carrier frequency, then the signals generated after modulation is transmitted over fiber channel.

The companded signal is transmitted over the optical link with length equal to 900 Km (60 Km×15 loops). The Fiber link contains a Standard Single Mode Fiber (SSMF), a Dispersion Compensation Fiber (DCF), and an optical amplifier. Accordingly, Table (1) summarizes the parameters that are used in implementing the proposed system.

Finally, the reverse sequences have been applied at the receiver side to pick up and restore the original signal that is previously transmitted.

Table 1: Simulation Parameters for Proposed OOFDM

Global parameters	
BitRate	10 Gbps
Sample Rate	40 Gbps
Sequence length	8192
Bits per symbol	2
OFDM modulator	
Max subcarriers	128
Cyclic Prefix	1/8
Global parameters	
BitRate	10 Gbps
CW Laser	
Carrier Frequency	193.1 THz
Power	10 mw
Line Width	0.1 MHz
Optical Link	
SMF length	50 km
DCF length	10 km
Number of loops	15
Attenuation for SMF	0.2 dB/km
Attenuation for DCF	0.5 dB/km
Dispersion SMF	16 ps /nm/km
Dispersion DCF	-80 ps /nm/km
CoreArea of SMF	80 μm^2
CoreArea of DCF	50 μm^2
optical amplifier gain	12 dBm
optical amplifier Noise Fig	4 dBm

6. Results and discussion

Importantly, the coded OFDM signal (real and imaginary part of companded OFDM) is up-converted at 7.5 GHz an Intermediate Frequency (IF) as shown in Fig. 6.

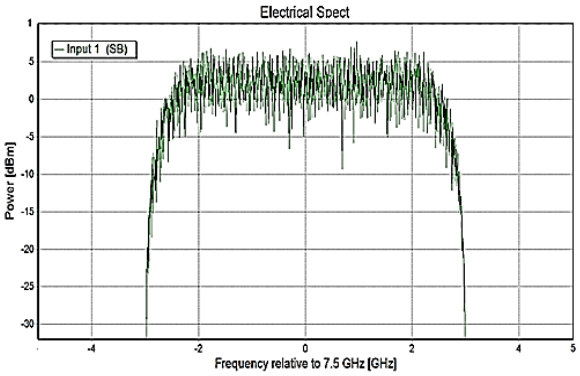


Fig. 6: Electrical Spectrum of Proposed Logarithmic OOFDM at IF=7.5 GHZ.

Furthermore, the output spectrum power from MZM contains an optical carrier that is targeted at 193.1 THz in this case and two side-bands targeted at 7.5 GHz of the optical OFDM signal as shown in Fig. 7.

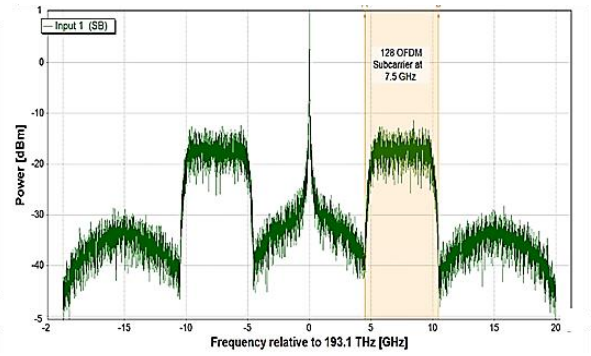


Fig. 7: Optical Spectrum of the Proposed Modified Logarithmic OOFDM.

Generally, Fig. 8 summarizes the performance of various parameter (y) with the PAPR of OFDM companded signals. Moreover, the PAPR values for degrees larger than 0.2 are almost the same as that for less than 0.15. To give an illustration, the minimum PAPR must be obtained at this range where $0.15 \leq y \leq 0.2$ due to these values add more compression at the transmitter's side system with reverses at the receiver's side correspondingly.

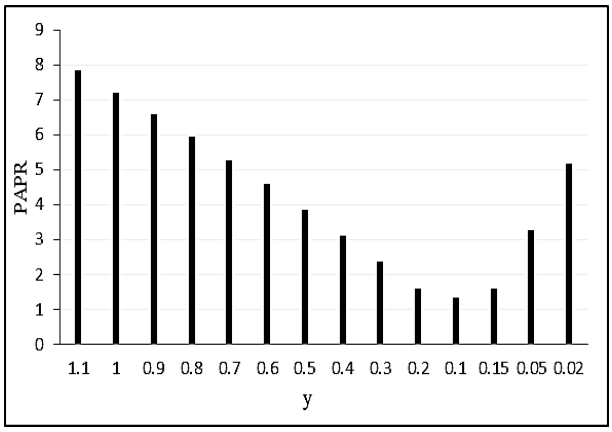


Fig. 8: PAPR Reduction as A Function of Control Parameter Y.

The PAPR reduction is based on a modified logarithmic technique depends on the two-control parameters k and y as shown in Fig. 9 and Fig. 10.

To put it another way, the CCDF is often used to display the PAPR probability distributions of OFDM transmissions. It has been noticed from Fig. 9 and Fig. 10 that the PAPR of the companded OFDM signal is much lower than the un-companded signal. Companding the 128-subcarrier signal with k=30, gives the PAPR as 1.5 dB for k=30 where y=1 as shown in Fig. 9.

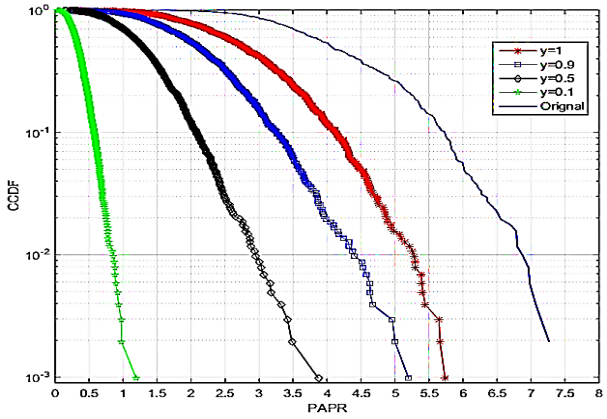


Fig. 9: CCDF Plot as A Function of PAPR Based on Modified Logarithmic Technique for Different Control Degree Y Where K= 30.

It has been illustrated that there is a slightly increase to 2.5 dB for k=50 where y = 1 in Fig. 10. There is no doubt that the reduction in PAPR is smaller for higher values of k.

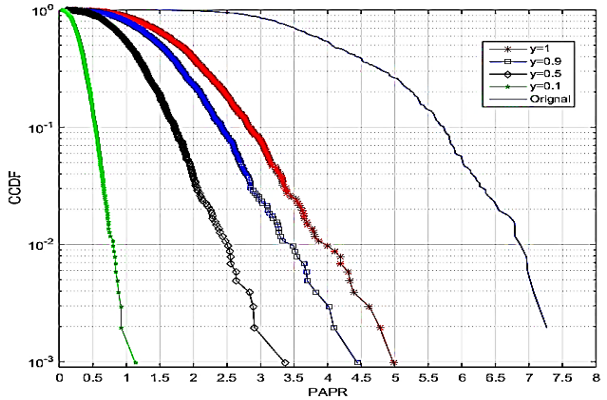


Fig. 10: CCDF Plot as A Function of PAPR Based on Modified Logarithmic Technique for Different Control Degree Y Where K=50.

In addition, Fig. 11 shows the CCDF performance with companding parameter y = 1 with different value of k.

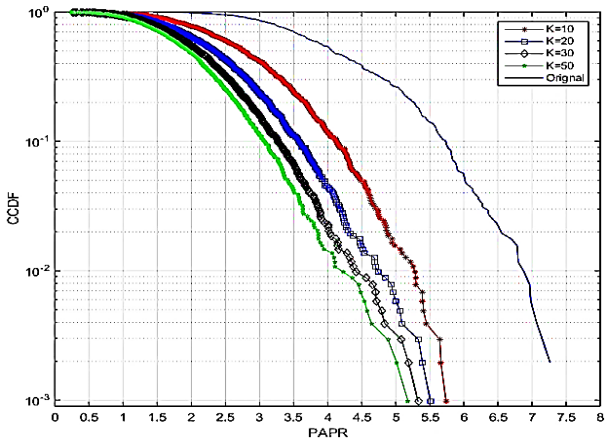


Fig. 11: CCDF Plot as A Function of PAPR Based on Modified Logarithmic for Different Control Parameter K where Y = 1.

Notably, Fig. 12 shows the CCDF performance at y= 0.1. Moreover, it can be illustrated that y = 0.1 providing a better performance than y = 1 regardless the overall values of k.

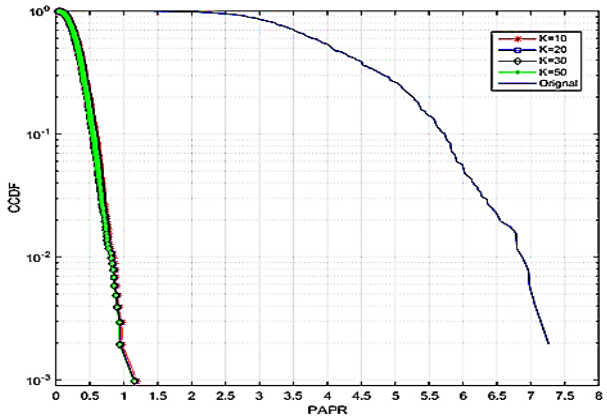


Fig. 12: CCDF Plot as A Function of PAPR Based on Modified Logarithmic for Different Control Parameter K Where Y = 0.1.

As well as, after the fiber length at 900 Km (60 Km × 15) with 4QAM modulation formats the Quality Factor (QF), BER and constellation diagram at the receiver end is shown in Fig. 13, Fig. 14 and Fig. 15 respectively.

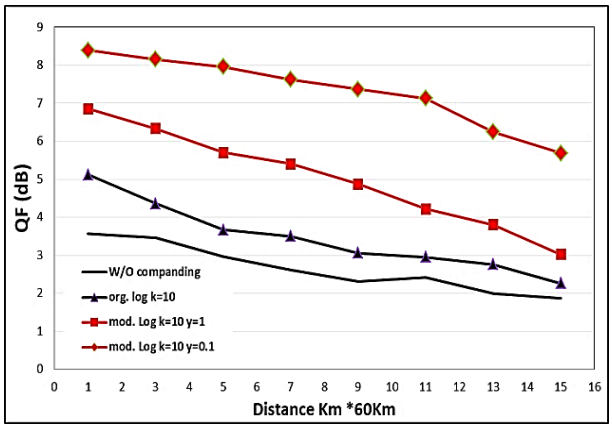


Fig. 13: QF as A Function of Transmission Length.

Likewise, the measured QF is 1.9 dB of the original system without using companded technique. The measured QF of modified logarithmic that has been imbedded in FPGA is 5.8 dB at y = 0.1 and 3 dB at y = 1. To put it another way, making a comparison with the original signal, 3.8 dB of QF improvement at y = 0.1 has been gained. The BER plotted with distance at 900 km is illustrated in fig. 14. Besides, the BER is 1.58×10^{-3} that has been observed in the original system without companded technique. Furthermore, the values of y at 1 and 0.1 the BER are 4.96×10^{-4} at 4.8×10^{-5} respectively of modified technique at 900 km end receiver.
Moreover, the degradation has been observed in fig. 13, fig. 14 of the original signal. This degradation is considered the maximum because of the increase in the chromatic dispersion when increasing the transmission length.

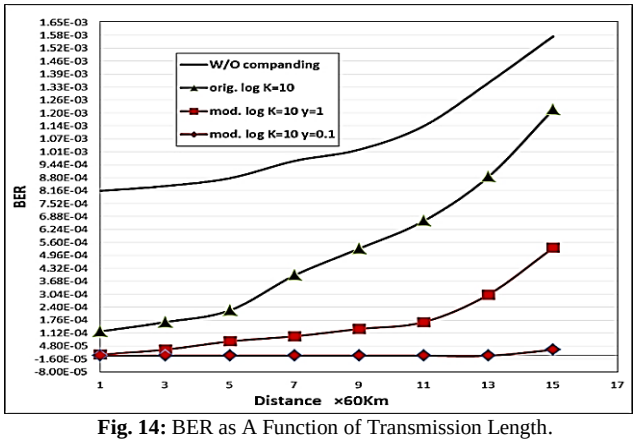


Fig. 14: BER as A Function of Transmission Length.

Not only, but also the modified technique is clearly improving the OOFDM system performance that is described as constellation. Clearly, as shown in fig. 15, the companding with y = 1 provides a degraded constellation diagram. However, with y = 0.1 a significant high improvement in constellation performance over without companded or companded at y = 1.

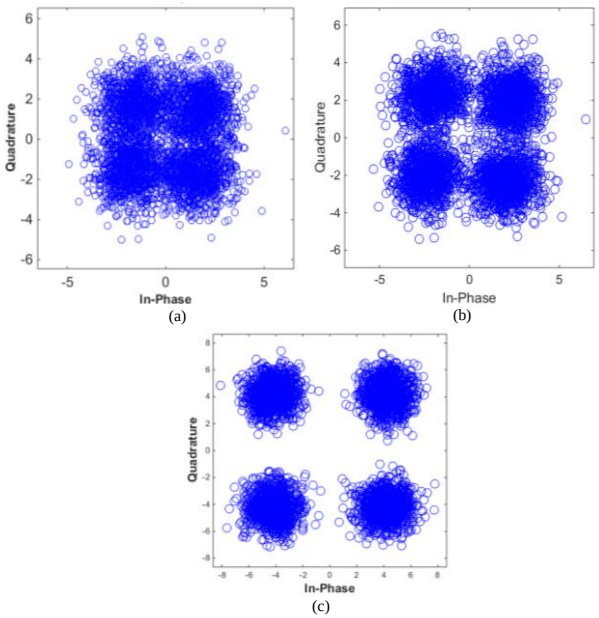


Fig. 15: Constellation Diagram of Modified OOFDM System at the Receiver End after 900 Km at (A) Original without Companded (B) Proposed Companded at Y=1 and K=10 (C) Proposed Companded at Y=0.1 and K=10.

7. Conclusions

In this paper, the modified logarithmic companding technique that is used in IM/DD OOFDM system has been implemented in the proposed FPGA (NI MyRIO) by the way of using LabView software tools. Above all, the proposed FPGA performs all baseband computation as a companding at the transmitter side in order to reduce the PAPR of transmitted signal as well as de-companding at the receiver side. Importantly, all results of QF, BER, and constellation diagram have been presented by combination the VPI Transmission Maker, MATLAB, LabView, and FPGA hardware. The results have shown that the parameter y at 0.1 is the best one to reduce the PAPR system performance regardless of any value of k. in the proposed system, getting 3.8 dB improvement of QF with PAPR enhancement by 6.2 dB in comparison with the original system. Finally, the performance of transceiver systems can be completely more improved by proposing another technique to make the hydride techniques.

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