Design of Simulink Model for Constant Envelop OFDM and Analysis of Bit Error Rate

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Abstract— This paper describes a transformation technique aimed at solving the peak-to-average power ratio (PAPR) problem associated with OFDM (Orthogonal Frequency Division Multiplexing). The Constant Envelop-OFDM solves the problem of high peak-to-average power ratio (PAPR) in OFDM, reducing PAPR to 0 dB. The constant envelope signal can be efficiently amplified with nonlinear power amplifiers thus achieving greater power efficiency. It is shown that CE-OFDM's performance is better than conventional OFDM when taking into account the effects of the power amplifier. The performance of CE-OFDM is analyzed in additive white Gaussian noise (AWGN) channel. CE-OFDM is shown to achieve good performance with the use of cyclic prefix transmission. By way of computer simulation, CE-OFDM is shown to compare favorably to conventional OFDM. OFDM and CE-OFDM is analyzed on grounds of BER with additive white Gaussian noise (AWGN). The BER is calculated and the performance of OFDM and CE OFDM is compared.
Key words: OFDM, AWGN, BER

I. INTRODUCTION

Currently, OFDM is of great interest by the researchers in the Universities and research laboratories all over the world. The Orthogonal Frequency Division Multiplexing (OFDM) digital transmission technique has several advantages in broadcast and mobile communications applications. It supports high data rates, has high bandwidth efficiency, low implementation complexity and is robust against frequency selective fading or narrowband interference. OFDM primarily has two drawbacks. The first drawback is that OFDM is more sensitive to frequency offset and phase noise. The second drawback is that the OFDM has a relatively large peak-to-average power ratio (PAPR), which tends to reduce the power efficiency of the RF amplifier. The occurrence of large signal peaks substantially complicates implementation of the analog radio frequency front end at the transmitter side since amplifiers operating linearly over a wide dynamic range have to be employed. The power amplifier cannot work in the saturation region, influencing the volume and efficiency of power amplifier. Without sufficient power back off, the system suffers from spectral broadening, inter-modulation distortion, and, consequently performance degradation. High levels of back off reduce the efficiency of the PA. This is a particularly detrimental problem for mobile battery-powered devices due to limited power resources. A new PAPR mitigation technique is presented. The Constant Envelop-OFDM solves the problem of high peak-to-average power ratio (PAPR) in OFDM, reducing PAPR to almost 0 dB. The constant envelope signal can be efficiently amplified with nonlinear power amplifiers thus achieving greater power efficiency. CE-OFDM's performance is better than conventional OFDM when taking into account the effects of the power amplifier. The technique is based on signal transformation, and is a combination of conventional OFDM and constant envelope modulation technique. Its essence is the phase transformation prior to the amplifier at the transmitting terminal, and the inverse transformation (phase demodulation) before conventional OFDM demodulator. The goal of the current paper is to extend the basic concept of transmitting OFDM by way of phase modulation. The CEOFDM system described shares many of the same functional blocks as conventional OFDM. Therefore an existing OFDM system can provide an additional CE-OFDM mode with relative ease, particularly for the case of software defined platforms. This point is further illustrated in Section II where the system model is explained. In Section III performance analysis of CE-OFDM corrupted by Additive White Gaussian Noise (AWGN) is conducted. The results lead to the study of spectral efficiency versus bit error rate performance tradeoff. In Section IV, simulation results are shown. Spectral efficiency versus bit error rate performance is shown in section V. A comparison between conventional and constant envelope OFDM is conducted. It is shown, by way of computer simulation that CE-OFDM compares favorably to conventional OFDM in the presence of PA nonlinearities. Concluding remarks are made in Section VI.

II. CE-OFDM'S CARDINAL PRINCIPLES

Constant envelope (CE) waveforms are appealing since the optimum operating point for power amplifiers is attainable. The baseband CE signal representation is

$$\mathbf{s(t) = A\, e^{j\,\varphi(t)}} \qquad (1.1)$$

Where A is the signal amplitude and φ(t) is the information bearing phase signal. The advantage of the CE waveform is that the instantaneous power is constant: Consequently, the PAPR is 0 dB and the required back off is 0 dB. Fig.1 is the signal processing system model of CE-OFDM. As is seen in Fig.1, the difference in CE-OFDM is the adding of modem unit to it, compared with OFDM. At the transmitting terminal, a binary code element of T_B length is firstly symbol mapped with modulation order M (like pulse amplitude modulation PAM mapping), turning into data symbol vector {X[K]}. And after the discrete Fourier transform (DFT) at the N dft point, a discrete-time sampling sequence {x[n]} is transformed. Consequently, sampling rate is reduced to $F0=NLog_2M/T_B$. The followed step is the processing of adding a Tg–length discrete cyclic prefix CP (it means copying the tail of signal and inserting it at the head of signal). Moreover, the discrete-time sequence with high peak-to-average power ratio (PAPR) is converted into a sequence {s[n]}, which is of 0 dB PAPR after phase modulation and finally the signal is sent into the AWGN channel. At the receiving terminal, the received signal is r(t) added with the Gaussian noise ω(t). Next, the CE-ODFM signal is recovered after operating phase inverse transformation. Finally, by removing cyclic prefix and inverse mapping, the symbol sequence once been transformed by DFT would revert to binary target bit. Compared with conventional OFDM which concentrates on amplitude modulation on carrier, signal processing of CE-OFDM is to operate angle modulation on the carrier using OFDM signal. In this way, conducting phase modulation on carrier by an amplitude modulated signal would produce a constant envelope signal with constant amplitude.

III. CE-OFDM MODELLING IN MATLAB (SIMULINK)

The constant envelope OFDM modulator and demodulator systems are simulated in Matlab and the performance of system is analyzed at various levels of Eb/N0 (signal-to-noise ratio per bit) in AWGN channel. The block diagram of the simulated system is shown in Fig.3. A random input sequence is generated at a sampling rate of 10 KHz and symbol mapping is done using 4-PAM modulation. The high rate PAM symbol stream is converted to 64 low rate substreams by serial to parallel converter. Since CE-OFDM requires a real valued OFDM message signal. Therefore, the 128 point IFFT is performed after adding 64 additional zero valued substreams to obtain the real valued IFFT output. The adding of zero valued substreams is equivalent to zero padding of symbols. The output of IFFT block is OFDM symbols at 10 KHz data rate. 25% cyclic prefix i.e 32 symbols are added as cyclic prefix after IFFT block which yields an OFDM symbol stream at 12.5 KHz data rate. This final OFDM symbol stream is phase modulated using a phase modulator at a carrier frequency of 40 KHz with different values of modulation index, h = {0.75, 1.0, 1.25, 1.5}. The generated constant envelope OFDM signal is passed though the AWGN channel. At the receiving terminal the noise distorted signal is first passed through a front-end FIR band pass filter, centered at the carrier frequency fc, which limits the bandwidth of the additive noise. The signal is then converted to baseband using a phase demodulator and low pass filter as shown in fig.2.The baseband signal thus recovered is the original transmitted OFDM symbol stream at a data rate of 12.5 KHz. This stream still contains the 32 symbol cyclic prefix added in the modulation path. Hence cyclic prefix is removed before performing the 128 point FFT which yields a block of 128 4-PAM symbols. Out of these 128 PAM symbols, the first 64 symbols are actual information symbols where as last 64 symbols are due to zero padding at the modulator. Removal of these 64 symbols is termed as zero removal. The resultant symbols are converted into binary information using the inverse mapping. The symbol mapping used in this simulation is 4-PAM. Simulation parameters are listed in Table 1.

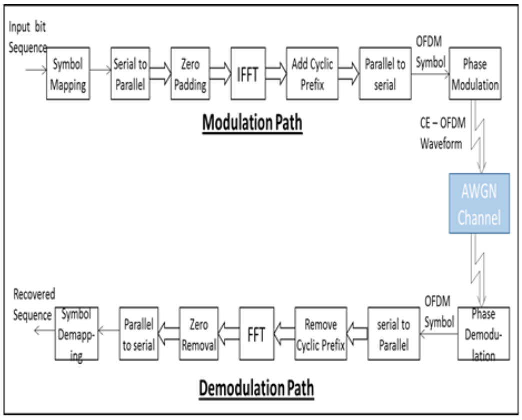

Fig. 1: Block diagram of CE-OFDM system

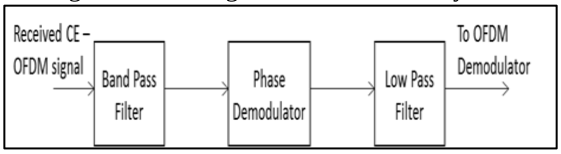

Fig. 2: Band pass to base band conversion

IV. SIMULATION RESULT

The simulation result of the produced binary signal after symbol mapping is shown as,

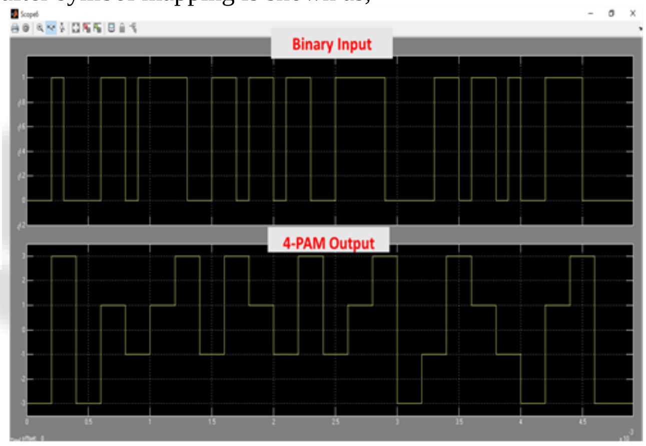

Fig. 4: Symbol Mapped Binary Signal

The simulation result of the cyclic prefix (means copying the tail of the signal and inserting it at the head of the signal) is shown below:

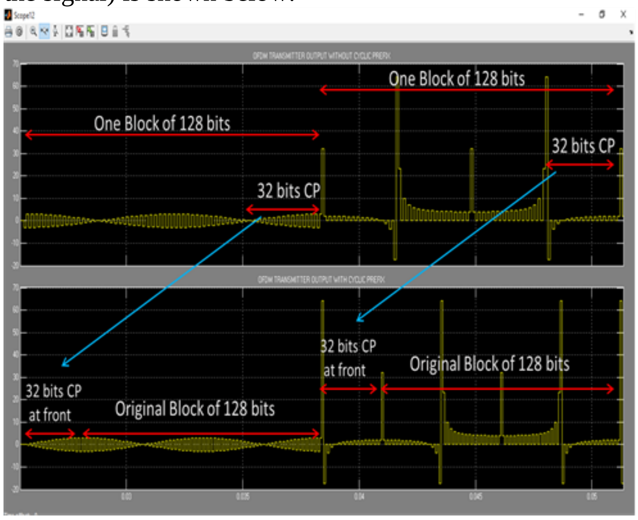

Fig. 5: Cyclic prefix added binary signal

Simulation result of the binary data after conventional OFDM and CE-OFDM Modulated is shown below:

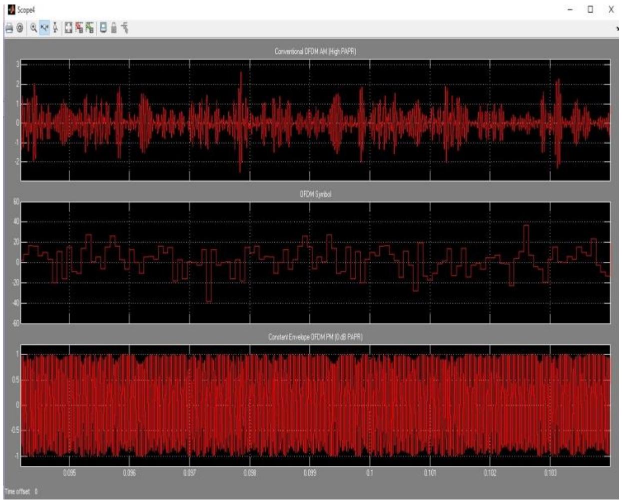

Fig. 6: Conventional OFDM with high PAPR, baseband OFDM Symbol and Constant Envelop OFDM (PM) With 0 dB PAPR

The simulation result of conventional OFDM spectrum is Shown below:

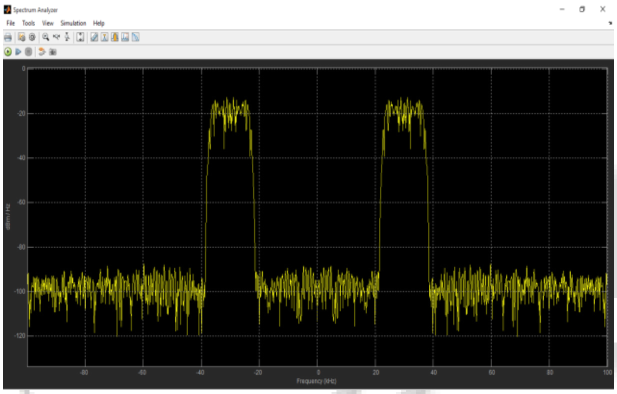

Fig. 7: Standard OFDM Spectrum

The simulation result of CE-OFDM spectrum is shown below

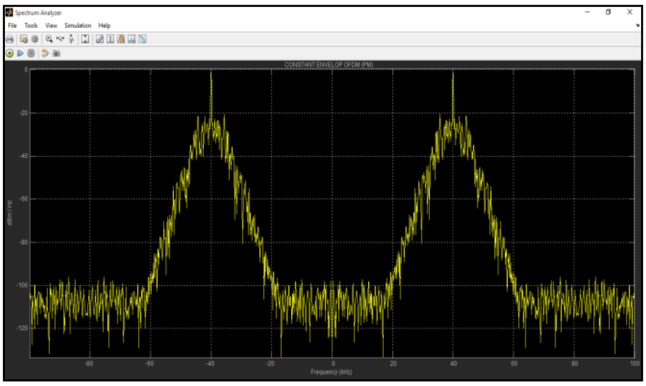

Fig. 8: CE-OFDM Spectrum

The signal at the receiving terminal is added into the Gaussian noise. The received signal in the receiving terminal which has passed through the channel is shown below. It can be seen that the received CE-OFDM signal has changed enormously.

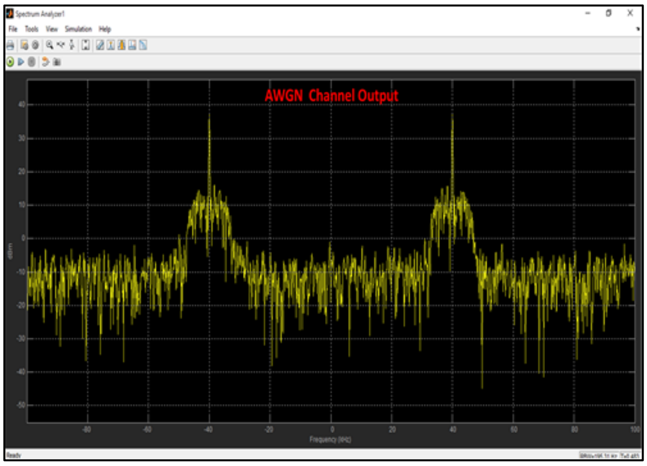

Fig. 9: Received CE-OFDM Spectrum

Finite impulse response (FIR) filter functions to constrain the out-of-band (OOB) noise in the conversion process of constant envelope signal, and improve the receiver's performance. And the simulation result of the signal been through FFT and then filtered is shown below:

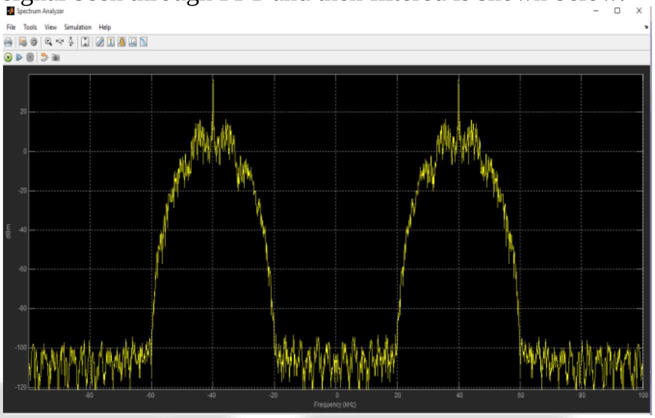

Fig. 10: CE-OFDM band pass filter output

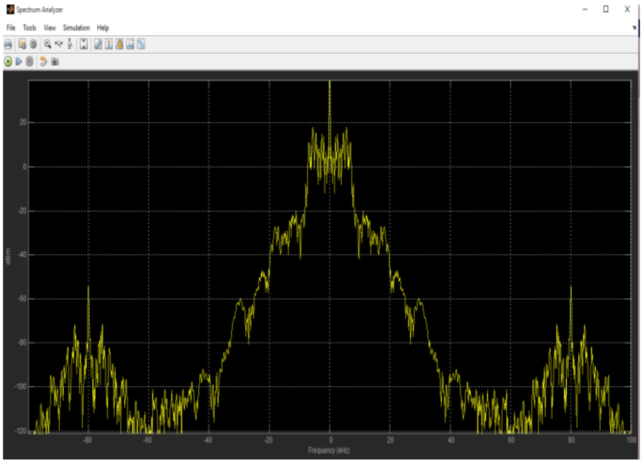

Fig. 11: CE-OFDM Demodulator Output

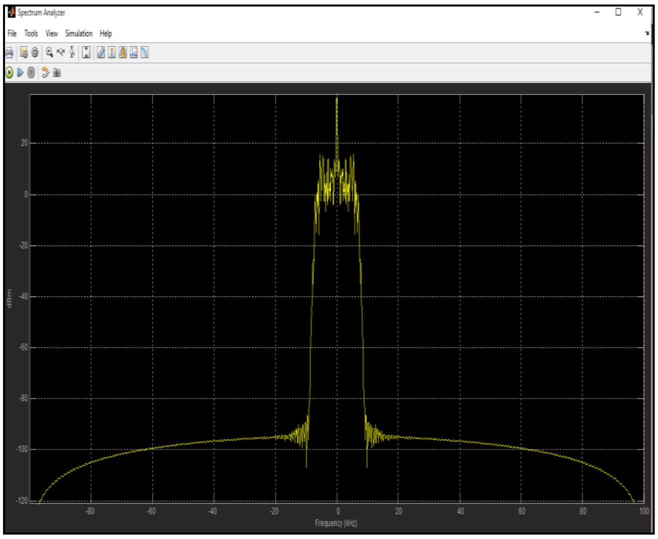

Fig. 12: CE-OFDM low pass filter output

A. Spectral Efficiency versus Bit Error Rate Performance:

The performance of CE-OFDM is determined by the modulation index (h), which also controls the signal bandwidth. It is first demonstrated in Fig.13, that CE-OFDM with modulation index h >1, can outperform the underlying M-PAM subcarrier modulation. Fig.14 shows simulation results for M = 2 and 4. The bit error rate is plotted against the Eb/No (bit energy to noise density ratio). It has been observed that, for M = 4 and h > 1, CE-OFDM outperforms M-PAM Conventional OFDM. This is predicted by Fig.13. For h= 1.0, the performance is almost equal to the performance of M-PAM, and for h > 1, it is better than M-PAM. Since the subcarriers are centered at the frequencies ± i/T Hz, i = 1, 2, . . ., N/2, so an effective double-sided bandwidth of the message signal is defined as W = N/T Hz. A useful bandwidth expression for the CE-OFDM signal is the RMS bandwidth,

$B = \max(2\pi h, 1)\, W$ Hz ....(1.2)

The bit rate is,

$R = (N \log_2 M)/T$ b/s, ...(1.3)

And the spectral efficiency is,

$S = \frac{R}{B} = \frac{\log_2 M}{\max(2\pi h, 1)}$ bps/Hz ……….. (1.4)

where, N is the number of subcarriers, h is the modulation index, and M is the modulation order.

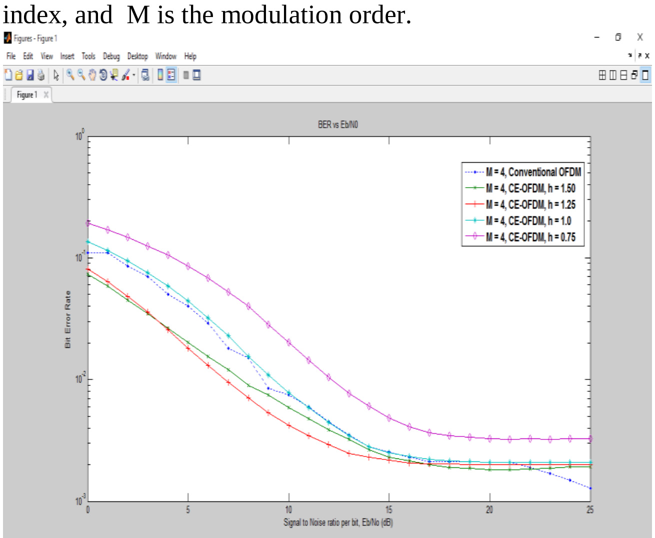

Fig. 13: Performance of Constant Envelop OFDM

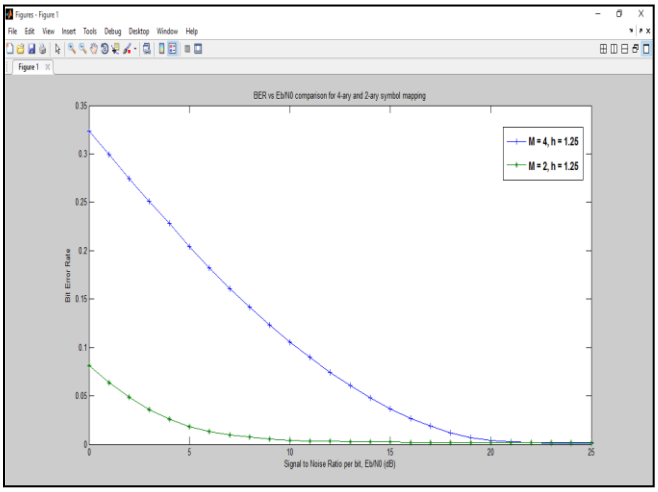

Fig. 14: Bit Error Rate Performance of Constant Envelop OFDM

Parameters	Nomenclature	Values
Input sequence data rate	R_{ip}	10 KHz
Symbol Mapping	M	4 – PAM
Distance Between Symbol	D	2
Constellation Ordering		Gray
Block Size	N_B	64 Symbols
Zero Padding	N_{ZP}	64 Symbols
FFT Length	$N_{FFT} = N_B + N_{ZP}$	128 points
Cyclic Prefix Length	$N_{CP} = N_{FFT}/4$	32 Symbols
OFDM Symbol Length	$N_{Tot} = N_{FFT} + N_{CP}$	160
OFDM Symbol Rate	$R_{OFDM} = (N_{Tot}/N_{FFT}) * R_{ip}$	12.5 KHz
Oversampling Factor	J	16
Carrier Frequency	f_c	40 KHz
Modulation Index	H	{0.75 1.0 1.25 1.5}
Power Amplifier Modeling		Rapp Model
Simulation Time	T_s	10 sec
No. of Bits Sent	$T_s * R_{ip}$	100000

Table 1: Simulation Parameters

V. Conclusion

In this paper, a signal transformation method for solving the PAPR problem is presented and analyzed. The OFDM signal with high PAPR is transformed to a 0 dB PAPR constant envelope waveform. At the receiver, the inverse transform is performed prior to the OFDM demodulator. For the CE-OFDM technique described, phase modulation is used. The effect of the phase modulator on the transmitted signal's spectrum is studied. CE-OFDM technique can notably reduce the high PAPR of OFDM. From theoretical analysis and simulated result, PAPR of CE-OFDM could reach 0dB. It is shown that the modulation index controls the spectral containment. The modulation index also controls the system performance. The performance of CE-OFDM can improve with increased M so long as the modulation index increases as well. However, the signal bandwidth grows with h, which in turn reduces spectral efficiency. Thus, the trade-off between spectral efficiency and performance is made with the two parameters M and h.

Modulation Order	Modulation Index	Spectral Efficiency
2	1.25	0.8 b/s/Hz
4	0.75	2 b/s/Hz
4	1	2 b/s/Hz
4	1.25	1.6 b/s/Hz
4	1.5	1.33 b/s/Hz

Table 2: Results of Spectral Efficiency

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