PERFORMANCE ANALYSIS OF PAPR REDUCTION TECHNIQUES FOR OFDM SIGNALS IN DVB-T SYSTEM

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Abstract— Digital Video Broadcast-Terrestrial is the most extensively employed standard for terrestrial digital television (TV). The DVB-T system is based on OFDM and it has the problem of high Peak to Average Power Ratio (PAPR). One way to mitigate the high PAPR is by using efficient PAPR reduction techniques. In this paper, we analyze and compare the performance of different PAPR reduction techniques of OFDM based on implementation complexity, bandwidth expansion, BER degradation and data rate loss. Also we investigate the effects of High power amplifier (HPA) and channel noise on the OFDM signals with QAM modulation and Performance study/analysis of selective mapping as a reduction technique for PAPR with phase rotation is carried out using MATLAB 7.10.0(R 2010a).

Index Terms—DVB-T, OFDM, PAPR, QAM, IFFT, BER, DAC, Power Amplifier

1. INTRODUCTION

DVB-T (Digital Video Broadcast-Terrestrial) is the leading standard that offer digital video broadcast by means of different communication technologies [1]. The DVB-T has three modes of operation such as 2k, 4k and 8k modes and each modes is having different number of sub-carriers and different in symbol length. The modeling of a DVB-T is carried out using orthogonal frequency division multiplexing (OFDM) by taking parameters of different value or different modes. The selection of one of the two modes (2k and 8k mode) of operation of DVB-T can be done by terrestrial network operator. In 2k mode, DVB-T uses 1705 carriers and it is appropriate for single transmitter operations with limited transmitter distances and small single frequency networks (SFN). In 8k mode, DVB-T uses 6817 carriers appropriate for single transmitter operations and also for small and large single Frequency networks (SFN). Existing DVB-T modes produce a transport capacity of 5 to 15 Mbps (1-3 Television programs) suitable for mobile receivers [2].

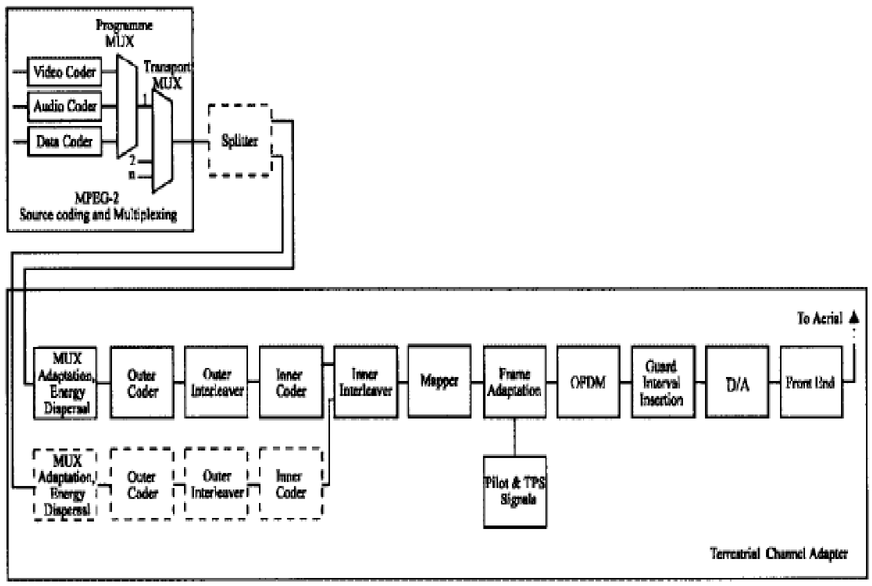

Fig.1. DVB-T transmitter

The DVB-T system utilizes OFDM to transmit the compressed digital audio signal, video signal and data through a MPEG transport stream. OFDM is very much suitable for DVB-T application due to its features like high data rate transmission capability and robustness to multipath delay [3]. Fig.1 shows DVB-T system based on OFDM can be used for both stationery and mobile reception applications [4]. DVB-T permit the efficient use of available radio frequency (RF) spectrum, resulting in superior audio/sound and image quality and also the chance of adding high definition (HD) pictures services [5]. One of the major disadvantages of OFDM based DVB-T is high peak to average power ratio (PAPR). The performances of Power amplifier (PA), A/D (analog to digital) and D/A (digital to analog) convertors as shown in Fig.2 are degraded by high PAPR [6]. The influencing factors such as modulation schemes used are BPSK (Binary phase shit keying), QPSK(quadrature phase shit keying),, 16-QAM(quadrature amplitude modulation), 64-QAM and 128-QAM.

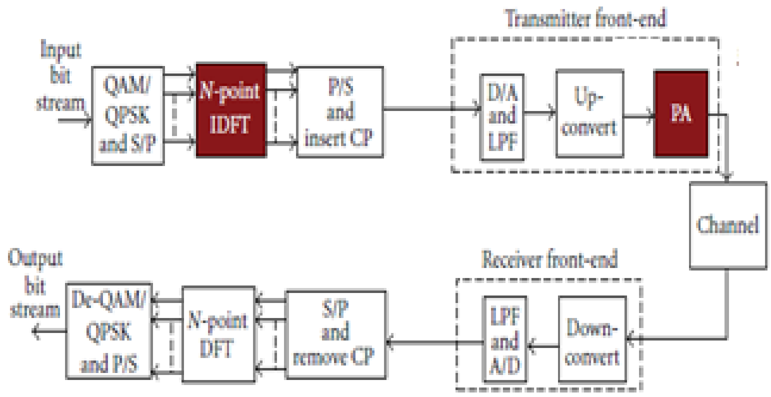

Fig.2 Block diagram of an OFDM transceiver with the Power amplifier, D/A and A/D converter

II. PEAK TO AVERAGE POWER RATIO IN OFDM

In OFDM, the output is the superposition (IFFT operation) of multiple subcarriers. This multiple subcarriers are independently modulated, having different amplitudes and phases. The subcarriers in OFDM signal occupy different spectra in the frequency domain and are transmitted simultaneously [7], [8]. When the subcarriers are coherently added, the OFDM signal instantaneous peak power is much larger as compare to average power and this gives a large PAPR. High PAPR is one of the most serious problems in OFDM based DVB-T system. Transmission of OFDM signals with high PAPR value needs large linear dynamic ranges for power amplifiers, Analog-to-Digital converters and Digital-to-Analog converters. If there are no measures to decrease the high PAPR, OFDM based DVB-T might be having restriction for practical applications. Also High PAPR destroys orthogonality of subcarrier and degrades the performance of OFDM system [9]. Theoretically, the PAPR of OFDM signal is expressed as

$$PAPR = \frac{P_{peak}}{P_{average}} = 10\log_{10}\frac{\max\,[|x_n|^2]}{E[|x_n|^2]} \tag{1}$$

Where P_{peak} denotes peak output power and $P_{average}$ denotes average output power. [·] indicates the expected value, x_n denotes the transmitted OFDM discrete signals which are obtained by taking IFFT(inverse fast Fourier transform) operation on modulated input symbols X_k. Fig.3 shows power samples of one symbol OFDM signal indicating peak power and average power values

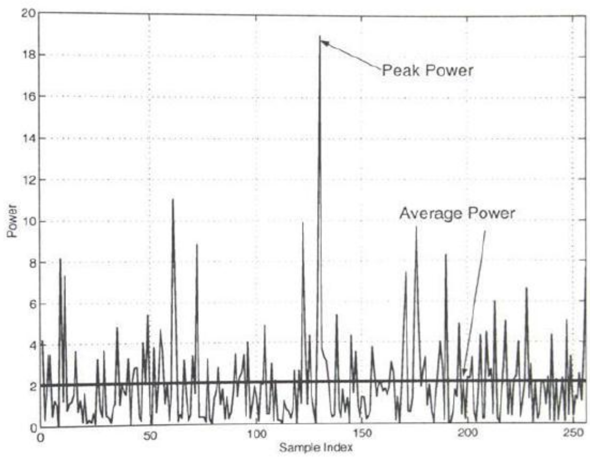

Fig.3 Power samples of one symbol OFDM signal

Mathematically x_n can be expressed as

$$x_n = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} X_k\, W_N^{nk} \tag{2}$$

For an OFDM system with N sub-carriers and when phase values are the same, the peak power of received OFDM signals is an N *time* the OFDM signal's average power. Theoretical, the maximum PAPR of baseband signal is given as $PAPR(dB)$ =10log N.For example, for a 16 sub-carriers OFDM system, the maximum PAPR is $PAPR$(decibels) = 10log16=12dB. However, this is only a theoretical hypothesis. In reality the probability of reaching this maximum is very low.

1. Motivation of PAPR

To combat high PAPR of OFDM signal, one intuitive solution is to adopt power amplifiers to have larger trade-off range. But, these types of power amplifiers are usually costly and having efficiency-price low, and therefore are of no practical use. On the other side, certain algorithms were introduced and been proved to have a good performance of high PAPR reduction. Hence, in this paper, some currently promising PAPR reduction methods are studied and compared. There are a number of techniques for PAPR reduction.

2. Influencing Factors of PAPR

The PAPR of OFDM signal is closely related to different influencing factors such as modulation schemes, number of sub-carriers and oversampling rate.

i. Modulation schemes

The different modulation schemes such as BPSK, QPSK, 16-QAM and 64-QAM with the number of sub-carriers N=128 produces different PAPR performance and have minimum influence on PAPR performance.

ii. Number of sub-carriers

The result of different number of sub-carrier will be different PAPR performances of OFDM due to the varying information carried. When the number of sub-carriers (N = 16, 68, 128, 256 and 1024) increases the PAPR of OFDM will also increase. The maximum PAPR of OFDM signal is $PAPR\,(dB)$ =10log N. For N=16 the $PAPR(dB)$ =10log16=12dB and for N=1024 then $PAPR(dB)$ =10log(1024) = 30.1dB. Hence, the number of sub-carriers is a very key influence factor on the PAPR.

iii. Oversampling rate

In real implementation, continuous-time OFDM signal cannot be expressed exactly because of insufficient N points sampling. Some of the peaks of OFDM signal might be missed and PAPR reduction performance is unduly precise.. To overcome this difficulty, oversampling is generally employed, it can be realized through taking L·N point IFFT/FFT (fast Fourier transform) operations of original data by (L-1)·N zero-padding operation. For a fixed probability, higher oversampling rate will give higher PAPR value and superior PAPR reduction performance. Possible values of oversampling factor L are 1, 2, 4, 8 and 16. But L = 4 are sufficient to capture the peaks. It is important to oversamples OFDM signals by oversampling factor L to get superior value of PAPR.

III. PAPR REDUCTION TECHNIQUES FOR OFDM SIGNALS IN DVB-T SYSTEM

Several PAPR reduction techniques to reduce high PAPR of OFDM signals are proposed in the literature [7], [8], [9]. The PAPR reduction techniques for OFDM signal in DVB-T system can be broadly classified into three main categories.

1. Signal distortion techniques
2. Signal distortion less techniques
3. Coding techniques

1. Signal distortion techniques

Signal distortion techniques reduce the Peak power of OFDM signal but causes distortion of signal prior to passing it through the Power Amplifier (PA). These techniques are useful after the generation of OFDM signal (after the IFFT operations). The signal distortion techniques are as:

i. Clipping and filtering techniques

Clipping technique [10] is the simple and effective for PAPR reduction and in this the high amplitude peaks are clipped off. The process of clipping is nonlinear that leads to in-band and out-of-band distortions which destroy Orthogonality of sub carriers. The effect of out-of-band distortion is spectral spreading and it can be eliminated through filtering the signal after clipping and filtering cannot reduce the bit error rate (BER) performance degradation caused by in-band distortion. However, oversampling through longer IFFT operation can reduce the in-band distortion effect. The iterative clipping and filtering technique reduces the PAPR of signal without spectrum expansion and increases the computational complexity of an OFDM transmitter. The iterative clipping and frequency domain filtering is used to avoid peak re-growth.

ii. Peak Windowing Techniques

Van Nee and Wild proposes a peak windowing technique in which certain window such as Gaussian shaped window, cosine, Kaiser or Hamming window is used to multiple with large single peak to attenuate peak signals. This method removes infrequently occurring of large peaks and causes little interference. Peak windowing technique reduces PAPR of OFDM signal and causes increase in both BER and out-of- band radiation. The peak windowing technique offers better reduction of PAPR through better spectral properties as compare to clipping technique [11], [12].

iii. Envelope Scaling Technique

Foomooljareon P and Fernando W.A.C[13] have been proposed a technique called Envelope scaling. In this technique, the scaling of input envelope of some subcarriers out of 256 is carried out before applying IFFT operation to obtain the minimum PAPR. As the envelopes of all the sub carriers are equal, the receiver of the OFDM system doesn't require any side information for decoding the received sequence. The Envelope scaling technique seems only suitable to PSK (Phase shift keying) s schemes, where all the envelope of all subcarriers input are equal. When the OFDM system implements the QAM modulation scheme, the carrier envelope scaling will result in the serious BER degradation. To limit the BER degradation, amount of the side information would also be excessive when the number of subcarriers is large.

iv. Peak Reduction Carrier Technique

Tan and Wassell, [14] have proposed a peak reduction carrier(PRC) technique in which the data bearing peak reduction carriers are used to reduce the PAPR of OFDM signal. In this technique the higher order modulation scheme is used to represent a lower order modulation symbol. In PSK modulation schemes the envelope of all the subcarriers are same so it is very much suitable for peak reduction carrier. But use of QAM Scheme will increases the probability of error and results in serious BER performance degradation. Consequently there exists a tradeoff between reduction of PAPR of signal and BER performance while selecting the constellation of the PRCs.

v. Random Phase Updating Technique

The random phase updating algorithm is proposed by Nikookar and Lidsheim, [15] for the peak to average power ratio reduction of the OFDM signal. In this algorithm, a random phase is generated and allocated for each carrier. The random phase update is continuously done until the peak value of the signal is under the threshold value. The threshold can be dynamic and the number of iterations for the random phase update is limited. After each random phase update, the PAPR is calculated and the iteration is continued till the minimum threshold level is achieved or the maximum number of iterations has been reached. The phase shifts have to be known at the transmitter and the receiver. In this scheme, the BER performance won't degrade only if the receiver knows all the phase changes. This implies a large amount of side information. The efficiency of the algorithm is mainly related to the selected threshold level and consequently number of iterations and not the number of carriers. The algorithm can be improved using the quantization and grouping of phases, and with dynamic threshold.

vi. Companding Techniques

In Companding techniques [16], [17], the signal is compressed on the transmitter side and expanded on the receiver side. Companding techniques are commonly used to provide higher resolution for lower amplitude signals and lower resolution for higher amplitude signals. There two companding techniques one is µ-law companding and another is A-law companding for PAPR reduction. The companding techniques are simple to implement and has low complexity, while providing better performance of the DVB-T system. The commanding techniques have better performance gain for the 8k mode, where the decrease of the BER is larger in comparison to the 2k mode. The utilization of the companding techniques can lead to decreased BER for the right choice of the companding profile. The A-law companding technique gives slightly better results than the µ-Law companding technique. The µ-Law companding may introduce companding noise because of peak regrowth after DAC to cause in-band distortion and out-band noise. Another disadvantage of companding technique is the quantization error which is considerably large for large signals and degrades the OFDM system BER performance. Consequently, there is tradeoff between PAPR and BER performance of the OFDM system.

2. Signal Distortion less Techniques

These techniques are also called as signal scrambling techniques. The techniques like selective mapping (SLM), Partial Transmit Sequence (PTS), Interleaving Technique, Tone Reservation (TR), and Tone Injection (TI) are Signal distortion less Techniques.

i. Selective mapping (SLM)

In 1996 Bauml, Fischer and Huber have introduced the first SLM scheme [18].The basic principle of SLM technique is phase rotation. The basic concept of SLM technique is first generate a number of alternative OFDM signals from the original data block and then select the OFDM signal with minimum PAPR value for transmission. This SLM technique can reduce PAPR considerably. SLM is an effective and distortion less technique used for the PAPR reduction in OFDM. The two basic disadvantages for this technique are increase circuit complexity due to the multiple numbers of IFFT operations at the transmitter side and also there is data rate loss [19].

ii. Partial Transmit Sequence (PTS)

Müller S H, Huber J B have been proposed the partial transmit sequence (PTS) algorithm in 1997 [20], which is a technique for improving the statistics of a multi-carrier signal. The basic idea of PTS technique is to divide the input data block of N symbols into non-overlapping sub blocks and each sub block is weighted by a statistically independent phase factor. The phase factors are chosen such that the PAPR value of the combined signal is minimized. The phase factor is also transmitted to the receiver as side information. When differential modulation is employed in each sub block, no side information needs to be transmitted to the receiver [21]. PTS scheme can be interpreted as a structurally modified case of SLM scheme and, it is found that the PTS scheme performs better than SLM schemes. But by using this technique there will be data rate loss.

iii. Interleaving Technique

Jayalath and Tellambura, [22] proposes interleave based technique for reducing the PAPR of an OFDM signal. The low threshold value will force the adaptive interleaving to search for all the interleaved sequences, while for the large threshold value, adaptive interleaving will search only a fraction of the interleaved sequences. The interleaved technique is distortion-less but it requires transmission of side information causing reduced bandwidth efficiency. The adaptive interleaving technique is less complex than the PTS technique but achieves comparable results. The scheme does not provide the guaranteed PAPR reduction and for the worst case PAPR value of N. Therefore, higher order error correction method should be used in addition to this scheme.

iv. Tone Reservation (TR)

The basic concept of Tone reservation technique[23] is to reserve a small set of tones having low signal to noise ratio (SNR) for PAPR reduction. These tones don't carry information data and are added to the original OFDM symbols so that the summation has minimum PAPR values. The amount of PAPR reduction will be based on the numbers of reserved tones, their location within the frequency vector, and the amount of complexity. Optimizing set of peak reduction tones increases the complexity of transmitter and also increases required transmission power. The advantages of TR technique are less complex, no special receiver operation, and no need for side information.

v. Tone Injection (TI)

In Tone Injection (TI) technique[24] the constellation size is increased by mapping the points from original constellation into several equivalent points in the expanded constellation to reduce PAPR of OFDM signal. This process is equivalent to injecting a tone of the suitable frequency and phase in the OFDM signal, so this technique is known as tone injection. Tone Injection technique reduces PAPR of OFDM signals without data rate loss. The drawbacks of this technique are requirement of side information to the receiver for decoding the signal and additional IFFT operation.

vi. Active Constellation Extension (ACE) technique

Knongold and Jones [25] propose an Active Constellation Extension (ACE**)** technique for PAPR reduction which is similar to Tone Injection Technique. The only difference is that in ACE technique, PAPR of data block is reduced by dynamically extending the outer signal constellation points away from the original constellation and it increases the spacing between the constellation points. Poor BER performance due to clipping used in ACE and gives a generalization of the ACE constraints to limit BER degradation. The pre-distortion technique in place of clipping based ACE (CB-ACE), the metric pre-distort those frequency domain symbols which have large contribution to output thus the PAPR. An adaptive clipping control algorithm is used to achieve better PAPR as compared to clipping based ACE at reduced number of iterations. In this way ACE offers dual advantage of BER and PAPR reduction. Side information transmission is not required in this technique and hence there is no data rate loss. Only the drawback of this scheme is that it increases the requirement of transmission power.

3. Coding Techniques

The basic concept of coding technique is to choose a set of codeword for reducing the PAPR of OFDM signal. The coding technique uses forward error correction (FEC) codes for PAPR reduction and these codes are classified as block codes and run length codes. In block codes, a block of data bits are used together to encode them and while the run length codes utilizes memory and lower values of n. The block codes which are used for PAPR reduction are linear block codes, Golay complementary codes, Reed Mullar, Bose Chaudhari Hochquenghem (BCH), low density parity check (LDPC) and Turbo codes which are derived from convolution codes. Coding techniques suffers from a key problem of exhaustive search to find a suitable code which can reduce PAPR but at the same time these techniques are restricted to small number of subcarriers due to high complexity of encoders and decoders. These techniques find it difficult to exploit the error correction capability and PAPR reduction simultaneously.

i. Linear Block Coding

E. Jones, T. A. Wilkinson and S. K. Barton have been proposed a simple linear block coding in which 3-bits are mapped into 4 -bits through adding a parity bit. A simple rate- ¾ cyclic code [26] is designed for any number of subcarriers namely a multiple of 4 to reduce PAPR of signal by more than 3 Db. A combined (8, 4) LBC [27] is used to give error control capability and reduce PAPR of a OFDM by 4 dB. Another simple LBC based on the observation [28] that despite of the number of subcarriers, codewords by means of equal odd and even bit values have high PAPR. Therefore by adding a simple bit code, the codewords are eliminated and this results in reduction of PAPR of signal. The basic concept of low complexity block coding technique [29] is that in the middle of information bits a few complement bits are inserted to design the codeword and this technique reduces PAPR.K. Yang and S. Chang [30] have been proposed a standard arrays of linear block codes for reduction of PAPR of OFDM signal. This technique is known as a modified version of SLM.

In this scheme, scrambling is performed using co-set leaders of linear block, thus there is no need of transmitting side information and the syndrome decoding is used to decode received signal. The fountain codes [31] are used for controlling of PAPR of OFDM system. The primary practical application of fountain codes are Luby Transform (LT) codes [32] and later a Raptor codes is proposed for additional enhancement [33]. The motivation of this scheme is to generate OFDM packets having best fountain coded with a low PAPR.

ii. Golay Complementary Sequences

Golay codes are used for PAPR reduction using various modulation methods like 16-QAM and 64-QAM. Golay Complementary Sequences are used as codewords for modulation of OFDM symbols subcarriers and attaining a maximum PAPR value of 2. In [34], relation among Golay complementary sequences and second order Reed Mullar code [35] is exploited to achieve minimum PAPR of approximately 3dB.

iii. Turbo Coding

Turbo codes are very popular for capacity approach coding and these codes are also being used for reduction of PAPR. In [36], three turbo coded OFDM system for reduction of PAPR were proposed, first using m-sequences for reduction of PAPR of OFDM signals and short codes for side information, second utilizes interleaving and third is combination of first two techniques. A tail-biting turbo coded OFDM is proposed in [37] to produce candidates in a selective mapping technique, without require of side information protection.

iv. Bose Chaudhari Hochquenghem (BCH)

In [38], dual BCH codes are proposed to reduce PAPR of OFDM. In BCH coding scheme, turbo structure can be used to fill the gap in Shannon limit and PAPR improvement of 7 dB is achieved. BCH codes don't need practical realizable decoders and it works much below the Shannon limit.

v. Low Density Parity Check (LDPC)

R.G. Gallanger was first to invent LDPC codes [39]. LDPC codes dominated the forward error correction codes in terms of error correction capabilities. In [40] the authors proposed the LDPC code technique as an alternate to turbo coding to achieve good error correction performance and to reduce the PAPR in an OFDM system.

IV. SIMULATION OF OFDM SYSTEM AND SLM WITH PHASE ROTATION

1. Simulation of OFDM system

In this section, we investigate the effects of High power amplifier (HPA) and channel noise on the OFDM signals[41] with QAM modulation using MATLAB 7.10.0(R 2010a). Table I shows the parameters used for simulations.

Parameters	**Values**
Input	Random data
QAM signal constellation	M = 16
Number of data points	64
Block size	8
Number of IFFT points	8
Number of FFT point	8

TABLE I Simulation parameters

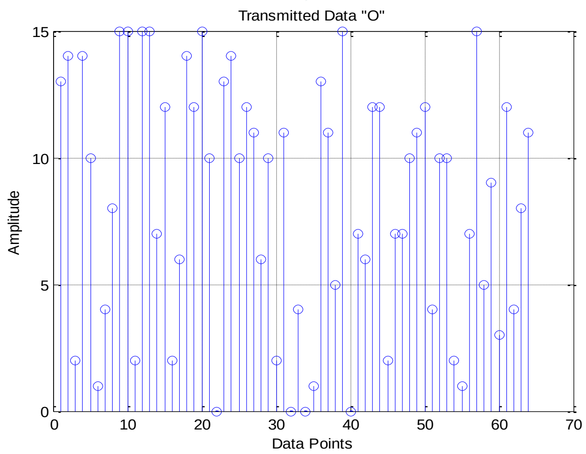

Fig.4 Transmitted data

Fig.4 shows the input random data consisting of 64 data points. Fig.5 shows the 16 constellation points of QAM modulation for modulated transmitted data. Fig.6 shows the generated OFDM signal in time domain without noise effect.

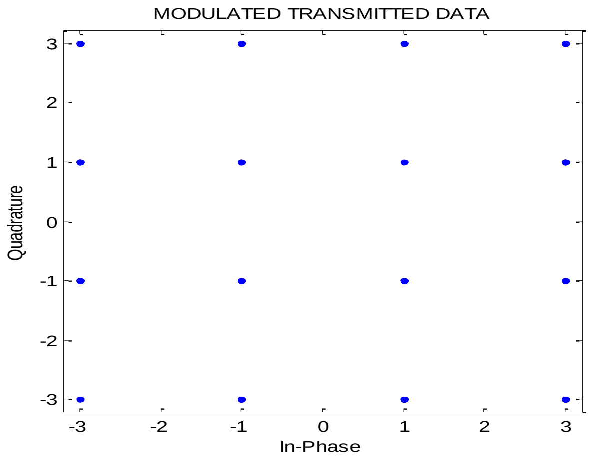

Fig.5 Modulated transmitted data

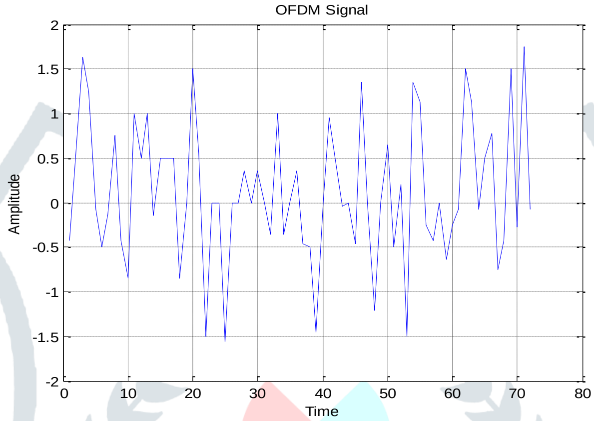

Fig.6 OFDM signal in time domain

To show the effect of the Power Amplifier, random complex noise is added when the power exceeds the average value, otherwise it adds nothing. Fig.7 shows the result of effect of high power amplifier on the OFDM signal.

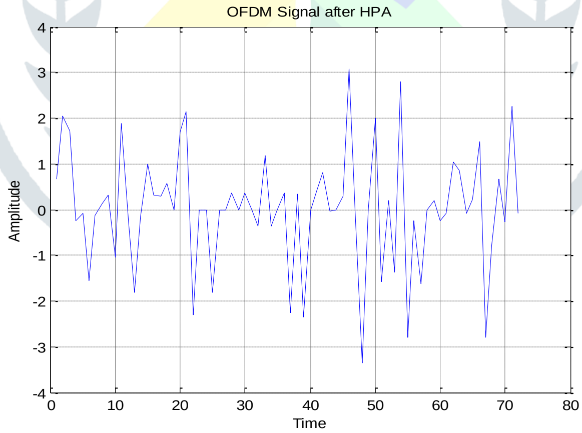

Fig.7 OFDM signal after HPA

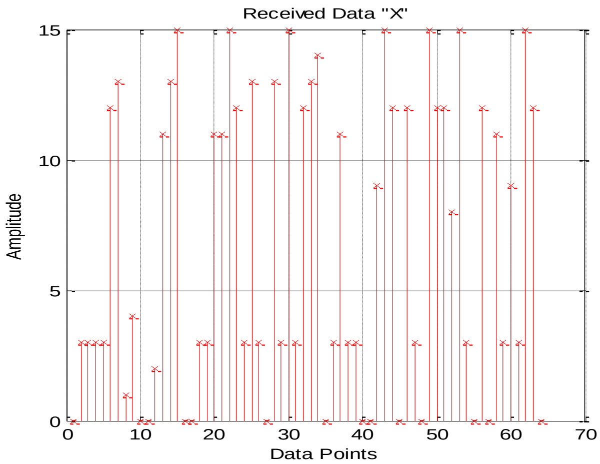

Fig.8 Received data

2. Simulation of Selective mapping with Phase rotation

Performance study/analysis of selective mapping (SLM) as a reduction technique [42] for PAPR with phase rotation is carried out using MATLAB 7.10.0(R 2010a).

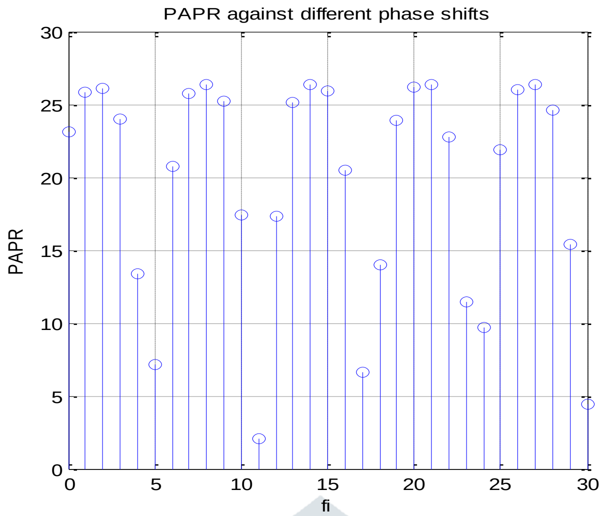

Fig.9 PAPR against different phase shifts

From the graph of Fig.9 it's clear that 11 degrees is the optimum phase shift that gives the least PAPR (2.0623 db). The subcarriers of OFDM signal are modulated by using QAM. Total sub carriers used are 16.

Fig.10 OFDM signal with phase shift 11

A simulation result shows that SLM with phase rotation is most effective method to mitigate PAPR of OFDM signal to large extent and also improve BER performance of the system. Phase rotation techniques are the best solution for PAPR reduction of OFDM signal in DVB-T system**.** The basic principle of SLM and PTS techniques is phase rotation.

V. OVERALL ANALYSIS OF PAPR REDUCTION TECHNIQUES

The factors that must be considered while selecting a specific technique for peak power reduction of OFDM signal in DVB-T system are

i. Capability of PAPR reduction
ii. Power increase in the transmit signal
iii. BER increase at the receiver
iv. Loss in data rate and
v. Computational complexity increase

The other factors that should be considered are the effect of transmitter filter, D/A converters and power amplifier present in the OFDM transmitter. In practice, reduction of PAPR techniques for OFDM must be used on careful analysis of performance and also cost for realistic environment.

TABLE I Comparison of Different PAPR Reduction Techniques for OFDM signals in DVB-T systems

PAPR reduction technique	**Distortion**	**Power Increase**	**Data Rate loss**	**Implementation Complexity**	**Bandwidth Expansion**	**BER Degradation**
Clipping and filtering	Yes	No	No	Low	No	Yes
Interleaving	No	No	Yes	Low	Yes	No

SLM	No	No	Yes	High	Yes	No
PTS	No	No	Yes	High	Yes	No
Coding	No	No	Yes	Low	Yes	No
Tone Reservation (TR)	No	Yes	Yes	High	Yes	No
Tone Injection (TI)	No	Yes	No	High	Yes	No
Active Constellation Extension	No	Yes	No	High	Yes	No

Hence, an efficient PAPR reduction must be the minimum possible value of PAPR of OFDM signals whereas keeping a minimal level BER. In Table II, we summarize the eight typical PAPR reduction techniques based on the theoretical analysis and simulation results.

VI. CONCLUSION AND FUTURE WORK

In this paper, we have analyzed and made overall comparison of various PAPR reduction techniques for OFDM signals in DVB-T system for different parameters successfully. Also we have investigated the effects of HPA and channel noise on the OFDM signals with QAM modulation and performance study/analysis of selective mapping as a reduction technique for PAPR with phase rotation is carried out using MATLAB 7.10.0(R 2010a) successfully. The simulation results indicate that selective mapping with phase rotation technique is the best solution for PAPR reduction of OFDM signals in DVB-T system.

In future work, we implement and simulate phase rotation techniques such as Selective mapping (SLM) and Partial transmit sequence (PTS) for OFDM signals in DVB-T system with input: image, audio and video signal using MATLAB tool. The performance analysis and comparison of PTS and SLM is also carried out.

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