# Reducing Error Vector Magnitude of OFDM Signals Using Threshold Vector Circle Method

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*Abstract:* The main disadvantage of Orthogonal Frequency Division Multiplexing (OFDM) signal is the high peak-to-average power ratio (PAPR) which influences the system power efficiency and system performance in the presence of nonlinearities within the high power amplifier (HPA). The error vector magnitude (EVM) is one of the performance metrics by communications standards in OFDM system. In this paper, a novel EVM reduction method from geometric angle analysis is proposed which keeps the bit-error-rate (BER) performance after PAPR reduction. In our method, a threshold vector circle is designed in frequency domain in order to adjust the amplitude and phase of the OFDM signal constellation points to near the ideal points. Simulation results show that PAPR of a QPSK modulated OFDM signal is reduced from 10.56dB to 7.496dB with an EVM reduction of 2.34%. This technique should vastly improve the performance of OFDM signal in communication system

*Key–Words:* Error vector magnitude (EVM), orthogonal frequency division multiplexing (OFDM), peak-to-average power ratio (PAPR), threshold vector circle method

## 1 Introduction

Orthogonal Frequency Division Multiplexing (OFDM), which has been adopted by many wireless communication standards [1]-[3], offers many advantages for multicarrier transmission such as high spectral efficiency and robustness against frequency-selective fading channels. However, the main disadvantage of OFDM signal is the high time-domain peak-to-average power ratio which becomes a major obstacle in the implementation of power-efficient transmitters [4]. PAPR reduction is necessary to alleviate the contradiction between high power amplifier (HPA) linearity and power efficiency.

Various technologies have been developed to reduce the PAPR of OFDM signals such as active constellation extension (ACE) with smart gradient-project (SGP) algorithm [5], repeated clipping and frequency domain filtering [6], and etc. However, those PAPR reduction technologies which aim to reduce the signal peak value directly will cause distortions. It is well known that error vector magnitude (EVM) is frequently used in communication standards to quantify the amount of in-band distortion that occurs in the communication system. For example, in [5], the SGP-ACE method which substantially reducing the peak magnitude of an OFDM transmit block and requiring no side information offers fast PAPR reduction because of the step size setting. The simulation results show that only two iterations of the SGP-ACE algorithm are needed to make PAPR under 6dB. Unfortunately, as the simulation results show in [7], the more PAPR is reduced, the higher EVM gets. In other words, the value of EVM in SGP-ACE method is uncontrollable which greatly affects the implementation of power-efficient transmitters. Therefore it is necessary to control the balance between PAPR reduction and EVM which predefined by communication standards.

In [8], a PAPR reduction method formulated into an optimization problem to reduce EVM subject to deterministic PAPR and interior-point method (IPM) is proposed. Our paper presents a novel EVM reduction method from geometric angle analysis which keeps BER performance. After PAPR reduction by SGP-ACE method which will simultaneously decreases the bit-error-rate (BER) slightly [5], a threshold vector circle is designed in frequency domain to adjust the amplitude and phase of the OFDM signal constellation points to near the ideal points. Detailed introduction of the threshold vector circle method will be presented in part 3. Simulation results from MATLAB software show that PAPR of a QPSK modulated OFDM signal is reduced from 10.56dB to 7.496dB with an EVM reduction of 2.34%.

## 2 Definition

This section defines the metric to quantify OFDM system performance——Constellation Error Vector Magnitude.

Let $c_0 \in C^n$ be an ideal constellation and let $c \in C^n$ be the constellation that is actually transmitted. Many OFDM standards transmit data on a subset of available carriers $c_i$ , $i = i_1, ...i_d$ (where $d < n$) because of tone reservation or filtering limitations in the receiver. The average EVM of $c$ is defined as [2]:

$$EVM = \sqrt{\frac{\frac{1}{d}\sum_{i=i_1}^{i_d}||c_i - c_{oi}||^2}{P_0}} \quad (1)$$

Where d is the number of data carriers and $P_0$ is the average power of the carrier modulation scheme (QPSK, 16QAM, etc.).EVM can be reduced by minimizing the difference between a collection of actually transmitted symbols and ideal symbols from the formula (1) since $P_0$ is a fixed value. The proposed threshold vector circle method in this paper is derived from this idea which aims at minimizing the molecular value.

Mathematically, the goal of EVM reduction is [7]:

$$min||S(c - c_0)|| \quad (2)$$

Where $S \in R^{n\times n}$ is a diagonal carrier selection matrix defined to simplify notation as follows:

$$S_{ii} = \begin{cases} 1, & if\ carrier\ i\ contains\ data \\ 0, & otherwise \end{cases} \quad (3)$$

Let the constellation $c$ be $c = c_0 + \Delta$ , and $\Delta \in C^n$ stands for the difference between a collection of transmitted symbols and ideal symbols which aim to be reduced under the tolerance of EVM by communication standards.

## 3 Customized Threshold Vector Circle Method

Differ from the EVM reduction method in [8], the threshold vector circle method is a novel constellation points adjustment method which is easily explained with geometric graph directly in the case of OFDM with QPSK modulation. For an individual channel, there are four possible constellation points, which lie in each quadrant in the complex plane. Fig.1 and Fig.2 show the principle of the threshold vector circle method.

The two components in the rectangular coordinate system represent the in-phase and quadrature (I and Q) components. Every point in the figures stands

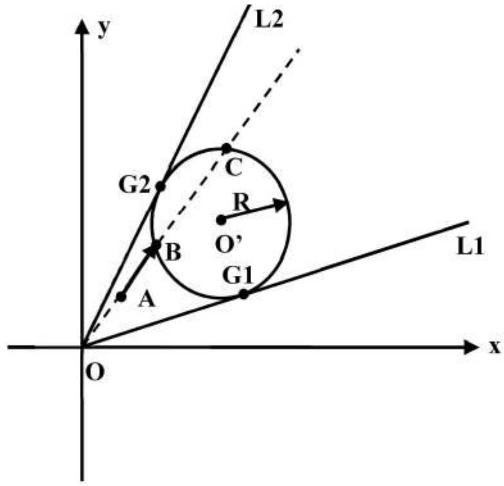


Figure 1: Principle of the Threshold Vector Circle Method by adjusting amplitude only

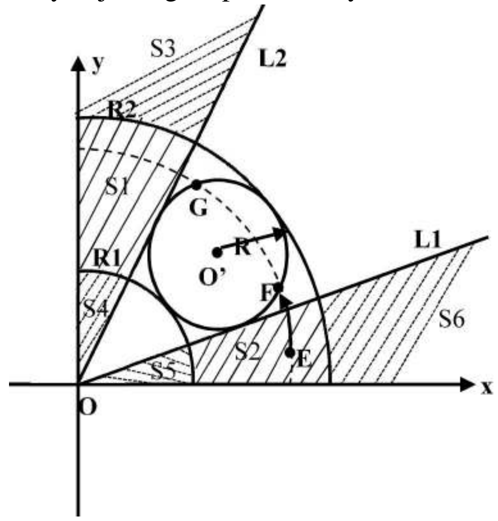


Figure 2: Principle of the Threshold Vector Circle Method by adjusting phase only

for a complex signal in frequency domain after PAPR reduction by SGP-ACE method. As show in Fig.1, a threshold vector circle is first drawn with its radius of R at point O'. The R is the predefined threshold which based on $c - c_0$ in formula (2) and O' stands for the ideal constellation point $(1 + i)$. The points in the circle were kept unchanged because of the distortion restriction and others were adjusted according to the following three cases.

Case1: In this situation, only amplitude was adjusted in Fig.1. From the rectangular coordinate system original point O, we can draw two tangent lines (L1,L2) in each side to the circle O' with the tangent point G1 and G2. From the points between two tangent lines like A, draw a line which goes through the point O. Meanwhile, two intersection points of the line with the circle O' can be obtained, i.e., B, C in

Fig.1, which are the new possible locations that point A can be moved to. To keep the amplitude change as small as possible, the closest point B is normally chosen to be the new location of the point A.

Case2: Since the sampling points are randomly distributed on the constellation plane, some points can also be seen outside the two tangent lines such as shadows S1 and S2 in Fig.2, which also need to be considered. In this situation, we draw two circles (R1, R2) at the point O which contact with the circle O'. For the points in the shadow S2 such as point E, draw a circle at the point O which goes through point E and two intersection points with the circle O' can be obtained, i.e., F, G. The closest point F is chosen to be the new location of the point E.

Case3: The rest constellation points in the first quadrant can be divided two situations. For the points in the shadows S3 and S4, we move them to point G2, because the change of phase and amplitude can get small as well as the amount of the rest points are less. At the same time, the points in the shadows S5 and S6 can be moved to point G1.

The points in the other three quadrants can be adjusted in the same way. Its worth reminding that severe distortion to the signal and great influence on PAPR reduction can be introduced with large changes in phase and amplitude. As a result, we only adjust amplitude in case1 and phase in case2.

# 4 Simulation Results

In this paper, simulation parameters are chosen as follows: 100 QPSK OFDM symbols with 512 carriers each symbol are taken as the input signal. L = 4 is accepted as the oversampling rate. Additive white Gaussian noise (AWGN) channel model has been used in the simulation. We select the radius R=0.6 for threshold vector circle.

Fig.3 compares the constellation diagram after SGP-ACE algorithm and threshold vector circle method. From the comparison diagram, we can draw that after adjustment the constellation points get much closer to the ideal points and a clearly threshold circle was created.

Fig.4 shows PAPR versus EVM performance of SGP-ACE algorithm and threshold vector circle method. The simulation results show that after 5 times iteration, the PAPR convergence rate of SGP-ACE algorithm gets slow with EVM greater than 21.23% which exceed the communication standard with SNR designed as 16dB. But after threshold vector circle method, the EVM and PAPR performance becomes controllable by setting the radius of the circle from 0.05 to 0.6 and the step size is 0.05. We got a balance between PAPR reduction and EVM performance.

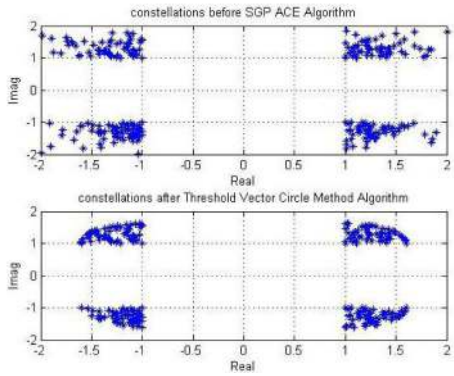


Figure 3: Constellation Diagram after SGP-ACE Algorithm and Threshold Vector Circle Method

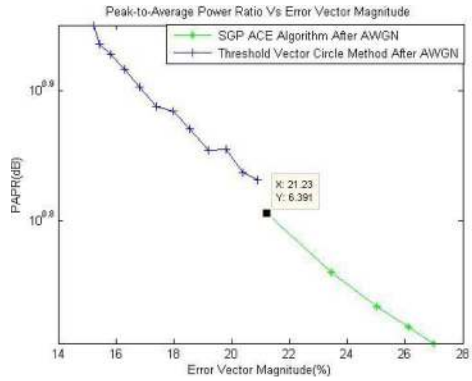


Figure 4: PAPR Versus EVM Performance of SGP-ACE Algorithm and Threshold Vector Circle Method

Fig.5 shows EVM versus SNR performance of threshold vector circle method. Since the constellation points which stand outside the threshold vector circle has been adjusted on the circle which means the value of $\Delta$ gets smaller, EVM can be reduced directly based on the formula (1). When SNR is 16 dB, the EVM can be reduced below the communication standard 18.5% of QPSK OFDM signals after AWGN channel.

Fig.6 shows BER performance of threshold vector circle method. It shows that BER performance got improved slightly after EVM reduced, because the paper [9] shows the inverse relationship that exists between BER and EVM (with power term in log scale) based on a given equation.

# 5 Conclusions

In this paper, a novel threshold vector circle approach for EVM reduction from geometric angle analysis is developed. From the simulation results, substantial EVM reduction is obtained while simultaneously improves BER performance slightly. Besides, the EVM

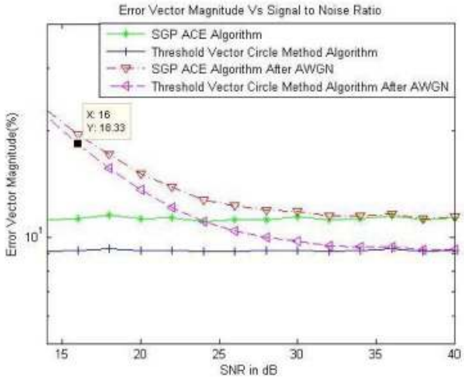


Figure 5: EVM Versus SNR Performance of SGP-ACE Algorithm and Threshold Vector Circle Method before and after AWGN channel

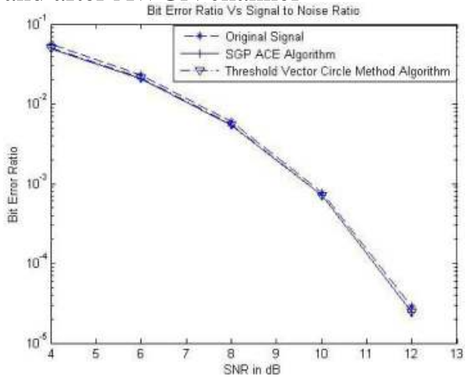


Figure 6: BER Versus SNR Performance of SGP-ACE Algorithm and Threshold Vector Circle Method after AWGN channel

value becomes controllable in comparison with SGP-ACE method. Furthermore, our method can employ a combination of any clipping PAPR reduction method and has a practical application in communication system.

**Acknowledgements:** The research was supported by the National Natural Science Foundation of China under Grant 61301020, the Natural Science Foundation of Jiangsu under Grant BK20130772, the Priority Academic Program Development of Jiangsu Higher Education Institutions and the Open Research Program of State Key Laboratory of Millimeter Waves under Grant K201410.

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