PTS and AICF Combined PAPR Reduction Techniques in Multi-Antenna OFDM Systems

Arifin[1], Silvi Fitriah Ditasari[2], Yoedy Moegiharto[3], Ida Anisah[4], Hendy Briantoro[5]

***Abstract* — A high PAPR value is one of important weaknesses in OFDM systems. Several reduction techniques are applied to reduce PAPR including Partial Transmit Sequence (PTS) as well as Clipping and Filtering (CF). Adaptive iterative clipping and filtering is a development of iterative clipping and filtering techniques. In this paper, a combination of Partial Transmits Sequence and Adaptive Iterative Clipping Filtering (PTS-AICF) techniques on multi-antenna OFDM transmitters was carried out. The simulation results showed that combined technique application had a better performance than non-combined technique (PTS), either for two or four antennas, and also for different sub-block numbers. Performance was also influenced by iterations number on AICF section. The more iterations were used, the better the reduction technique performance was, because it produced smaller PAPR$_0$ value.**

***Keywords*— MIMO multi-antenna, PAPR, Partial Transmits Sequence, Adaptive Iterative Clipping Filtering.**

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) modulation technique has been widely applied in modern communication system because it has a good efficiency in bandwidth utilization and is immune to multipath fading channels influence. Whereas the multi-antenna transmitters application can increase transmission rate or channel capacity. Therefore, the OFDM MIMO technique can meet high speed transmission requirements for data rates with good quality in future wireless communication systems.

On the other hand, one of the OFDM techniques main weaknesses is that it has a high peak-to-average power ratio (PAPR) [1]. High PAPR can reduce Signal-to-Quantization Noise Ratio (SQNR) in Analogue-to-Digital Converter (ADC) and Digital-to-Analogue Converter (DAC) and cause a power amplifier decrease in the efficiency at the transmitter [2]. To overcome this problem, PAPR reduction techniques such as Clipping-Filtering (CF) [3], [4], and Partial Transmits Sequence (PTS) were employed [5]. PTS technique divided the row of symbols into several sub-blocks and then performs an Inverse Fast Fourier Transform (IFFT) process for each sub-block. Each IFFT result in each sub-block was multiplied by a rotating phase factor, producing each OFDM signal, then summed to produce an OFDM signal candidate to be transmitted. The phase factor was selected from the combination that produces an OFDM signal candidate with the smallest PAPR value. PTS techniques have a high complexity with increasing numbers of sub-block. Clipping technique is the simplest PAPR reduction technique. Its working principle is to limit signal amplitude transmitted in certain threshold value [3], [4]. The drawback of clipping technique is the occurrence of out-of-band radiation (spectrum spreading) which can reduce bandwidth efficiency, so that it is necessary to do filtering process after clipping to reduce the spectrum spreading. However, filtering process can increase signal amplitude beyond clipping threshold value [3]. Therefore, it is necessary to repeat clipping filtering process several times so that it can minimize PAPR value and lessen the out-of-band spectrum [4].

In this paper, the two PAPR reduction techniques (PTS and CF) were combined into a joint scheme to obtain an adequate reduction in the PAPR value. Then, a joint reduction technique was applied to MIMO system.

[1,3,4,5] *Telecommunication Engineering Study Program, Electronic Engineering Polytechnic Institute of Surabaya,, ITS Campus Sukolilo, Jl. Raya ITS, Keputih, Sukolilo, Keputih, Sukolilo, SBY City, East Java 60111 (phone: 031-594 7280 fax: 031-594 6114; e-mail: arifin@pens.ac.id, ymoegiharto@pens.ac.id, ida@pens.ac.id, hendy@pens.ac.id)*

[2] *Student, Telecommunication Engineering Study Program, Electronic Engineering Polytechnic Institute of Surabaya,, ITS Campus Sukolilo, Jl. Raya ITS, Keputih, Sukolilo, Keputih, Sukolilo, SBY City, East Java 60111 (phone: 031-594 7280 fax: 031-594 6114)*

II. SYSTEM DESIGN

A. *Partial Transmits Sequence*

In a PTS technique as shown in Fig. 1, A input block symbol was divided into V disjoint sub-block $\boldsymbol{A_V}$ = $[A_1, A_2, \ldots, A_V]^T$ with A_v in each sub-block had a same size, i.e. as many as subcarriers numbers, N. In each sub-block, IFFT process was carried out and IFFT results for each sub-block were multiplied by a rotating phase factor, $b_v = e^{j\varphi v}$, v = 1, 2, ... , V and the results were added to produce an OFDM signal candidate as in (1).

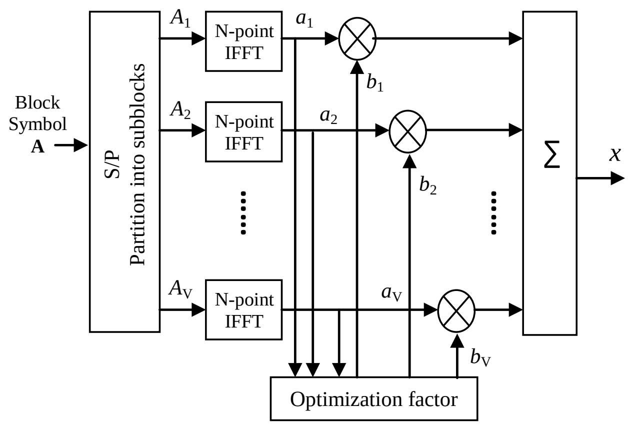

Fig. 1 PTS block diagram.

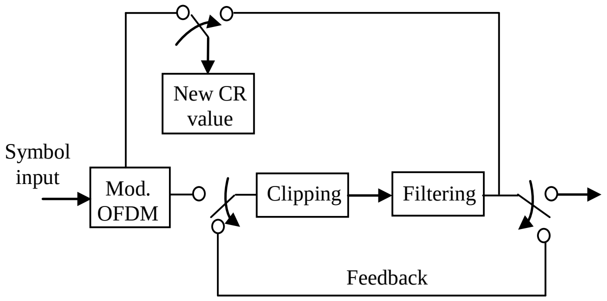

Fig. 2 Adaptive iterative clipping filtering.

PTS technique selects a phase vector factor (weighting), **b** = $\{b_1, b_2, \dots b_v\}$ that can yield an OFDM signal candidate, x, with the lowest PAPR value, which mathematically expressed as in (2). The advantage of PTS technique is that OFDM signal candidate is not impaired.

$$x = IFFT\ \{\sum_{i=1}^{V} b_v A_v\} = \sum_{i=1}^{V} b_v\ IFFT\{A_v\}\ = \sum_{v=1}^{V} b_v a_v \ . \quad (1)$$

$$b = \arg min\ \{\max|\sum_{v=1}^{V} b_v a_v\ |\}. \quad (2)$$

B. Adaptive Iterative Clipping Filtering

The easiest and most effective way to reduce OFDM signal PAPR value is by clipping signal amplitude. A block diagram of adaptive Iterative Clipping Filtering (AICF) technique is shown in Fig. 2 [6].

OFDM signal amplitude is limited with a threshold through (3).

$$\hat{x}_m^k = \begin{cases} Ae^{j\theta_m(k)}, & |x_m(k)| > A \\ x_m(k), & |x_m(k)| \le A \end{cases} \quad (3)$$

with:

for $1 < k \le LN$

$\hat{x}_m^k$ is OFDM signal resulted from clipping in *m*-iteration;

$x_m(k)$ is OFDM signal in*m*-iteration;

A is a value of the clipping threshold value; and

$\theta_m(k)$ is $x_m(k)$ phase.

From the equation above, a signal whose amplitude does not exceed A threshold value, with a phase similar to the original signal is obtained. A value is determined by a clipping ratio parameter (CR) stated by (4).

$$A = CR * \sigma \quad (4)$$

with *CR* is a clipping ratio, A is clipping threshold value, and σ is rms level of OFDM signal.

In conventional Iterative Clipping Filtering (ICF) techniques the clipped signals (clip) will be clipped back in next iteration at the fixed clipping threshold value. Iteration process was carried out because after filtering process the signal peak regrew (peak regrowth), so it was necessary to adaptively modify clipping threshold value to prevent regrowth in each iteration. To obtain an adaptive threshold value, it is necessary to determine an adaptive CR value according to (5).

$$CR_e[k] = \frac{A_{\max}(k)}{A_{\text{ave}}(k)} \quad (5)$$

with $A_{\max}(k)$and $A_{\text{ave}}(k)$ state each maximum amplitude and average signal at -*k* iteration.

With a fixed CR value, $A_{\max}(k)$ and $A_{\text{ave}}(k)$ values will change for ach iteration, so the clipping threshold value will be renewed for each iteration. In addition, generally, conventional ICF techniques do many iterations to reach a desired amplitude level. In an AICF technique, a threshold value is calculated at each iteration. The AICF technique is proven to be able to increase performance compared to conventional ICF techniques, i.e. with three and four iterations showing the same good performance as five and ten conventional iteration techniques [6].

C. PAPR on OFDM MIMO System

In an OFDM transmitter with N_T antenna number, through transmitter antenna number -*i*, a series of symbols A_i, ($A_i = [A_{i,0}, \dots, A_{i,N-1}]$) with $i = 1, \dots, N_T$ is transmitted. IFFT process was carried out at each antenna with N length a series of A_i symbols which will produce an OFDM signal stated as in (6).

$$a_{i,k} = \frac{1}{\sqrt{N}} \sum_{v=0}^{N-1} A_{i,v} \, . \, e^{\frac{j2\pi kv}{N}} \text{ for } k = 1, \dots, N-1. \quad (6)$$

PAPR value can be stated as in (7).

$$PAPR_i = \frac{\max_{k=0,1,\dots,N} |a_{i,k}|^2}{E[|a_{i,k}|^2]}. \quad (7)$$

Cumulative distribution function or CDF is one of the most frequently used functions to measure performance of PAPR reduction technique. Whereas complementary CDF (CCDF) can be used to replace the CDF itself. CCDF from a PAPR shows a PAPR value probability exceeding a predetermined threshold value. Then, a PAPR value probability can be written as in (8).

$$\begin{aligned} \Pr(PAPR > PAPR_0) &= 1 - \Pr(PAPR \\ &\le PAPR_0) \\ &= 1 - (1 - e^{PAPR_0})^N. \end{aligned} \quad (8)$$

In order to avoid nonlinear distortion in power amplifier and to reduce undesired spectrum spreading, signals sent simultaneously on all transmitting antennas must have the smallest possible PAPR value. In multi-antenna OFDM systems, system performance is determined by the worst PAPR conditions, which is defined as in (9) [7].

$$PAPR_{Multi} = \max_{i=1,..,N_T} PAPR_i. \quad (9)$$

Thus, in multi-antenna OFDM transmitters, CCDF values can be written as in (10) [7]

$$\begin{aligned} CCDF &= \Pr(PAPR_{MIMO} > PAPR_0) \\ &= 1 - (1 - e^{PAPR_0})^{N_T N}. \end{aligned} \quad (10)$$

D. Directed PTS Technique in MIMO System

Directed PTS is one of techniques for applying PTS techniques in a multi-antenna system [8]. Directed PTS technique always pays attention to antenna that is producing the highest PAPR value and tries to decrease it. Basic idea of this technique is to increase the number of possible alternative OFDM signals by rotating ***b*** weighting factors combination but keeping process complexity remains low. The process was sequentially carried out, i.e. testing a new phase composition in each rotation stage to obtain OFDM signals with the lowest PAPR value.

Block diagram of directed PTS scheme is shown in Fig. 3.

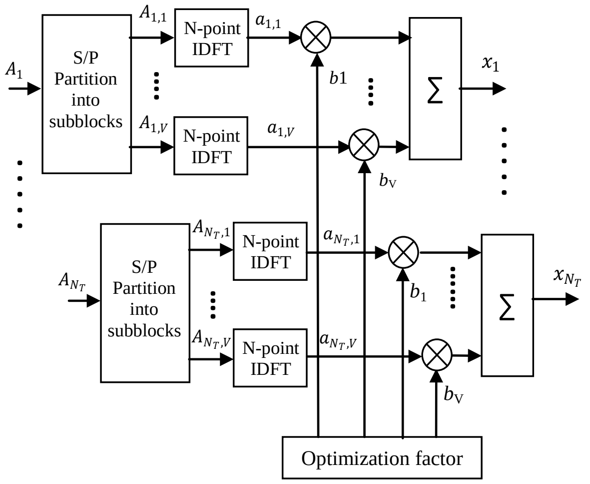

Fig. 3 Directed PTS scheme in MIMO system.

In this paper, PTS and AICF reduction technique were combined into joint scheme to reduce PAPR value of OFDM signal in multi-antenna transmitter as shown in Fig. 4. For each antenna, PTS output signal, $a_1, \ldots, a_{N_T}$ (with N_T = number of antennas), each is an input signal for clipping and filtering process.

The number of sub-block (V), phase factors (b_v) in PTS technique, and Clipping Ratio (CR) value, and the number of iterations in identical AICF are applied to all antennas. 16-QAM modulation was selected to generate A symbol vector.

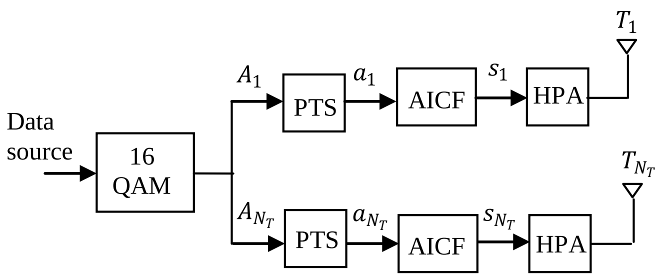

Fig. 4 PTS-AICF multi-antenna block diagram.

Performance of this PAPR reduction technique was analyzed with MATLAB simulation.

III. Simulation Results and Discussion

In this section, PAPR reduction performance was evaluated by a simulation. Some parameter that were changed to be observed were the number of antennas, sub-block numbers in PTS technique, and iterations number in AICF technique. 16-QAM modulation was used, and the algorithm to look for phase factors was PTS iterative. For sub-block partitions an adjacent partition technique was used.

A. Joint Reduction Techniques Performance PTS-AICF, Transmitter Antenna Difference and Sub-block Number

The performance of the PTS-AICF joint reduction technique is shown in Fig. 5 and Fig. 6. The used parameters were the subcarriers number N = 512, sub-block number = 2 (Fig. 5) and sub-block number = 4 (Fig. 6). In AICF, CR value = 1.2 with two times of iterations. Oversample factor was 4. Parameter for observed antennas number were two and four transmiting antennas.

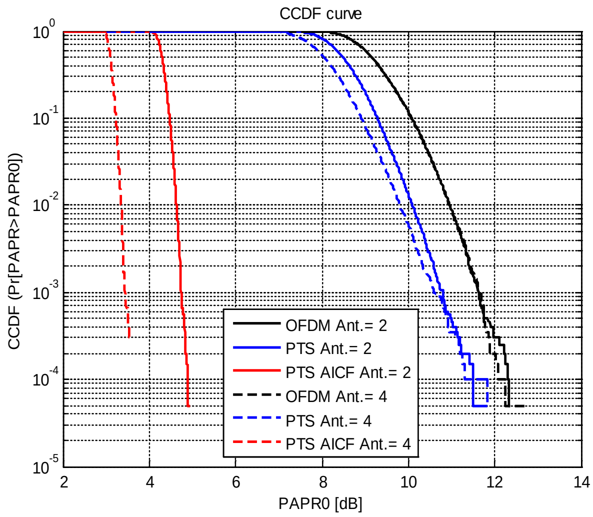

Fig. 5 OFDM system CCDF curve, PTS reduction technique, and PTS-AICF joint reduction technique with sub-block number = 2.

In Fig. 5, observations were made on CCDF values of 10^{-3} for two and four antennas. For two antennas, PTS-AICF joint reduction techniques produced a better performance of 6.7 dB compared to OFDM system and of 6 dB compared to PTS reduction technique. For four antennas, PTS-AICF joint reduction techniques produced a better performance of 8.1 dB compared to OFDM system and of 7.2 dB compared to PTS reduction technique.

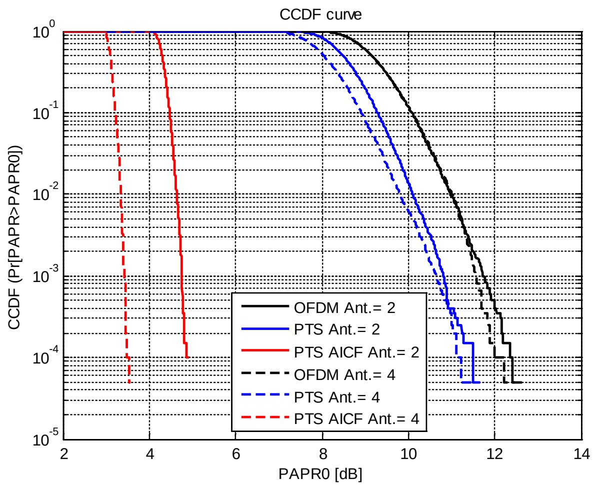

Fig. 6 OFDM system CCDF curve, PTS reduction technique, and PTS-AICF joint reduction techniques with sub-block number = 4.

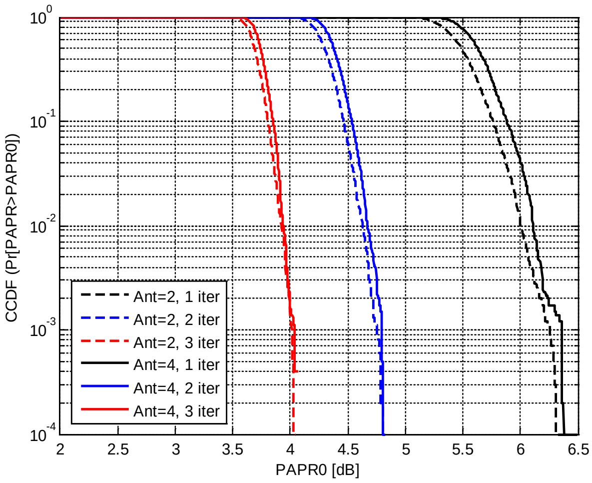

Fig. 7 CCDF Curve of Multi-antenna OFDM system with PTS-AICF technique, sub-block number = 2.

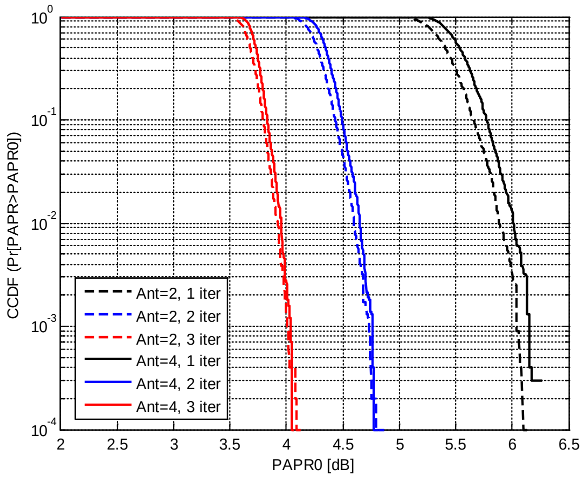

Fig. 8 PTS-AICF technique CCDF curve, sub-block number = 4.

In Fig. 6, for two antennas, PTS-AICF joint reduction techniques produced a better performance of 6.8 dB compared to OFDM system and of 6 dB compared to PTS reduction technique. For four antennas, PTS-AICF joint reduction techniques produced a better performance of 8 dB compared to OFDM system and of 7.2 dB compared to PTS reduction technique.

B. PTS-AICF Joint Reduction Techniques Performance, Different Transmitting Antennas and Iteration Number.

The employed parameters were subcarriers number $N = 512$, two and four transmitting antennas number, and CR value = 1.2, with the number of sub-block of 2 and 4 pieces.

Fig. 7 shows, for two antennas, PTS-AICF joint reduction technique iteration 3 produced a better performance of 2.1 dB compared to iteration 2 and = 0.6 dB compared to iteration 1. For four antennas, PTS-AICF joint reduction technique iteration 3 produced a better performance of 2.2 dB compared to iteration 2 and 0.6 dB compared to iteration 1.

Fig. 8 also showed observations on CCDF values of 10^{-3} to distinguish PTS-AICF reduction techniques performance with 4 sub-block with different antenna and iteration number. For two antennas, PTS-AICF joint reduction technique iteration 3 produced a better performance of 2.1 dB compared to iteration 2 and 0.7 dB compared to iteration 1. For four antennas, PTS-AICF joint reduction technique iteration 3 produced a better performance of 2.2 dB compared to iteration 2 and 0.7 dB compared to iteration 1.

IV. CONCLUSION

From simulation results it can be shown that PTS-AICF joint reduction techniques performance is better than PTS technique for application on multi-antenna system. Iteration number on AICF has little effect on system performance. Antenna number has more influence on system performance.

REFERENCES

[1] M.-O. Pun, M. Morelli, and C.-C.J. Kuo, *Multi-Carrier Techniques for Broadband Wireless Communications, A Signal Processing Perspective*, London, UK: Imperial College Press, 2007.

[2] Y.S. Cho, J. Kim, W.Y. Yang, and C.G. Kang, *OFDM-MIMO Wireless Communications with MATLAB*, Singapore: John Wiley & Sons, 2010.

[3] X. Li and L.J. Cimini Jr., "Effects of Clipping and Filtering on the Performance of OFDM," *1997 IEEE 47th. Vehicular Technology Conference*, 1997, Vol. 3, pp. 1634-1638.

[4] J. Armstrong, “Peak-to-Average Power Reduction for OFDM by Repeated Clipping and Frequency Domain Filtering,” *Electronics Letters*, Vol. 38, No. 8, pp. 246–47, Feb. 2002.

[5] L.J. Cimini Jr. and N.R. Sollenberger, "Peak-to-Average Power Ratio Reduction of an OFDM Signal Using Partial Transmit Sequences," *IEEE Communications Letters*, Vol. 4, No. 3, pp. 86-88, 2000.

[6] B.M. Lee and Y. Kim. "An Adaptive Clipping and Filtering Technique for PAPR Reduction of OFDM Signals," *Circuits, Systems, and Signal Processing*, Vol. 32, No. 3, pp. 1335–1349, 2013.

[7] R.F.H. Fischer and M. Hoch, "Peak-to-Average Power Ratio Reduction in MIMO OFDM," *2007 IEEE International Conference on Communications (ICC'07)*, 2007, pp. 762-767.

[8] C. Siegl and R.F.H. Fischer, "Partial Transmit Sequences for Peak-to-Average Power Ratio Reduction in Multiantena OFDM," *EURASIP Journal on Wireless Communications and Networking*, Vol. 2008, pp. 1-11, 2008.