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# An Efficient Zadoff-Chu Based Communication System

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**Abstract:** Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique in which the subcarriers are orthogonal to each other. OFDM provides high data rate, resistance to multipath fading. OFDM provides an effective and low complexity means of eliminating inter symbol interference for transmission over frequency selective fading channels. OFDM is becoming widely applied in wireless communications systems like digital audio broadcasting (DAB) systems, digital video broadcasting (DVB) systems, digital subscriber line (DSL) standards, and wireless LAN standards. Signal to noise ratio is used as an indicator for evaluating the quality of communication. So it is very important to estimate the SNR value for the modern wireless communication. By introducing a specific pilot sequence built from ZC sequences, pilot can be used as synchronizing mechanism in time domain as well as channel estimation. In this paper OFDM Systems with Zadoff-Chu pilots is proposed. Also Selected Level Mapping (SLM) and Clipping and Filtering techniques have been used for Peak-to-Average Power Ratio (PAPR) reduction, since high PAPR of the transmit signal is considered to be one major drawback of OFDM systems. The proposed system can be used for providing better performance of the communication systems.

**Keywords:** OFDM, Zadoff-Chu, PAPR, SLM, Clipping and Filtering.

## I. INTRODUCTION

Wireless systems requires high data rates with low delay and low bit-error-rate (BER). Orthogonal Frequency Division Mutipexing (OFDM)) is being widely used in wireless communications systems owing to its high rate transmission capability with high bandwidth efficiency and robustness agianst multi-path fading and delay. OFDM eliminates inter symbol interference in transmission over frequency selective fading channels. The radio channel is usually frequency selective and time variant. So OFDM has an important role in wireless communication area.

For any communication system, synchronization and channel estimation are essential for detection and initiating the receiver operation. Also help to compensate the radio frequency effects introduced by the channel. Synchronization is usually done through the correlation with a known sequence or by exploiting the known property of the transmitted signal. Channel estimation [2] is usually performed by measuring the degradation of a pre-known sequence. For OFDM systems these sequences are called pilots.

In broadcast standards, the synchronization sequences are positioned in a fixed location inside the frame called "preamble" (usually at the beginning) and repeated each transmitted frame. It contains the synchronization sequence, signaling, pilot structure and RF information. This information is needed for the proper correction and decoding of the payload data. If ZC sequences are used as pilots, then the same can be used for synchronization in time domain as well as for channel estimation.

The proposed system based on modified ZC sequence [1] requires no overhead compared to the normal broadcasting scattered pilot patterns, and also reduces or eliminates the need of a Preamble symbol at the beginning of each frame, which inturn increases the throughput.

## II. OFDM

OFDM is a method of encoding digital data on multiple carrier frequencies. OFDM is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. So in OFDM the sub-carrier frequencies are chosen so that the sub-carriers are orthogonal to each other.

Each subcarrier in an OFDM system is a sinusoid with a frequency that is an integer multiple of fundamental frequency. Each subcarrier can be expressed as a Fourier

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series component of the composite signal, i.e. an OFDM symbol. The sum of these subcarriers is then referred to baseband OFDM signal.

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization filters.

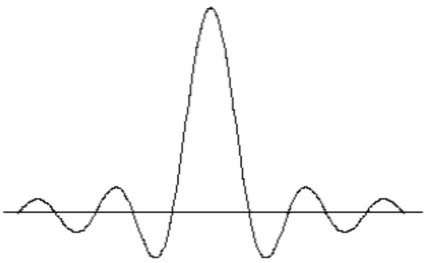

Fig.1 Spectrum of an OFDM subcarrier

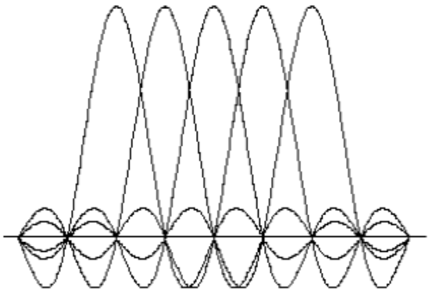

Fig.2 OFDM spectrum

The cross-talk between the sub-channels is eliminated and inter-carrier guard bands are not required. This greatly simplifies the design of both the transmitter and the receiver. Also a separate filter for each sub-channel is not required as in the case with normal FDM.
OFDM has become a promising scheme for wideband digital communication, used in applications such as digital television and audio broadcasting, DSL Internet access, wireless networks, 4G mobile communications etc.

## III. ZADOFF-CHU SEQUENCES

A Zadoff–Chu (ZC) sequence, also referred to as Chu sequence or Frank–Zadoff–Chu (FCZ) sequence, is a complex-valued mathematical sequence which, when applied to radio signals, gives rise to an electromagnetic signal of constant amplitude, whereby cyclically shifted versions of the sequence imposed on a signal result in zero correlation with one another at the receiver. A generated Zadoff–Chu sequence that has not been shifted is known as a "root sequence".

ZC sequences exhibits the property that cyclically shifted versions of itself are orthogonal to one another if each cyclic shift is greater than the combined propagation delay and multi-path delay-spread of that signal between the transmitter and receiver, in the time domain.

ZC sequences are used in the 3GPP LTE [3] air interface in the Primary Synchronization Signal, random access preamble, uplink control channel, uplink traffic channel and sounding reference signals . The spectrum of the ZC sequence is shownn Fig.3.

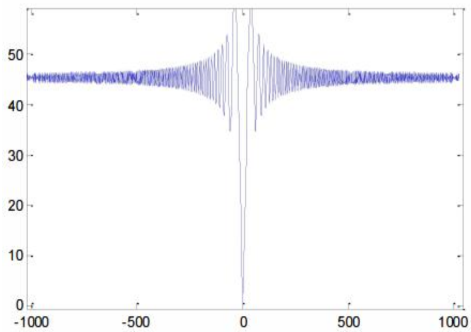


Fig.3. Spectrum of the ZC sequence

Two modifications are required for using this spectrum as pilot. One is a spectrum that is constant in the centre is needed. For this the spectrum is shifted by letting the carriers having amplitude near zero be on the side lobes as shown in Fig. 4.

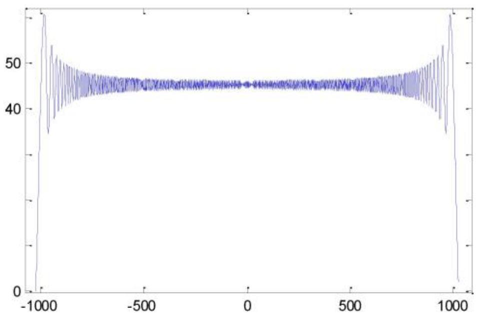


Fig.4. Spectrum of the ZC sequence with FFT shift.

The second modification is to create three cells equal to zero (to carry data) for every cell used by the pilot and spreading the overall spectrum over an 8k symbol. For this the time domain sequence obtained from the IFFT of the previous spectrum (Fig. 2.) is repeated four times.

## IV. PAPR

High Peak to Average Power Ratio of the transmitted signal is one of the major drawbacks of OFDM which causes no-linearity in the receiver side. PAPR gives the relation between the maximum power of a sample in an OFDM transmit symbol and the average power of that OFDM symbol and is defined as the ratio of the square of the maximum power to the square of the average power of the signal.

$$\mathrm{PAPR} = \frac{\max |x(t)|^2}{E|x(t)|^2}$$

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Since OFDM contains more subcarriers, there will be peaks in the signal spectrum when majority of the subcarriers align themselves in phase. These large peaks cause saturation in power amplifiers, leading to intermediation products among the subcarriers and disturbing out of band energy. Also increases the complexity in the analog to digital and digital to analog converter. Therefore, it is desirable to reduce the PAPR.

## V. PAPR REDUCTION

Several techniques are there such as Selected Level Mapping (SLM), clipping and filtering, coding, peak windowing, Tone Reservation[8], Partial Transmit Sequence[7] etc to reduce the PAPR. In this paper SLM and clipping and filtering techniques have been used and compared for the PAPR reduction in OFDM system based on ZC pilots.

In SLM technique [5] whole set of signal represent the same signal but form it most favorable signal is chosen related to PAPR transmitted. The side information must be transmitted with the chosen signal. This technique is probabilistic based.
In selected mapping method, firstly M statistically independent sequences which represent the same information are generated and next the resulting M statistically independent data blocks are then forwarded into IFFT operation simultaneously. Finally, at the receiving end, OFDM symbols in discrete time-domain are acquired, and then the PAPR of these M vectors are calculated separately. The sequences with the smallest PAPR will be elected for final serial transmission. The main drawback is that side information must be transmitted along with chosen signal.

One of the simple PAPR reduction techniques is clipping, which cancels the signal components that exceed some amplitude level called clip level. But clipping yields distortion power, called clipping noise, and expands the transmitted signal spectrum, which inturn causes interfering. Clipping is nonlinear process and causes in-band noise distortion, which causes degradation in the performance of bit BER and out-of-band noise, which decreases the spectral efficiency. Clipping and filtering technique[6] is effective in removing components of the expanded spectrum. Although filtering can decrease the spectrum growth, filtering after clipping can reduce the out-of-band radiation, but may also cause some peak re-growth, which the peak signal exceeds in the clip level. The technique of iterative clipping and filtering reduces the PAPR without spectrum expansion.

## VI. SIMULATION RESULTS

Implemented a basic OFDM system, ZC generator and OFDM system using ZC pilots in Matlab platform. Different modulation schemes have been considered chosing AWGN channel.

The PAPR problem is reduced using various techniques like SLM and Clipping and filtering and it is seen that clipping and filtering method provides more reduction in PAPR.

The fig.5 shows the BER Vs SNR for an OFDM system with 16-QAM modulation and constellation diagram is shown in Fig.6

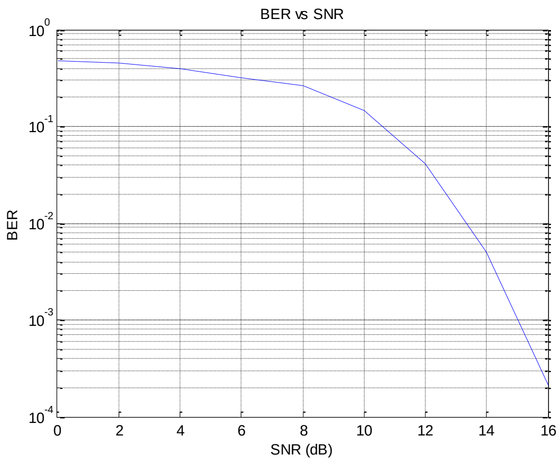


Fig.5 BER Vs SNR over AWGN channel using 16 QAM

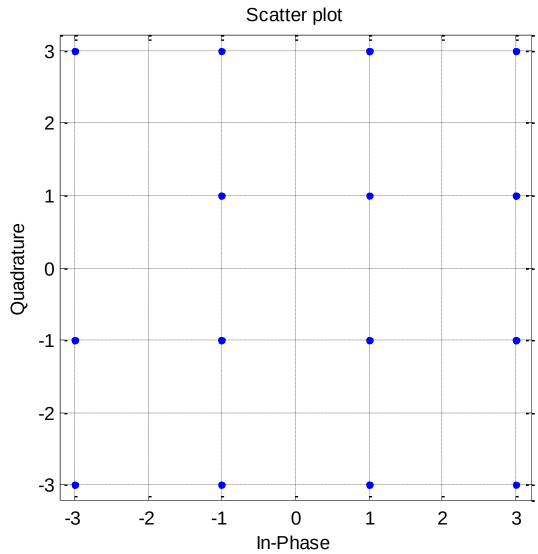


Fig.6 16-QAM constellation signal

The following plots are the simulated results for the generation of ZC Sequence and its use as pilot. For simplicity, the base sequence is assumed to be a simple bandwidth limited ZC sequence with expression

$$ZC_{u,q,N}(n) = e^{-j\pi\frac{un\,(n+1+2q)}{N}}$$

where $0 \leq n \leq N$,
$0 < u < N$,
$q \in Z$,
N= length of sequence.

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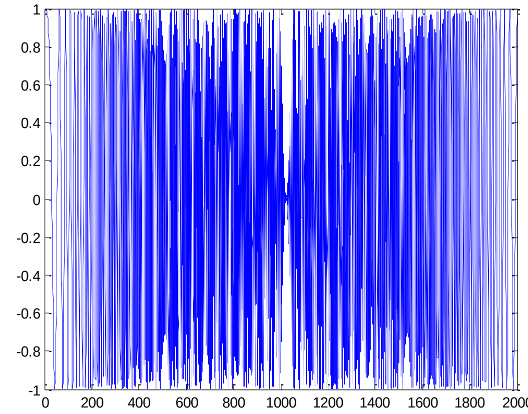

Fig.7 Real part of ZC sequence with n= 2048, u= 1, q=0

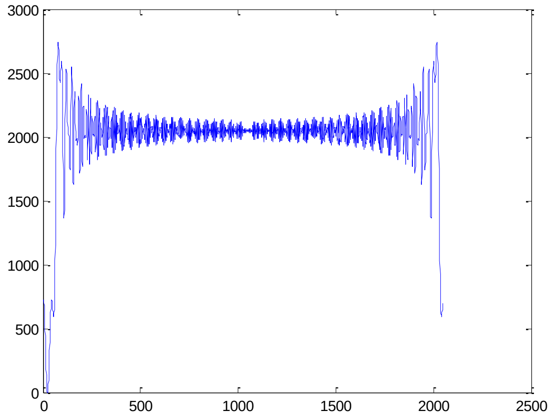

Fig.8 Spectrum of the ZC sequence with FFT shift

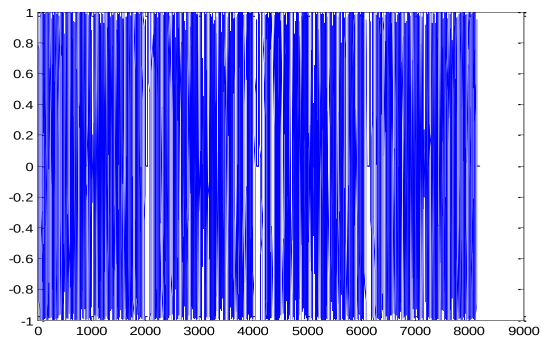

Fig. 9 ZC sequence repeated four times

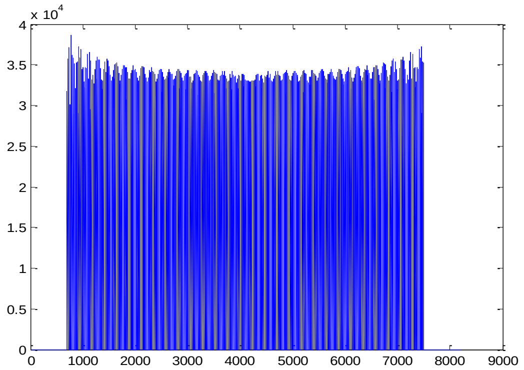

Fig. 10 ZC only pilot structure

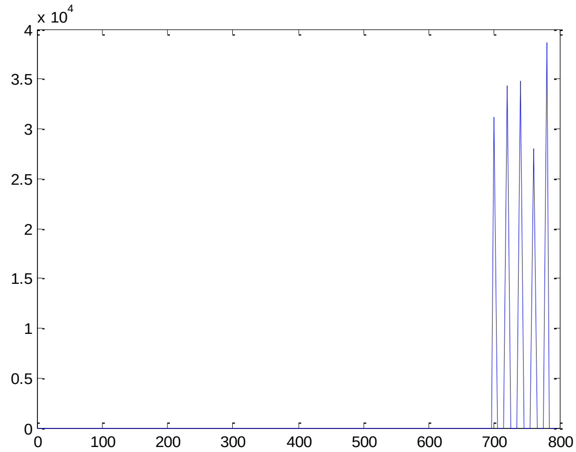

Fig.11 Pilot sequence occupies one cell in four leaving the remaining cells for data

The following plots show the simulated results for the transmission of OFDM signal with ZC as pilot. Here modulation chosen is QPSK with IFFT size 2048, No. of carriers 1000

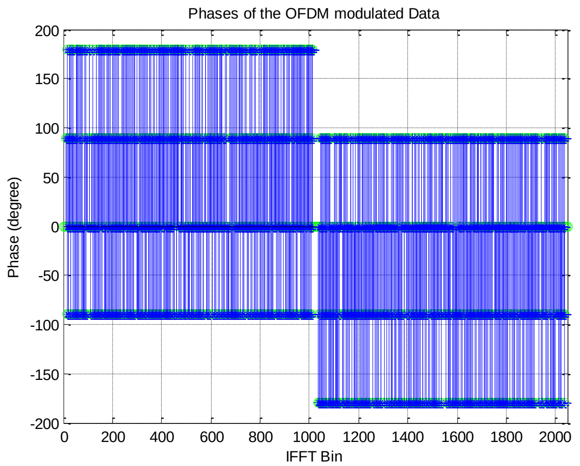


Fig.12 Phases of the OFDM modulated data

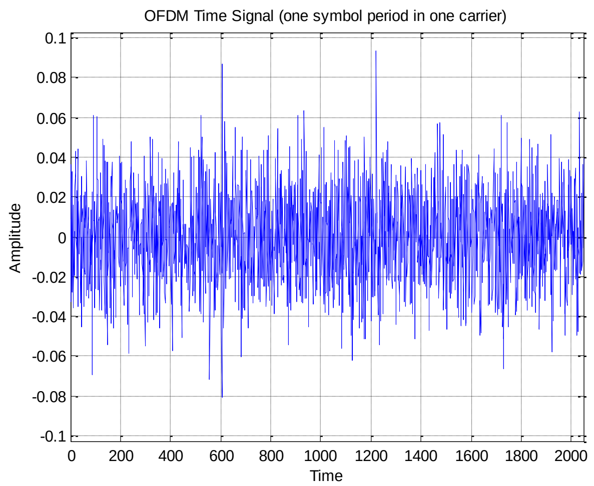


Fig.13 OFDM signal (one symbol period in one carrier)

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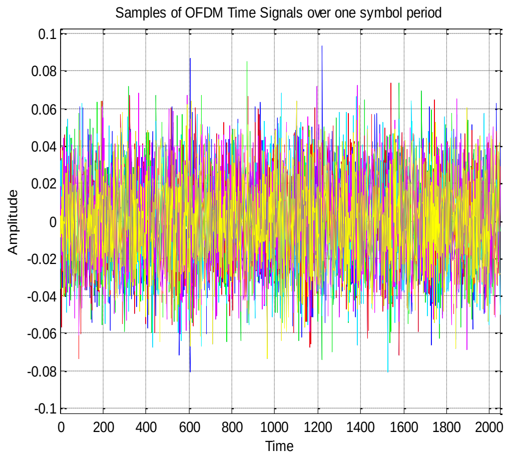


Fig.14 Samples of OFDM signals over one symbol period

The plots below show the simulated results for PAPR reduction in OFDM using SLM and Clipping and filtering.

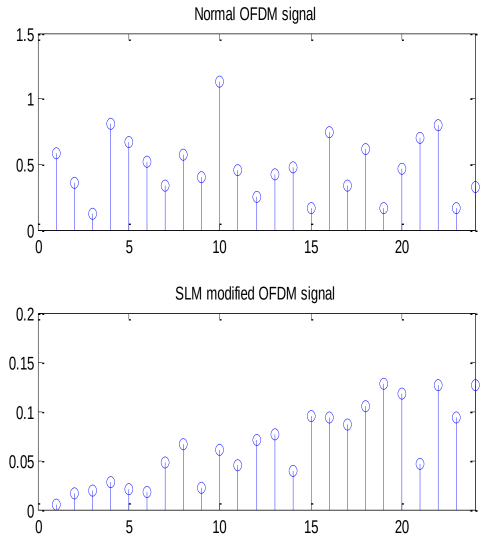


Fig.15 Normal OFDM and SLM modified OFDM

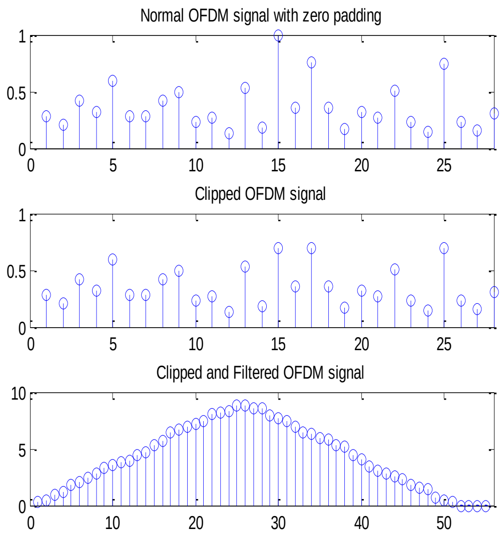


Fig.16 Clipped and Filtered OFDM

The simulated results for OFDM- ZC reception are shown below

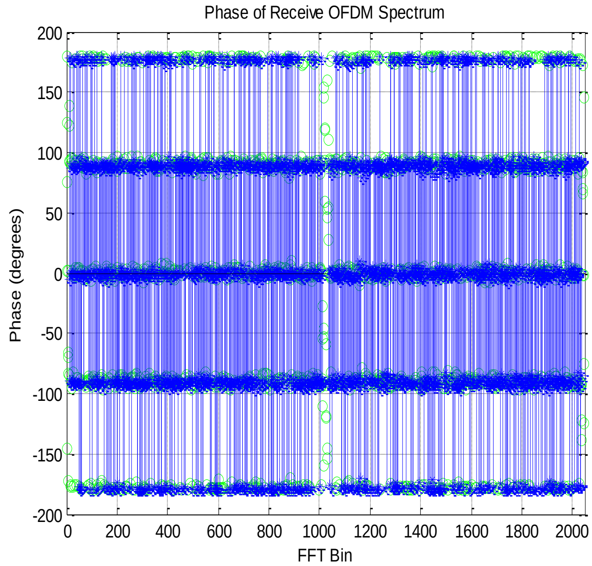


Fig.16 Phase of received OFDM spectrum

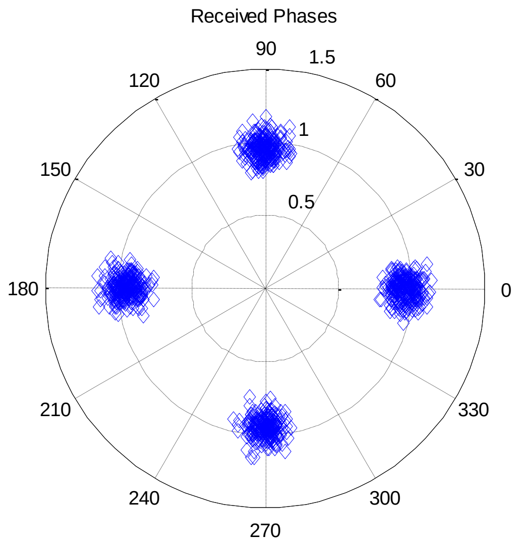


Fig.17 Polar plot for the received phases

## VII. CONCLUSION

In this paper, an OFDM system based on ZC pilot has been proposed and implemented in Matlab platform. QPSK modulation is chosen and corresponding plots are seen considering AWGN channel. PAPR reduction is achieved through SLM and Clipping and filtering techniques. The comparison shows clipping and filtering provides more reduction in PAPR. Other modulation shemes such as QAM, BPSK can also be considered according to the broadcasting standard. So the proposed system is found to be an efficient scheme for the wireless communication system, which provides better performance.

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