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# Walsh Hadamard Transform based SLM for PAPR reduction in OFDM

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**Abstract— To optimize the PAPR in conventional OFDM, Low Complexity Selective Level Mapping (SLM) is considered in this paper as it reduces PAPR significantly without loss of information. OFDM (Orthogonal Frequency Division Multiplexing) is a multicarrier modulation technology that offers excellent spectral efficiency, minimal implementation complexity, and reduced sensitivity to echoes and distortion. Because of these benefits, the OFDM system is widely utilized in a variety of communication systems. However, because of the coherent addition of sub carriers, the fundamental disadvantage of the OFDM system is an increase in peak power. The amplitude of an OFDM signal is virtually Rayleigh distribution since it is made up of several independently modulated sinusoidal waves. The amplitude of the OFDM signal fluctuates a lot, resulting in a high Peak-to-Average ratio. Many strategies have been presented to reduce PAPR; in this research, we will use Low Complexity SLM to reduce PAPR in an OFDM system. PAPR can be decreased in a low-complexity SLM by multiplying the input signals with a Hadamard orthogonal phase vector and generating statistically independent sequences that reflect the same information before the OFDM system's IFFT operation. The generated independent data blocks are then concurrently forwarded into IFFT operation, generating OFDM signal sequences. The PAPR for all OFDM signal sequences should then be computed. Finally, the sequence with the lowest PAPR will be chosen to be transmitted. When compared to the standard SLM technique, the suggested SLM scheme provides similar PAPR reduction performance with significantly less computing complexity. The suggested SLM scheme's performance is tested using various modulation methods. MATLAB is used to simulate the outcomes.**

**Keywords— Selective Level Mapping (SLM), OFDM, Peak to Average Power Ratio**

## I.INTRODUCTION

The Orthogonality Frequency Division Multiplexing (OFDM) system is a Multicarrier Modulation (MCM) system in which all subcarriers are orthogonal. Serial to Parallel converter, Inverse Fast Fourier Transform, Cyclic Prefix, Fast Fourier Transform, and Parallel to Serial converter modules are all part of the OFDM System.

## II. PAPR REDUCTION TECHNIQUES

PAPR reduction techniques are vary according to the requirements of the system. The PAPR reduction technique, those are PAPR reduction capability, Power increase in transmit signal, BER increase at the receiver, Loss in data rate and Computational complexity increase. Other considerations include the transmit filter, the digital to analogue converter, and the transmit power amplifier.

- **Signal distortion techniques**

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It clips the peak amplitudes of a signal at the expense of introducing a slight distortion of the spectrum of the signal. Signal distortion techniques are Clipping and Filtering, Companding, Peak windowing, Peak cancellation, Peak Reduction Carrier and Envelope Scaling

- **Coding Techniques**

Different coding sequences are used in the use of generating OFDM symbols. Coding Techniques are Block Coding Techniques and Block Coding Scheme with Error Correction.

- **Symbol-scrambling techniques:**

The main purpose of the technique is to scramble the input OFDM symbols by using number scrambled sequences. The output scrambled signal is equivalent to the smallest PAPR transmitted. Symbol-scrambling techniques are Partial Transmit Sequences and Selected Mapping.

Some other popular techniques have been used to reduce PAPR are Tone reservation, Tone injection, Active Constellation Extension, and Interleaving Technique

## Comparison of different PAPR reduction schemes:

TABLE I. COMPARISON AMONG DIFFERENT PAPR REDUCTION SCHEMES

| PAPR Reduction Method | PRC | API | BER | DRL | CC | OBR |
|---|---|---|---|---|---|---|
| **Clipping and Filtering** | Good | N | Y | N | Low | Y |
| **Companding** | Good | N | Y | N | Med | Y |
| **Coding** | Good | N | N | Y | High | N |
| **PTS** | Good | N | N | Y | High | N |
| **SLM** | Good | N | N | Y | High | N |
| **TR** | Good | N | N | Y | High | N |
| **TI** | Good | Y | N | N | High | N |

Table I compares the PAPR reduction capability (PRC), average power increase (API), BER degradation (BER), data rate loss (DRL), out-of-band radiation (OBR), and computational complexity of several types of PAPR reduction techniques (CC).

## III. THE CONVENTIONAL SLM SCHEME

The input symbols in an OFDM system are X=X(0), X(1)...X(N-1), and the OFDM samples are x=x(0), x(1)...x(N-1), where N is the number of sub carriers. Converting the input symbol sequence X in the frequency domain to the OFDM signal sequence x in the time domain using the IFFT and expressing as:

$$x(n)=\sum_{n=0}^{N-1} X(k)e^{-\frac{j2\pi nk}{N}} \qquad 0 \le n \le N-1$$

By multiplying the same input sequence with U various phase rotation vectors, the typical SLM technique generates U alternative OFDM signal sequences xu, 0 u U-1 for the same input symbol sequence X. Both the transmitter and receiver are familiar with the pu and phase factors. where $P^u = \{P^u(0), P^u(1) \dots P^u(N-1)$ with $P^u(k)=e^{j\emptyset u(k)}$, $\emptyset u(k) \epsilon$ [0,2π], 0 ≤ u ≤ U-1 [6][7].

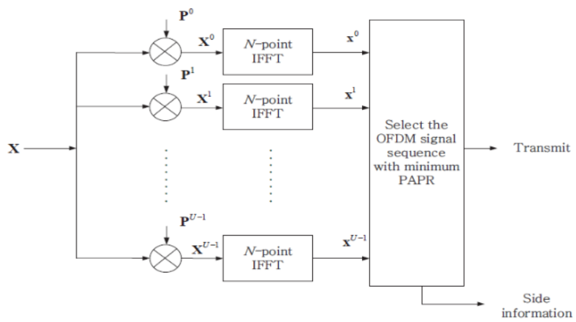

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Fig. 1. Block diagram of the conventional SLM scheme

In general, all the elements of the phase rotation vector $P^u$ are the power of the primitive $K^{th}$ root of unity $e^{\frac{j2\pi}{K}}$ and generally K = 2 or 4 is used. $P^0$ is all-one vector to generate the original OFDM signal and thus $x^0$ = x. In conventional SLM technique, the input symbol sequence X is multiplied by the each phase rotation vector $P^u$ element by element and generating the U different alternative input symbol sequences $X^u$, where

$$X^u(k) = X(k)P^u(k), 0 \le u \le U-1.$$

The generated U alternative input symbol sequences are transferred to the IFFT block and generates the U alternative OFDM symbol sequences $x^u$ = IFFT($X^u$) and then calculate the PAPR for all the OFDM signals [6][7].

In general, all members of the phase rotation vector Pu are powers of the fundamental Kth root of unity, with K = 2 or 4 being the most common values. To construct the original OFDM signal, P0 is an all-one vector, hence x0 = x. The input symbol sequence X is multiplied by each phase rotation vector Pu element by element in the traditional SLM technique, resulting in U distinct alternative input symbol sequences Xu, where $X^u(k) = X(k)P^u(k), 0 \le u \le U-1$The IFFT block receives the created U alternative input symbol sequences and generates the U alternative OFDM symbol sequences $x^u$ = IFFT($X^u$) before calculating the PAPR for all OFDM signals [6][7].

$$PAPR= \max(|x^u(n)|^2)/E[|x^u(n)|^2$$

Finally, minimum PAPR is selected from the alternative OFDM signal sequence $x^u$.

Note that in conventional SLM, to properly demodulate the OFDM signal at the receiver must transmit the Side Information (SI) on u.

## IV. PROPOSED A NEW SLM SCHEME WITH LOW COMPLEXITY

The input symbols in an OFDM system are X=X(0), X(1)...X(N-1), and the OFDM samples are x=x(0), x(1)...x(N-1), where N is the number of sub carriers. Converting the input symbol sequence X in the frequency domain to the OFDM signal sequence x in the time domain using the IFFT and expressing as:

$$x(n)=\sum_{n=0}^{N-1} X(k)e^{-\frac{j2\pi nk}{N}} \qquad 0 \le n \le N-1$$

The conventional SLM scheme, will generate U alternative OFDM signal sequences $X^u$, $0 \le u \le U-1$, for the same input symbol sequence X. Multiply the input signal sequence with the Hadamard orthogonal Phase rotation vector to obtain U alternative OFDM signal sequences.

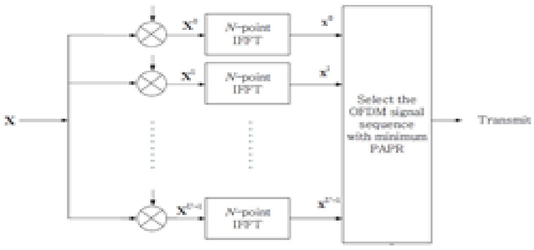


Fig. 2. Block diagram of the Modified SLM scheme

A Hadamard orthogonal vector multiplies an input symbol sequence X element by element, yielding U distinct alternative input symbol sequences Xu, where $X^u(k) = X(k)*H^u(k), 0 \le u \le U-1$. The U alternative symbols are transmitted to the IFFT block, which generates the U alternative OFDM signal sequences $x^u$ = IFFT($X^u$) and calculates the PAPR of the U alternative OFDM signal sequences.

$$PAPR= \max(|x^u(n)|^2)/E[|x^u(n)|^2$$

Finally, for transmission, choose the alternate OFDM signal sequence $x_u$ with the lowest PAPR.

### HADAMARD MATRIX:

In Hadamard matrix, the rows are mutually orthogonal, and all the entries are either +1 or −1. Hadamard matrix is the square matrix.

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In Hadamard matrix each pair of the rows are orthogonal and each pair of the rows are exactly matching with the half of the columns and in the remaining columns have the mismatching entries.

**Example:**

Hadamard (1) [1]

Hadamard (2)

```
1  1
1 -1
```

[1 1].*[1-1]= 0(each pair of rows in a Hadamard matrix are perpendicular)

Hadamard (4)

```
1  1  1  1
1 -1  1 -1
1  1 -1 -1
1 -1 -1  1
```

## Orthogonal Property:

Assume H be an order of n Hadamard matrix. The inverse of H is almost equal to its transpose.

$HH^T = n I_n$

where $I_n$ is the identity matrix of order n and $H^T$ is the transpose of Hadamard matrix H.

## Sylvester's construction:

Firstly, James Joseph Sylvester was constructed Hadamard matrices in 1867. Let H be an order of n Hadamard matrix. Then the partitioned matrix

[H H
H -H]

is a Hadamard matrix of order $2_n$. This observation will be applied continually and produce the below sequence of Hadamard matrices. These matrices also called Walsh matrices.

Hadamard (1) = [1]

Hadamard (2) =

```
1  1
1 -1
```

Hadamard (4)

```
1  1  1  1
1 -1  1 -1
1  1 -1 -1
1 -1 -1  1
```

## Signal Recovery at Receiver:

For example, Input signal x = [1 2 3 4]

Hadamard (4) = H =

```
1  1  1  1
1 -1  1 -1
1  1 -1 -1
1 -1 -1  1
```

Generation of Multiple statistically independent signal:

x.*H = = [1 2 -3 -4] .*

```
1  1  1  1
1 -1  1 -1
1  1 -1 -1
1 -1 -1  1
```

Assume,3rd signal $x_h(3)$ = [1 2 -3 -4] has low PAPR and sent to the receiver.

Generation of original signal with Low PAPR signal at receiver:

Original signal x = $x_h(3)$ .* $H^T$

= [1 2 -3 -4] .*

```
1  1  1  1
1 -1  1 -1
1  1 -1 -1
1 -1 -1  1
```

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| | | | | |
|---|---|---|---|---|
| = | 1 | 2 | -3 | -4 |
| | 1 | -2 | -3 | 4 |
| | **1** | **2** | **3** | **4** |
| | 1 | -2 | 3 | -4 |

### Algorithm for Calculation of PAPR:

- Step 1: Generate the message bits.
- Step 2: In order to generate code words message bits are encoded.
- Step 3: Multiply Hadamard Orthogonal vector to the input symbol sequence and generate phase rotated symbol sequences
- Step 4: Apply the IFFT for the phase rotated symbol sequences and generate samples
- Step 5: Compute the PAPR for the each OFDM sample
- PAPR= Peak Power/Average Power
- (i)Compute the maximum power of the sample
- (ii)Compute Mean or Average value of the sample
- (iii)Compute the PAPR of the sample
- (iv)Convert the PAPR into dB, i.e., $10*\log_{10}$(PAPR)
- (v)repeat the above steps for all samples

  Step 6: Finally, compute the alternative OFDM signal sequence $x^u$ having the minimum PAPR is selected for transmission.
- Step 7: Find the CCDF (complementary cumulative distribution function) for PAPR values
- Step 8: Draw the Semi log Graph between PAPR and CCDF(PAPR)

## V. Simulation Results

For different orders of FFTs and IFFTs, an OFDM transmitter is developed using M-array QAM in this study. The CCDF plot comparing the performance of PAPR in OFDM with SLM and modified SLM employing 4-QAM modulation is shown in the following figure.

TABLE II. PAPR IMPROVEMENT IN MODIFIED SLM OVER CONVENTIONAL OFDM AND SLM FOR 4-QAM

| Modulation | SLM 4-QAM | Modified SLM 4-QAM |
|---|---|---|
| **No of Input Symbols** | 49152 | 49152 |
| **No of Symbol Blocks** | 192 | 192 |
| **IFFT Size** | 128 | 128 |
| **PAPR (in dB)** | 10 | 6.8 |

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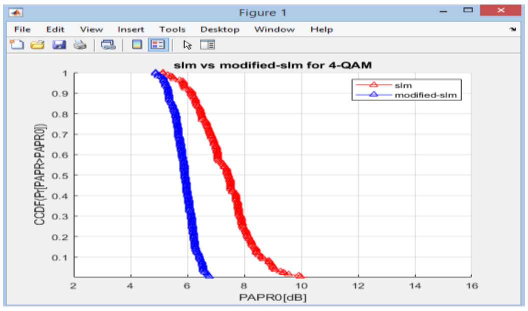


Fig. 3. PAPR improvement in Modified SLM over conventional OFDM and SLM for 4-QAM

In terms of OFDM performance, modified SLM surpasses normal SLM using 4-QAM, as shown in Fig.3. The modified SLM outperforms the normal SLM in terms of PAPR, as seen in Figure 3.
Figure.3 illustrates a 3.4 dB PAPR enhancement over standard OFDM at BER 10-2.
Figure.4. indicates, the CCDF plot comparing the performance of PAPR in OFDM with SLM and modified SLM using 8-QAM modulation.

TABLE III. PAPR IMPROVEMENT IN MODIFIED SLM OVER CONVENTIONAL OFDM AND SLM FOR 8-QAM

| Modulation | SLM 8-QAM | Modified SLM 8-QAM |
|---|---|---|
| No of Input Symbols | 49152 | 49152 |
| No of Symbol Blocks | 128 | 128 |
| IFFT Size | 128 | 128 |
| PAPR (in dB) | 9 | 6.5 |

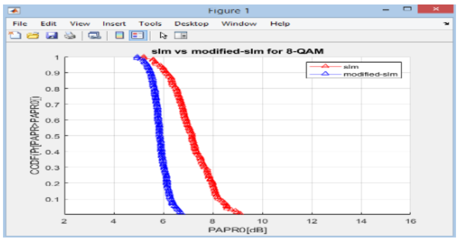


Fig. 4. PAPR improvement in Modified SLM over conventional OFDM and SLM for 8-QAM

The performance in OFDM in modified SLM is better than in conventional SLM employing 8-QAM, as shown in Figure.4. Figure 4 shows the modified SLM, which outperforms the traditional SLM in terms of PAPR.At BER 10-2, Figure.4 shows a 2.5 dB PAPR improvement over traditional OFDM.

The CCDF graphic compares PAPR's performance in OFDM with SLM and modified SLM modulation using 64-QAM modulation.

TABLE IV. PAPR IMPROVEMENT IN MODIFIED SLM OVER CONVENTIONAL OFDM AND SLM FOR 64-QAM

| Modulation | SLM 64-QAM | Modified SLM 64-AM |
|---|---|---|
| No of Input Symbols | 49152 | 49152 |
| No of Symbol Blocks | 64 | 64 |
| IFFT Size | 128 | 128 |
| PAPR (in dB) | 8.1 | 6.3 |

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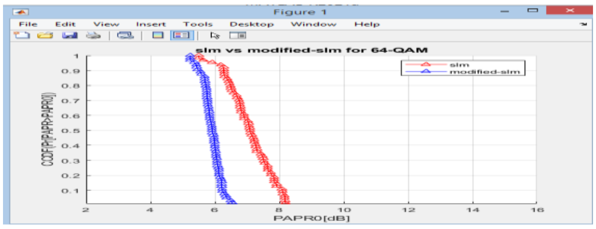


Fig. 5. PAPR improvement in Modified SLM over conventional OFDM and SLM for 64-QAM

The performance of modified SLM in OFDM is better than standard SLM utilizing 64-QAM, as shown in Fig.5.
Figure 5 shows the modified SLM, which outperforms the traditional SLM in terms of PAPR. At BER 10-2, Figure.5 shows a 1.8 dB PAPR improvement over traditional OFDM. The PAPR performance of modified SLM is clearly superior to traditional SLM, as shown in Figures 3, 4, and 5.
The key benefit of modified SLM over traditional SLM is that it reduces computing complexity by using Hadamard vectors instead of complex phase rotation vectors.

## VI. CONCLUSIONS

SLM is used to implement an OFDM transmitter in this project. In SLM OFDM, the PAPR improvement of modified SLM is similar to that of conventional SLM, but modified SLM has a significantly lower computational complexity than conventional SLM because it uses a Hadamard orthogonal phase rotational vector to generate multiple statistically independent sequences that represent the same information, rather than the complex phase rotation vectors used in conventional SLM.

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