Efficient And Low Complexity Peak To Average Power Ratio Reduction Methods For Orthogonal Frequency Division Multiplexing Based Wireless System

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- Problem Statement
- Literature Review
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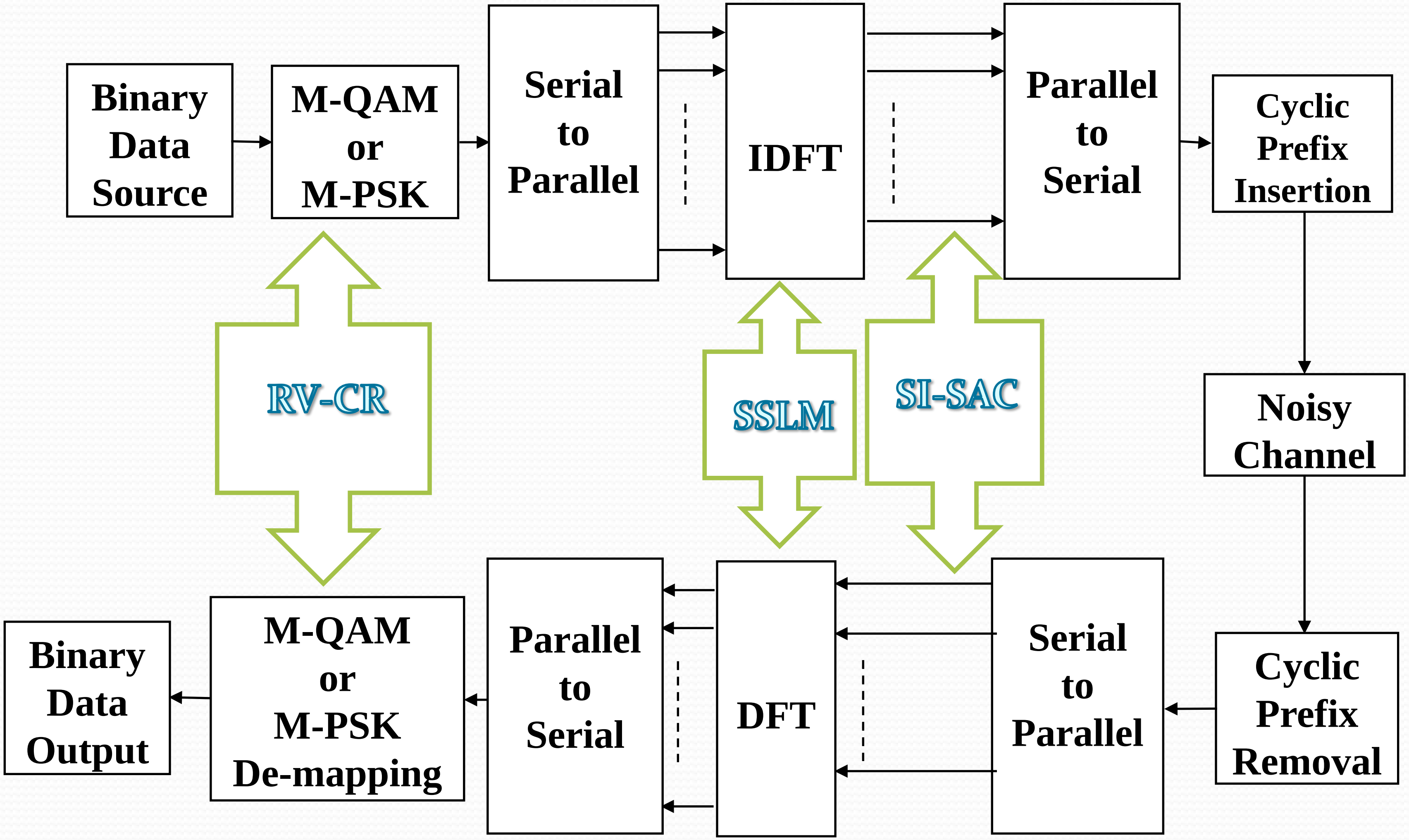
Introduction

- Orthogonal Frequency Division Multiplexing (OFDM) has become an important system for the new generations of telecommunications systems.
- **WiMAX**, **LTE**, **LTE-A** are such examples of the systems that utilizes the OFDM signals.
- Some **limitations** surround the usability of OFDM signals such as the **PAPR**, which put more limitations on the **baseband mapping (PSK/QAM)** or the **complexity** leading to a **degradation in the BER-performance**.



Binary Data Source
M-QAM or M-PSK
Serial to Parallel
IDFT
Parallel to Serial
Cyclic Prefix Insertion
RV-CR
SSLM
SI-SAC
Noisy Channel
Binary Data Output
M-QAM or M-PSK De-mapping
Parallel to Serial
DFT
Serial to Parallel
Cyclic Prefix Removal

Systems that utilize the OFDM signals with different Mappings and symbol size

system	M			N						
	4	16	64	64	128	256	512	1024	2048	4096
IEEE802.11a	×	×	×	×	-	-	-	-	-	-
IEEE802.11g	×	×	×	×	-	-	-	-	-	-
IEEE802.11n	×	×	×	×	×	-	-	-	-	-
IEEE802.15.3a	×	×	×	×	×	×	-	-	-	-
IEEE802.16a	×	×	×	-	-	×	-	×	-	-
IEEE802.16d	×	×	×	-	-	-	×	-	×	-
IEEE802.16e	×	×	×	-	-	-	-	-	×	-
DVB-T	×	×	×	-	-	-	-	-	×	×
DVB-T2	×	×	×	-	-	-	-	×	×	×
DVB-H	×	×	×	-	-	-	-	-	×	×
DVB-T/H	×	×	×	-	-	-	-	-	×	×
3GPP-LTE/A	×	×	×	-	×	×	×	×	×	-

"×" : used
"-" : not used

Problem Statement

- **The existing methods of PAPR reduction techniques introduce higher transceiver complexity.**

- **Low complexity PAPR transceivers are not efficient and may produce side effects such as the degradation in the BER or the degradation in the PAPR reduction gain.**

- **Although existing OFDM transceiver may be simple and efficient but only tailored and support certain modulation/mapping technique.**

Example of design and target parameters

Required:

- OFDM symbol size: N = 256,
- Mapping order M = 16,

Target:

- **PAPR** less than 12 dB,
- Number of **multiplication operations** less than 9216,
- Number of **addition operations** less than 18944,
- **BER** degradation should be enhanced according to the scheme, such as AC should be corrected at max SNR = 12 db

Literature Review Study

Most famous approaches	Complexity	Adaptive modulation	Requires processing at transmitter (Tx) and receiver (Rx)
Amplitude Clipping (**AC**) (Mestdagh et al. 1993)	Medium	Yes	Tx: Amplitude clipping, filtering Rx: None
Armstrong 2002 (**AC**)	Very High	Yes	**Recursive filtering**
Deng & Lin 2007 (**AC**)	High	Yes	**Optimizing** the error for each subcarrier to reduce the BER
Constellation Reshaping (**CR**) (Kou et al. 2004)	Medium	No	Tx: **Optimization** Rx: None
Chau-Yun et al. 2006 (**CR**)	High	No	DFT-based constellation reshaping
Hsu & Chao 2008 (**CR**)	High	No	the approach should be jointly used with the SLM scheme
Selected Mapping (**SLM**) (Bauml et al. 1996)	High	Yes	Tx: **U** IDFTs Rx: Side information extraction, inverse SLM
Shih-Kai et al. 2011 (**SLM**)	High	Yes	Fountain PRVs
Chin-Liang et al. 2003 (**SLM**)	High	Yes	modifications in the IFFT function
SI-SAC (**AC**)	Low	yes	Tx: None Rx: None
SSLM (**SLM**)	Low	yes	Tx: None Rx: None
RV-CR (**CR**)	Very low	yes	Tx: None Rx: None

Objectives

- To investigate the existing PAPR based reduction techniques for OFDM systems in terms of **PAPR reduction gain** and **computational complexity**.
- To develop methods to reduce the PAPR in OFDM systems with **minimal computational complexity**. Furthermore, a **balance between the computational complexity reduction, the PAPR reduction gain and the BER performance must be accomplished**. As follows:

a) **Side information supported amplitude clipping**;

b) **Sliding selected mapping**; and

c) **Random variable constellation reshaping**.

List of Contributions

1. **New clipping method**, a new equation for the soft limiter has been introduced.
2. **New phase rotation mechanism**, instead of multiple PRV, only one PRV was employed and the data will be slided over that only one PRV.
3. **New constellation shaping method** based on random variable transformation

Methodology

- **This research adopts the following methodology. It is worth mentioning that all contributions of this work share a similar methodology as discussed below:**

i. Defining the problem : The problem of the PAPR is explained in chapter II.

ii. Problem statement: According to the literature survey, the ***problem statement was formed and the conceptual approach and problem formulation will be done accordingly.***

iii. Design specifications : The most important parameters that directly affect the PAPR values will be specified according to the standards. The standard parameters are shown as tables in chapters III

iv. Mathematical model : **There are three novel techniques in this thesis; SI-SAC, SSLM, RV-CR**. After specifying the design parameters, the mathematical formulation of each technique is developed.

v. Simulation model : Using the mathematical model in the fourth step, a simulation model was developed for each technique.

vi. Simulation and validation : The simulation and validation is to find the **plots for the PAPR** beside the **BER-performance plots** and **PSD-performance plots**.

vii. Performance analysis : The analysis of the performance is represented by the **BER and PSD plots**.

Methodology

Side information-supported amplitude clipping (SI-SAC)

- In the conventional amplitude clipping scheme,

-The number of samples that are clipped is unknown,

-The original amplitudes of the clipped samples are also unknown.

For these reasons, we do not expect accurate values to be recovered at the receiver side without the use of expensive components in the transmitter and/or the receiver.

Side information-supported amplitude clipping (SI-SAC)

- We propose a method to determine

-The number of samples that are clipped,

-The location of each clipped sample,

-The original amplitude of each clipped sample,

-to send these information as side information to the receiver,

such that the receiver could recover the original signal's samples

Side information-supported amplitude clipping (SI-SAC)

Old-function

$$\tilde{r}_k = f(r_k) = \begin{cases} r_k & \text{for } r_k \le A \\ A & \text{for } r_k > A \end{cases}$$

proposed-function

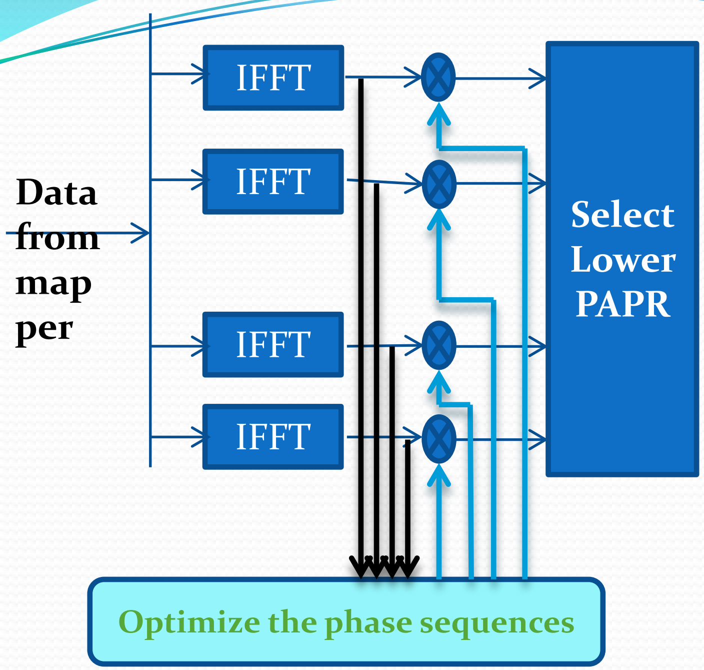
$$\hat{r}_k = \begin{cases} r_k & \text{for } r_k \le A \\ \dfrac{\sqrt{r_k}}{B} & \text{for } r_k > A \end{cases}$$

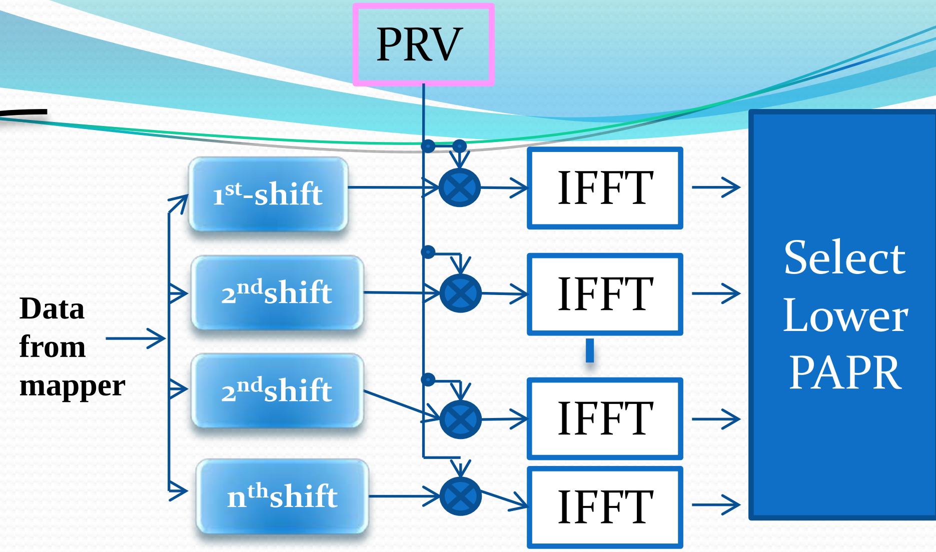
```
function clipped_ofdm=nclip(x,r)
N=length(x);
A=r*(P(x)); % clipping level r=1.28
x_clipped=abs(x);
for u=1:N
   if x_clipped(u)>A
      x_clipped(u)=A;
   end
end
clipped_ofdm=x_clipped.*exp(1j*angle(x));
```

```
function [sinfo A clipped_ofdm]=clip(x,B,a)
N=length(x);
A=a*(P(x)); % clipping level= input back off
t=zeros(N,1);
x_clipped_index=find(abs(x)>=A);
x_clipped=abs(x);
x_clipped(x_clipped_index)=sqrt(x_clipped(x_clipped_in
dex))/B;
t(x_clipped_index)=(x_clipped_index);
sinfo=t;
clipped_ofdm=x_clipped.*exp(1j*angle(x));
```

Sliding Selected Mapping (SSLM)

- The major hindrances of SLM is the high computational complexity.
- Thus, the number of IFFT blocks in the transmitter side will increase the computational complexity,
- In other words, the number of additions and multiplications operations will be increased, therefore, the system will be not reliable.





Movement step size = *r*

Phase vector size = w=*N.f*

0<f<1

```
function [si ofdms]=ssm(s,r,z)
%% input are
% s: original serial data
% r: step size
% z: window size
% outputs are:
% si: side information
% ofdms: OFDM symbol in serial format
N=length(s);
k_z8r4=z;
steps=r;
data=s;
k=k_z8r4;
L=N-k;
threshold=1000;
h=hadamard(k);
prv=h(k/2,:);
counter=0;
for r = 0:steps:L
    counter=counter+1;
    d2=[data(1:r) data(1+r:k+r).*prv data(k+r+1:end)];
    dstp2=reshape(d2,N,1);
    difft2=ifft(dstp2,N);
    dpts5=reshape(difft2,1,N);
    par_ss_z8r4=papr(dpts5);
    if par_ss_z8r4<threshold
        threshold=par_ss_z8r4;
        index=r;
        d_t=dpts5;
    end
end
ofdms=d_t;
si=index;
```

Random Variable-Constellation Reshaping

- Changing the point locations in a constellation diagram is critical; because of the minimum distance between the points must not change, or else, a **large degradation in the BER performance may occur**.
- If it was possible to reshape the *M*-PSK family, or both *M*-(PSK/QAM), some side effects will appear such as a **degradation in the BER performance**, or maybe **the computational complexity will be escalated up**.

Random Variable-Constellation Reshaping

- The key point of the proposed approach is:

an RV can be transformed to any other form by adding or subtracting constants to or from the RV or by adding two RVs together without affecting the PDF of the RVs

- Hence, such transformation can be used as a method to put a novel constellation mapping fashion.

Random Variable-Constellation Reshaping

- Assume two Gaussian RVs are $z_1(\bar{z}_1, \sigma_1)$ and $z_2(\bar{z}_2, \sigma_2)$ then,

$$Z_3 = Z_1 + Z_2$$

- thus, Z_3 is another normal random variable with mean $\bar{Z}_3 = \bar{Z}_1 + \bar{Z}_2$ and variance $\sigma_3 = \sigma_1 + \sigma_2$. So, the probability density function of Z_3 can be expressed as,

$$g_{Z_3}(Z_3) = \frac{1}{\sqrt{2\pi\sigma_3^2}} e^{\left(-\frac{(Z_3 - \bar{Z}_3)^2}{2\sigma_3^2}\right)}$$

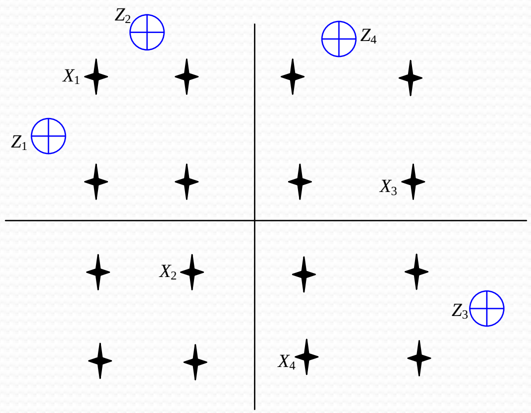
Random Variable-Constellation Reshaping

Transmitter

$$Z = \begin{bmatrix} Z_n \\ Z_{n+1} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} X_n \\ X_{n+1} \end{bmatrix}$$

Receiver

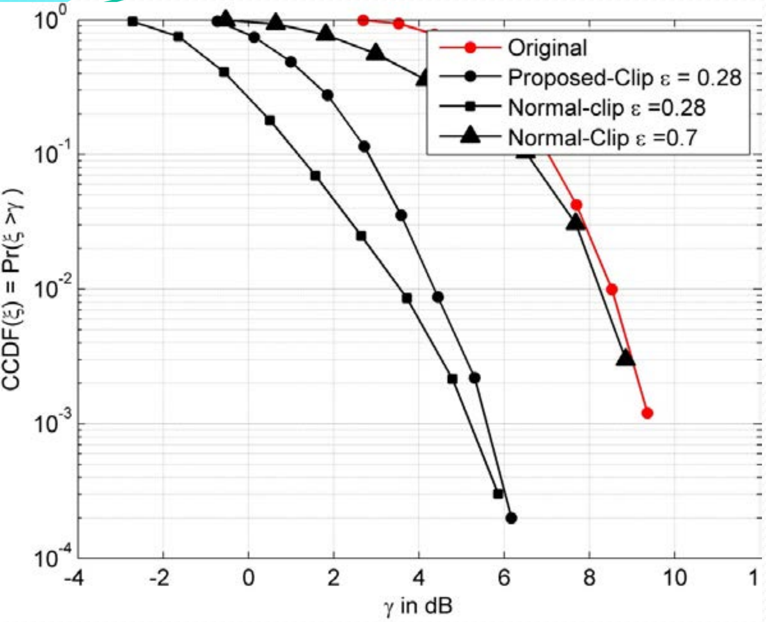
$$\begin{bmatrix} X_n^r \\ X_{n+1}^r \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} Z_n^r \\ Z_{n+1}^r \end{bmatrix} + \omega$$



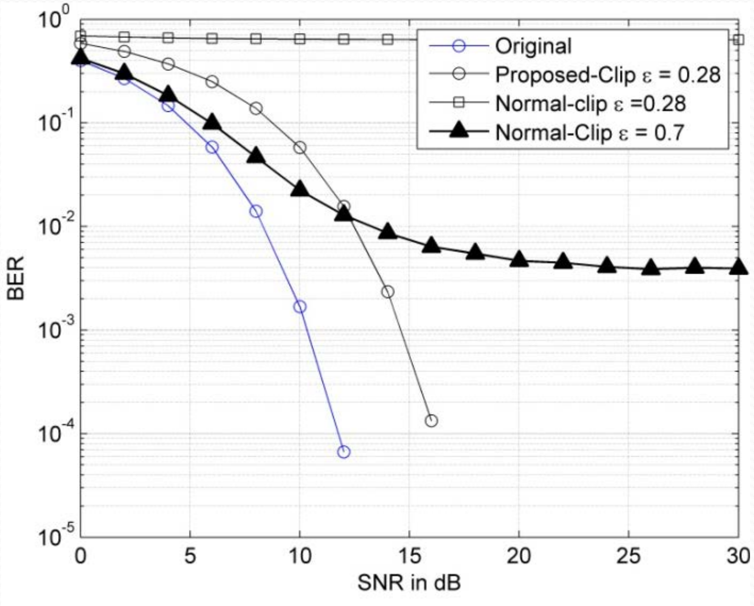

```
function [out par]=pifft(x,p)
N=length(x);
xp=reshape(x,N/p,p);
xpifft=fwht(xp);
out=reshape(xpifft,N,1);
par=papr2(out);
```

```
function out=pfft(x,p)
N=length(x);
xp=reshape(x,N/p,p);
xpifft=ifwht(xp); %fft
out=reshape(xpifft,N,1);
```

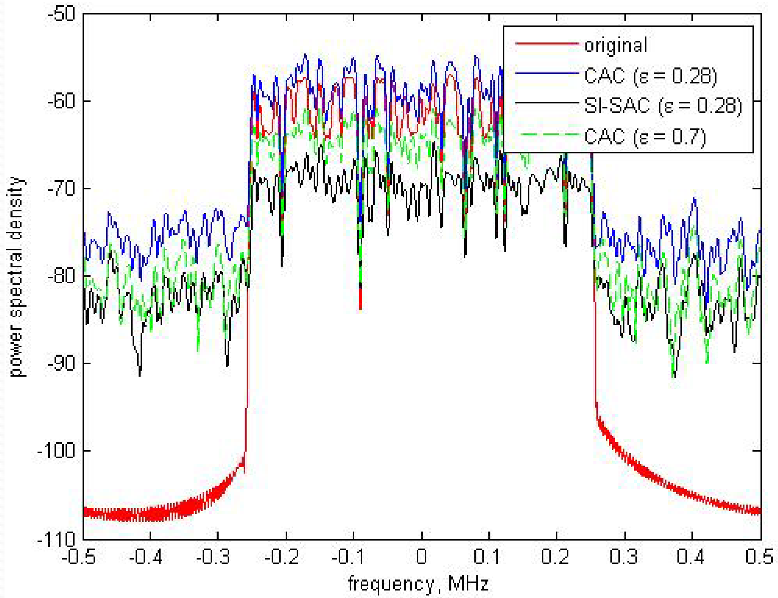
Results: (SI-SAC)



PAPR: N=64, M=16



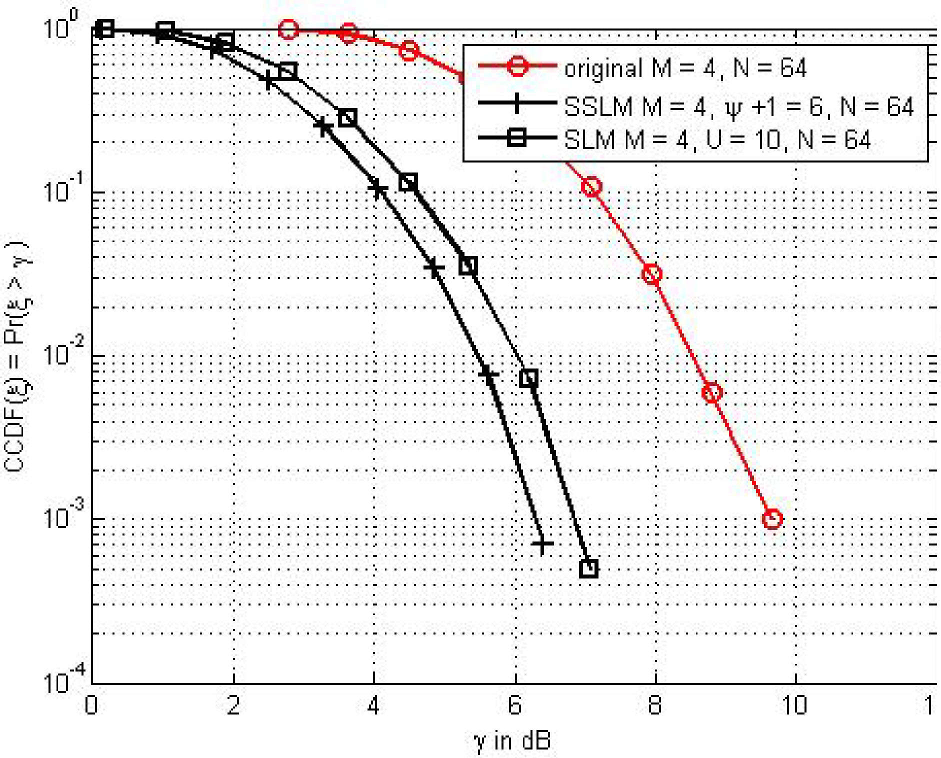
BER: N=64, M=16

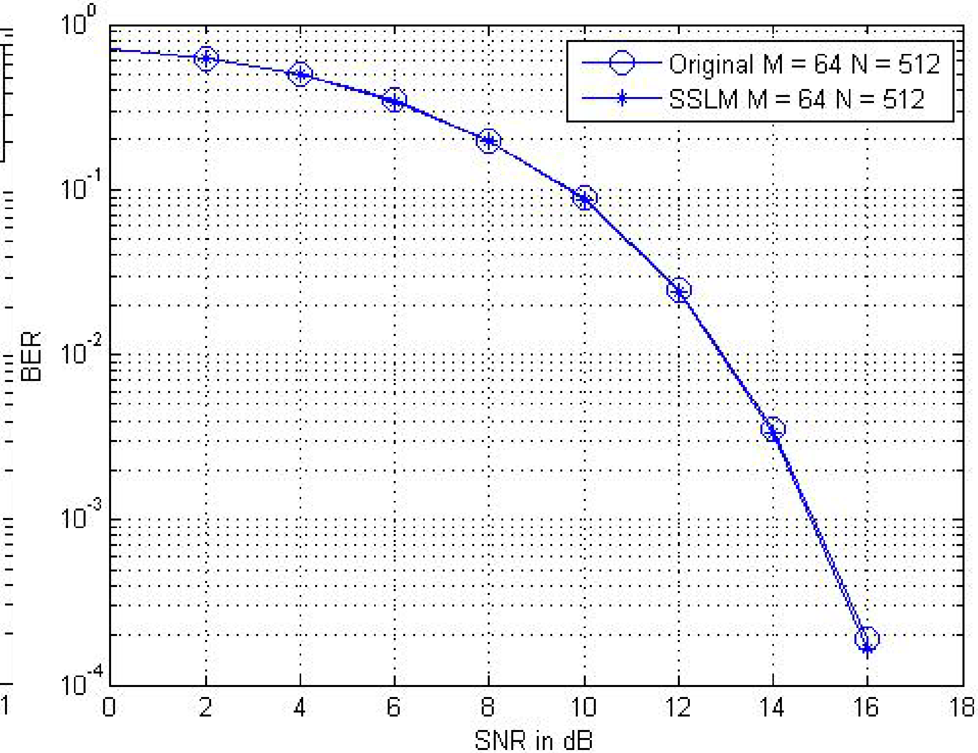


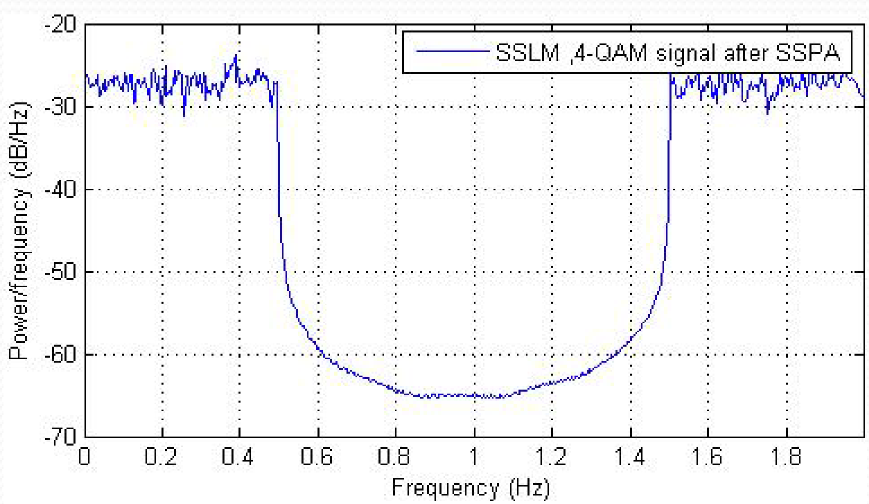
Side information supported amplitude clipping (SI-SAC)

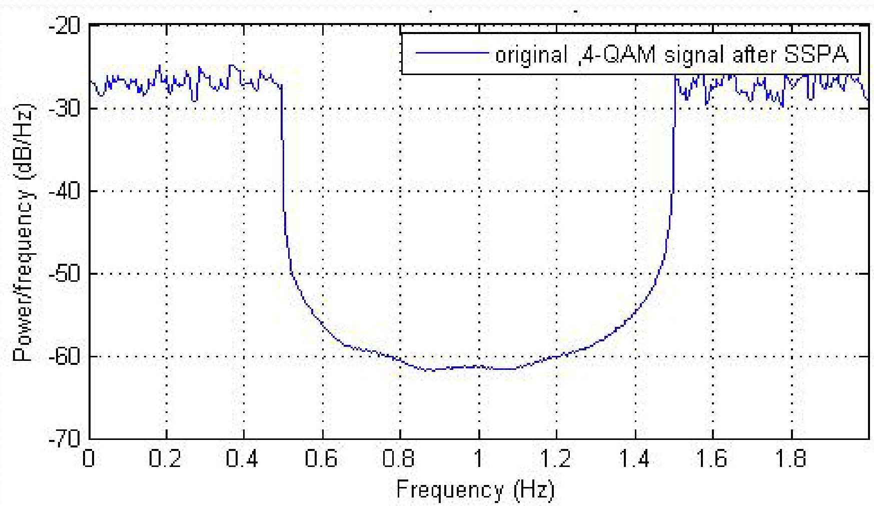
N	CAC		SI-SAC		Armstrong 2002		Deng & Lin 2007	
	$\mathcal{A}$ %	$\mathcal{M}$ %	$\mathcal{A}$ %	$\mathcal{M}$ %	$\mathcal{A}$ %	$\mathcal{M}$ %	$\mathcal{A}$	$\mathcal{M}$
64	--	--	25.93	25.93	61.58	94.11	80.58	97.09
128	--	--	30.16	30.16	63.64	94.12	81.59	97.08
256	--	--	33.33	33.33	65.22	94.12	82.35	97.06
512	--	--	35.8	35.8	66.45	94.12	82.95	97.05
1024	--	--	37.78	37.78	67.44	94.12	83.43	97.04
2048	--	--	39.39	39.39	68.25	94.12	83.83	97.035
4096	--	--	40.74	40.74	68.93	94.12	84.16	97.03

Results: (SSLM)







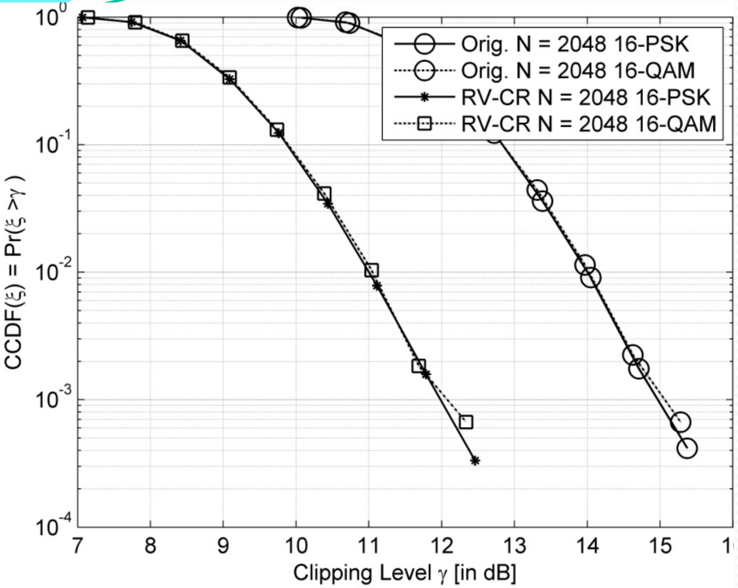


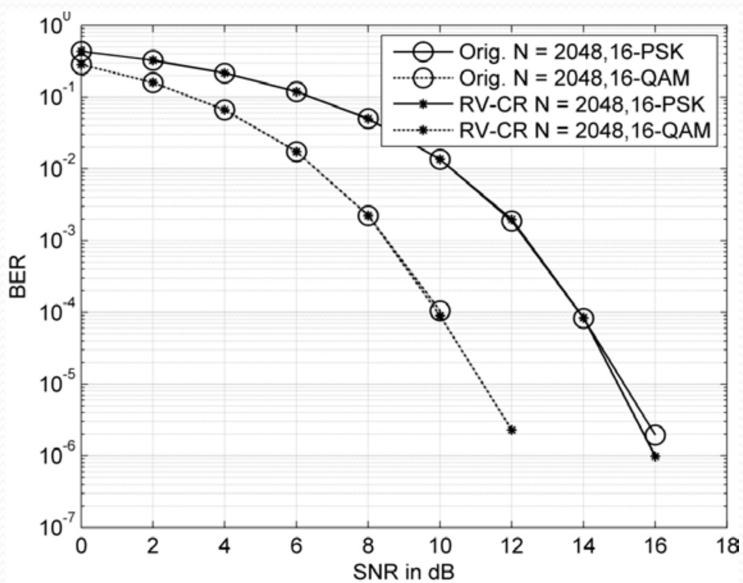
Sliding Selected Mapping (SSLM)

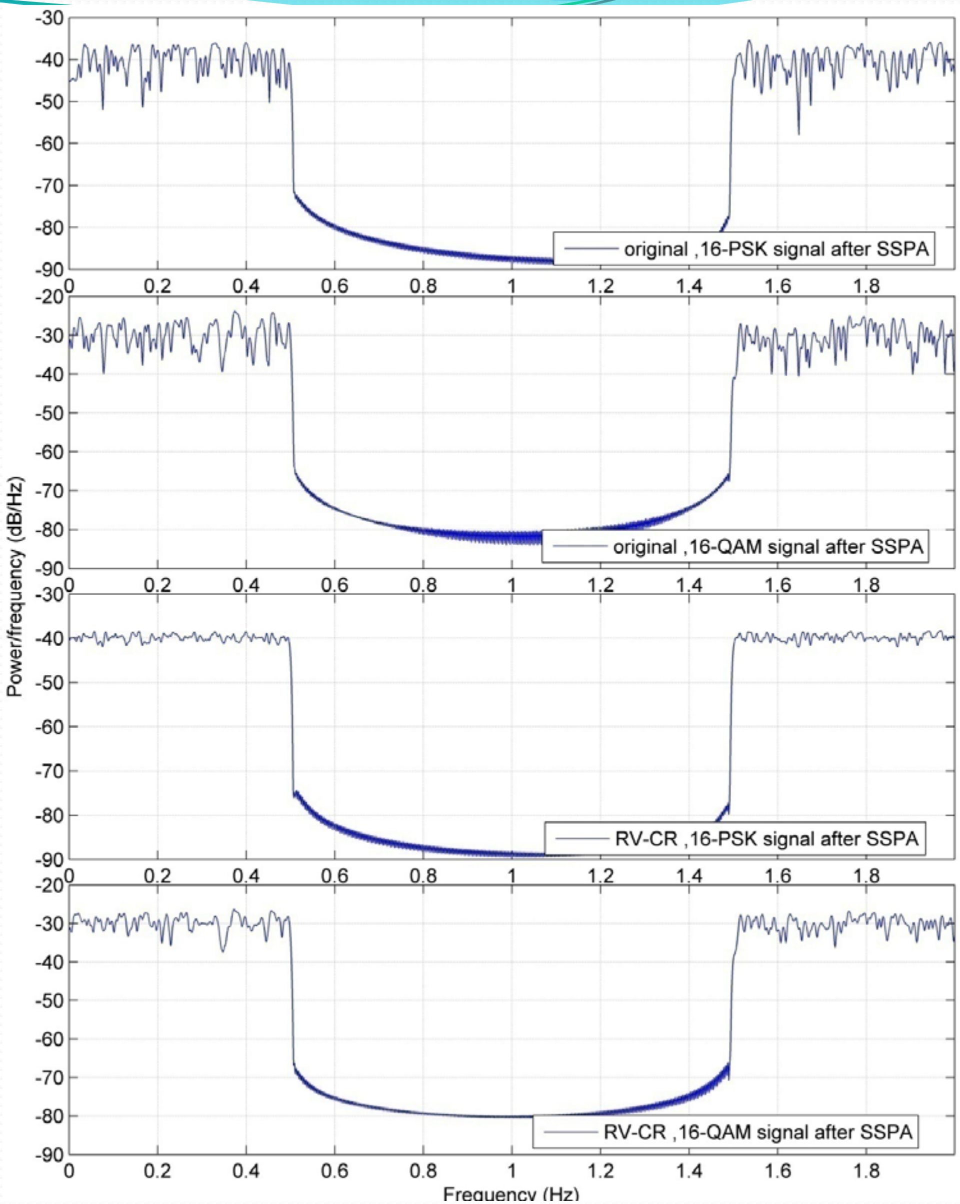
A: SSLM
B: CSLM
C: Jayalath et al 2000
D: Zhou et al 2004
E: Chin-Liang et al 2007
F: Irukulapati et al 2009
G: Shin-Kai et al 2011

N	A/A		A/B		A/C		A/D		A/E		A/F		A/G	
	$\mathcal{M}$ %	$\mathcal{A}$ %	$\mathcal{M}$ %	$\mathcal{A}$ %	$\mathcal{M}$ %	$\mathcal{A}$ %	$\mathcal{M}$	$\mathcal{A}$	$\mathcal{M}$	$\mathcal{A}$	$\mathcal{M}$	$\mathcal{A}$	$\mathcal{M}$	$\mathcal{A}$
64	-	-	40	40	40.49	40.25	45.45	45.45	63.07	47.93	40	40	40	40
128	-	-	40	40	40.42	40.21	45.45	45.45	52.67	43.67	40	40	40	40
256	-	-	40	40	40.37	40.18	45.45	45.45	46.29	41.66	40	40	40	40
512	-	-	40	40	40.33	40.16	45.45	45.45	42.97	40.75	40	40	40	40
1024	-	-	40	40	40.29	40.15	45.45	45.45	41.37	40.34	40	40	40	40
2048	-	-	40	40	40.27	40.13	45.45	45.45	40.63	40.15	40	40	40	40
4096	-	-	40	40	40.24	40.12	45.45	45.45	40.29	40.07	40	40	40	40

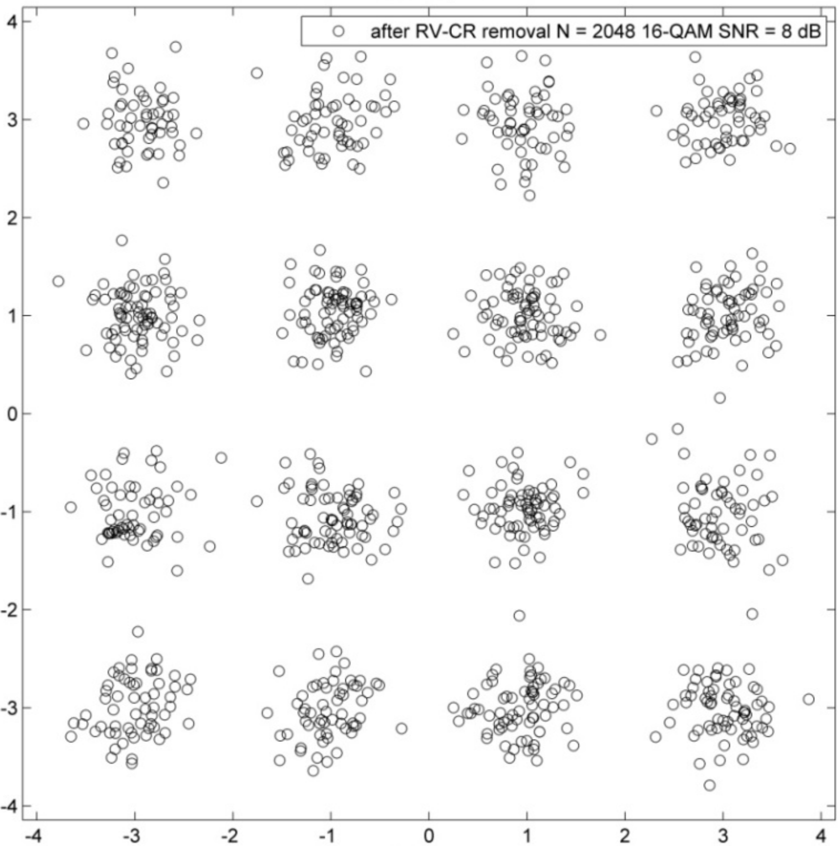
Results: (**RV-CR**)

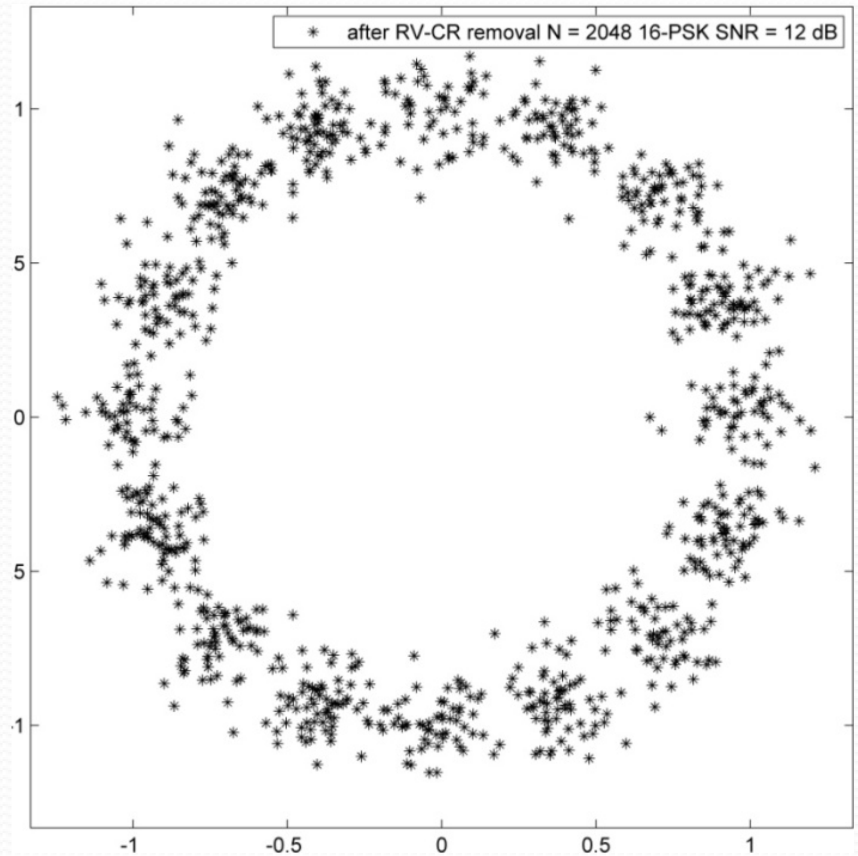






Results: (RV-CR)





Random Variable Constellation Reshaping (RV-CR)

N	A/A		A/B		A/C		A/D		A/E		A/F	
	M %	*A* %	*M* %	*A* %	*M* %	*A* %	*M*	*A*	*M*	*A*	*M*	*A*
64	-	-	100	66.66	-	83.33	100	98.68	100	97.91	100	97.92
128	-	-	100	71.42	-	85.71	100	98.83	100	98.21	100	98.22
256	-	-	100	75	-	87.5	100	98.95	100	98.43	100	98.44
512	-	-	100	77.77	-	88.88	100	99.05	100	98.61	100	98.61
1024	-	-	100	80	-	90	100	99.13	100	98.75	100	98.75
2048	-	-	100	81.81	-	90.90	100	99.20	100	98.86	100	98.86
4096	-	-	100	83.33	-	91.66	100	99.26	100	98.95	100	98.96

A: RV-CR
B: Chau-Yun et al. 2006
C: Mobasher & Khandani 2006
D: Hsu & Chao 2008
E: Yang & Tao 2009
F: Cai et al. 2011

Conclusions

- **The investigation** for the existing PAPR based reduction techniques for OFDM systems **in terms of PAPR reduction gain and computational complexity has been done**.
- **Development of methods** to reduce the PAPR in OFDM systems **with minimal computational complexity has been achieved**. Furthermore, the **balance between the computational complexity reduction, the *PAPR reduction gain* and the *BER performance* has been accomplished. As follows:**
- **a) Side information supported amplitude clipping;**
- **b) Sliding selected mapping; and**
- **c) Random variable constellation reshaping.**

List of Publications: (Journals)

1. **Montadar A. T., Singh, M.J., Ismail, M.B., Samad, S.A., Islam, M.T. Islam. 2013. Reducing the PAPR of OFDM systems by random variable transformation. *ETRI Journal* 35 (4): 714 – 717. SCOPUS/ISI-Q3**

RV-CR

2. **Montadar A. T., Singh, M.J., Ismail, M.B., Samad, S.A., Islam, M.T. Islam. 2013. Sliding the SLM-technique to reduce the non-linear distortion in OFDM systems. *Elektronika ir Elektrotechnika* 19(5): 03 – 111 . SCOPUS/ISI-Q4**

SSLM

3. **Montadar A. T., Singh, M.J., Ismail, M.B., Samad, S.A., Islam, M.T. Islam. 2013. Reducing the power envelope fluctuation of OFDM systems using side information supported amplitude clipping approach. *International Journal of Circuit Theory and Applications*. SCOPUS/ISI-Q2**

SI-SAC

4. **Montadar A. T., Singh, M.J., Ismail, M.B., Samad, S.A., Islam, M.T. Islam, Hussain F. M., 2014. Post-IFFT-Modified Selected Mapping to Reduce the PAPR of an OFDM System. *Circuits, Systems, and Signal Processing* . SCOPUS/ISI-Q2**

PI-MSLM

5. **Montadar A. T., Singh, M.J., Ismail, M.B., Samad, S.A., Islam, M.T. Islam. 2012. Peak to average power ratio reduction of orthogonal frequency division multiplexing system with a significant low complexity. *American Journal of Applied Sciences* 9(12): 1985 - 1989. SCOPUS**

6. **Montadar A. T., Singh, M.J., Ismail, M.B., Samad, S.A., Islam, M.T. Islam. 2012. An additive scaling factor to reduce the PAPR of the OFDM systems. *Journal of Electrical and Electronics Engineering* 5(1): 247 – 250. SCOPUS**

7. **Montadar A. T., Singh, M.J., Ismail, M.B., Samad, S.A., Islam, M.T. Islam. 2012. A novel way to enhance the PAPR of OFDM systems. *Journal of Applied Sciences Research* 8(3): 1589 - 1593 . SCOPUS**

List of Publications: (Conferences)

- Montadar A. T., Singh, M.J., Ismail, M.B., Samad, S.A., Islam, M.T. Islam. 2011. Amplitude phase grouping algorithm to enhance the PAPR problem. 7th International Conference on Information Technology and Application, (ICITA 2011) 245 – 248.

- Montadar A. T., Singh, M.J., Ismail, M.B., Samad, S.A., Islam, M.T. Islam. 2011. Blind technique to lower the PAPR of the MC-CDMA system without complexity. 17th Asia-Pacific Conference on Communications, (APCC 2011) 688 – 691.

- Montadar A. T., Singh, M.J., Ismail, M.B., Samad, S.A., Islam, M.T. Islam. 2011. A novel simple algorithm to enhance the peak to average ratio of MC-CDMA system. 2011 IEEE International Conference on Signal and Image Processing Applications, (ICSIPA 2011) 324 - 326

Thank You