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Performance Analysis of OFDM Based System for PAPR Reduction Techniques with Optical Fiber Link

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Abstract— Optical OFDM is a promising technology and which is advantageous than wireless medium. The demand of bandwidth for higher data rate and this will meet the growing internet traffic, digital audio and video broadcasting applications growing exponentially. This paper highlights multi-dimensional while considering fiber optic communication with OFDM. To achieve good performance in optical systems, OFDM must be adapted in various ways. This paper is a review of the various PAPR reduction techniques used in optical fiber link and compares their performance in terms of transmitter power, data loss, complexity and distortion. We have considered amplitude clipping and filtering, peak windowing, coding, partial transmit sequence, selected mapping technique, tone reservation, interleaving technique and tone injection for QAM modulated OFDM. All these techniques have the potential to reduce peak to average power ratio (PAPR) at the cost of data loss. However one should make a right choice the PAPR reduction technique depending on the requirement. Our study shows that amplitude clipping is the right choice as it is simple, minimum data loss if the distortion is within the tolerance limit.

Index Terms— Clipping and filtering, dispersion compensating fiber, orthogonal frequency division multiplexing, peak-to average power ratio, partial transmits sequence.

I. INTRODUCTION

OFDM system have another challenge to face is the accommodation of the large dynamic range of a signal. This large dynamic range, often described in terms of peak average ratio (PAPR), means that the OFDM signal has a large variation between average signal power and the maximum signal power [1]. A large dynamic range is inherent to multicarrier modulations, since each subcarrier is essentially independent. As a result, subcarriers can add constructively or destructively, which may contribute to large variation in signal power. In other words, it is possible for the data sequence to align all subcarriers constructively and accrue to a very large signal. It is also possible for the data sequence to make all subcarriers align destructively and diminish to a very small signal. This large variation creates problem for transmitter and receiver design, requiring both to accommodate a large range of signal power with minimum distortion. The large dynamic range of the OFDM systems presents, in particular, a challenge for the power amplifier (PA) and the low-noise amplifier (LNA) design. The large output drives the PA to nonlinear regions (i.e., near saturation), which causes distortion. To minimize the amount of distortion and to reduce the amount of out-of-band energy radiation by the transmitter, the OFDM and other modulations, alike need to ensure that the operation of a PA is limited as much as possible in the linear amplification region. With inherently large dynamic range, this means that the OFDM must keep its average power well below the nonlinear region of the PA to accommodate the signal power fluctuations. However, lowering the average power hurts the efficiency and subsequently the range since it corresponds to a lower output power for the majority of the signal in order to accommodate infrequent peaks. As a result, OFDM designers must make careful trade-offs between allowable distortion and output power. That is, they must choose an average input level that generates sufficient output power and yet does not introduce too much interference or violate any spectral constraints. The exact value is highly dependent on the PA characteristics and other distortions in the transmitter chain. In other words, the distortions caused by peaks above this range are infrequent enough to allow for low average error rates. This paper divided into 5 sections. The section 2 will discuss PAPR of multicarrier system; section 3 will focus on PAPR reduction schemes; in section 4 we have present simulation models and results; section 5 will give the conclusion.



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II. PAPR OF MULTICARRIER SYSTEM

OFDM has several properties, which make it an attractive modulation scheme for high speed transmission links. However, one major drawback is its large peak to average power ratio (PAPR). The PAPR of an OFDM symbol is defined as the square of the maximum amplitude divided by the mean power, refer to “(1),” “(2),” “(3).”
If

$$s_1^1 = \max[s(t)] \quad (1)$$

is the maximum amplitude and
$$s_2^2 = \frac{1}{T_s} \int_0^{T_s} [s(t)]^2 dt \quad (2)$$

is the mean power of an OFDM symbol, then the PAPR is defined as

$$PAPR = \frac{s_1^1}{s_2^2} \quad (3)$$

If all subcarriers are occupied and if we allow all subcarrier phases, the time domain samples of the transmit signal are approximately Gaussian distributed. Without oversampling, the time domain samples are mutually uncorrelated and the probability that the PAPR is below a certain threshold z , i.e. the cumulative distribution function (CDF), can be written as

$$P(PAPR \leq Z) = CDF(Z) = (1 - e^{-z})^N \quad (4)$$

For large N and if we choose the subcarrier phases randomly, refer to “(4),” is also valid for the case of OFDM-multiple frequency-shift keying (MFSK), where not all subcarriers are occupied. However there is a difference in the maximum PAPR. For the case where all subcarriers are occupied, the maximum amplitude is achieved when all subcarriers add coherently and is \sqrt{N} . Due to the normalization, refer to “(1),” the mean power of such an OFDM symbol is 1. Therefore the maximum PAPR is N . If we now consider OFDM-MFSK power is $1/M$, so that the maximum PAPR becomes N/M . The PAPR of equation deals with the pass band signal $S(t)$ with a carrier frequency of f_c which is much higher than inverse of one symbol period of $S(t)$, hence the PAPR of the continuous time base band OFDM signal and its corresponding pass band signal will have almost the same PAPR. But, the PAPR of discrete time baseband signal $x[n]$, refer to “(1),” may not be the same as that for the continuous time baseband signal $x(t)$ and it will be low, since $x[n]$ may not have all the peaks of $x(t)$. Measurement of the PAPR for $x(t)$ from the PAPR of $x[n]$ can be done by $L(\geq 4)$ times interpolating the $x[n]$. Various PAPR reduction techniques are discussed below. The complex discrete-time base band equivalent time-domain OFDM signal can be expressed as, refer to “(5),”

$$x[n] = IFFT\{X[k]\} = \frac{1}{\sqrt{N}} \sum X[k] \times e^{j2\pi nk/N} \quad (5)$$

Where, $n = (0, 1, 2, \dots, N)$; $N \rightarrow$ No. of subcarriers; $X[k] \rightarrow$ denotes the k^{th} modulated phase shift keying (PSK) or quadrature amplitude modulated (QAM). The PAPR of equation deals with the pass band signal $S(t)$ with a carrier frequency of f_c which is much higher than inverse of one symbol period of $S(t)$, hence the PAPR of the continuous time base band OFDM signal and its corresponding pass band signal will have almost the same PAPR. But, the PAPR of discrete time baseband signal $x[n]$, refer to “(1),” may not be the same as that for the continuous time baseband signal $x(t)$ and it will be low, since $x[n]$ may not have all the peaks of $x(t)$.

III. PAPR REDUCTION SCHEMES

A large number of solutions have been proposed to solve the PAPR problem in OFDM. Clipping OFDM signal before amplification is a simple solution [2]. However, clipping may cause inter-modulation among subcarriers and undesired out-of-band radiation. Another solution uses block coding, where the data sequence is embedded in a larger sequence and only a subset of all the possible sequences are used, specifically, those with low peak powers[3] – [5]. While block coding reduces PAPR, it also reduces transmission rate, significantly so for a large



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number of subcarriers. Furthermore, there is no efficient coding scheme for a large number of subcarriers. Recently, a promising technique for improving the statistics of the PAPR of OFDM signals has been proposed: the partial transmit sequence (PTS) technique. In the PTS technique, the input data block is broken up into disjoint sub-blocks. Sub-blocks are multiplied by phase factors and then added. Together to produce alternative transmit signals containing the same information. The phase factors, whose amplitude is usually set to 1, are selected such that the resulting PAPR is minimized. The number of allowed phase factors should not be excessively high, in order to keep the number of required side information bits and the search complexity within a reasonable limit. However, the exhaustive search complexity of the ordinary PTS technique increases exponentially with the number of sub-blocks, so it is practically not realizable for a large number of sub-blocks. The various PAPR reduction techniques are discussed below.

A. Amplitude Clipping

Deliberate clipping is a simple approach and, since the large peaks occur with a very low probability, clipping could be an effective technique for the reduction of the PAPR (O'Neill and Lopes, 1995). However, clipping is a nonlinear process and may cause significant in band distortion, which degrades the bit error rate performance, and out of band noise, which reduces the spectral efficiency. Filtering after clipping can reduce the spectral splatter but may also cause some peak regrowth (Li and Cimini, 1998). If digital signals are clipped directly, the resulting clipping noise will all fall in-band and can not be reduced by filtering. To avoid this aliasing problem, oversample each OFDM block by padding the original input with zeros and taking a longer IFFT. Filtering after clipping is required to reduce the out of band clipping noise. The other approach to clipping is to use Forward Error Correcting codes and band pass filtering with clipping (Wulich and Goldfeld, 1999). This method improves the bit error rate performance and spectral efficiency.

One of the simple and effective PAPR reduction techniques is clipping, which cancels the signal components that exceed some unchanging amplitude called clip level. A threshold value of the amplitude is set in this case to limit the peak envelope of the input signal. Signal having values higher than this pre-determined value are clipped and the rest are allowed to pass through un-disturbed,

$$B(x) = x \quad |x| \leq A \quad (6)$$

$$= Ae^{j\phi x} \quad |x| \geq A \quad (7)$$

Where, $B(x)$ = the amplitude value after clipping. x = the initial signal value. A = the threshold set by the user for clipping the signal. The problem in this case is that due to amplitude clipping distortion is observed in the system which can be viewed as another source of noise. This distortion falls in both in band and out of band. Filtering can't be implemented to reduce the in-band distortion and an error performance degradation is observed here. On the other hand spectral efficiency is hampered by out of band radiation. Out-of-band radiation can be reduced by filtering after clipping but this may result in some peak regrowth. A repeated filtering and clipping operation can be implemented to solve this problem. The desired amplitude level is only achieved after several iterations of this process.

B. Peak Windowing

The simplest way to reduce the PAPR is to clip the signal, but this significantly increases the out of band radiation. A different approach is to multiply large signal peak with a Gaussian shaped window proposed by Pauli and Kuchenbecker (1997). But, in fact any window can be used, provided it has good spectral properties (Van Nee and Wild, 1998). Since the OFDM signal is multiplied with several of these windows the resulting spectrum is a convolution of the original OFDM spectrum with the spectrum of the applied window. So, ideally the window should be as narrow band as possible. On the other hand, the window should not be too long in the time domain, because that implies that many signal samples are affected, which increases the bit error ratio. Examples of suitable window functions are the Cosine, Kaiser and Hamming window. Van Nee and Wild (1998) showed that PAPR could be achieved independent from number of sub-carriers, at the cost of a slight increase in BER and out-of-band radiation [6] – [8].

The peak windowing method has been suggested by Van Nee and Wild. This method, proposes that it is possible to remove large peaks at the cost of a slight amount of self interference when large peaks arise infrequently. The peak windowing reduces PAPRs at the cost of increasing the BER and out-of-band radiation. The clipping is a one



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kind of simple introduces PAPR reduction technique, which is self interference. The technique of peak windowing offers better PAPR reduction with better spectral properties. In peak windowing method, we multiply large signal peak with a specific window, for example; Gaussian shaped window, Cosine, Kaiser and Hamming window. In view of the fact that the OFDM signal is multiplied with several of these windows, consequential spectrum is a convolution of the original OFDM spectrum with the spectrum of the applied window. Thus, the window should be as narrow band as possible, conversely the window should not be too long in the time domain because various signal samples are affected, which results an increase in bit error rate (BER).

Windowing method, PAPRs can be obtained to 4 dB which from the number of independent subcarriers. The loss in signal-to-noise ratio (SNR) due to the signal distortion is limited to about 0.3 dB. A back of relative to maximum output power of about 5.5 dB is needed in spectra distortion at least 30 dB below the in-band spectral density.

C. Coding

A block coding scheme for reduction of PAPR proposed by Jones, Wilkin- son and Barton (1994) is to find code words with minimum PAPR from a given set of code words and to map the input data blocks of these selected code words. Thus, it avoids transmitting the code words which generates high peak envelop power. But, this reduction of PAPR is at the expense of a decrease in coding rate. It has 2.48 dB with rate block code for four carrier signal. For large number of carriers, necessary code sets exist but encoding and decoding is also difficult task. It is not suitable for higher order bit rates or large number of carriers. M sequences the use of m-sequences for PAPR reduction is proposed by Li and Ritcey (1997). This is done by mapping a block of m input bits to an m - sequences $[C_0, \dots, C_{N-1}]$ of length $N = (2^m - 1)$. This results in a code rate of $(m / (2^m - 1))$. The m-sequences are a class of $((2^m - 1), m)$ cyclic codes obtained from a primitive polynomial of degree m over GF (2). Tellambura (1997) showed that the achievable PAPR is only between 5 dB to 7.3 dB for m between 3 and 10. The problem with this approach is the extremely low rate for large values of m.

Eetvelt, Wade and Tomlinson (1996) proposed this technique to reduce PAPR. The method is to form four code words in which the first two bits are 00, 01, 10 and 11 respectively. The message bits are first scrambled by four fixed cyclically in equivalent m-sequences. Then the one with the lowest PAPR is selected and one of the pair of bits defined earlier is appended at the beginning of the selected sequence. At the receiver, these first two bits are used to select the suitable descrambler. When a scrambled binary sequence with high proportion of 1's or 0's is applied to N- point IFFT OFDM modulator, it will give a signal with high PAPR. A scrambled binary sequence of length 2N with a Hamming weight close to N will often generate low PAPR. Selecting structured scrambled sequence is critical. PAPR is typically reduced to 2 percent of the maximum possible value while incurring negligible redundancy in a practical system. Coding can also be used to reduce the PAPR. A simple idea introduced here is to select those code words that minimize or reduce the PAPR for transmission. This idea is illustrated here in table I below.

D. Partial Transmit Sequence

In the PTS technique, an input data block of N symbols is partitioned into disjoint sub blocks. The subcarriers in each sub-block are weighted by a phase factor for that sub block. The phase actors are selected such that the PAPR of the combined signal is minimized. In the ordinary PTS technique input data block X is partitioned into M disjoint sub blocks $X_m = [X_{m,0}, X_{m,1}, \dots, X_{m,N-1}]$; $m = 1, 2, \dots, M$, each partitioned sub block is multiplied by a corresponding complex phase factor and the sub blocks are combined to minimize the PAPR in the time domain signal.

Example: Here, we show a simple example of the PTS technique for an OFDM system with eight subcarriers that are divided into four sub blocks. The phase factors are selected in $P = 1$. The adjacent sub block are partitioning for a data block X of length 8. The original data block X has a PAPR of 6.5 dB. There are 8 ways to combine the sub blocks with fixed $b_1 = 1$.

Among them $[b_1, b_2, b_3, b_4] = [1, 1, 1, 1]$ achieves the lowest PAPR. The modified data block will be $X = [1, 1, 1, 1, 1, 1, 1, 1]$ whose PAPR is 2.2 dB, resulting in a 4.3 dB reduction. In this case, the number of required IDFT operations is 4. The side information must be transmitted to the receiver to recover the original data block. One way to do this is to transmit these side information bits with a separate channel other than the data channel. It is also possible to include the side information within the data block; however, this results in data rate loss.

E. Selected Mapping Technique

In the SLM technique, the transmitter generates a set of sufficiently different candidate data blocks, all representing the same information as the original data block, and selects the most favorable for transmission. A block diagram of the SLM technique is shown in Fig. 1. Each data block is multiplied by U different phase sequences, each of length N , $B(u) = [b_{u,0}, b_{u,1}, \dots, b_{u,N-1}]$, $u = 1, 2, \dots, U$, resulting in U modified data blocks. To include the unmodified data block in the set of modified data blocks, we set $B(1)$ as the all-one vector of length N . Let us denote the modified data block for the u^{th} phase sequence as follows $X(u) = [X_{0b_u, 0}, X_{1b_u, 1}, \dots, X_{N-1b_u, N-1}]^T$, $u = 1, 2, \dots, U$. Among the modified data blocks $X(u)$, $u = 1, 2, \dots, U$, the one with the lowest PAPR is selected for transmission. Information about the selected phase sequence should be transmitted to the receiver as side information. At the receiver, the reverse operation is performed to recover the original data block [9] – [14].

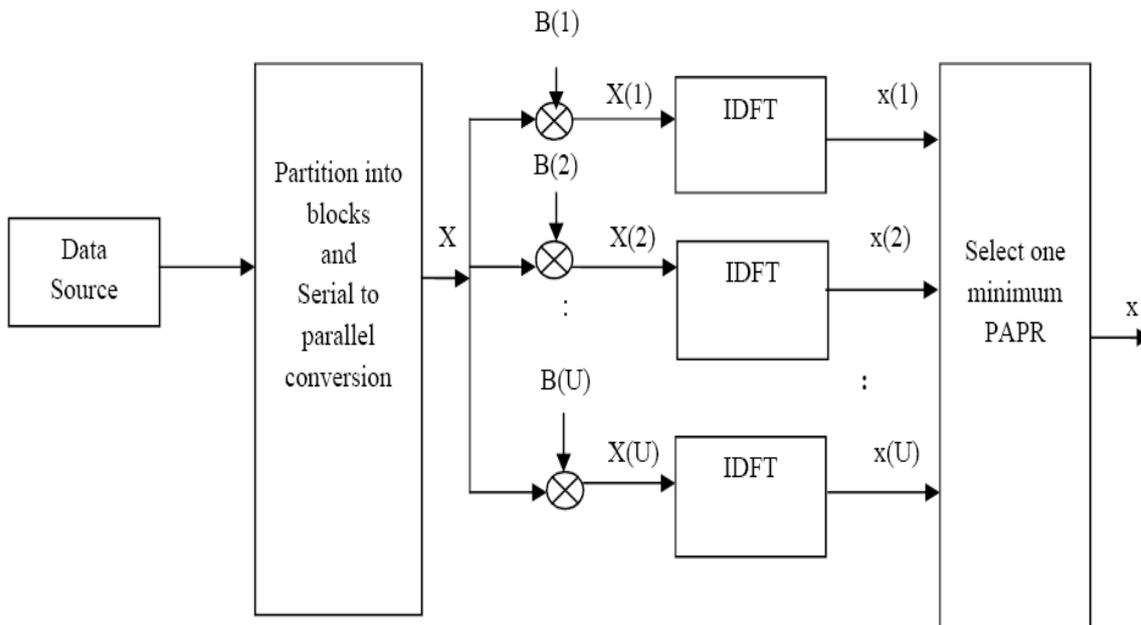


Fig 1: Selected mapping

Here, we show a simple example of the SLM technique for an OFDM system with eight sub carriers. We set the number of phase sequences to $U = 4$. The data block to be transmitted is denoted $X = [1, 1, 1, 1, 1, 1, 1, 1]$, whose PAPR before applying SLM is 6.5 dB. We set the four phase factors as $B(1) = [-1, -1, 1, 1, 1, 1, 1, 1]$, $B(2) = [1, 1, -1, -1, -1, 1, -1, 1]$, $B(3) = [1, -1, 1, 1, -1, 1, 1, -1]$, and $B(4) = [-1, 1, 1, 1, -1, -1, 1, 1]$. Among the 4 modified data blocks $X(u)$, $u = 1, 2, 3, 4$; $X(2)$ has the lowest PAPR of 3.0 dB. Hence, $X(2)$ is selected and transmitted to the receiver. For this data block, the PAPR is reduced from 6.5 to 3.0 dB, resulting in a 3.5 dB reduction.

F. Tone Reservation

A tone reservation (TR) technique partitions the N subcarriers (tones) into data tones and peak reduction tones (PRTs) [192]. Symbols in PRTs are chosen such that OFDM signal in the time domain has a lower PAPR. The positions of PRTs are known to the receiver and transmitter. Fig. 2 shows the block diagram of the TR scheme for PAPR reduction. Since the data tones and PRTs are exclusively assigned, the input vector to IFFT block is divided into data vector X and PAPR reduction vector C . Let R and denote the set of R PRT positions and its complement, respectively, where R denotes the number of tones reserved for peak reduction. Then the input symbols to IFFT block can be expressed as where $X[k]$ and $C[k]$ denote the data symbol and PRT symbol, respectively. By taking IFFT of the symbols given, we obtain the OFDM symbol to be transmitted as note that the PRT signal $c[n]$ does not cause any distortion on the data signal $x[n]$ in equation due to the orthogonality among subcarriers. With the TR technique, additional power is required for transmitting the PRT symbols and the effective data rate decreases since the PRT tones work as an overhead.

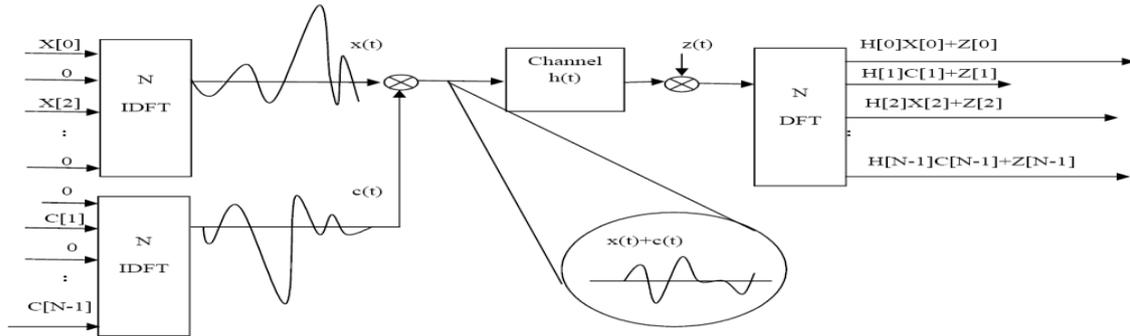


Fig 2: Tone reservation

G. Interleaving Technique

The interleaving technique for PAPR reduction is very similar to the SLM technique. In this approach, a set of interleavers is used to reduce the PAPR of the multicarrier signal instead of a set of phase sequences. An interleaver is a device that operates on a block of N symbols and re-orders or permutes them. To recover the original data block, the receiver need only know which interleaver is used at the transmitter.

H. Tone Injection

The amount of PAPR reduction depends on the number of interleavers and the design of the interleavers. While the TR technique can reduce the PAPR without additional complexity, it costs the reduced data rate since the additional PRTs are required. A tone injection (TI) technique can be used to reduce the PAPR without reducing the data rate. It allows the PRTs to be overlapped with data tones. Fig. 3 shows a block diagram for the TI technique.

The PAPR reduction signal is constructed as $C[k] = p[k].D + jq[k]$. Where D is a fixed constant, while p[k] and q[k] are chosen to minimize the PAPR. The basic idea of TI technique is to increase the constellation size so that each of the points in the original constellation can be mapped into several equivalent points in the expanded constellation. Since the data tones and PRTs are not separated orthogonally in the frequency domain, we need means of removing the effect of C[k] at the receiver.

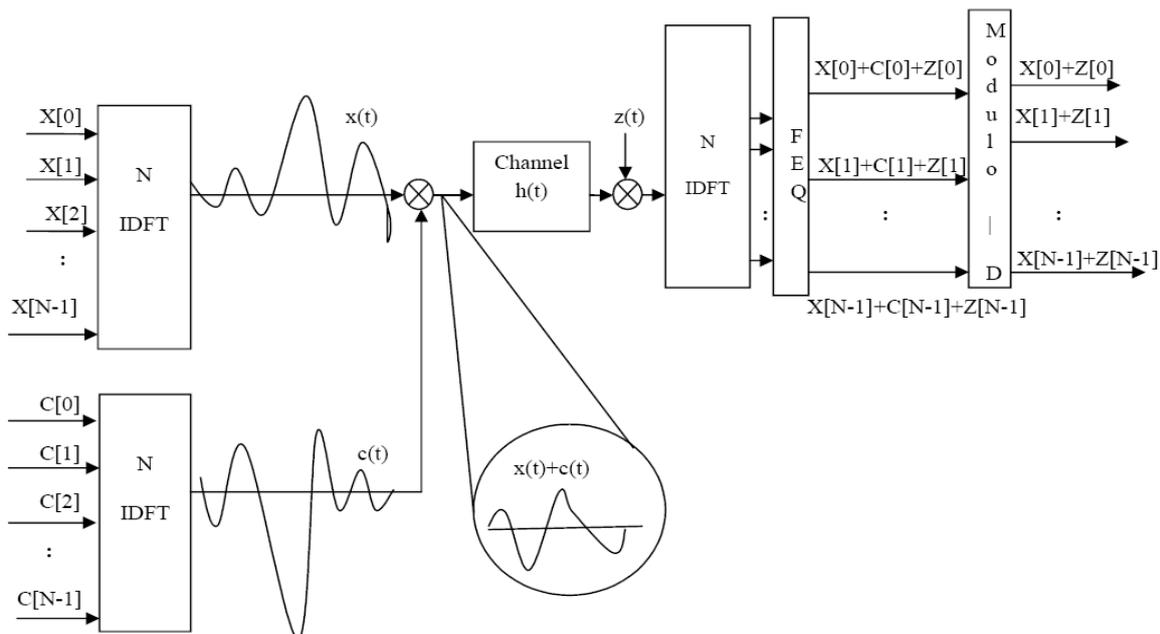


Fig 3: Tone injection

Considering all the above techniques, we can write comparison as given in the table I as shown below.



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Table I: Comparison of PAPR reduction techniques

Techniques	Distortion less	Power Increase	Data Loss	Rate	Processing Requirement
Clipping and filtering	No	No	No		Tx: Amplitude clipping, filtering, Rx: RX: None
Coding	Yes	No	Yes		Tx: Encoding or table search Rx: Decoding or table search
PTS	Yes	No	Yes		Tx: IDFTs and complex vector sums. Rx: Side Information Extraction, Inverse PTS
SLM	Yes	No	Yes		Tx: IDFTs Rx: Side Information, Extraction, Inverse SLM
Interleaving	Yes	No	Yes		Tx: K IDFTs, interleaving. Rx: Side Information, Extraction, Inverse Interleaving
TI	Yes	Yes	Yes		Tx: IDFTs, Search for maximum point In time, tones to be modified. Rx: Modulo-D operation
TR	Yes	Yes	Yes		Tx: IDFTs. Rx: Ignore non data-bearing Subcarriers

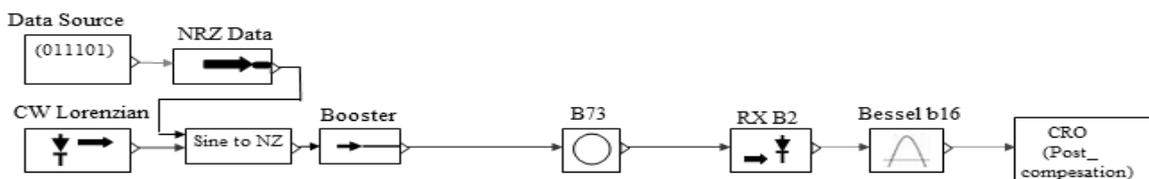
IV. SIMULATION MODELS AND RESULTS

This paper highlights on comparison of various techniques like dispersion compensated fibers (DCF), amplitude clipping model with pre and post clipping method and OFDM system with 8 subcarriers using optical fiber communication of about 10 km. We have concentrated on few parameters like instantaneous optical power, phase deviation and their eye diagrams.

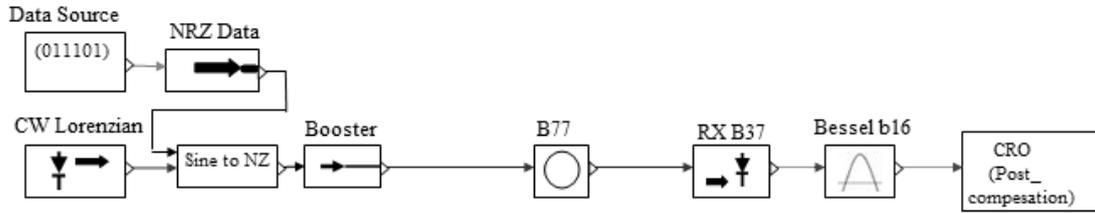
A. Dispersion Compensation Fiber

The block diagrams for simulation of pre, post and symmetrical-compensation methods using dispersion compensated fibers are shown below in Fig. 4 (a), (b), (c). Each transmitter section consists of data source, electrical driver, laser source and amplitude modulator. The data source is non-return to zero format at 10 Gb/s bit rate and is indicated by b6, b36 and b54 blocks for pre, post and symmetrical compensation respectively. The electrical driver is important component that generates the desired data transmission format. It converts the logical input signal, a binary sequence of zeros and ones into an electrical signal. It is indicated by b15, b33 and b51 blocks for pre, post and symmetrical configurations respectively. The laser source (b9, b35 and b53 for three configurations) generates laser beam at 1550 nm. The output of modulator (b12, b34 and b52) is fed to optical link through EDFA amplifier (b24, b28 and b46).

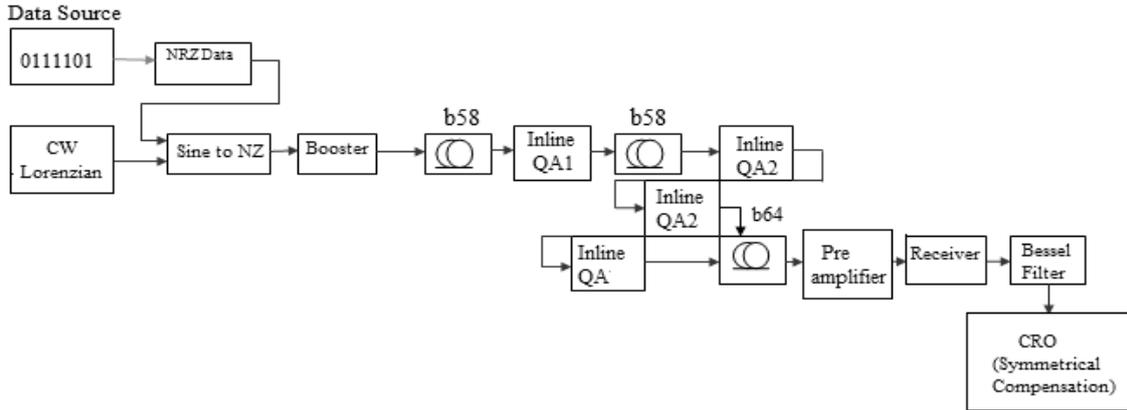
In the first case, the optical communication system is pre-compensated by the dispersion compensated fiber of negative dispersion (80 ps/nm/km of length 24 km) against the standard fiber (16 ps/nm/km of length 120 km) over the span. In the second case, the optical communication system is post-compensated by the dispersion compensated fiber of negative dispersion against the standard fiber. In order to compare the three compensation configurations, we define equivalent symmetrical compensation configuration in the third case whereby the system is symmetrically compensated by two dispersion compensated fibers of same negative dispersion against two standard fibers.



(a)



(b)



(c)

Fig 4: DCF

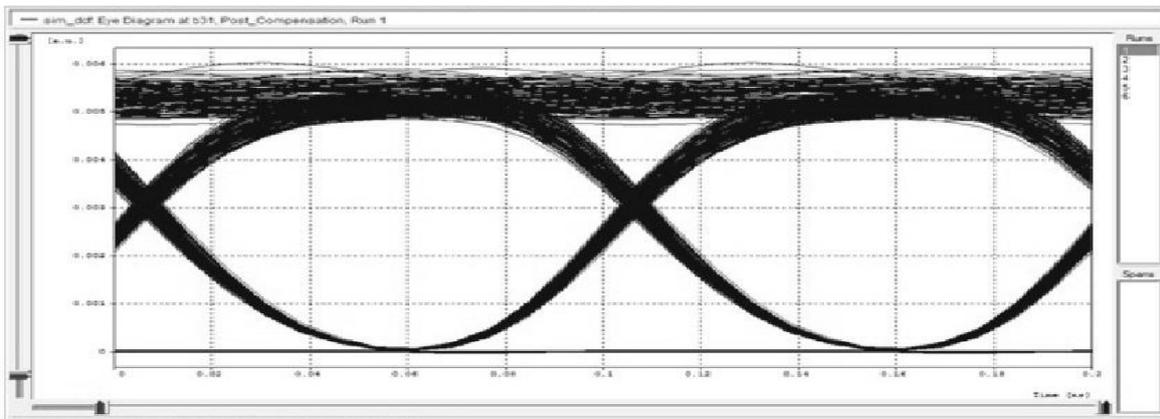


Fig 5: DCF pre/post compensation eye diagram

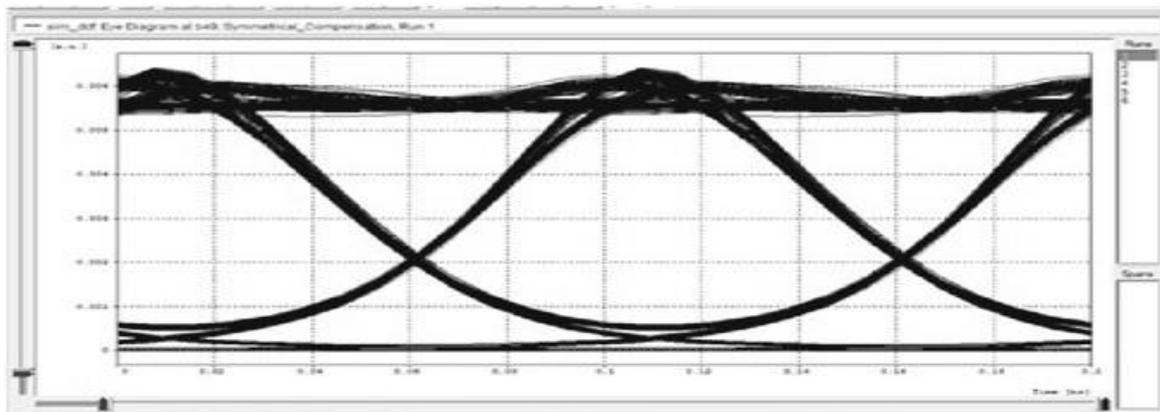


Fig 6: DCF symmetrical compensation eye diagram

EDFA power in terms of eye diagram for post compensation configuration is shown in Fig. 5. Eye opening is defined as the difference between the minimum values of the samples decided as logical one and maximum value of the sample decided as logical zero. For post compensation method, the bit error rate is up to 6 dBm EDFA power and increases slowly on increasing the power further to 12 dBm. EDFA power in terms of eye diagram for symmetrical compensation configuration is shown in Fig. 6. Eye opening is defined as the difference between the minimum values of the samples decided as logical one and maximum value of the sample decided as logical zero. For symmetrical compensation, the bit error rate is minimum indicating the best performance. For EDFA power up to 10 dBm, the bit error rate is but if the power is increased from 10 to 12 dBm, it increases to which is acceptable for high data rate optical transmission.

B. Amplitude Clipping Model - Pre Clipping (PAPR Calculation without Clipping)

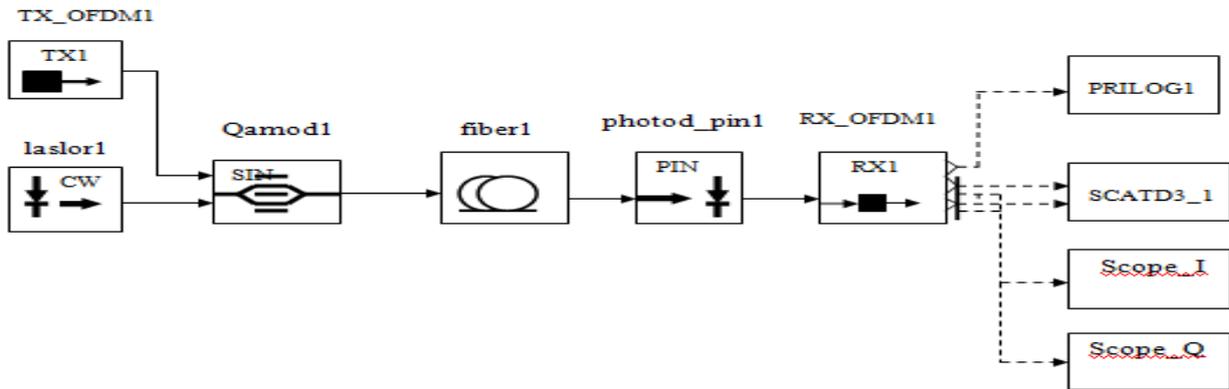


Fig 7: PAPR calculation for optical OFDM before clipping

OFDM model for Pre clipping is as shown in Fig. 7. The length of optical fiber between transmitter and receiver is 10 km. The various scopes are used to view results at transmitter and receiver. PRILOG icon is used to view logical signal and SCATD icon is used to view scattering diagram. Probe is used to view optical spectrum. Scope icon is used to view electrical signal, electrical spectrum, eye diagram. Modulation scheme is QAM, IFFT is used at transmitter and FFT is used at receiver. Laser1 is the laser source whose output is modulated by OFDM signal. Photod_pin1 is PIN photodiode used at receiver to convert optical signal into electrical signal. Here peak to average power ratio (PAPR) is calculated without clipping. Pre clipping logical signal consists of Time along x axis and logic level along y axis. In binary logic the two levels are logical high and logical low, which generally correspond to a binary 1 and 0 respectively. Scattering diagram for Pre clipping is as shown in can suggest various kinds of correlations between variables with a certain interval.

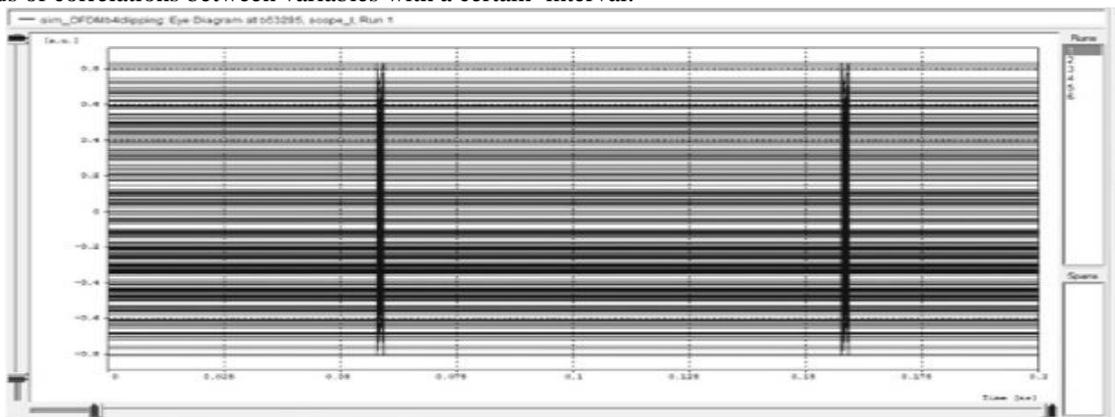


Fig 8: Pre clipping scope I/Q eye diagram

Eye diagram of OFDM model for Pre clipping is as shown in Fig. 8. The length of optical fiber between transmitter and receiver is 10 km. The width of eye opening defines the time interval over which the received wave can be sampled without error due to inter-symbol interference (ISI). Height of eye opening at a specified sampling time defines the margin over noise. The sensitivity of system due to timing error is determined by the rate of closure of eye. To view this eye diagram, scope-I is connected at the output of RX_OFDM at receiver.

Electrical signal of OFDM model for Pre clipping to view this electrical signal, scope I is connected at the output of RX_OFDM at receiver. Frequency is along x axis and amplitude is along y axis. From the plot we can view the maximum and minimum value of signal. To view this eye diagram, scope Q is connected at the output of RX_OFDM at receiver.

C. Amplitude Clipping Model: Post Clipping

OFDM model for Pre clipping is as shown in Fig. 9. The length of optical fiber between transmitter and receiver is 10 km. The various scopes are used to view results at transmitter and receiver. PRILOG icon is used to view logical signal and SCATD icon is used to view scattering diagram. Probe is used to view optical spectrum. Scope icon is used to view electrical signal, electrical spectrum, eye diagram. Modulation scheme is QAM. IFFT is used at transmitter and FFT is used at receiver. Laser1 is the laser source whose output is modulated by OFDM signal. Photod_pin1 is PIN photodiode used at receiver to convert optical signal into electrical signal. Here, peak to average power ratio (PAPR) is calculated after clipping. To clip OFDM signal multiplier block MULTBB1 is used having multiplication constant less than 1.

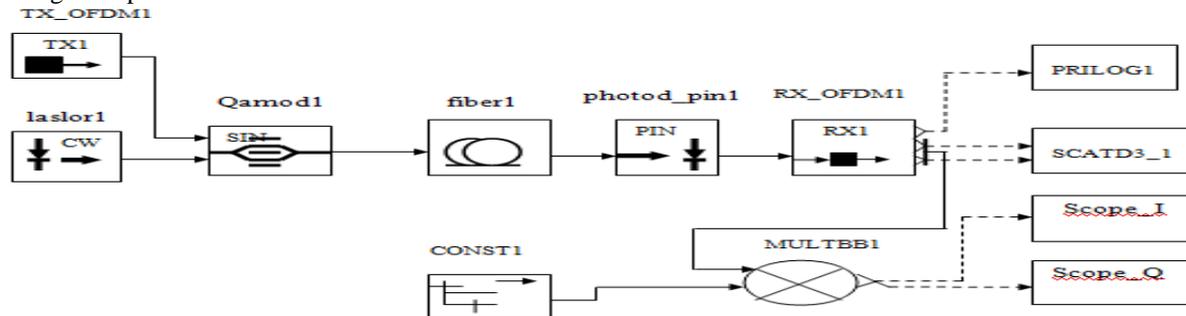


Fig 9: OFDM post clipping

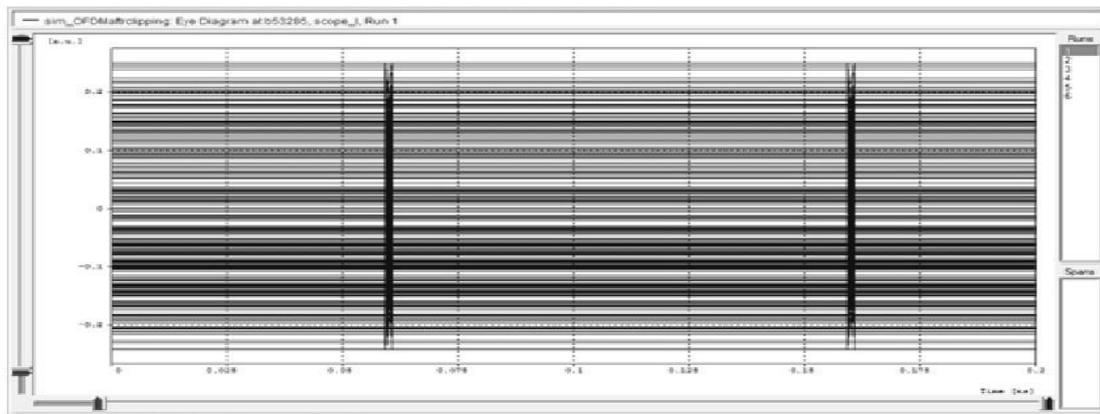


Fig 10: Post clipping scope- I eye diagram

Eye diagram of OFDM model for post clipping is as shown in Fig. 10. The length of optical fiber between transmitter and receiver is 10 km. The width of eye opening defines the time interval over which the received wave can be sampled without error due to inter symbol interference (ISI). The height of eye opening at a specified sampling time defines the margin over noise. The sensitivity of system due to timing error is determined by the rate of closure of eye. To view this eye diagram, scope-I is connected at the output of multiplier at receiver.

D. OFDM Model with 8 Subcarriers

OFDM model for 8 subcarriers is as shown in Fig. 11. The length of optical fiber between transmitter and receiver is 10 km. The various scopes are used to view results at transmitter and receiver. PRILOG icon is used to view logical signal and SCATD icon is used to view scattering diagram. Probe is used to view optical spectrum. SCOPE icon is used to view electrical signal, electrical spectrum, and eye diagram. Modulation scheme is QAM. IFFT is used at transmitter and FFT is used at receiver. Laser1 is the laser source whose output is modulated by OFDM signal. Photod_pin1 is PIN photodiode used at receiver to convert optical signal into electrical signal.



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